CHAPTER 2

LIQUID PENETRANT INSPECTION METHOD

SECTION I LIQUID PENETRANT (LT) INSPECTION METHOD

2.1 GENERAL CAPABILITIES OF LIQUID PENETRANT INSPECTION.

2.1.1 Introduction to Liquid Penetrant Inspection. Penetrant inspection is a method used to detect surface-breaking discontinuities (e.g., cracks, pits, etc.) in nonporous materials. This method utilizes a dye containing fluid which penetrates surface discontinuities through capillary action. The trapped penetrant increases the visibility of the discontinuity by providing a visual contrast between the discontinuity and the surrounding surface, (Figure 2-1).

2.1.2 Background of Liquid Penetrant Inspection. Liquid penetrant inspection is one of the oldest nondestructive inspection methods. It was first used in the railroad maintenance shops in the late 1800s. Parts to be inspected were immersed in used machine oil. After a suitable immersion time, the parts were withdrawn from the oil and the excess surface oil wiped off with rags or wadding. The part surfaces would then be coated with powdered chalk or a mixture of chalk suspended in alcohol (whiting). Oil trapped in cracks or flaws would bleed-out causing a noticeable stain in the white chalk coating. This became known as the oil-and-whiting method.

2.1.2.1 The oil-and-whiting method was replaced by magnetic particle inspection on steel and ferrous parts in 1930. However, industries using non-ferromagnetic metals, especially aircraft manufacturers, needed a more reliable and sophisticated tool than discolored machine oil and chalk. In 1941, fluorescent dye materials were added to highly penetrating oil to make a penetrant material. Colored dyes, primarily red, were introduced a little later. Since then, a large number of penetrant systems or families have evolved. These include developments in various types and concentrations of dye materials, types of penetrating oils and additives, materials and methods for removing the excess surface penetrant, and various materials and forms of developing agents.

2.1.3 Why Use Liquid Penetrant Inspection. Penetrant inspection is an inexpensive and reliable nondestructive inspection method for detecting discontinuities open to the surface of the item to be inspected. It can be used on metals and other nonporous materials not harmed by penetrant materials. With the proper technique, it will detect a wide variety of discontinuities ranging in size from large, readily visible flaws down to the microscopic discontinuities, as long as the discontinuities are open to the surface and are sufficiently free of foreign material.

2.1.3.1 Penetrant is also used to detect leaks in containers. The same basic fundamentals apply, however, the penetrant removal step is typically omitted. The container is either filled with penetrant or the penetrant is applied to one side of the container wall. The developer is applied to the opposite side. After an appropriate dwell time, the developer coated side is inspected for evidence of penetrant leaking through the container wall. This method is most applicable on thin parts where access is available to both internal and external surfaces and the discontinuity is expected to extend through the material.

2.1.3.2 Due to its ability to inspect ferrous and nonferrous parts of all sizes and shapes, and its portability, the liquid penetrant NDI method can be used at both depot and field repair stations. For a specific aircraft type, a technical manual on nondestructive inspection is used to define the method, technique, equipment, component preparation, and precautions required to perform NDI on each component of the aircraft. A separate manual is used for engines.

2.1.3.3 With wider use of the eddy current NDI method, liquid penetrant is now becoming the secondary method for many applications. This is a result of the improved sensitivity of new eddy current inspection techniques and the fact that eddy current does not require use and disposal of potentially hazardous chemicals. For batch inspection of large areas, the penetrant method is still preferred due to the shorter total process time when compared to eddy current. In addition, penetrant is often used as a backup method for verification of defects found by eddy current inspection.

2.1.4 Limitations of Liquid Penetrant Inspection.

2.1.4.1 Restricted Flaw Openings. Penetrant inspection depends upon the ability of the penetrant to enter and exit the flaw opening. Any surface condition, such as coatings (e.g., paint, plating), dirt, oil, grease, or resin that interferes with the entry or exit, reduces the effectiveness of the inspection. Even when the coating does not cover the opening, the material at the edge of the opening may affect the entry or exit of the penetrant and greatly reduce the reliability of the inspection. Coatings at the edge of a discontinuity will also retain penetrant, causing background interference. An inspection method other than penetrant SHALL be used if the organic coating cannot be stripped or removed from the surface to be inspected.

2.1.4.2 Smeared Metal.

CAUTION

- Mechanical operations such as shot peening, plastic media blasting (PMB), machine honing, abrasive blasting, buffing, brushing, grinding, and sanding will smear or peen the surface of metals and close or reduce the surface opening of any existing discontinuities. Penetrant inspection may not reliably detect discontinuities when performed after a mechanical operation or service that smears or peens the surface. Any operation which results in surface material smearing or peening SHOULD NOT precede liquid penetrant inspection unless effective chemical etching is performed or unless specifically authorized by the cognizant engineering authority. Further discussion of mechanical working processes and surface preparation methods are provided further in this chapter.

- Once the part has been put back in service and has experienced normal service loads, it MAY be assumed any cracks closed by any of the above mechanical operations except shot peening will be reopened by the service loads and penetrant inspection MAY again be performed without etching. This mechanical working closes or reduces the surface opening of any existing discontinuities. Mechanical working (smearing or peening) also occurs during service when parts contact or rub together.

2.1.4.3 Porous Surfaces. Penetrant inspection is impractical on porous materials, such as some types of anodized aluminum surfaces, and other protective coatings on other metals. The penetrant enters the pores of the material and becomes trapped. This can result in background that would reduce contrast or mask any potential discontinuity indications. In addition, removal of the penetrant may not be possible after the inspection.

2.1.5 Advantages of Liquid Penetrant Inspection.

NOTE

Although advantages and disadvantages may appear to be straightforward, the decision to select the penetrant test method or any other NDI method is often not obvious and depends upon a large number of factors. A thorough knowledge of the capabilities and limitations of all NDI methods is required. The decision on which method to use should be referred to the responsible NDI engineering activity.

- Liquid penetrant inspection is capable of examining all of the exterior surfaces of objects. Complex shapes can be immersed or sprayed with penetrant to provide complete surface coverage. Other nondestructive methods cover a specific area or location and must then be repeated to cover other areas or locations.
- Liquid penetrant inspection is capable of detecting very small surface discontinuities. It is one of the more sensitive nondestructive inspection methods for detecting surface flaws.
- Liquid penetrant inspection can be used on a wide variety of materials: ferrous and nonferrous metals and alloys, fired ceramics, powdered-metal products, glass, and some types of organic materials.
- Liquid penetrant inspection can be accomplished with relatively inexpensive, unsophisticated equipment. If the area to be inspected is small, the inspection can be accomplished with portable equipment.
- Through penetrant bleed-out, liquid penetrant inspection magnifies the apparent size of discontinuities resulting in a more visible indication. In addition, the discontinuity location, orientation, and approximate length are indicated on the part, making interpretation and evaluation possible.
- Liquid penetrant inspection is readily adapted to volume processing, permitting 100-percent inspection of all accessible surfaces. Small parts may be placed in baskets for batch processing. Specialized systems may be semi- or fully automated to process as many parts per hour as required.
- The sensitivity of a penetrant inspection process may be adjusted through selection of materials and techniques. This allows suppression of indications from small, inconsequential discontinuities while indicating larger discontinuities of concern.

2.1.6 Disadvantages of Liquid Penetrant Inspection.

- Penetrant inspection depends upon the ability of the penetrating media to enter and fill discontinuities. Penetrant inspection will only reveal discontinuities open to the surface.
- The surfaces of objects to be inspected must be clean and free of organic or inorganic contaminants that will prevent the action of the penetrating media. It is also essential for the inside surface of the discontinuities be free of materials such as corrosion, combustion products, or other contaminants that would restrict the entry of penetrant.
- Penetrants are usually oily materials with strong solvent powers and highly concentrated dyes. They will attack some non-metallic materials such as rubber and plastics. There is also the possibility of permanent staining of porous or coated materials.

WARNING

- Due to the oily nature of most penetrants, they SHALL NOT be used on parts such as assemblies where they cannot be completely removed and will subsequently come in contact with gaseous or liquid oxygen. Oils, even residual quantities, may explode or burn very rapidly in the presence of oxygen. Only materials specifically approved for this application SHALL be used if penetrant inspection is required and complete removal of the residue is not possible. Each application of these special oxygen-compatible materials SHALL be directed by the applicable technical order and/or upon direction by the responsible NDI engineering agency.

- Some penetrant materials may contain sulfur and/or halogen compounds (chlorides, fluorides, bromides, and iodides). These compounds may cause embrittlement or cracking of austenitic stainless steels if not completely removed prior to heat-treating or other high temperature exposure. Entrapped halogen compounds may also cause corrosion of titanium alloys if not completely removed after the inspection is completed and the part is subjected to elevated temperatures. Use of these materials SHALL be directed by the applicable technical order and/or upon direction by the responsible NDI engineering agency.

2.1.7 Basic Penetrant Inspection Process. A simplified description of the fundamental penetrant process steps is located in (paragraph 2.4.2.1).

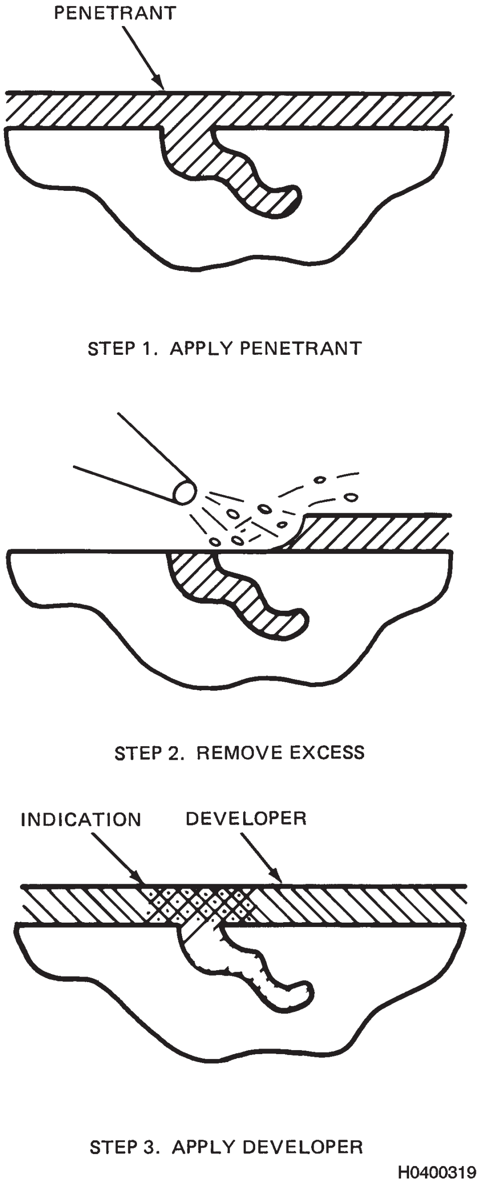


Figure 2-1. Basic Penetrant Inspection Process

2.1.8 Personnel Requirements.

NOTE

> All individuals who apply penetrant materials or examine components for penetrant indications SHALL be qualified as specified in accordance with (paragraph 1.2).

The apparent simplicity of the penetrant inspection is deceptive. Very slight variations in the inspection process performance can result in reduced inspection sensitivity and failure to indicate serious flaws. It is essential for personnel performing penetrant inspection be trained and experienced in the penetrant process.

2.1.9 Understanding Penetrant Classification and Processes. This section defines the various classifications of penetrant testing materials and the general process steps of penetrant inspection. The information in this section is intended as introductory material for management, supervisors, and other personnel who are required to know the general applications and classifications of penetrants, but do not require detailed NDI information. It can also be used in the training of beginning NDI personnel. We will review the various specifications, which define the penetrant material performance requirements and control the application of the penetrant process. Finally, we will also discuss the quality control and process testing requirements for penetrant materials. Detailed, technical information on penetrant materials and application processes is provided in subsequent sections.

2.1.9.1 Classification of Penetrant Materials and Processes.

2.1.9.1.1 SAE AMS 2644 Categories. The aerospace materials specification SAE AMS 2644 defines the categories universally used for classifying penetrant inspection materials. The categories are defined as follows and are further defined in (Table 2-1).

- Type - Specifies the type of contrast dye used in the material.
- Method - Specifies the method used to remove the penetrant material.
- Level - Specifies the sensitivity level of a particular penetrant system.
- Form - Specifies the form (type) of developer being used.
- Class - Specifies the class of solvent remover to be used.

Table 2-1. Classification of Penetrant Materials Contained in SAE AMS 2644

Type	
Type I	Fluorescent Dye
Type II	Visible Dye
Method	
Method A	Water-Washable
Method B	Postemulsifiable, Lipophilic
Method C	Solvent Removable
Method D	Postemulsifiable, Hydrophilic
Sensitivity Level	
Level 1/2	Ultra Low
Level 1	Low
Level 2	Medium
Level 3	High
Level 4	Ultra High
Developer	
Form a	Dry-Powder
Form b	Water-Soluble
Form c	Water-Suspendible
Form d	Nonaqueous (Solvent based ; for Type I)
Form e	Nonaqueous (Solvent based ; for Type II)
Form f	Special Application
Solvent Remover	
Class 1	Halogenated
Class 2	Nonhalogenated
Class 3	Special Application

2.1.9.1.2 Penetrant Types.

2.1.9.1.2.1 Type I - Fluorescent Penetrant. Some chemical compounds have the capability of emitting visible light when exposed to near-ultraviolet radiation (UV-A, energy with a wavelength of 320 to 400 nanometers), commonly called UV-A or black light. This property is termed fluorescence (paragraph 2.2.3.2.2.6). Type I penetrants are formulated with a dye that emit visible light when excited by UV-A radiation. Type I penetrants provide excellent detection sensitivity to small surface discontinuities as very small quantities of fluorescent penetrant will emit highly visible indications when exposed to UV-A.

2.1.9.1.2.2 Type II - Visible Penetrant.

CAUTION

> DoD prohibits the use of visible penetrant on aircraft, engines, and missiles, except for those parts with specific engineering approval.

Visible-dye or color-contrast penetrants contain a red dye dissolved in the penetrating oil. The visibility is further enhanced during the penetrant process by the application of a layer of white developer. The white developer provides a high contrast background for the bright red penetrant when viewed under natural or white light.

2.1.9.1.3 Methods of Penetrant Removal. Penetrants are formulated and categorized by the specific removal method, not the material used to formulate it. The following are definitions of these methods:

2.1.9.1.3.1 Method "A" - Water Washable Penetrant.

CAUTION

> The water washable (Method A) process is prohibited for use on all flight critical aircraft components and on all engine components. Water washable (Method A) processes SHALL NOT be used without specific written approval from the responsible engineering authority.

The usual liquid base or vehicle for a penetrant is petroleum oil, which is insoluble or immiscible in water. This means the penetrant cannot be removed with water, however, there are chemical compounds called emulsifiers that when mixed with the oil vehicle form a mixture that can be removed with water. The chemical compound forming the emulsifiable mixture is called an emulsifying agent or an emulsifier. Water-washable penetrants are formulated with an emulsifier as an integral component of the penetrant vehicle. This permits direct removal by water immediately after the penetrant dwell.

2.1.9.1.3.2 Method "B" - Postemulsifiable Lipophilic Penetrant.

CAUTION

> Postemulsifiable Lipophilic (Method "B") penetrants are prohibited for use on critical rotating engine components.

Lipophilic is a word derived from the Greek words "lipo" for oil or fat, and "philos" meaning loving. Lipophilic emulsifiers are oil-based products, which are applied with the sole purpose to convert the excess surface penetrant into an emulsifiable mixture that can be removed with water. Method B penetrants are formulated to optimize their penetrating and visibility characteristics. They do not contain emulsifying agents and cannot be completely removed with water alone. Removal is made possible by applying an emulsifier in a separate process step.

2.1.9.1.3.3 Method "C" - Solvent Removable Penetrant.

WARNING

> Solvents used may contain aromatic, aliphatic, or halogenated compounds. Aromatic compounds are characterized by a strange aroma and are formed from hydrocarbons and benzene. Aliphatic compounds are derived from fat; paraffin is an example. Halogenated compounds are materials in combination with the halogens, fluorine and/or chlorine. Many solvents are highly flammable while others may decompose at elevated temperatures. Keep all solvents away from heat and open flame. Vapors may be harmful, so use adequate ventilation. Avoid contact with skin and eyes. Do not take internally.

Method "C" is most often used with spray cans. The solvent removable method utilizes a solvent wipe to remove excess surface penetrant. Usually the penetrants used in the solvent removable process are the postemulsifiable penetrants; however, water washable penetrants can also be used. This method may be deceiving since all penetrants can be removed with solvents.

2.1.9.1.3.4 Method “D” - Postemulsifiable, Hydrophilic Penetrant. The word hydrophilic is derived from the Greek words “hydro” meaning water and “philos” meaning loving. The penetrants are often the same as those used in the lipophilic method; however, the hydrophilic emulsifier method requires the use of a separate water-based remover solution. Hydrophilic emulsifiers, also more accurately known as hydrophilic removers, are water-soluble and actually remove excess surface penetrant by means of a detergent action rather than an emulsification action. In this chapter, “remover” will be used when discussing hydrophilic material. This is the method generally used by the aerospace industry.

2.1.9.1.4 Levels of Penetrant Sensitivity. The following are the different levels of penetrant sensitivity you will see.

- Sensitivity Level 1/2 - Ultra-Low sensitivity
- Sensitivity Level 1 - Low sensitivity
- Sensitivity Level 2 - Medium sensitivity
- Sensitivity Level 3 - High sensitivity
- Sensitivity Level 4 - Ultra-high sensitivity

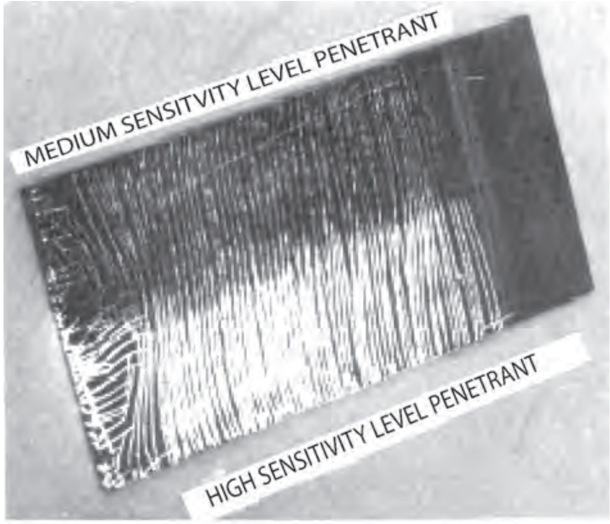


Figure 2-2. The Results of Inspection With a Medium Sensitivity Level Penetrant and a High Sensitivity Level Penetrant

2.1.9.1.5 Forms of Developer Application. The following are the developer forms you may see during penetrant inspection.

- Form a - Dry-powder
- Form b - Water-soluble
- Form c - Water Suspendible
- Form d - Nonaqueous, Type I, Fluorescent Systems (solvent based)
- Form e - Nonaqueous, Type II, Visible Dye Systems (solvent based)
- Form f - Special/Applications

2.1.9.1.5.1 Other Classification Documents for Developers. The Aerospace Materials Specification SAE AMS 2644 classifications are also referenced in latest version of the process standard ASTM E 1417, the American Society for Testing and Materials (ASTM) Practice for Liquid Penetrant Examination. The Type and Method classifications and the descriptions of the first four kinds of developers are referenced in ASTM E 165, Standard Test Method for Liquid Penetrant Examination.

2.1.9.1.6 Classifications of Solvent Removers. The following are the classifications of solvent removers you may see during penetrant inspection.

- Class 1 - Halogenated
- Class 2 - Nonhalogenated
- Class 3 - Special Application

2.1.9.1.7 Developers, Solvents, and the Penetrant Family System Concept.

CAUTION

> The penetrant family system concept does not permit penetrant inspection materials of different types or from different manufacturers to be mixed together. For example, a qualified nonhalogenated solvent remover from "manufacturer A" SHALL NOT be mixed with a qualified nonhalogenated solvent remover from "manufacturer B", and a qualified water-soluble developer from "manufacturer C" SHALL NOT be mixed with a qualified water-soluble developer from "manufacturer D".

A penetrant family system is defined as a penetrant and emulsifier together, from the same manufacturer. SAE AMS 2644 requires a penetrant/emulsifier combination be qualified and used together for both the lipophilic emulsifier and hydrophilic remover methods. For the water washable and solvent removable methods, the penetrant system consists of the penetrant alone. Solvent removers and developers are qualified independently and may be used with any qualified penetrant system. Therefore, a qualified post-emulsifiable penetrant system from one manufacturer may be used with any qualified developer; a qualified solvent removable system may be used with any qualified solvent and developer, and a qualified water washable penetrant system may be used with any qualified developer (approved for water washable systems). There may be a rare occasion where an incompatibility may exist between specific penetrant formulations and developer forms. The manufacturer's restrictions as well as any restrictions defined in SAE AMS 2644 SHALL be followed.

2.1.10 Qualification of Penetrant Material. The SAE AMS 2644 defines the penetrant material performance requirements and is used to procure penetrant materials. This document requires extensive testing on new penetrant material formulations. The test results and a sample of the material are then submitted to the qualifying agency. The qualifying agency reviews the reports and conducts additional tests to verify the acceptability of the material. If the candidate material(s) meets or exceeds the requirements of the specification, a letter of notification approving the material(s) for listing is issued and at the next revision, the material(s) and manufacturer are listed on the Qualified Products List (QPL) SAE AMS 2644. All materials listed in a given classification category are considered equivalent in meeting the generic specification requirements. Consequently, any manufacturer's penetrant system listed in the QPL, for a given type, sensitivity, and removal mode may be substituted for any other penetrant system listed to the same classification. QPL can be found on website http://quicksearch.dla.mil/qsDocDetails.aspx?ident_number=203153. Once connected select "View QPD Data".

2.1.11 Qualification of Penetrant Sensitivity. The qualification test for penetrant sensitivity involves a comparison of the brightness of indications produced by a candidate penetrant system (penetrant and emulsifier) versus the indications produced by a penetrant system designated as a reference standard. The test panels for visible-dye penetrants are thermally cracked aluminum blocks. The test panels for fluorescent-dye penetrants are a series of titanium or nickel alloy panels containing various sizes of laboratory generated fatigue cracks. There is only one set of the latter qualification test panels, and it is not presently possible to produce duplicate fatigue cracks with identical penetrant performance characteristics. Therefore, non-qualification sensitivity comparison tests, which are not used for qualification purposes, may be accomplished with fatigue cracks or cracked-chrome plated panels.

2.1.12 Penetrant Material Performance.

2.1.12.1 Quality Conformance Testing of Penetrant Materials. Listing of materials on the QPL does not guarantee subsequent products of the same formulation will be acceptable. Listing on the QPL merely indicates the original raw materials, formulation, and compounding practice can result in an acceptable product. There are many factors and conditions involved in compounding and manufacturing penetrants that can affect their performance. QPL SAE AMS 2644 includes an option for a procuring activity to contractually require a manufacturer to provide quality conformance test results and a sample of the material from the lot or batch to be supplied. The procuring activity itself has the option of performing tests to verify the conformance of a material, whether a sample and test report is or is not contractually required.

2.1.12.2 Reporting of Nonconforming Materials.

NOTE

Knowledge of penetrant problems, even relatively minor ones, is essential for improvement of the NDI program, the materials specification, and the qualification tests.

Information copies of written correspondence concerning unsatisfactory penetrant materials SHALL be submitted to the Air Force NDI Office, AFLCMC/EZPT-NDIO, aflcmc-ezpt-ndio@us.af.mil; DSN 339- 4931; and AFRL/RXSA, Bldg.651, 2179 Twelfth Street, Wright-Patterson Air Force Base, OH 45433-7718. Unsatisfactory materials SHALL be reported in accordance with TO 00-35D-54 (Air Force) or AR 735-11-2 (Army). A copy of the quality conformance test results SHALL be included as substantiating data.

SECTION II PRINCIPLES AND THEORY OF LIQUID PENETRANT INSPECTION

2.2 PRINCIPLES AND THEORY OF LIQUID PENETRANT INSPECTION.

2.2.1 General. This section provides basic, operating, and advanced level information on the theory and mechanisms of penetrant action, and on the physical and chemical properties of penetrant materials. Also included is a discussion on their effects on the inspection process. In addition, a discussion of the mechanisms of penetrant removal and the development process are provided.

2.2.2 Characteristics of a Penetrant. There are a number of characteristics desired in a material for it to function as a penetrant. The four primary requirements are as follows:

- It SHALL be capable of entering and filling surface openings even though they may be very small.
- Penetrant in a discontinuity SHALL resist washing out during removal of the excess penetrant material on the surface of the part.
- It SHALL exit from the discontinuity after the surface penetrant has been removed.
- It SHALL present a readily visible or noticeable indication of the discontinuity on the part surface.

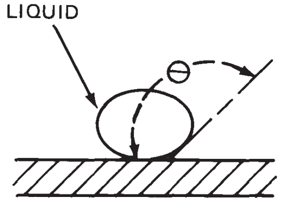
2.2.2.1 The primary requirements listed do not include the factors of being economical, safe, and practical to use. The primary requirements, combined with the additional factors, complicate the formulation of a penetrant material. The behavior of a penetrant is controlled by a number of physical and chemical properties, many of which are conflicting. As a result, commercial penetrants are a complex mixture of chemicals formulated for specific performance characteristics. Unfortunately, there is no simple rule for formulating a penetrant material, nor is there a set of characteristics which, if provided, will ensure a final material is completely satisfactory for all applications.

2.2.3 Mechanisms of Penetrant Action. To understand how penetrant works one must first understand the principles and properties associated with it. These are discussed in the following paragraphs.

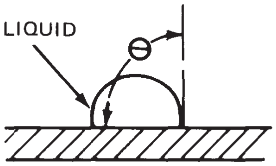
2.2.3.1 Physical Principles. The penetrant inspection process requires a liquid that can flow over and wet a surface. The ability of a liquid to cover the surface of a part and enter any surface opening depends on 1) surface tension, 2) wetting ability, and 3) capillary action.

2.2.3.1.1 Surface Tension. Surface tension can be defined as the force required to expand (or pull apart) the surface of a liquid. The surface of a liquid exhibits certain features resembling the properties of a stretched elastic membrane. These features are due to the cohesive forces holding the surface molecules together, hence the term “surface tension”. As an example, one may lay a needle or safety razor blade upon the surface of water and it will lie at rest in a shallow depression caused by its weight. The forces drawing surface molecules together can be strong. These forces, or surface tension, cause a droplet of liquid to have a spherical shape. A sphere has the smallest surface for a given volume of liquid. This has a direct effect upon the ability of a penetrant to wet a surface.

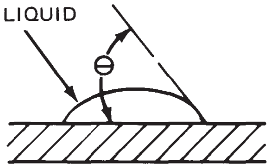
2.2.3.1.2 Wetting Ability. When a liquid comes into contact with a solid surface, the cohesive force responsible for surface tension competes with or is countered by the adhesive force between the liquid molecules and the solid surface. These forces determine the contact angle the liquid forms with the surface. The contact angle is the measured angle a drop of liquid makes with a solid surface. If the contact angle is zero the liquid will “wet” and spread. If the contact angle is 90-degrees or more the liquid will not “wet” the surface and will remain as a rounded drop. Intermediate contact angles indicate intermediate degrees of wetting. Three examples of contact angle are illustrated (Figure 2-3). The Greek letter θ “theta” designates contact angle.



(a) θ GREATER THAN 90°
VERY POOR WETTING



(b) θ EQUALS 90°
POOR WETTING



(c) θ LESS THAN 90°
GOOD WETTING

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Figure 2-3. The Contact Angle, θ, is the Angle Between the Liquid and Solid Surface and is a Measure of the Wetting Ability

2.2.3.1.3 Capillary Action. Capillary action is defined as the tendency for a liquid to penetrate or migrate into small openings, such as cracks, pits, or fissures. Capillary action is associated with wetting ability. For example, when a tube with a small inside diameter is inserted into a liquid, the liquid level inside the tubing may rise above, remain even, or be lower than the outside liquid level. If the contact angle between the liquid and the tubing wall is less than 90-degrees (the liquid wets the tube wall), the liquid will be higher in the tube than on the outside. When the contact angle is 90-degrees or greater (poor wetting and high surface tension), the liquid will not rise above the outside level and may even be depressed. Capillary rise occurs when a liquid wets the inside of a tube and the surface tension draws additional liquid into the wetted area. The effects of contact angles and capillary action are illustrated (Figure 2-4).

2.2.3.2 Penetrant Properties. Surface tension and wetting action are only two requirements of a penetrant. In addition to penetrating ability, a satisfactory penetrant must resist removal from discontinuities when excess surface penetrant is removed from the surface, produce a noticeable indication, and be practical and economical to use. Formulation, selection, and application of penetrant materials requires consideration of many physical and chemical properties. Some of these properties, other than surface tension and wetting ability, are discussed in the following paragraphs.

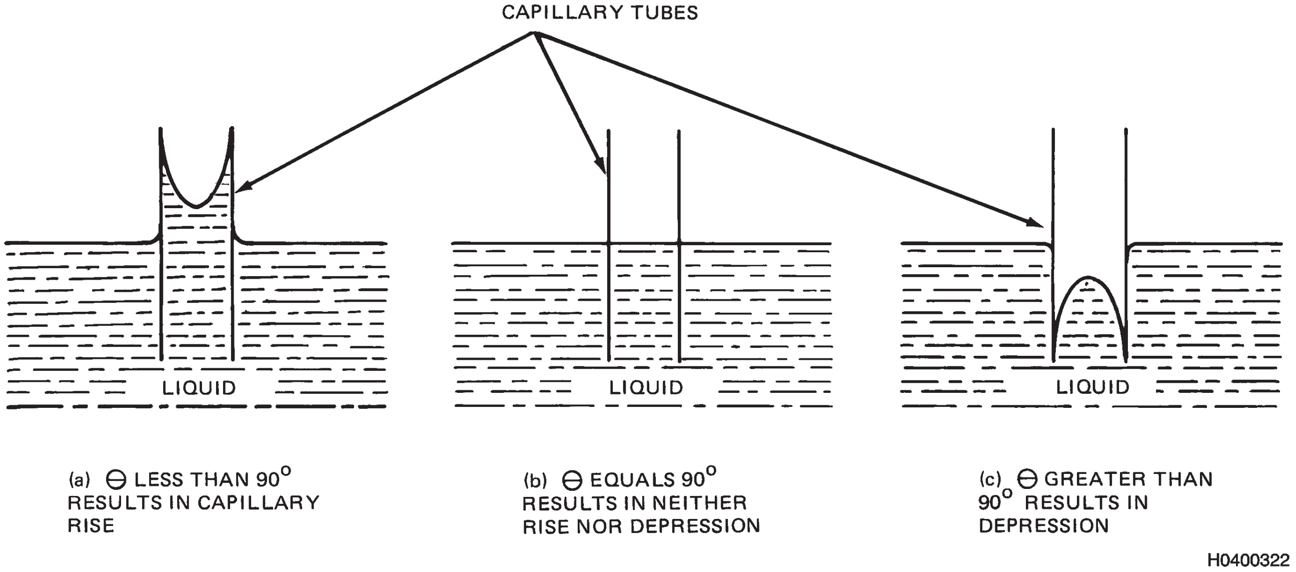


Figure 2-4. The Rise and Depression of Liquid in a Capillary Tube is Dependant Upon the Contact Angle

2.2.3.2.1 Physical Properties.

2.2.3.2.1.1 Viscosity. Viscosity is a measure of a liquid's resistance to a change in physical shape and is related to internal friction. The viscosity of a liquid decreases as the temperature is raised and viscosity increases as the temperature is lowered. Viscosity has no effect on penetrating ability. Some highly viscous fluids, such as molasses, have very good penetrating ability, while some low viscosity liquids, such as pure water, have very poor penetrating ability. However, from an application viewpoint, viscosity affects the speed with which a penetrant enters a discontinuity. Viscosity also determines how much penetrant will remain on a part surface during the dwell period. High viscosity penetrants cling to the surface, requiring increased effort for removal. Very thin penetrants (low viscosity) may drain from the part surface so quickly insufficient penetrant remains to enter into discontinuities.

2.2.3.2.1.2 Specific Gravity. Specific gravity is the ratio of the density of a substance to the density of distilled water usually measured at 60°F (15.6°C). This is also the ratio of the weight of the substance to an equal volume of water. Specific gravity has no direct effect on the performance of a penetrant. Most commercial penetrants have a specific gravity of less than one, primarily because they are made up of organic materials having low specific gravities. For this reason, water contamination sinks to the bottom of the penetrant tank.

2.2.3.2.1.3 Flash Point. Flash point is the lowest temperature at which vapors of a substance ignite in air when exposed to a flame. The flash point does not affect the performance of a penetrant. High flash points are desirable to reduce the hazard of fire. Penetrants and lipophilic emulsifiers meeting the requirements of SAE AMS 2644 have a minimum flash point of 200°F (93°C) if they are to be used in open tanks.

2.2.3.2.1.4 Volatility. The vapor pressure or boiling point of a liquid characterizes it's volatility. It is associated with the evaporation rate of liquids and is desirable for penetrant materials to have a low volatility, i.e., a high boiling point. However, in the case of petroleum products, viscosity increases as the boiling point goes up. In this group of materials, the lower viscosity is preferred because they require less penetrating time. Still, for practical purposes, high volatility should be avoided before viscosity becomes a problem. High volatility results in a loss of penetrant in open tanks and can result in penetrant drying on a part during the penetrant dwell, leaving a film difficult to remove. Entrapped, highly volatile penetrant would also have a tendency to dry or lose its liquid properties, resulting in failure to bleed back out of a discontinuity and to produce an indication. In general, low volatility provides four advantages:

- Low economic loss due to low evaporation loss.
- Low fire hazard because few flammable vapors form above the liquid.

- Low toxicity because of low hazardous vapor concentrations in the test area.
- Uniform removal and fluorescent properties because of minimal evaporation.

2.2.3.2.1.5 Fluorescent Dye Thermal Stability. The dyes used in fluorescent-dye penetrants lose their brightness or color when subjected to elevated temperature. Loss of brightness or color also occurs at moderate temperatures, but at a slower rate. This loss is termed "heat fade". SAE AMS 2644 specifies the maximum allowable brightness loss (heat fade) as a function of penetrant sensitivity. This test is performed after a penetrant has been subjected to an elevated temperature. Thermal stability is an important consideration during hot air drying before or after developer application.

2.2.3.2.1.6 Water Washable Penetrant Thermal Stability. Thermal stability is the ability of water washable penetrants to resist physical changes under normal operating (temperature) conditions. SAE AMS 2644 requires water washable penetrants submitted for qualification to be thermally cycled between 0°F and 150°F for 8-hours without separation or major degradation in performance.

2.2.3.2.1.7 Storage Temperature Stability.

NOTE

Penetrant materials, excluding dry developer, SHALL NOT be stored in direct sunlight or at temperatures above 130°F (55°C) or below 32°F (0°C).

Storage temperature stability is the ability of a penetrant to resist physical and chemical changes when stored in sealed containers within a controlled environment (i.e. typical room temperature). SAE AMS 2644 requires penetrants to resist physical changes including settling, or gelling after a 1 year storage period. Most liquid penetrant materials are not greatly affected over time as long as they are kept in closed storage containers.

2.2.3.2.2 Chemical Properties.

2.2.3.2.2.1 Chemical Inertness.

CAUTION

Penetrant materials MAY cause deterioration and damage to materials that react to hydrocarbons. Penetrant materials SHALL NOT react with the materials to be inspected.

It is necessary that the penetrant, emulsifier, and developer material be chemically inert relative to the parts being inspected. Most oil based materials meet this requirement; however, water contamination of many oils may cause the mixture to become alkaline. This is one of the reasons why water contamination must be avoided. While oily penetrant materials are generally inert to most metals, there is no one material that can be formulated for all parts. Chemical reactivity of penetrant materials must be considered whenever a new application is encountered. Some rubber (natural and synthetic) and plastic (transparent and opaque) parts are susceptible to attack by the solvents and oils in the penetrant materials. Some metals can be degraded at elevated temperatures by the trace amounts of sulfur or chlorine in conventional penetrants. Special low sulfur and low chlorine materials are available and are discussed in (paragraph 2.7.3).

2.2.3.2.2.2 Toxicity. Toxicity is the measure of adverse effects on humans resulting from contact with the material. It applies to any abnormal effects ranging from nausea and dermatitis through dysfunction of major organs, such as the liver or kidneys. It is essential for penetrant materials to be nontoxic. In qualifying penetrant materials for the QPL, the manufacturer must submit a certified statement identifying each ingredient in the product by a recognizable chemical or trade name.

2.2.3.2.2.3 Solvent Ability. The visibility of indications depends upon the fluorescent or visible dye dissolved in the penetrant oils. The oils used in penetrants must have good solvent properties to dissolve and hold the dye in solution. It must maintain the dye in solution under the wide range of temperatures encountered during transit and storage of the penetrant. If even a small amount of separation occurs, recombination may be very difficult or impossible, resulting in decreased penetrant performance.

2.2.3.2.2.4 Removability. This term describes two conflicting requirements for a penetrant: a) the ability to be removed from a surface leaving little or no residual background and b) resistance to being removed from discontinuities. In order to meet the first requirement, the penetrant must maintain the dyes in solution even when in the form of a thin film on the surface of a part and without its more volatile components lost during the dwell time. This is more difficult for water washable penetrants than postemulsifiable penetrants because the water washable penetrant does not receive the additional solvent or surfactant of the emulsifier/remover during the removal process. For water washable penetrants and postemulsifiable penetrants used with a lipophilic emulsifier, the penetrant resists removal by the formation of a gel with the penetrant/water mixture during washing that protects the penetrant in discontinuities from removal. For postemulsifiable penetrants used with a hydrophilic remover (Method D), the resistance to removal is due to the lack of diffusion of the surfactants into the surface penetrant layer, thus making only the thin surface layer emulsifiable and not the penetrant in discontinuities beneath the layer. When using solvent removable penetrants the same effect can be achieved by minimizing the amount of solvent used during the removal process.

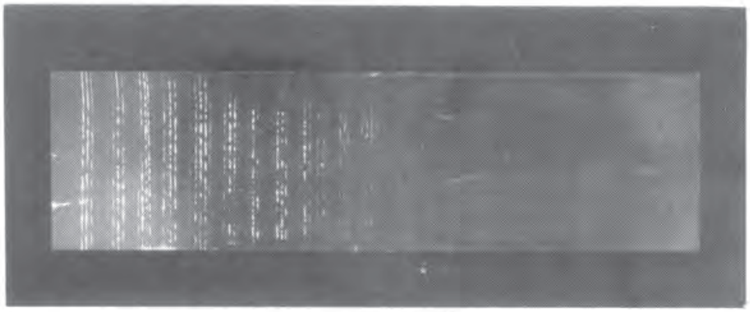
2.2.3.2.2.5 Water Tolerance. When penetrants are used in open tanks some water contamination is inevitable. Postemulsifiable penetrants are inherently tolerant to water intrusion. Since they are oil based materials, any extraneous water will settle to the bottom of the tank. Although their performance is not degraded, corrosion of the tank can occur. However, water washable penetrants contain emulsifiers and will combine with water. They can tolerate the addition of small amounts of water without losing their properties. The penetrant material procurement specification, SAE AMS 2644, requires Method A penetrants to tolerate the addition of 5-percent of water, based on volume, without gelling, separating, clouding, coagulating, or floating of water on the surface.

2.2.3.2.2.6 Mechanism of Fluorescence. The mechanism of fluorescence involves two factors: the atomic structure of the fluorescent material and the energy level or wavelength of the radiation source. The basic component of all matter is the atom that consists of protons, neutrons, and electrons. The protons and neutrons form a positively charged nucleus or core, while the negatively charged electrons circulate in orbits around the nucleus. The orbits are actually shells or rings of discrete energy levels with a definite number of electrons in each shell. A material will fluoresce only if it has a certain atomic structure: 1) the energy holding the electrons in orbit in the outer shells must be low, and 2) there must be vacant electron space in the outermost shell. When a photon of electromagnetic radiation from an X-ray or ultraviolet light impacts an electron in an atom of fluorescent material, the electron absorbs some of the photon energy and jumps from its natural shell to a higher energy shell. The electron is unstable in this condition and immediately returns to its natural shell or orbit. In returning to equilibrium, the electron releases its excess energy as electromagnetic radiation. The released electromagnetic energy always has a longer wavelength than the exciting radiation. Thus, ultraviolet radiation with a wavelength of 365 nm (nanometer, a unit of length) causes some fluorescing materials to release energy that has a longer wavelength of 400 to 700 nm. This is the wavelength range of visible light. The human eye is most sensitive to yellow-green light at approximately 510-560 nm in darkness. Most dyes are formulated to emit this range.

2.2.3.2.2.7 Brightness. One of the more important factors responsible for the effectiveness of the penetrant process is the visibility of the indication. Penetrants containing fluorescent dyes are not especially visible under white light. However, when subjected to near ultraviolet (365 nm) radiation (UV-A), the dyes emit visible light. Some dyes emit more visible light per unit of ultraviolet energy than others. In addition, the amount of light given off is proportional to the amount of dye in the penetrant. Brightness is a measure of the amount of visible light given off when fluorescent dye is exposed to ultraviolet radiation. It is controlled by the particular dye’s efficiency in converting ultraviolet radiation into visible light and by the quantity of dye dissolved in the penetrant. High efficiency dyes are brighter than low efficiency dyes when exposed to the same wavelength and intensity of ultraviolet radiation.

2.2.3.2.2.8 Ultraviolet Stability. Fluorescent dyes lose their ability to fluoresce after prolonged exposure to ultraviolet radiation. Resistance to this loss is termed ultraviolet stability. SAE AMS 2644 requires a diluted sample of fluorescent penetrant to retain a minimum brightness, after a 1 hour exposure to 800 $\mu W/cm^2$ (micro-watts per square centimeter) of ultraviolet (UV-A) exposure.

2.2.3.2.2.9 Penetrant Sensitivity. The term "sensitivity", when used to describe a penetrant performance characteristic, is the ability to produce indications from very small, tight cracks. This characteristic involves the combined properties of penetrating ability and brightness. The flaw opening in discontinuities is usually restricted, and the void volume is such that only a very small amount of penetrant can be entrapped. The penetrant must enter and exit the flaw with enough dye to produce a noticeable indication.



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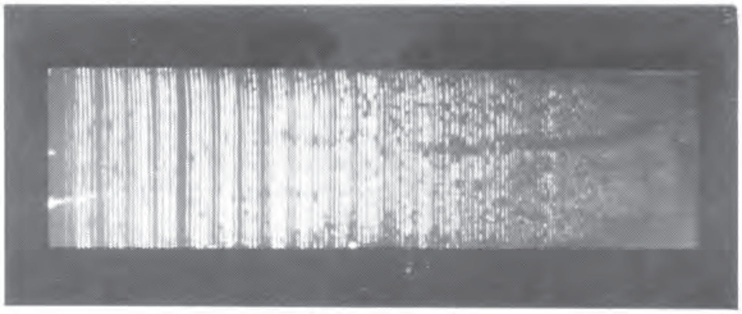

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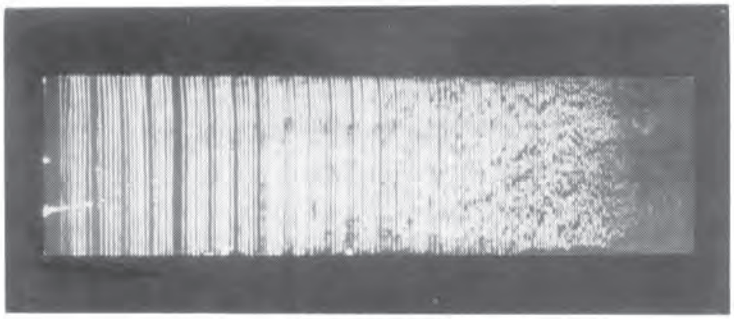

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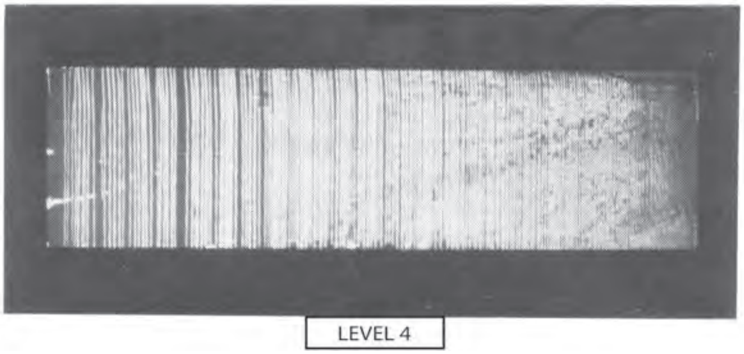


LEVEL 4

Figure 2-5. Indications Produced by Penetrant of Four Different Sensitivity Levels Using Dry Developer

2.2.4 How Liquid Penetrant Enters Discontinuities. If one end of a capillary tube is closed, such as occurs in the case of a flaw, the capillary rise is affected by compression of the air trapped in the closed end. The phenomenon of capillary action enables penetrant to enter a flaw, even in an inverted position, such as on a lower wing surface. However, flaws are not capillary tubes as the sides are not parallel and are not circular. The ability of penetrant to successfully enter and exit discontinuities is dependent on a number of factors. The points to remember about penetrant entry into discontinuities are as follows:

- A high surface tension and small contact angle are desirable in a penetrant, however these are conflicting properties. High surface tension tends to increase contact angle and decrease wetting ability, but enhances drawing penetrant into wetted areas.
- Capillary force increases with smaller flaws.
- Viscosity does not affect the penetrating ability but it can affect the time required for penetration.
- Shape of a discontinuity can affect penetrant entry.
- Temperature affects the surface tension.
- Roughness of the flaw walls will impede penetrant entry.
- Contamination in the flaw can impede penetrant entry.
- Residual cleaning solution in the flaw can impede penetrant entry.

2.2.5 Mechanisms and Principles of Penetrant Removal.

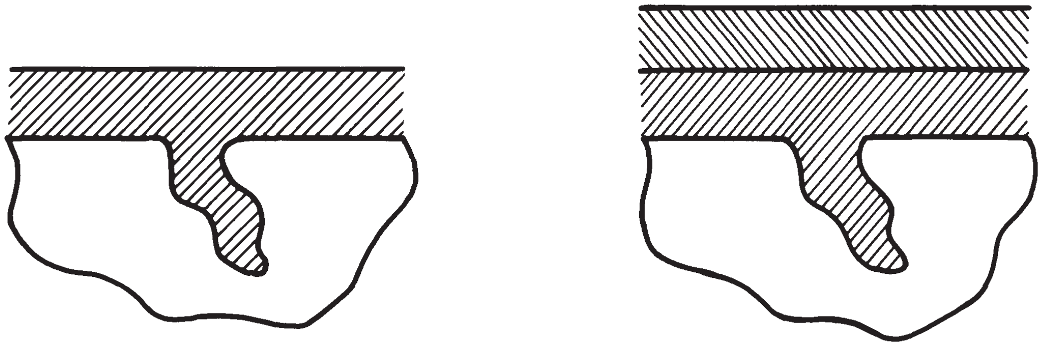
2.2.5.1 Mechanisms of Method "A" Water Washable Penetrant Removal. Water washable penetrants contain an emulsifying agent. Following the penetrant dwell time excess Method A penetrants are removed with a water spray. The water washable penetrant is converted into small, suspended oil droplets by the mechanical force of the water spray. A separate process step of applying emulsifier is not required. Water washable penetrants are often called "self-emulsifying" and are one of the most widely used NDI methods. Water washable penetrants exist in all penetrant system sensitivity levels.

2.2.5.1.1 Method "A" Emulsification. Generally, oil and water do not mix; however, this is not always the case. If equal amounts of oil and water are placed in a bottle, they will immediately separate into two distinct layers. If the bottle is shaken, the oil will form into globules, which are dispersed throughout the mixture. When the bottle is allowed to rest, the globules will rise to the surface and reform into a separate oil layer. The process of the globules combining to form this layer is called coalescence. If the amount of oil is small compared to the quantity of water, and the bottle is violently shaken, the oil will be separated into very small droplets. On standing, most of the droplets will coalesce at a slower rate than previously described. However, some of the very small droplets will remain suspended in the water giving it a cloudy or milky appearance. Depending on the droplet size, it may require an extremely long time for separation to take place. This cloudy water mixture is called a colloidal suspension and the process by which it is formed is termed emulsification. Certain chemicals have the ability to combine with oily materials to form an easily emulsifiable mixture. This is the case when an emulsifier is applied to a penetrant on a part. The penetrant is oil that repels water and resists removal. However, when combined with an emulsifier, the resulting colloidal mixture can be removed with a water spray.

2.2.5.2 Mechanisms of Method "B" and Method "D" Penetrant Removal.

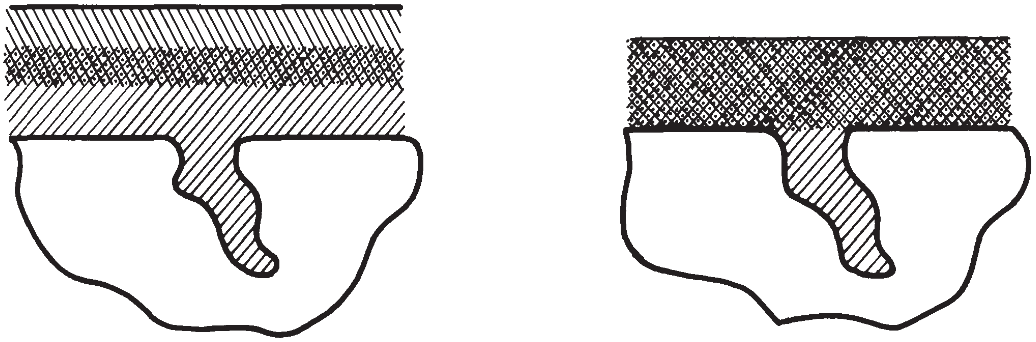
2.2.5.2.1 Lipophilic Emulsifier (Method "B") Mechanism and Modes of Action. The lipophilic emulsifier has two primary modes of penetrant removal, chemical diffusion, and draining. These processes are described as follows:

2.2.5.2.1.1 Mode 1 - Chemical Diffusion. For lipophilic emulsifiers, diffusion into the oil-base penetrant is the primary mode of action. Diffusion is the intermingling of molecules or other particles as a result of their random thermal motion. If two miscible (capable of being mixed) liquids or gases are placed in a container, they will eventually mix into a uniform solution. For example, if a sugar solution (a heavy solution) is placed in the bottom of a glass, and plain water (lighter medium) is placed on top, the sugar will migrate across the boundary. After a period of time, the entire quantity of liquid will reach a nearly uniform concentration. This is what happens when emulsifier (Method B) is applied to a layer of penetrant on a part (Figure 2-6).



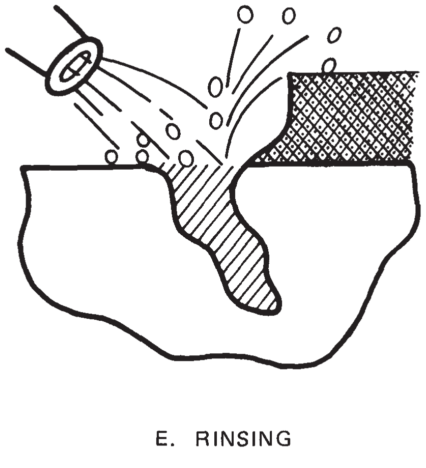
A. APPLY PENETRANT

B. APPLY EMULSIFIER



C. DIFFUSION

D. DIFFUSION COMPLETE



E. RINSING

H0400324

Figure 2-6. Diffusion of Emulsifier Into Penetrant During Lipophilic Emulsifier Dwell

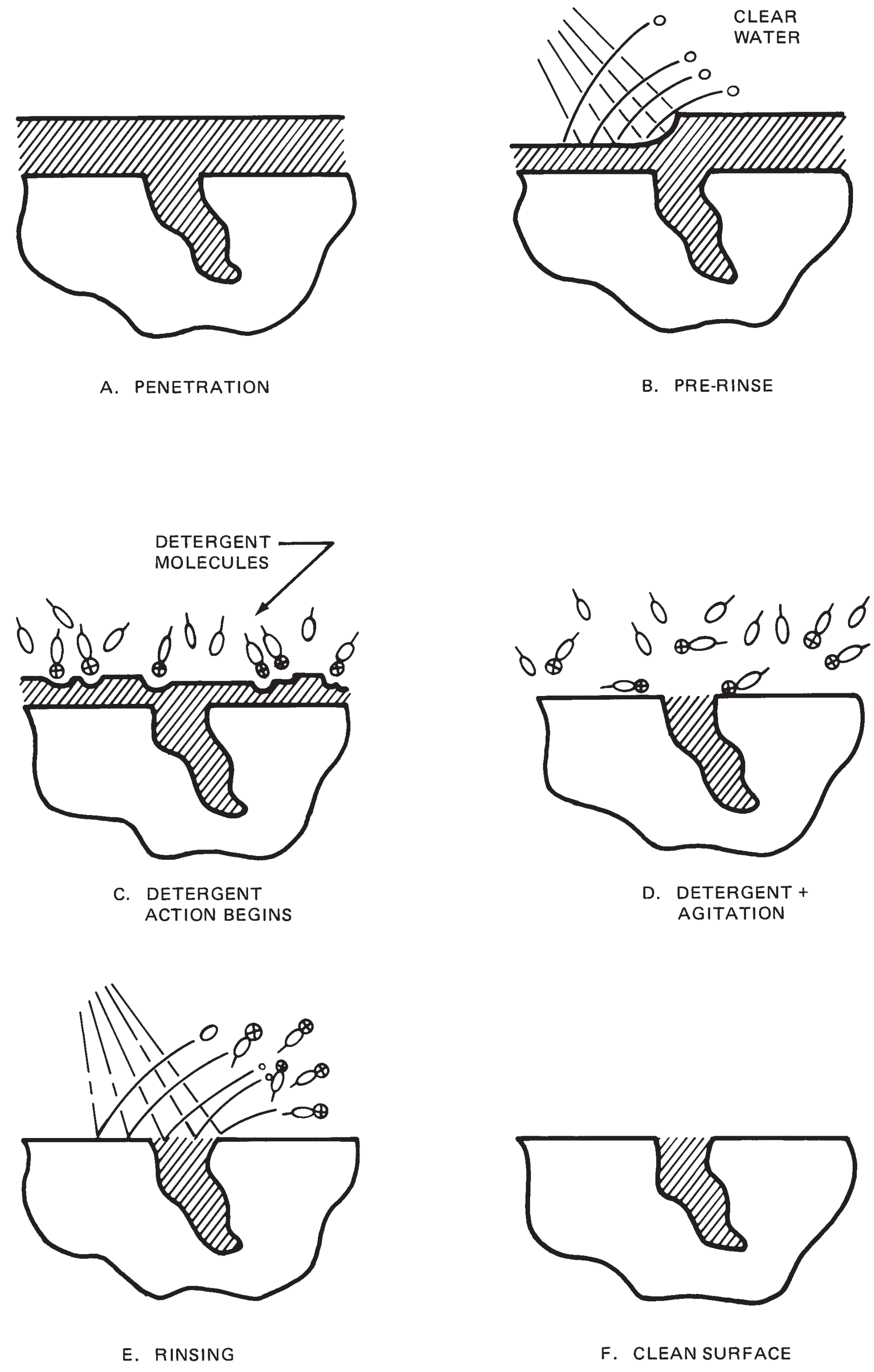
2.2.5.2.1.2 Mode 2 - Drain and Dwell.

NOTE

Parts SHALL NOT remain in the emulsifier and care SHALL be exercised to prevent pooling in cavities during the dwell.

It was once thought emulsification occurred only through the chemical action of diffusion. It should be recognized a second mode of emulsification is also involved. This mode occurs as the emulsifier drains from the part surface during the dwell period. As the emulsifier drains, the movement carries with it considerable surface penetrant. This scrubbing or mechanical action reduces the amount of penetrant to be emulsified and also initiates the chemical or diffusion action. Without this mixing action, emulsifier dwell time might be as long as ten or twenty minutes. It is for this reason parts SHALL NOT be left in the emulsifier and care SHALL be exercised to prevent pooling in cavities during the dwell.

2.2.5.2.2 Hydrophilic Remover (Method "D") Mechanism and Mode of Action. Hydrophilic removers are basically detergent/dispersing concentrates consisting of water-soluble chemicals, usually non-ionic surface-active agents called surfactants. They are supplied as concentrated liquids and are mixed with water either before or during the removal process. The surface-active agent in the remover displaces a small quantity of penetrant from the surface and disperses or dissolves it, preventing it from recombining with the remaining penetrant layer. Unlike lipophilic emulsifier, hydrophilic remover is immiscible with penetrant and diffusion does not occur. All of the removal action takes place at the exposed surface, and penetrant just below the surface is not involved until it becomes exposed. Gentle agitation of the liquid helps remove the displaced penetrant and allows fresh remover to contact the remaining penetrant layer. The action stops when the part is withdrawn from the remover. This process is significantly different from lipophilic emulsifiers that become active after withdrawal and during drainage. Hydrophilic remover action is illustrated (Figure 2-7).



A. PENETRATION

B. PRE-RINSE

C. DETERGENT ACTION BEGINS

D. DETERGENT + AGITATION

E. RINSING

F. CLEAN SURFACE

H0400325

Figure 2-7. Action of the Hydrophilic Remover Process

2.2.5.2.3 Solvent Removable (Method "C") Mechanism and Mode of Action. The solvent-wipe method for removal of excess surface penetrant relies on a combination of dilution and mechanical action. Solvent removers are formulated to dissolve and dilute surface penetrant to enable effective absorption and removal by wiping the surface with a solvent dampened rag or towel. Desirable properties are low toxicity, solvency for liquid penetrant, and a compromise between maximum drying speed and minimum fire hazard.

2.2.6 Mechanisms of Developer Action.

2.2.6.1 Functions of a Developer. The basic function of all developers is to improve the visibility of the entrapped penetrant indication. The improvement in visibility is achieved through a number of mechanisms including the following:

- Assist in extracting the entrapped penetrant from discontinuities.
- Spread or disperse the extracted penetrant laterally on the surface, thus increasing the apparent size of the indication.
- Improve the contrast between the indication and the background.

2.2.6.1.1 Adsorption and Absorption. The mechanism of development is a combination of both adsorption and absorption (Figure 2-8). Adsorption refers to the collection of a liquid on the outer surface of a particle due to adhesive forces. This action contributes to the developer particle build-up at a crack as the particles adhere to the exuded penetrant. Absorption refers to the blotting action that occurs when a liquid merges into an absorbent particle.

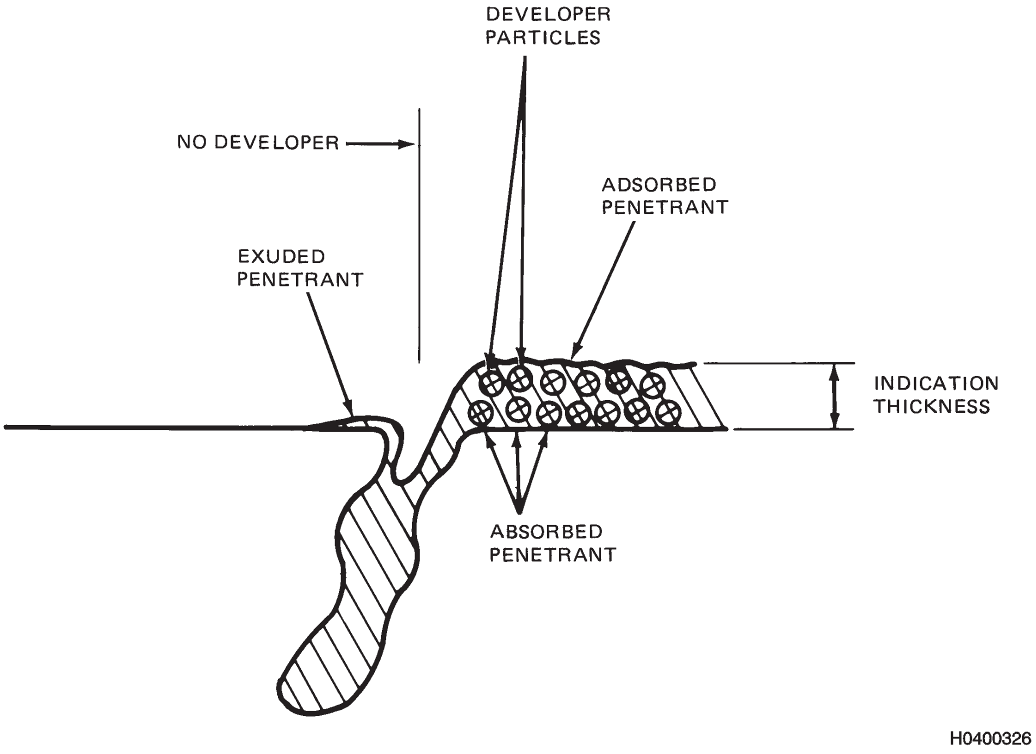


Figure 2-8. The Effects of a Developer

2.2.6.1.2 Contrast Enhancement. Developers improve the visibility of indications by providing a contrasting background. They reduce reflections from a part surface and appear blue-black under UV-A illumination. The blue-black background provides a high contrast with the fluorescent yellow-green penetrant indication. Water-suspended and some nonaqueous developers produce a solid white coating, which provides a contrasting background for red visible-dye penetrant.

2.2.6.1.3 Solvent Action. Nonaqueous developers contain solvents that hold the developer particles in suspension. When sprayed on the part, the solvent combines with any entrapped penetrant, diluting it. This increases the volume and reduces the viscosity of penetrant that exudes from the discontinuity, thus improving the visibility of the indication. Nonaqueous developers are capable of providing the highest sensitivity of any of the developer forms.

2.2.6.1.4 Scattering of Light. The developer particles scatter both the incoming ultraviolet light and the exiting visible light. This property enhances the brightness of a fluorescent indication by causing more of the ultraviolet light to be absorbed by the penetrant and more of the visible (fluorescent) light to escape the penetrant layer and reach the inspector's eye.

2.2.7 Cleaning and Surface Preparation.

2.2.7.1 Responsibility for Cleaning and Surface Preparation.

CAUTION

> Due to the various and potentially catastrophic effects various surface preparation processes may have on different materials, only properly trained personnel SHALL accomplish surface preparation processes. This training SHALL be documented in personnel training records. Nondestructive inspection personnel are neither trained nor experienced in performing paint stripping or cleaning.

Properly performing surface treatment operations, such as paint stripping and cleaning of military system metals and alloys, require skill and knowledge. Improper methods, materials, or procedures can result in severe damage to surfaces and parts.

2.2.7.2 Need for Clean Surfaces. The proper preparation of parts prior to inspection is critical. Successful detection of discontinuities by penetrant inspection depends upon the ability of the penetrant to enter and exit from the discontinuity. The resulting indication must be readily distinguishable from the background. Surface conditions, such as coatings or soil contamination, can reduce the effectiveness of the inspection by interfering with the entry and exit process or producing a high residual background. Penetrant inspection is reliable only when the parts to be inspected are free of contaminants. Foreign material, either on the surface or within the discontinuity, can produce erroneous results. Proper cleaning or surface treatment prior to penetrant application must remove any interfering conditions.

2.2.8 Surface Conditions Affecting Penetrant Inspection. There are three general categories of surface condition that have detrimental effects on penetrant inspection. These conditions are classified as contaminants/soils, coatings, and surface deformation. Each of these conditions can negatively affect penetrant inspection and must be corrected before penetrant inspection can be properly performed. The following sections provide a discussion of each category and highlight the methods used to correct these conditions.

2.2.9 Contaminants and Soils. In this section, the terms "contaminants" and "soils" are used interchangeably and refer to matter on a part or component that may affect the penetrant testing process. Contaminants may be intentionally applied, such as greases or corrosion prevention compounds, which may result from prior processes, such as heat-treating, or cleaning, or may be the consequence of service, e.g., corrosion, carbon deposits, lubricating fluids, or dirt particles. The effects of contaminants on the penetrant inspection process depend on the type of soil and whether it is on the part surface or entrapped in a discontinuity.

2.2.9.1 Contamination/Soil Removal - Factors in Selecting a Cleaning Process.

CAUTION

- Improper cleaning methods can cause severe damage or degradation of parts. Only properly trained/qualified personnel SHALL select or apply cleaning processes. This training SHALL be documented in personnel training records.

- The success of any penetrant inspection procedure depends upon the cleanliness of the part surface and discontinuities being free of any contaminants or soils. There are a variety of cleaning methods which may be utilized. The methods are generic and are used principally for corrosion prevention and preparation of items for surface treatments. The most common cleaning methods are discussed in the following paragraphs.

2.2.9.1.1 Cleaning is a broad term covering methods and materials used to remove contaminants or soils from a surface. Cleaning is routinely used for corrosion control and to prepare surfaces for other treatments. There are no special methods or materials specifically dedicated to penetrant inspection. Different materials and parts require separate or individual cleaning processes. No one cleaning method is equally effective on all contaminants. The selection of a suitable cleaning process is complex and depends on a number of factors, such as:

- Type of soil(s) or contaminant(s) to be removed.
- Part material - Strong alkaline or acid cleaners can attack some nonferrous metals, e.g., aluminum and magnesium. Steels, especially in the heat-treated condition, are likely to become embrittled by acid cleaners. Cleaning compounds containing halogen and sulfur compounds can attack other metals, e.g., titanium and high nickel alloys, if residual cleaning compounds are present and are exposed to high temperatures.
- Part surface condition - Rough surfaces tend to hold soil, making it harder to remove.
- Part surface accessibility and geometry - Complex shapes make it difficult to clean all of the surfaces, and soils lodged in restricted areas may escape the effects of cleaning.
- Required degree of cleanliness - The degree of cleanliness may be dictated by the postpenetrant inspection surface treatment or the service conditions the component will encounter.
- Availability and adequacy of cleaning facilities - For example, a large part cannot be placed in a small alkaline or ultrasonic cleaning tank.

2.2.9.2 Types of Contaminations and Soils.

2.2.9.2.1 Light Oils and Soft Films. Examples of light oils and soil films are: hydraulic oils, lubricating oils, machining and cutting fluids, thin greases, e.g., petroleum jelly, and film corrosion preventive compounds.

2.2.9.2.1.1 Effect: Light oils and soft films have several adverse effects on the penetrant inspection process. They readily enter surface openings, thus reducing or preventing penetrant entrapment. Oily materials on the part surface interfere with mechanisms which enable penetrants to enter and exit from discontinuities. Also, many oils and greases fluoresce under UV-A illumination. When on a part surface, this fluorescence could obscure a discontinuity indication or produce a false indication.

2.2.9.2.1.2 Removal: Oils and soft films may be removed by solvent washing, aqueous degreasing, or by ultrasonic cleaning with detergent or solvent. Vapor degreasing was the most effective method but has been discontinued due to environmental damage caused by the release of 1-1-1-Trichloroethane into the atmosphere. When present as thin films, these contaminants are easily removed by solvents. However, when they contain solid particles, e.g., metal chips, sand, or dirt, removal is more difficult. The oily phase is readily removed, leaving the solid particles adhering to the surface. Removal of the solid particles may require a mild mechanical action, e.g., hand wiping, pressure spray, solution agitation, or ultrasonic vibration.

2.2.9.2.2 Heavy Oils and Solid Films. Examples of heavy oils and solid films are viscous oils, thick greases, hard film corrosion preventative compounds, and particulate lubricants such as graphite and molybdenum disulfide. These contaminants or soils are more difficult to remove than light oils.

2.2.9.2.2.1 Effect: Heavy oils and solid films have the same adverse effects on penetrant inspection as light oils and soft films. Heavy oils and films on the surface of a part, even in trace amounts, interfere with the entry and exit of penetrant discontinuities. The heavy oils and greases are viscous and flow very slowly; many of them have excellent penetrating ability and readily enter surface discontinuities. Many heavy oils and semi-solid films fluoresce under UV-A illumination. This fluorescence can obscure valid indications and produce false indications.

2.2.9.2.2.2 Removal: Complete removal may require solvent or chemical action plus considerable mechanical action. Mechanical action can be solution agitation, manual scrubbing or pressure spraying. Cleaning for penetrant inspection presents special problems. Removal of heavy oils requires considerable mechanical action where the forces are concentrated at the surface. Use of excessive mechanical forces to remove heavy oils and films may further aggravate problems by smearing metal over narrow discontinuities.

2.2.9.2.3 Carbon, Varnish, and Other Tightly Held Soils. Examples of origins of carbon, varnish, and other tightly held soils are; partially burned petroleum and other combustion products, residues from evaporated fuel and oils, and dry film lubricants. The soils may have been baked at elevated temperatures to form a vitreous or glass-like coating.

2.2.9.2.3.1 Effect: Tightly held soils, e.g., carbon, engine varnish, and other dry soils, can seriously interfere with the penetrant inspection process. The soils can bridgeover or partially fill the discontinuity, blocking or reducing the amount of penetrant in the void. When on the part surface, soils interfere with the forces or mechanism causing penetrant entry and exit from discontinuities. When dry, they tend to absorb moisture that also interferes with penetrant entry and exit. As surface contaminants, soils retain the penetrant, leading to a residual background and false indications during inspection.

2.2.9.2.3.2 Removal: Carbon, varnish, and tightly held soils are generally adherent and are difficult to remove. The soils require special cleaning compounds and processes to dissolve and loosen the soil. There are special solvent and alkaline cleaners for baked soil removal. Many of the paint removal materials and processes are used in removing carbon, varnish, and other tightly held soils that are not baked. Strong mechanical action, such as scrubbing, pressure spray, or solution agitation may also be required. Care must be used, since many of the cleaning compounds will attack metals and alloys.

2.2.9.2.4 Scales, Oxides, and Corrosion Products. Scale and oxides generally occur as a result of exposure to high temperatures.

2.2.9.2.4.1 Effect: Scale, oxides, and corrosion products can bridge or partially fill discontinuities restricting penetrant entry. When on the part surface, they interfere with the mechanism of penetration, impeding both penetrant entry and exit from discontinuities. They also retain penetrant on the surface, leading to a high residual background and false indications. Stress corrosion products occur within the flaws and may be impossible to completely remove. Penetrant inspection for stress corrosion cracking flaws generally requires extended dwell times to permit penetrant entry.

2.2.9.2.4.2 Removal: Scale and oxides are usually very difficult to remove and may require aggressive cleaning methods, such as acid pickling, abrasive blasting, or other metal removal operations. Some of these processes will have an adverse effect on the penetrant inspection process and should be avoided. Corrosion products, particularly from stress corrosion, often occur or are lodged within discontinuities resulting in removal problems.

2.2.9.2.5 Water or Moisture. Water or moisture on a part can occur from many sources. The most common source is inadequate drying after aqueous (water solution) cleaning.

2.2.9.2.5.1 Effect: Water or moisture on the part surface or in the discontinuity seriously interferes with the penetration process. It is essential that water be removed not only from the part surface but also from the inside of any discontinuities that may be present. Moisture in the form of condensation from high humidity or low temperatures may occur and must be removed.

2.2.9.2.5.2 Removal Method: Thorough drying of the component in an oven is the most effective method of removing water from part surfaces and within discontinuities.

2.2.9.2.6 Residues From a Cleaning Process. Effect: The chemicals used for cleaning solutions may contain strong alkalis and acids. If not completely removed from the part surface before penetrant inspection, they can interfere with the penetrant process in several ways. Residues can impede surface wetting and prevent the penetrant from evenly coating the inspection area. They also interfere with the mechanism causing the penetrant to enter and exit discontinuities. Strong alkalis and acids can decompose or degrade dyes and other chemicals in the penetrant, causing weak or faint indications. Chromate residues absorb UV-A, leaving less energy to excite the fluorescent dyes in the penetrant. Therefore, removal or neutralization of residual solution is always important and often imperative.

2.2.9.2.6.1 Removal: Complete removal of all cleaning process residues is very important. The usual process to accomplish removal is through the use of warm water and agitation followed by repeated immersions in fresh water. In some cases, residues of strong alkalis and acids are subjected to a rinse with a weak-neutralizing solution followed by fresh water rinses.

2.2.9.2.7 Residues From Previous Inspections. Residues from previous penetrant inspections can affect subsequent inspection results and the serviceability of the part. The effects of residues from previous penetrant inspections are discussed in the following paragraphs.

2.2.9.2.7.1 Inadequate Post-Inspection Cleaning Effects on Subsequent Inspections. If the post-inspection cleaning is inadequate, the residues must be considered as contaminants during a subsequent penetrant inspection. Developer residues on the part surface will retain penetrant causing a high residual background that can obscure valid indications. When retained in crevices, joints or faying surfaces, developer residues will cause false indications. Developer residues also absorb and retain moisture and, if not dried, may cause corrosion of the part. Penetrant residues, if not removed from discontinuities, will dry forming a varnish-like material in the flaw. This entrapped residue may not fluoresce and will reduce or prohibit entry of penetrant during future tests of the part.

2.2.9.2.7.2 Visible-Dye Penetrant Contamination.

CAUTION

DOD prohibits the use of Type II, visible-dye penetrant on aircraft, engine, and missile parts. Visible-dye penetrants SHALL NOT be used without specific engineering approval.

The red dye in visible-dye penetrant acts as a filter to UV-A radiation. When red dye residues mix with fluorescent penetrant in a discontinuity, the fluorescent brightness can be reduced or destroyed. Visible-dye penetrant SHALL NOT be used if the part may be inspected with fluorescent penetrant at some future time. If a part has been previously inspected with visible penetrant and requires re-inspection, the re-inspection should be performed using visible-dye penetrant. If fluorescent penetrant inspection is required to achieve the required sensitivity, special cleaning processes SHALL be used to ensure removal of all visible penetrant residues from previous inspections.

2.2.9.3 Cleaning Methods for Contamination/Soil Removal.

2.2.9.3.1 Alkaline Cleaning.

CAUTION

- With water based cleaning processes, drying time and/or temperature SHALL be sufficient for entrapped water to evaporate from within discontinuities before applying penetrant. A visibly dry surface may not be sufficient. Local procedures should specify minimum drying parameters.

- Some alkaline cleaning compounds will attack aluminum parts and components. Care SHALL be used in selecting the proper cleaning process for the materials to be cleaned. Traces of cleaner alkali remaining on test components after rinsing are objectionable because they might cause dermatitis or other health hazards or interfere with the action of liquid penetrants during the penetrant inspection operation.

- Aqueous cleaners containing silicates SHALL NOT be used before penetrant inspection. Cleaners with high silicate content can leave silicate residues in discontinuities blocking the penetrant from entering.

Alkaline cleaners are water solutions of chemicals, which remove soils by a chemical action such as saponifying (converting chemicals into soap) or displacement rather than dissolving the soils. Cleaners of this type usually have components to aid in lifting the soils from the part surface. After displacement, the soil may be carried as a suspension in the cleaner, it may separate, or in the case of fatty soils, react with the cleaner to form water-soluble soaps. Alkaline cleaning is usually accomplished in immersion tanks with the solution at or near its boiling point. The cleaning action is expedited by agitation. The four variables that affect the performance of an alkaline cleaning process are immersion time, agitation aggressiveness, solution concentration, and solution temperature. The cleaning process is more effective when each of these factors are increased. Following alkaline cleaning, parts and components must be thoroughly rinsed to remove any traces of the cleaning compound prior to penetrant inspection.

2.2.9.3.2 Steam Cleaning.

CAUTION

- Due to the risk of changes to material properties due to elevated temperature exposure, the Aircraft Corrosion Control Manual (NAVAIR 01-1A-509-1/TM 1-1500-344-23-1/TO 1-1-689-1) and (TO 1-1-691) restricts the use of steam cleaning.
- Steam cleaning SHALL NOT be used on aircraft and missile components unless specifically authorized. Elevated temperature exposure can result in changes to material properties, in addition steam cleaning can cause damage to composite structures, sealant, acrylic windows, and electrical wiring. Steam cleaning erodes paint, crazes plastic, debonds adhesives, damages electrical insulation, and drives lubricants out of bearings.
- Steam cleaning is a form of alkaline or detergent cleaning. Diluted solutions of alkaline cleaners, detergent cleaners, or mixtures of both are injected into a live steam spray. The steam/cleaner mixture is under pressure and the jet is directed at the part surface by a spray wand. Steam cleaning provides both chemical and strong mechanical action at elevated temperatures. Mobile steam generators permit application on parts and structures that cannot be brought into the cleaning shop.

2.2.9.3.3 Detergent Cleaning.

CAUTION

Detergent cleaners may be alkaline, acidic, or neutral but SHALL be non-corrosive to the material being inspected.

Detergent cleaners are water-based chemicals called surfactants, which surround and attach themselves to particles of surface soil. Solution agitation, pressure spray, or hand wiping then washes the particles of soil and detergent away. The action is identical to hydrophilic removers in the penetrant process. The cleaning properties of detergent solutions facilitate complete removal of light soils from the part surface, preparing it for penetrant inspection.

2.2.9.3.4 Emulsion Cleaning. Emulsion cleaners consist of an organic solvent and a detergent in a water-based solution. The organic solvent may be a petroleum-based liquid. The soils are removed through a combination of solvent and detergent action. The cleaner is lightly alkaline and is usually sprayed on the part. Emulsion cleaning may leave a light oil film (solvent residue) on the part surface; therefore, emulsion cleaned parts SHALL be hot water rinsed or wiped with a solvent to remove the oily residue prior to penetrant inspection.

2.2.9.3.5 Solvent Cleaning. Solvent cleaning removes soils by dissolving them. Solvents can be used on oils, greases, waxes, sealants, paints, and general organic matter. The resulting solution may leave a thin film or residue of an oily nature. This oily film must be removed with another solvent, vapor degreasing, alkaline, or detergent cleaning prior to penetrant inspection. Solvent cleaning may be accomplished by tank immersion, but more often applied by spraying or hand wiping when alkaline, detergent, or vapor degreasing is impractical.

2.2.9.3.6 Vapor Degreasing.

CAUTION

> Titanium alloys must not be placed in a vapor degreaser or exposed to halogenated solvents. Halogenated solvents are those containing chlorine, fluorine, or other halogens.

In vapor degreasing the hot vapors of a volatile solvent are used to remove oils, greases, and waxes from metallic test objects in preparation for liquid penetrant testing. A steel tank fitted with a heater, solvent reservoir, condensing coil, and removable cover is used to heat the solvent to boiling, generating a vapor zone above the solvent. The vapor condenses on the relatively cool metal surface of parts placed in the vapor zone. The condensed solvent dissolves the organic contaminants on the part. Contaminated solvent condensation then drips back into the tank reservoir, carrying the contaminants into the bath. During evaporation only clean solvents are produced so the test parts are exposed to only clean soil-free solvent. Vapor degreasing is particularly suitable for removal of soluble organic contaminants, such as mineral oils, and greases. Vapor degreasing is not effective for removal of solid contaminants (carbon, varnish, paints, scale, corrosion products, or oxides). In some cases, restrictions are placed on vapor degreasing of chloride sensitive metals and alloys with halogenated degreasing solvents.

2.2.9.3.7 Ultrasonic Cleaning. This method utilizes ultrasonic agitation within a solvent detergent solution to accelerate the cleaning process. The agitation is the result of cavitations of the liquid when subjected to the high and low pressure (partial vacuum) of the ultrasonic waves. The formation and collapse of the cavities in the liquid provides a scrubbing action to the surface of the part. The agitation increases action of the cleaning solution and decreases cleaning time. Ultrasonic cleaning is particularly effective in removing contaminants trapped in discontinuities; however, its effectiveness is dependent upon the cleaning medium. It should be used with water and detergent on inorganic soils, e.g., rust, dirt, salts, and corrosion products. It should be used with an aromatic or halogenated solvent if the soil to be removed is organic, such as oil or grease. Ultrasonic cleaning has limitations, which affects its efficiency, part size, configuration, and the effectiveness of the cleaning solution for the type of soil to be removed.

2.2.9.3.8 Salt Bath Descaling and Deoxidizing. Molten salt baths are used for removing heavy, tightly held scale, and oxide from low alloy steels, nickel, and cobalt base alloys, and some types of stainless steel. Salt baths cannot be used on aluminum, magnesium, or titanium alloys. The process involves immersing the parts in molten caustic soda at about 700°F (370°C). The difference in thermal expansion between scale and base metal separates some scale and causes the remainder to crack. The molten caustic soda also chemically reacts with the scale, reducing it to lesser oxides and metals. When the part is removed from the molten salt, it is plunged into water creating a thermal shock. Various amounts of scale can be blasted off as steam at the part surface, scours remaining scale from the part. Following quenching, the parts are rinsed in clean water.

2.2.9.3.9 Acid Cleaning.

CAUTION

> Acid cleaning requires very careful control of procedures and solutions to prevent damage to the parts. Acid cleaning SHALL BE conducted ONLY by properly trained/qualified personnel.

Solutions of acids or their salts are often used to remove rust, scale, corrosion products, and dry shop soils. The type of acid and its concentration depends on the part material and contaminant to be removed. Acid cleaners are not generally effective on oily soils. Oils and greases must first be removed by some other cleaning method so the acid can react with the scale, oxides, or other tightly held soil.

2.2.10 Coatings.

NOTE

- Penetrant inspection SHALL NOT be performed on painted components or on parts contaminated with sealant unless these coatings and their residues are completely removed.
- Penetrant inspection SHALL NOT be performed on ion vapor deposition (IVD) coated components, or on chrome, cadmium plated, or high velocity oxi-fuel coated components unless specifically authorized by technical directive. Penetrant inspection SHALL NOT be performed on IVD coated components that have been abrasively blasted. IVD aluminum coatings are often not visually apparent. Therefore, the inspector SHALL obtain a determination before inspecting.
- Removal of conversion coatings such as alodine and anodize is not required prior to penetrant inspection provided the coatings do not result in excessive penetrant background that would interfere with the inspection. If the presence of conversion coatings results in excessive penetrant background they SHALL be removed prior to penetrant inspection. Obtain engineering direction prior to removing anodize.

Surface coatings (e.g., paint, anodize, ion vapor deposition (IVD) coatings, chrome plating, high velocity oxi-fuel (HVOF) coatings, etc.), are intentionally applied to the part surface to provide corrosion or wear protection. However, they can have several adverse effects on the penetrant inspection process. Many of the coatings such as paint, fuel sealant, and IVD coatings are elastic or are more ductile than the substrate and may not form openings when the base metal cracks from service stress. When this occurs, the surface opening is bridged or covered, preventing penetrant entry. On aluminum components with IVD aluminum coating, inspection with eddy current is recommended to supplement penetrant inspection in critical locations. IVD aluminum coatings are pure aluminum, are more ductile (deforms more easily) than the aluminum alloy substrate, and may conceal tight fatigue cracks from detection by penetrant. In addition, abrasive blasting (even relatively gentle PMB) of an IVD coated surface peens the soft aluminum surface to the extent that commonly used pre-penetrant chemical etching processes are insufficient to open cracks. Hard coatings such as chrome plating, HVOF coatings may often crack before the substrate due to contact wear or coating damage. Damage or cracking of these hard surface coatings can result in excessive non-relevant indications or may interfere with proper interpretation of relevant indications. Some hard anodize coatings and paint (especially when oxidized or weather checked) can retain penetrant during removal causing high residual background or false indications. Chrome, HVOF, IVD, anodize, and alodine coatings require specialized electro-chemical or mechanical removal methods and will not be discussed further in this document. Consult the responsible engineering authority for removal of these surface treatments. Typical methods for removal of paint, primer, and fuel sealant are discussed in the following paragraphs.

2.2.10.1 Coating Removal Methods. There are a large variety of paint coatings, primers, fuel sealant, and finish systems in use on aircraft parts and surfaces. Some conventional coatings are readily removed using standard methods, however, advances in technology have resulted in finishes that can only be removed with unique materials and techniques. There are three general types of coating removal methods: (1) chemical, (2) mechanical, and (3) burning or ignition. Critical structures cannot tolerate the use of products that may be damaging to their metals or alloys. This requires careful attention when using abrasive techniques or chemical methods which may remove, etch, or embrittle the substrate.

2.2.10.1.1 Chemical Paint Stripping.

WARNING

When solvent removal techniques are used, it is essential to remove traces or residues of the solvents and other contamination using cleaning techniques discussed previously.

CAUTION

Paint strippers often contain toxic materials. Furthermore, only properly trained personnel SHALL accomplish surface preparation processes due to the various and potentially catastrophic effects various chemical paint strippers may have on different materials. This training SHALL be documented in personnel training records. NDI personnel are neither trained, nor experienced in performing paint stripping or cleaning.

NOTE

Many paint removal operations leave a thin film of dissolved or softened paint and remover chemicals on the part surface or in discontinuities. This often occurs when local or spot paint removal is performed. Care must be taken to ensure the area to be inspected is free of paint and remover residues since they interfere with the penetrant inspection process.

Chemical stripping is the preferred method for paint removal prior to penetrant inspection as it will not result in mechanical deformation of the substrate surface and if controlled properly, will result in a very clean surface. Various chemical paint strippers are available for both dip tank and in-place applications. There are two basic chemical paint stripping methods, solvent strippers and alkaline/acid strippers. The primary factors that influence the ease of paint removal include: (1) surface preparation before painting, (2) type of paint primer, (3) type of paint used, (4) number of paint coats, (5) age or cure of the paint finish, (6) type of paint removers used, and (7) nature of the substrate.

2.2.10.1.2 Mechanical Removal. Mechanical working removes soils and contaminates by physical action. This physical action may also remove or deform the part surface. Mechanical removal methods can be divided into two general categories: (1) abrasive blast, and (2) grinding/sanding/brushing.

2.2.10.1.2.1 Abrasive Blast. Abrasive blast media used to remove paint coatings include, but are not limited to, materials such as plastic media, glass bead, dry ice, and alumina grit. Plastic Media Blast (PMB) is often the preferred process for paint removal on aluminum and magnesium components due, largely, to its relatively minimal peening effect on the part surface. However, even though PMB has less effect on the surface than most other materials, it has been shown to cause enough surface deformation of aluminum and magnesium to cause crack closure and prevent fluorescent penetrant entry. In addition to closing cracks by the peening effect of the particles hitting the surface, abrasive blast may also clog cracks with residues of the abrasive media preventing effective penetrant inspection. Glass bead and alumina grit blast are considerably more aggressive processes and should only be used when specific engineering directive authorizes their use.

2.2.10.1.2.2 Grinding, Sanding, Brushing.

CAUTION

Power tools SHALL NOT be used for cleaning except when specific technical directives authorizes such use and should not be used if another cleaning method will work. Steel wire brushes SHALL NOT be used on nonferrous alloys.

Grinding, sanding, and brushing are typical mechanical methods used for localized removal of coatings such as paint and fuel sealant. These methods include the use of high-speed abrasive wheels, wire brushes, sand paper, emery cloth, and abrasive polishing pads. Mechanical removal methods such as grinding, wire brushing, hand polishing and hand sanding can cause crack closure due to surface metal disturbance or obstruction of the crack opening due to entrapped grit. Crack closure can occur even when using fine abrasive media. Mechanical removal methods SHALL NOT be performed prior to penetrant inspection unless specifically authorized by engineering authority.

2.2.10.1.2.3 Etching After Abrasive Blast, Grinding, or Sanding. When accomplishing penetrant inspections, the preferred finish removal method is chemical. If the finish must be removed by mechanical means, an etch should be required prior to penetrant inspection. Failure to etch following mechanical removal of surface coating prior to penetrant inspection will degrade inspection sensitivity. If mechanical removal methods are used, etching should be performed prior to penetrant inspection unless specifically authorized by the appropriate engineering authority. Where a chemical cleaning process is specified and a mechanical process is used in its place, contact the appropriate engineering authority for guidance. Navy and Marine Corps personnel SHALL perform etching prior to penetrant inspection on aluminum and magnesium test parts when mechanical paint removal methods (including abrasive blasting), have been employed prior to penetrant inspection. Swab application (ONLY) of etchants SHALL only be performed by NDI personnel who have properly documented training. Immersion application of etchants SHALL be accomplished by maintenance personnel who have properly documented training. Contact Navy engineering offices for guidance.

2.2.10.1.3 Burning/Ignition.

WARNING

Ignition or burning off of paint and primer SHALL NOT be used on aircraft components.

Many paint and elastomer coatings are easily removed or burned off by the application of high heat or flame. However, burning and ignition techniques are difficult to control and may result in damage to the substrate materials as a result of high temperature exposure. Removal of coatings by burning techniques is prohibited on aircraft components.

2.2.11 Effects of Surface Deformation, Wear, and Surface Roughness on Penetrant Inspection.

2.2.11.1 Surface Deformation and Wear.

CAUTION

- Surface deformation as a result of machining, grinding, wear, or shot-peening may reduce the surface opening of small discontinuities thus, reduce the effectiveness of the penetrant inspection process. Chemical etching may be necessary prior to penetrant inspection. Etching SHALL NOT be performed on shot-peened components unless specifically authorized by engineering authority.

- Severe mechanical working processes such as abusive machining, grinding, and shot peening can completely close the surface openings of large discontinuities and prevent the formation of penetrant indications. Penetrant inspection SHALL be accomplished prior to shot peening or other mechanical work processes that severely displace surface metal. If it is not feasible to perform penetrant inspection prior to these processes and pre-penetrant etch is not permitted, then another inspection method SHALL be considered. An exception to this requirement is when penetrant inspection is performed to detect discontinuities formed by mechanical working, such as machining tears or grinding cracks.

NOTE

If a conflict arises pertaining to the proper inspection method to use following mechanical working, the appropriate engineering activity SHALL be contacted for final determination.

Surface material deformation usually takes the form of metal flow or metal displacement. The amount of deformation depends on the type and severity of the working plus the ductility of the part. Deformation is typically a thin layer, surface metal flow that seals or reduces the opening of discontinuities. The smeared metal over the surface opening prevents or severely restricts the penetrant entry into any discontinuities. There are a number of mechanical processes that may deform the surface of a part. These processes include but are not limited to, machining, grinding, shot-peening, and surface wear. Forms of surface wear include fretting and galling. Mechanical polishing and/or etching is often required prior to penetrant inspection to remove disturbed material and re-expose defect opening to the surface. Polishing and etching SHALL NOT be performed on shot-peened surfaces unless specifically authorized by the appropriate engineering authority.

2.2.11.2 Surface Roughness. Parts with excessive surface roughness present a unique challenge to penetrant inspection. Rough surface hinders the removal of excess surface penetrant resulting in high residual background and poor defect detectability. Surface polishing and subsequent etching may be required to reduce surface roughness prior to penetrant inspection.

2.2.11.3 Chemical Etching for Removal of Disturbed Surface Metal.

CAUTION

> Chemical etching SHALL be performed by highly trained personnel and only with specific engineering approval and written detailed process and application instructions. Etching is not part of the NDI trade. NDI personnel are not qualified to perform chemical etching unless they have been separately trained and certified in the process(es).

Chemical removal or etching of deformed or disturbed surface metal is necessary if flaws are to be detected by penetrant inspection. Etching is performed using a mixture of appropriate acids or alkalis plus inhibitors. The type of etching solution depends on the part material and condition. Chemical etching requires very close control of the etching solution composition, process procedures, and time of contact. Minor deviations in processing parameters will result in a number of adverse effects, such as:

- Excessive metal removal.
- Selective etching (i.e. pitting) of critical surfaces.
- An increase in susceptibility to stress corrosion.
- Reduction of residual surface stress (shot peened surfaces) and a corresponding reduction in fatigue life.

SECTION III LIQUID PENETRANT INSPECTION EQUIPMENT

2.3 EQUIPMENT.

2.3.1 General. The equipment used in the penetrant inspection process varies from aerosol spray cans to complex automated systems. Some of the more generally used types of equipment are briefly described in the following paragraphs.

2.3.2 Portable Equipment. Portable penetrant inspection kits are for penetrant inspection of parts too large to be brought into the inspection lab, or for laboratories which process only a minimum number of parts requiring penetrant inspection. Penetrant materials are in small lightweight kits that can be easily transported to any location. Such kits are available for both visible and fluorescent penetrant processes and usually contain aerosol spray cans of penetrant, solvent remover, and developer. Penetrants may also be provided in small containers with a brush for penetrant application. Generally, portable penetrant applications are limited to localized area or spot inspections rather than entire part surfaces.

2.3.3 Stationary Inspection Equipment - General Purpose. The type of equipment most frequently used in fixed installations consists of a series of modular workstations. At each station an inspector performs a specific task. The number of stations in a processing line varies with the type of penetrant method used. A penetrant line will typically have the following stations:

- Penetrant dip tank.
- Emulsifier/remover (Methods “B” and “D”) dip tank. (This station is not applicable for Method “A” Method“D” systems SHOULD include a rinse station prior to the remover tank.)
- Rinse station with UV-A lamp.
- Developer tank (if liquid is used).
- Drying oven.
- Developer tank (if dry-powder is used).
- Inspection booth with UV-A lamp.

2.3.3.1 Drain and dwell stations may be placed between each primary station depending on the method and equipment configuration use.

2.3.4 Small Parts Inspection Systems. There are inspection systems designed specifically for processing small parts. These units are smaller than the general systems described in (paragraph 2.3.3) above, and some of the stations serve multiple purposes. In use, the parts are loaded into wire baskets, then batch processed through each of the stations. The wash station may contain a water-driven, rotary table with spray jets to supplement the hand-held spray wand.

2.3.5 Automated Inspection Systems. The penetrant inspection process can be adapted for use with fully and semi-automated processing equipment. Semi-automated systems consist of a conveyor belt or table for moving the parts through one or more of the processing steps. Applications of penetrant, emulsifier or remover, rinse, or developer are manually performed. In fully automated systems, all of the processing steps are mechanically performed without an operator. Automated equipment allows large numbers of parts to be rapidly processed with a minimum of personnel and time. Automated equipment also provides a more uniform, though not necessarily more sensitive, testing process.

2.3.6 Inspection Lamps.

2.3.6.1 Inspection Lamp Sources. Fluorescent materials used in nondestructive testing generally respond most actively to radiant energy with a wavelength of about 365 nm. This wavelength represents near ultraviolet or UV-A radiation, light just outside the visible range on the blue or violet side, but not sufficiently far removed to be in the ultraviolet range. Because it is invisible, radiation at this frequency is commonly referred to as UV-A. Common sources of near UV-A radiation include:

- Incandescent lamps.
- Metallic or carbon arcs.
- Integrally filtered tubular fluorescent lamps.
- Tubular fluorescent lamps.
- Enclosed mercury vapor arc lamps.

- High intensity discharge (HID), metal halide, micro-discharge, or xenon lamps.
- Light-emitting diodes (LED)

Because of the potential hazards associated with the high ultraviolet output as well as concerns with beam characteristics, and the potential for fluorescent penetrant fade from high intensity UV exposure, the following restrictions SHALL be enforced:

- Only mercury vapor, high intensity discharge or light emitting diodes lamps SHALL be used for part inspection.
- High intensity discharge and light emitting diode lamps SHALL be approved by the appropriate service NDI Program Office or engineering directive.
- Only lamps certified to emit peak wavelengths from 360 to 370 nm SHALL be used.
- Lamps that emit greater than 10,000 µW/cm^{2}at 15 inches SHALL NOT be used.
- Only lamps with effective beam diameters of at least 3 inches (i.e. diameter of the beam with intensity (UV-A irradiance) greater or equal to 1000 µW/cm ^{2} at 15 inches) SHALL BE used.
- Spot or variable focused reflectors or lens SHALL NOT be used.
- Single element LED lamps SHALL NOT be used for inspection of large areas or inspections within a stationary inspection booth.
- Single element LED lamps SHALL only be used for inspection of focused inspection zones in portable applications or where required by part specific procedure.
- Projected beams SHALL NOT exhibit a dead spot.
- Ultraviolet filtering safety eyewear SHALL be worn. Eyewear designed to filter out wavelengths below 400nm is recommended.
- Precautions SHALL be taken to cover exposed skin that is exposed to the direct beam of any UV-A lamp.
- UV-A intensity of battery powered UV-A lamps shall be tested before and after each job. More frequent checks are recommended when the intensity is approaching the required minimum.

2.3.6.1.1 Incandescent and Carbon Arc Systems. Electric current heating a tungsten element to incandescence is the most familiar visible light bulb familiar to everyone. The wavelength of the associated electromagnetic radiation is generally in the visible and infrared range. It is characterized by large amounts of heat (infrared) and visible light. Electric current arcing between two carbon electrodes generates a high quantity of electromagnetic radiation in the carbon arc lamp. The radiation spans a range of wavelengths from about 10 nanometers to over 10 micrometers. This covers the entire ultraviolet and visible light ranges and a portion of the infrared range; however, little if any useful ultraviolet radiation is produced. In addition, the lamps require a high electrical power supply and are very bulky or large due to the need for electrode drive mechanisms. Incandescent and carbon arc systems are not used for fluorescent penetrant inspection.

NOTE

Incandescent carbon arc lamps SHALL NOT be used for penetrant inspection.

2.3.6.1.2 Low Pressure Fluorescent “BL” Bulbs.

NOTE

Fluorescent bulbs SHALL NOT be used for detecting fluorescent indications.

Low pressure, fluorescent bulbs are similar to standard fluorescent tubes, however, instead of an inert gas, the tube contains metallic mercury. When an electric current is applied, the mercury vaporizes and emits hard (deeply penetrating) ultraviolet radiation with a wavelength of approximately 254 nm. This wavelength is not useful for fluorescent penetrant inspection. Therefore, the inside of the tube is coated with a phosphor activated by the hard ultraviolet and emits black and visible light in the wavelength range of 320 to 440 nm. The amount of useful UV-A at 365 nm is relatively small; however, there is a large amount of both harmful short wavelength ultraviolet radiation (below 320 nm), and visible light, (above 400 nm), emitted through the phosphor. Some of these undesirable wavelengths are removed by the use of filters. While this reduces the unwanted radiation, it also reduces the already low amount of useful UV-A in the range of 365 nm. In addition, fluorescent UV-A bulbs, because of their configuration, cannot be easily focused and their intensity per unit area is below other types of bulbs. Most fluorescent bulbs will not produce an output sufficient to meet the minimum UV-A intensity requirements (paragraph 2.5.4.1.3), also required by ASTM E 1417.

2.3.6.1.3 Mercury Vapor Arc Bulbs.

NOTE

Bulbs, less than 100-watts, SHALL NOT be used for penetrant inspection unless specifically authorized.

High pressure, mercury vapor arc bulbs are the most common sources for UV-A. They are also recommended for fluorescent penetrant inspection because they have an acceptable output at a reasonable distance from the bulb. They can be focused to increase their intensity over a localized area. They are available in a wide range of sizes from a 2-watt pencil type used for special applications, to a 400-watt floodlight. The most frequently used size is the 100-watt bulb mounted in a variety of fixtures or housings and fairly portable. A cross-section of a typical mercury vapor, arc discharge bulb is shown in Figure 2-9).

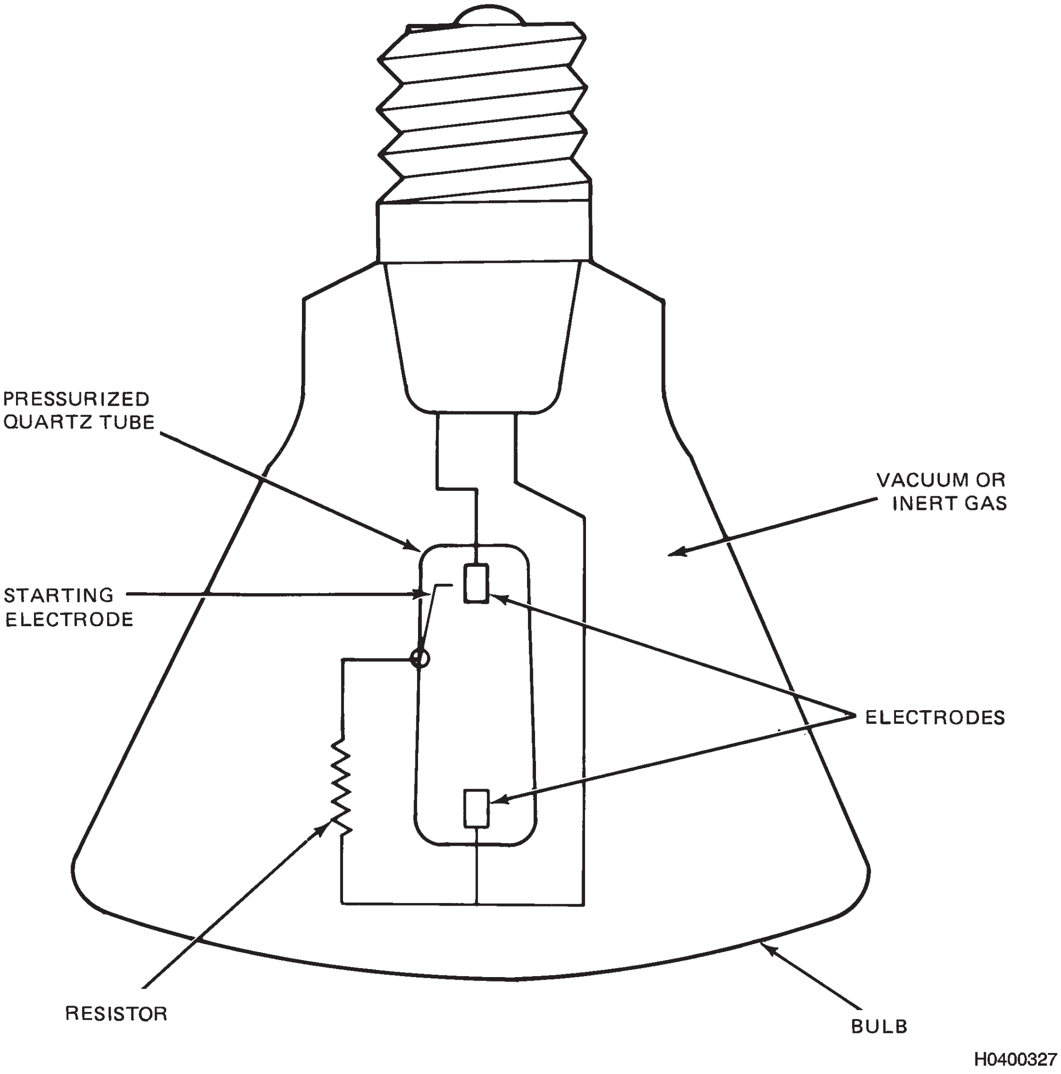


Figure 2-9. Cross-Section of a Typical High-Pressure Mercury Vapor Arc Bulb

2.3.6.1.3.1 Warm-Up Requirements for Mercury Vapor Bulbs.

NOTE

> UV-A lamps (UV-As) SHALL NOT be used for inspection before the required intensity at the inspection surface (paragraph 2.5.4.1.3) is achieved.

The high-pressure component is a quartz tube containing some mercury plus a small amount of neon gas. When the lamp is first turned on, the mercury is condensed as a liquid and an arc between the electrodes cannot be generated, this is the reason for the neon gas. A small amount of current, limited by the resistor, causes a discharge from the starting electrode through the neon gas. This glow is sufficient to vaporize the mercury, which then allows the arc to pass between the main electrodes. This starting procedure requires from 5 to 15 minutes to fully vaporize the mercury and produce full output of UV-A. Some UV-A lamps may be warmed-up in 2-3 minutes, refer to the owner's manual of the light you are using.

2.3.6.1.4 High Intensity Discharge (HID) UV-A Light Sources.

WARNING

- High intensity discharge (HID) lamps shall only be used when approved by the appropriate service NDI Program Office or by engineering directive due to problems associated with excessive white-light emission, veiling glare (see paragraph 2.5.4.1.6.1) and poor beam characteristics.

- Due to the potential for exposure to high intensity ultraviolet light, use of UV filtering safety glasses, goggles, or faceshields is required. Since highly focused UV-A lamps provided by some spot light configurations might result in eye injury if exposed for more than a few seconds, only flood reflector equipped gas discharge lamps SHALL be used. Skin exposure SHALL also be avoided. Precautions SHALL be taken to cover exposed skin that is exposed to the direct beam of any UV-A source.

- High intensity discharge (HID) lamps produce radiation by making an electric arc in a mixture of gases. HIDs have compact arc tubes that contain a high-pressure mixture of argon, mercury, and a variety of metal halides. The mixture of halides will affect the nature of radiation produced, influencing the correlated color temperature and intensity (i.e. emitting high UV content for example). The argon gas in the lamp is easily ionized, and facilitates striking the arc across the two electrodes when voltage is first applied to the lamp. The heat generated by the arc then vaporizes the mercury and metal halides, which produce light as the temperature and pressure increases.

- HID UV-A sources have broad emission spectra which may include more than one peak within the UV-A range. For use in fluorescent NDT, these lamps must have appropriate filters, either internal or external to the light source, to pass UV-A and minimize visible light output detrimental to the fluorescent inspection process.

2.3.6.1.4.1 There are three types of high intensity UV-A sources; metal halide, micro-discharge and Xenon.

- Metal Halide UV-A sources: The high intensity flood fixture normally uses a high wattage metal halide bulb. This lamp will also contain some type of specially coated parabolic reflector. The high intensity of this lamp will produce a great deal of heat, so some type of cooling fan must be used.
- Micro-Discharge Lamp (MDL) UV-A sources: The MDL lamp uses a 35 watt metal halide bulb and therefore produces very little heat. Normally, a cooling fan is not required.
- Xenon Bulb UV-A sources: These lamps use a high pressure arc bulb containing xenon gas or a mixture of mercury vapor and xenon gas.

2.3.6.1.4.2 HID lamps have many advantages over Mercury Vapor Arc lamps. These include: they have very short warm-up times (10-15 seconds), are lightweight, generate very little heat, and produce as much as 45 times greater ultraviolet output than most common lamps available.

2.3.6.1.5 Light Emitting Diodes (LEDs).

WARNING

- Light emitting diode (LED) lamps shall only be used when approved by the appropriate service NDI Program Office or by engineering directive due to problems associated with excessive white-light emission, veiling glare (see paragraph 2.5.4.1.6.1) and poor beam characteristics.
- Due to the potential for exposure to high intensity ultraviolet light, use of UV filtering safety glasses, goggles, or faceshields is required. Highly focused UV-A may be provided by some spot light configurations can result in eye injury if exposed for more than a few seconds, therefore, only flood reflector equipped gas discharge lamps SHALL be used. Skin exposure SHALL also be avoided. Precautions SHALL be taken to cover exposed skin that is exposed to the direct beam of any UV-A lamp.

2.3.6.1.5.1 Light emitting diodes (LEDs) are solid state electronic devices consisting of a semiconductor or semiconductor elements that emit radiation or light when powered by a current.

2.3.6.1.5.2 The color (wavelength) of the light (corresponding to the energy of the photon) is determined by the chemistry of impurities, called dopants, of the semiconductor. The selection of the dopant material determines the wavelength and intensity of the emitted radiation. Therefore a primary advantage of the LED technology is that the characteristics of the emitted radiation can be tailored by modifying the dopant.

2.3.6.1.5.3 Many LED UV-A hand-held lamps and overhead lamps consist of an LED array to provide a broad beam to irradiate large inspection areas. Individual LED elements are generally as small as 1 mm ^{2} and include integrated optical components that may be used to shape its radiation pattern or filter the spectral content (Figure 2-10). LED lamps provide many advantages over traditional mercury vapor light sources including lower energy consumption, longer lamp lifetime, improved robustness, smaller size, faster light-on times, and greater durability and reliability. LEDs powerful enough for high intensity UV-A lamps are relatively expensive but because of their low power requirements can be battery operated providing great portability.

2.3.6.1.5.4 Many LED UV-A lamps are currently available on the open market. Unfortunately many of these lamps are not designed for fluorescent penetrant or magnetic particle inspection and therefore do not have the optimum spectra content or beam quality required for NDI applications. Many LED lamps have been found to emit excessive white light or very high UV-A intensity that can result in excessive veiling glare. Others do not emit UV-A within the required 360-370 nm range and therefore may not adequately excite the fluorescent dye within the penetrant or magnetic particles. Some lamps have also been found to exhibit dead-spots (insufficient UV-A intensity) in the center of the projected beam as a result of poorly designed reflectors, filters, or LED array design. Poorly designed LED arrays can result in irregular project beam profiles and “dead-zones” within the beam pattern that do not provide sufficient UV-A intensity.

2.3.6.1.5.5 LED UV-A Lamp Classifications

CAUTION

- Type C, UV-A LED "torch" lamps SHALL NOT be used for inspection of large areas or inspection within a stationary booth. Type C lamps SHALL only be used for portable inspection of focused inspection areas.
- The irradiance (UV-A intensity) of Type B and C, UV-A (battery powered) lamps SHALL be checked before and after each inspection. The post inspection check SHALL be performed before turning off the lamp. If the lamp is accidentally turned off, then turn on the lamp for 5 minutes before conducting the post inspection check.

UV-A LED lamps used for nondestructive testing are classified as follows:

- Type A - Line-powered lamps - LED arrays for handheld and overhead applications.
- Type B - Battery powered hand-held lamps - LED arrays for stationary and portable applications.
- Type C - Battery powered hand-held torch lamps - single LED flashlight or torch for portable or special applications.

2.3.6.2 Battery Powered Lamps. Great care must also be exercised when using battery powered lamps. Depending on the lamp design, as the battery drains, a significant reduction in UV-A intensity may occur. As a result, the UV-A intensity may be adequate at the beginning of the inspection but may not be adequate at the end of the inspection, depending on the battery life and duration of the inspection. The UV-A intensity SHALL be checked before and after inspections using battery powered lamps. If the lamp is accidentally turned off before the post-inspection check, the lamp SHALL be turned on for 5-minutes before performing the post-inspection irradiance measurement. Figure 2-10 illustrates the drop in UV-A intensity (irradiance) for two different LED UV-A lamps as the battery depletes. Lamp A contains a circuit that provides a nearly constant irradiance (intensity) throughout the entire battery discharge time. This is the preferred design.

2.3.6.3 Inspection Lamp Fixtures.

CAUTION

UV-A bulbs SHALL NOT be operated without filters. Cracked, chipped, or ill-fitting filters SHALL be replaced before using the lamp. High intensity "super" UV-A lamps that use bulbs with integral filters SHALL have a splashguard attached to the front of the lamp housing to prevent accidental implosion of the bulb.

High pressure, mercury vapor bulbs require a housing, filter, regulating ballast or transformer, and connecting cables or wires. The housing, which may be metal or plastic, serves several functions:

- Hold and protect the bulb.
- Hold and support the filter.
- Prevent leakage of unwanted visible light.
- Permit directing the beam on the surface to be inspected.
- Provide a means for handling the bulb.

2.3.6.4 Inspection Lamp (UV-A Pass) Filters.

NOTE

All UV-A lamps, including LED lamps shall be fitted with a UV-A pass filter.

The filter is a special material that prevents the passage of short wavelength ultraviolet (< 320nm) and long wavelength visible light (400nm – 700nm) and allows UV-A (320nm – 400nm) to pass. This wavelength causes maximum fluorescence of the penetrant dyes. The transmission characteristics of typical UV-A pass filter is shown (Figure 2-11). Filters for penetrant inspection can be either a smooth or fluted surface. The fluted surface provides a slightly larger focused spot than a smooth surface filter.

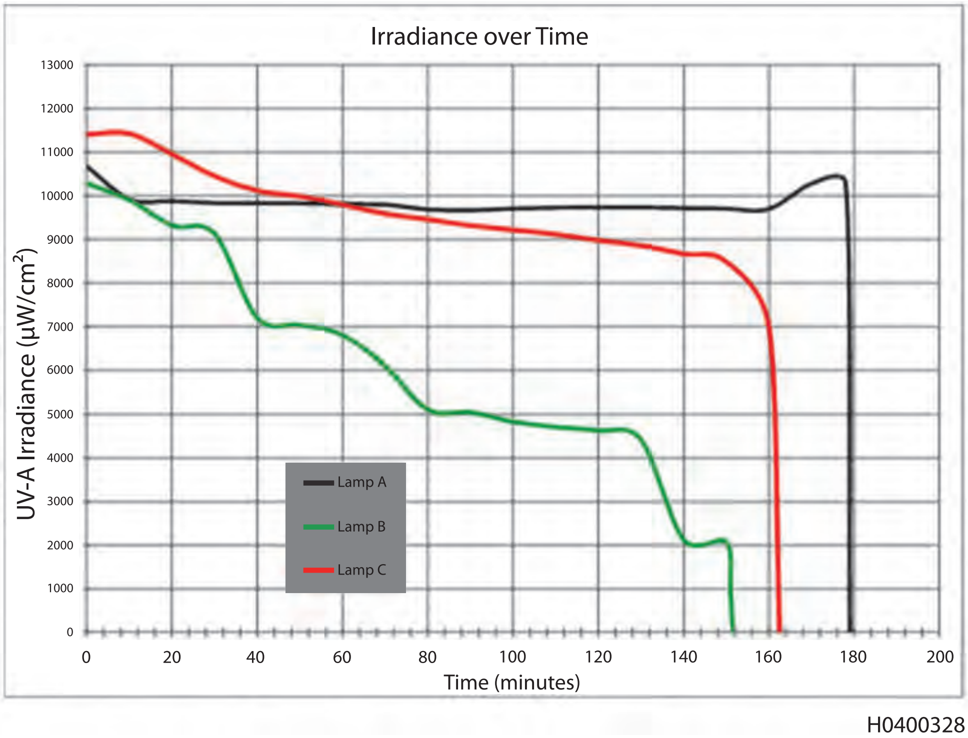


Figure 2-10. Change in UV-A Irradiance Over Time as Batteries Deplete

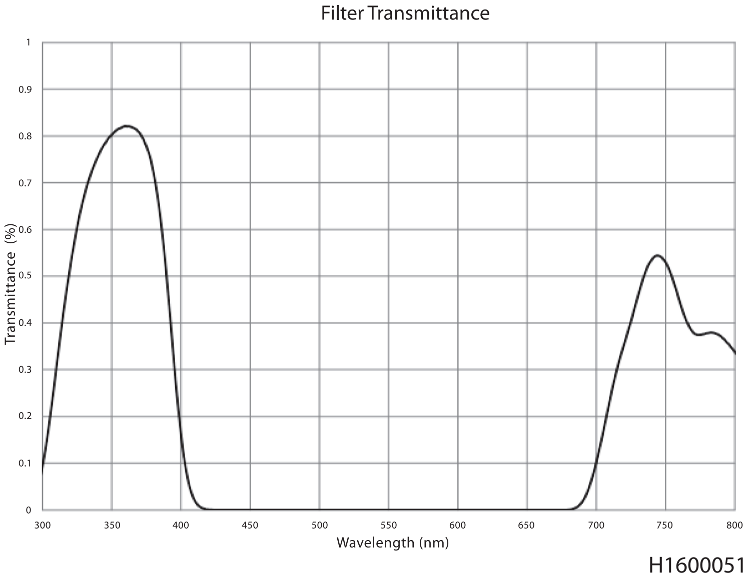


Figure 2-11. Transmission Curve for a Typical UV-A Pass Filter

2.3.7 Process Control Equipment. The performance of liquid penetrant inspection systems depends on the processing material quality of pre-cleaning chemicals, liquid penetrant, emulsifier, developer, and the continued proper functioning of the several processing stages. A sudden undetected deterioration of one of these processing stages may result in missing an indication. To learn more about the equipment used to monitor the penetrant process, (paragraph 2.6.7).

2.3.7.1 UV-A Lamp Performance Requirements.

NOTE

All UV-A lamps SHALL contain a UV-A pass filter.

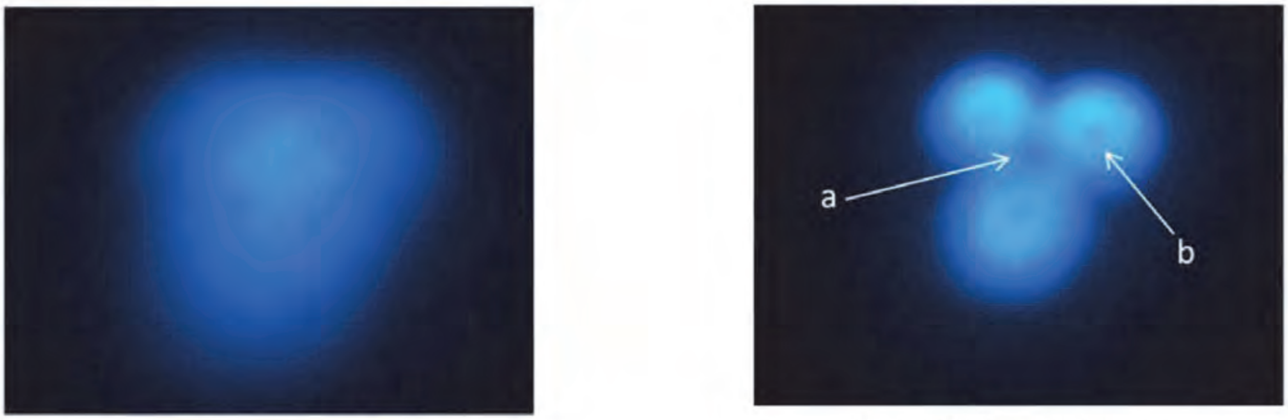
2.3.7.1.1 UV-A Intensity. UV-A lamps must produce a minimum of 1000 micro-watts/cm^2 UV-A radiation at the point of highest intensity and a minimum of 1000 micro-watts/cm^2 over a 3-inch diameter circle (minimum) as measured by a UV-A light meter placed at a distance of 15 inches from the lamp filter. Lights which do not meet this requirement even with new bulbs SHALL NOT be used.

2.3.7.1.2 LED Lamp Specific Requirements. Due to the unique characteristics of UV-A LED lamps, new industry standards are being developed to address their unique performance requirements. Lamp manufacturers SHALL provide a certification that the supplied UV-A LED lamp meets the following requirements when received:

- UV-A LED lamps SHALL provide minimum peak UV-A intensity (irradiance) of at least 2000 uW/cm^2 when measured at a distance of 15 inches.
- Type A and Type B Lamp LED Arrays SHALL provide a minimum projected beam profile of at least 5 inches when measured at a distance of 15 inches.
- Type C, single LED torches, SHALL provide a minimum projected beam profile of at least 3 inches when measured at a distance of 15 inches
- The Peak wavelength SHALL be between 360 nm and 370 nm.

In addition to the manufacturer's certifications, the following requirements SHALL also apply:

- Pulsed Firing and Pulsed Modulation LED drive circuits SHALL NOT be used. The lamp SHALL NOT exhibit any flicker or strobing during operation.
- All UV-A LED elements shall be fitted with UV-A pass filter.
- Visible light LEDs SHALL NOT be incorporated in the lamp.
- LED Arrays SHALL NOT exhibit beam non-uniformity "dead zones" when held greater than 6 inches from the inspection surface (see Figure 2-12).



Uniform Beam
3-LED Array - Away from Inspection Surface
(*Beam Profile may be rectangular, oval, circular or triangular*)

Non-Uniform Beam
3-LED Array - Near Inspection Surface
Arrow indicate regions of reduced irradiation, (a) between individual LED beams and (b) due to individual LED beam profiles

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Figure 2-12. Examples of Uniform Versus Non-Uniform Beam Profiles from an LED UV-A array

SECTION IV LIQUID PENETRANT APPLICATION METHODS

2.4 APPLICATION METHOD.

2.4.1 General. This section provides basic, intermediate, and detailed information on the specific processes relative to the performance of penetrant inspection. Functions not specifically performed by NDI personnel, such as general cleaning, are not covered under this section.

2.4.2 Basic Penetrant Processes. Abridged penetrant process flow charts illustrating the general process steps for the four penetrant methods are provided in (Figure 2-13 through Figure 2-16). Detailed descriptions of application procedures are contained in later sections and paragraphs. The process flow charts contain reference locations for the detailed information. Since the application procedures for fluorescent (Type I) and visible-dye (Type II) penetrants are similar, the process flow charts are applicable to both types of penetrants.

NOTE

Weapon system and commodity specific inspection techniques SHALL be developed and approved IAW paragraph 1.3.4.1 and TO 00-5-1. If needed, contact the responsible Air Logistic complex (ALC) NDI Manager or responsible engineering authority for assistance.

2.4.2.1 Basic Inspection Steps. The basic fundamentals of the penetrant process have not changed from the oil-and-whiting days. Figure 2-1 provides an illustration of the basic principles of the penetrant inspection process, while more explicit process details are discussed in subsequent sections of this chapter. The following provides a simplified description of the fundamental penetrant process steps.

a. Cleaning is performed to remove residues and soils from the part surface. Cleaning is a critical part of the penetrant process and is emphasized because of its effect on the inspection results. Contaminants, soils, or moisture, either inside the flaw or on the part surface at the flaw opening, can reduce the effectiveness of the inspection. For a complete discussion on the precleaning process (paragraph 2.4.4).

b. After cleaning is complete and the part is thoroughly dry, a penetrating liquid containing dye is applied to the surface of a clean part to be inspected. The penetrant is allowed to remain on the part surface for a period of time to allow it to enter and fill any surface breaking openings or discontinuities. For a complete discussion of the penetrant application and dwell process (paragraph 2.4.5 and paragraph 2.4.7).

c. After a suitable dwell period, the penetrant is removed from the part surface. Care SHALL be exercised to prevent removal of penetrant contained in discontinuities. For a complete discussion on the penetrant removal process (paragraph 2.4.8).

d. A material called a developer is then applied. The developer aids in drawing any trapped penetrant from discontinuities and improves the visibility of indications. For a complete discussion on the development process (paragraph 2.4.11).

e. Following developer application the next step is a visual examination under appropriate lighting conditions to identify relevant indications. For a complete discussion on the examination/interpretation process (paragraph 2.5).

f. The final step is a post-cleaning of the part. This step is very important as penetrant residues can have several adverse effects on subsequent processing and service. For a complete discussion on the post-cleaning process (paragraph 2.4.12).

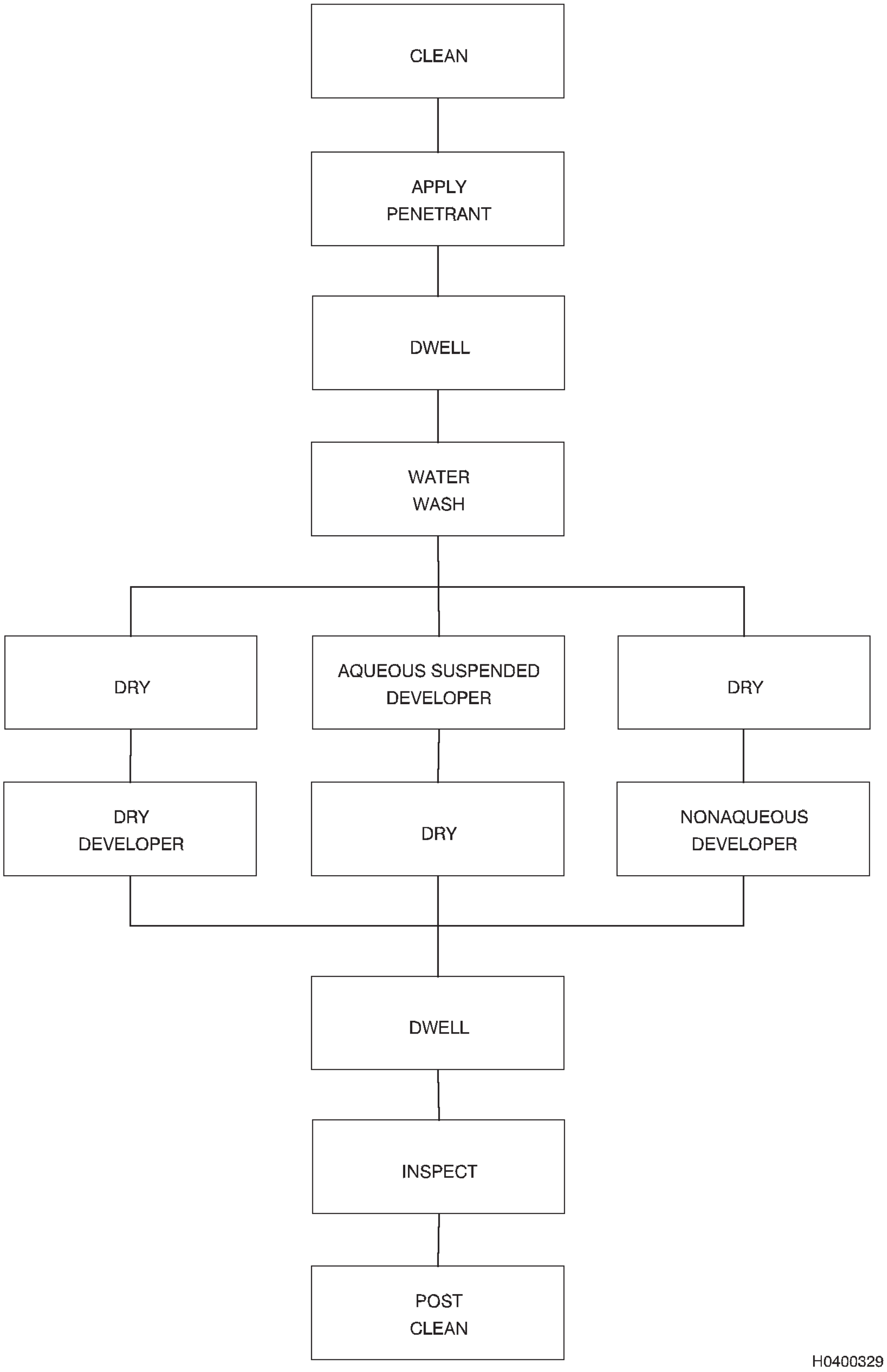

Figure 2-13. Flow Chart for Water Washable Penetrant Process (Method A)

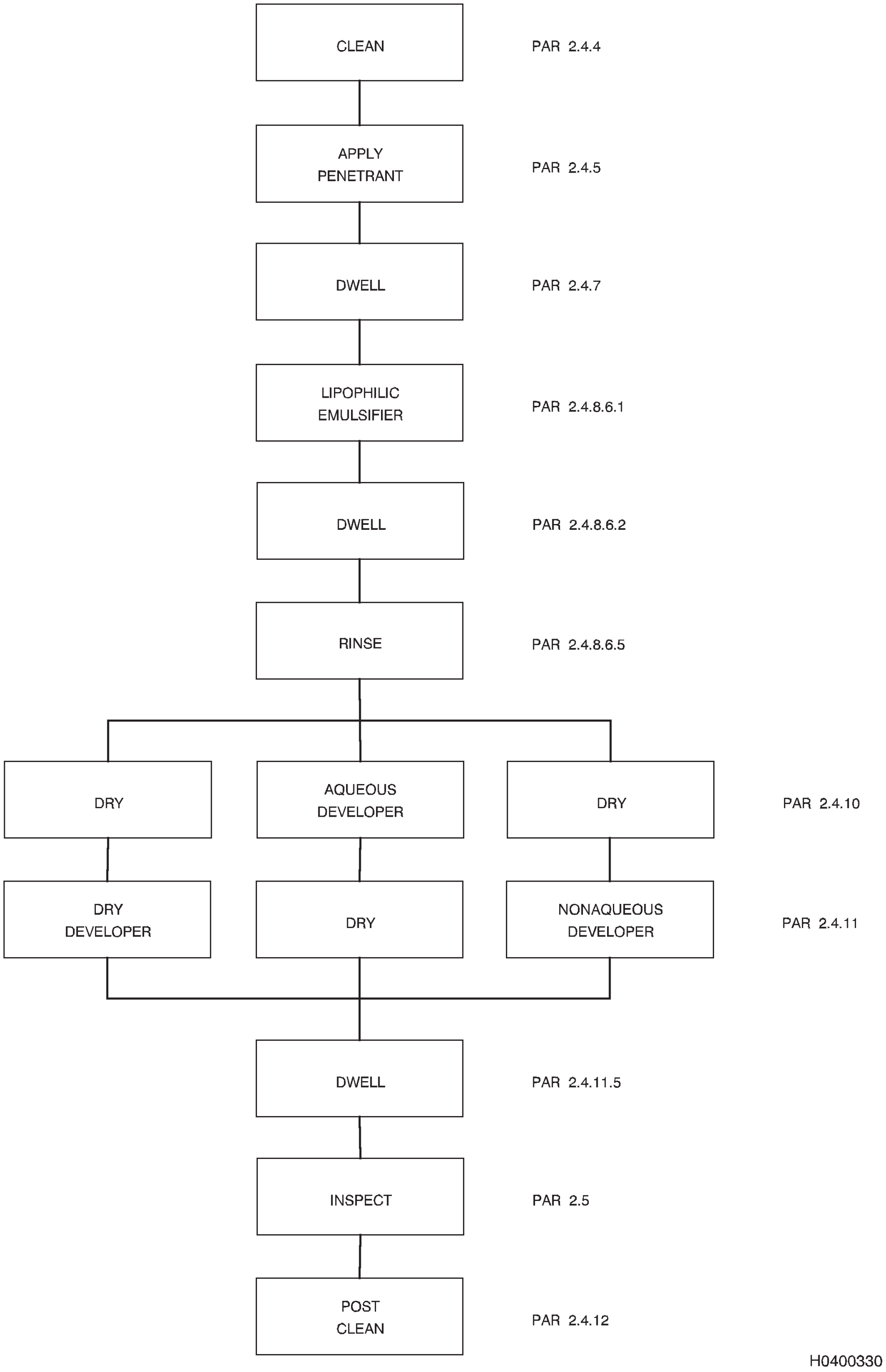

Figure 2-14. Flow Chart For Post-Emulsifiable Lipophilic Penetrant Process (Method B)

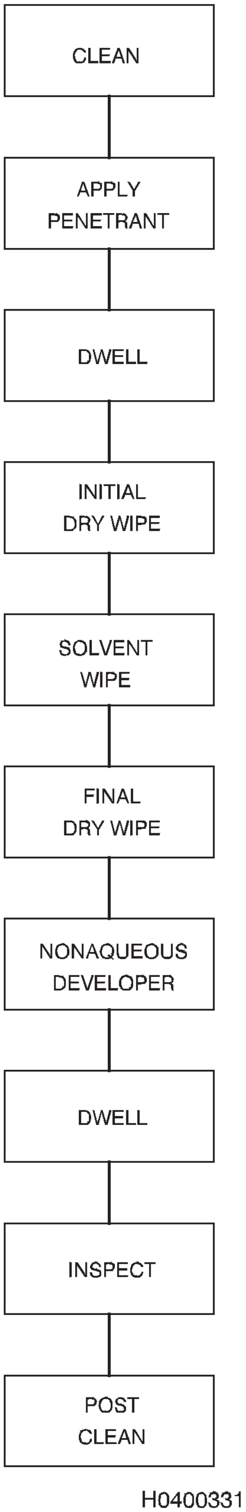

Figure 2-15. Flow Chart for Solvent Removable Penetrant Process (Method C)

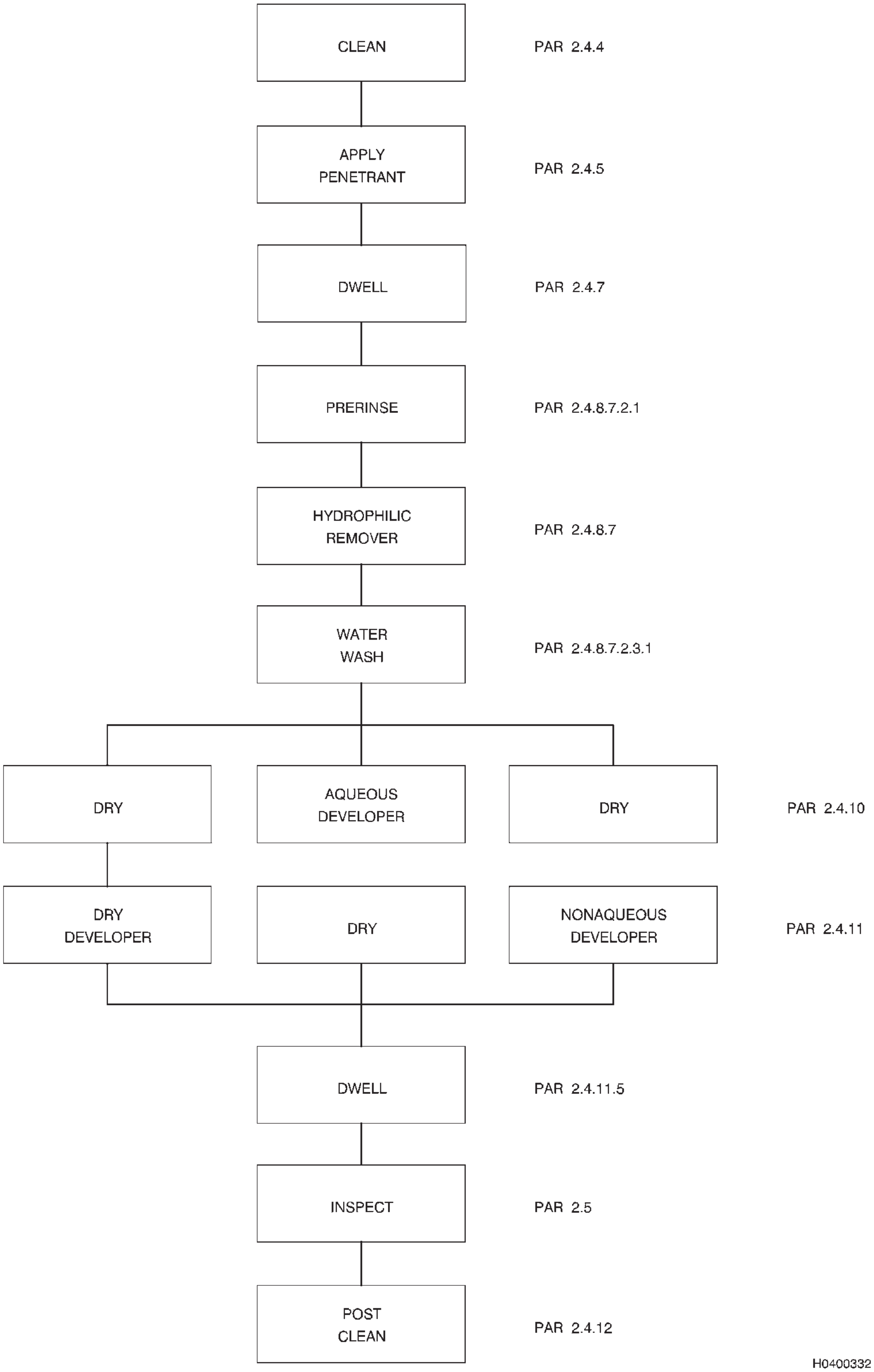

Figure 2-16. Flow Chart for Post-Emulsifiable Hydrophilic Penetrant Process (Method D)

2.4.3 Pre-Testing.

NOTE

> All nonmetallic parts not previously inspected, and which do not have approved technical or nondestructive inspection procedures SHALL be pre-tested.

Some nonmetallic parts, such as plastics, rubbers, and Plexiglas may react with the oils and solvents contained in penetrant inspection materials. These oils and solvents can cause swelling, softening, distortion, crazing, or other surface effects resulting in damage to the part. The purpose of pre-testing is to ensure parts to be inspected will not be damaged by penetrant materials.

2.4.3.1 Pre-Testing Procedure.

NOTE

> Specific inspection guidance SHALL be provided by the agency requiring the inspection. If necessary, the responsible Air Logistic Complex (ALC) NDI Manager or responsible engineering authority SHALL be contacted for assistance. Some materials may not show effects until they are subjected to service conditions (aging, cold, heat, moisture).

Pre-testing SHALL be performed as follows:

a. If spare or extra parts are available, the entire surface to be inspected may be pre-tested. If the part to be inspected must be reused, the pretest SHALL be performed on a small area where possible damage can be tolerated.

b. The part to be pre-tested SHALL be cleaned and visually examined for evidence of pre-existing damage.

c. Apply the penetrant to be used to the area selected and allow it to remain on the surface for at least twice the proposed dwell time. Wipe excess penetrant from the area and closely examine for any surface changes.

d. Repeat step c with the remover and developer to be used, examining the part surface for any evidence of change between each process step.

e. If any evidence of adverse effects is noted, the penetrant inspection method SHALL NOT be used.

2.4.4 Pre-Cleaning Performed by NDI Personnel. Pre-cleaning is the surface preparation performed by NDI personnel prior to an inspection. The purpose of pre-cleaning is to remove light soils and contaminates that have accumulated since major cleaning, touch-up critical areas such as bolt threads, and remove residue from other cleaning processes. Parts requiring more extensive cleaning will be sent to the appropriate cleaning shop or corrosion control facility.

2.4.4.1 Pre-Cleaning With Aerosol Spray Solvents.

WARNING

> Isopropyl Alcohol and most Class 2 solvent removers are flammable.

CAUTION

> With the elimination of the use of 1.1.1 trichloroethane (methyl chloroform), the solvent remover in portable penetrant kits is most likely to be Class 2 (non-halogenated). Only solvent removers listed in QPL-SAE-AMS-2644 SHALL be used for pre-cleaning just prior to penetrant inspection. Technical grade Isopropyl Alcohol (TT-I-735, Grade A) is also acceptable. Significant care must be taken to ensure solvent has completely evaporated before penetrant application.

Most Class 2 solvent removers are hydrocarbon solvents such as aliphatic naphtha. While they are excellent solvents, because of their high boiling point (in excess of 300°F or 149°C) such Class 2 solvent removers will not rapidly evaporate at room temperature. Consequently, when used as a pre-cleaner, care SHALL be taken to assure there is no residual solvent remover on the part surface prior to the application of penetrant. This can be accomplished by thoroughly drying the surface with a lint free cloth or rag, dry the part in an oven, or alternatively, use a more volatile solvent such as Isopropyl Alcohol to remove the less volatile solvent remover. Portable penetrant kits contain aerosol spray cans of penetrant, developer, and solvent remover. The solvent remover is used in three ways 1) it serves as a pre-cleaner before penetrant application, 2) it removes the last of the excess penetrant after completion of the penetrant dwell, and 3) it serves as a post-cleaner to remove residual penetrant materials when the inspection has been completed.

2.4.4.2 Method of Applying Spray Solvent as a Pre-Cleaner.

CAUTION

> When used as a pre-cleaner, the solvent remover may be sprayed directly on the test surface. Solvent SHALL NOT be sprayed directly on the surface of parts when removing excess surface penetrant during a penetrant inspection process.

The method of applying spray solvent remover as a pre-cleaner is different than when it is used to remove penetrant following penetrant dwell. As a pre-cleaner, a liberal amount of solvent should be applied and the excess solvent and contaminants wiped from the test surface with a dry, lint free cloth or paper towels. The spray and wiping operation SHALL be repeated until a clean, residue free surface is obtained. Following the application of spray solvent, sufficient dwell period SHALL be allowed to permit evaporation of any residual solvent before applying penetrant. A drying oven will accelerate the evaporation process, significantly reducing the dwell time and SHOULD be used whenever possible.

2.4.5 Penetrant Application.

2.4.5.1 General. This section provides basic, intermediate, and advanced information on the methods and procedures used in applying penetrant to components to be inspected. The first portion of the section contains information related to penetrant application methods. The second portion provides information related to the temperature limitations for application. The third portion covers dwell time requirements and considerations.

2.4.5.2 Penetrant Application Methods.

CAUTION

> Care SHALL be taken to avoid trapping air bubbles or pockets during penetrant application to complex shaped parts by immersion. Oil and air passages and blind holes SHALL be plugged prior to penetrant application by immersion. Remove the plugs immediately after the inspection process.

Penetrant can be applied by any of several methods, immersion or dipping, spraying, brushing, swabbing, or flowing. The method to be used depends on several factors, including size, shape, and configuration of the part or area to be inspected, accessibility of the area to be inspected, and availability of inspection equipment. All methods of application are acceptable provided the surface or area to be inspected is completely coated with penetrant, however, there are certain requirements that must be met for each method.

2.4.5.2.1 Immersion/Dipping.

NOTE

> When parts are batch processed in a basket, they SHALL be separated from each other during the immersion and dwell period. Contact between parts interferes with the formation of a smooth, even penetrant coating.

Immersing or dipping is the preferred method of applying penetrant when the entire surface of a part must be inspected. The method is limited by the size of the tank or penetrant container. Parts can be immersed one at a time or, if small, can be batch processed by placing them in a basket or rack.

2.4.5.2.1.1 Immersion Considerations.

NOTE

> It is difficult or impossible to completely remove penetrant from passages and blind holes following inspection. Therefore, oil or air-cooling passages and blind holes SHALL be plugged or stopped off with corks, rubber stoppers, or wax plugs prior to immersion in penetrant. These devices SHALL be removed immediately after the inspection process.

Certain part configurations require special attention during application of penetrant by immersion. Parts containing concave or recessed surfaces can trap an air bubble or pocket when immersed. Air bubbles or pockets will prevent the penetrant from contacting the part surface. Complex shaped parts SHALL be inverted or turned over while immersed to dislodge any entrapped air. Precautions must also be taken when immersing parts with air-cooling or oil passages and blind holes. During immersion, the passages and holes will fill with penetrant that will bleed out during development and obscure any discontinuity indications in the area. Air cooling passages and blind holes SHALL be plugged prior to immersion.

2.4.5.2.2 Spraying. Penetrant, emulsifiers or removers, and wet developers may be applied by any of several manual or automated spray methods. Spray application is especially suitable for parts too large to be immersed or processed via conveyor lines automated systems. The spray method is also applicable for on-aircraft inspections (portable), and when only a portion or local area of a large part or component requires inspection. In applying penetrant by the spray method, the requirement is to apply a penetrant layer that completely covers the area to be inspected. Spray application of penetrant provides several advantages over the immersion method. It is usually more economical since large tanks of penetrant are not needed, and pooling of penetrant in part cavities is reduced. In immersion application, pooling removes substantial amounts of penetrant by drag out.

2.4.5.2.2.1 Air or Pressure Spray.

WARNING

> Paint type respirators SHALL be required when spraying penetrant as determined by the local Base Bioenvironmental Engineering. Additionally, atomized penetrant is very flammable.

Penetrants can be applied from most types of spray equipment using liquid pressure only, air aspiration only, or a combination. The equipment used is similar to that used in spraying paint. It consists of a supply tank, hoses, and a spray gun or nozzle. The supply tank is pressurized to force the penetrant through the fluid hose to the gun. The gun, which may be hand held or mounted in a fixture for automated spraying, is connected to an airline. The air applied to the gun converts the stream of penetrant into a spray. The air pressure, usually between 10 and 90 psig, controls the size of the spray droplets. Too low a pressure may produce a solid stream of penetrant. This would cover only a narrow area requiring many passes to coat the surface, and it also splatters the penetrant on adjacent surfaces. Too high a pressure can atomize the penetrant into a fine fog with poor covering ability and which drifts away from the part. Spray gun application, other than isolated cases, requires a spray booth and exhaust system for confining and reducing overspray.

2.4.5.2.2.2 Electrostatic Spray. The equipment required for electrostatic spraying is similar to that used in air spraying. In addition, a high voltage power supply is connected to the gun. This puts a positive electrical charge on the penetrant particles as they leave the gun. The part is electrically grounded and attracts the charged penetrant particles. The attraction is strong enough to pull the particles to surfaces not in front of or perpendicular to the spray. This ability makes electrostatic spray a preferred method for automated lines where complex shaped parts are to be coated; however, coverage inside cavities is limited. An advantage of the electrostatic spray method is the large savings resulting from reduced material requirements. Electrostatic spraying deposits a thinner layer of penetrant on the part than air spraying and greatly reduces penetrant loss due to overspray. Savings of over 80-percent compared to immersion application have been claimed.

2.4.5.2.2.3 Aerosol Spray. Penetrant packaged in aerosol containers provides a convenient method of application. The advantages and disadvantages to aerosol spray are:

2.4.5.2.2.3.1 Advantages:

- Portability.
- Packaging in sealed containers also eliminates contamination and evaporation of penetrant.
- There is little to no need for special exhaust equipment, as the amount of penetrant involved is small.

2.4.5.2.2.3.2 Disadvantages:

- Aerosol packaging increases material cost.
- Should not be used on large areas due to small spray pattern and high material cost.
- Overspray coats adjacent surfaces and complicates penetrant removal.
- Aerosol cans are known to lose propellant resulting in having to discard unused penetrant.

2.4.5.2.2.3.3 Mixing Aerosol Penetrants.

NOTE

> The propellant pressure is directly proportional to the ambient temperature. At temperatures below 60°F (15.6°C), the pressure may be too low for proper spraying. Conversely, the pressure may become excessive and the container may burst if the temperature reaches 120°F (49°C).

Penetrants, unlike nonaqueous developers, do not settle out of solution. Therefore, a mixing ball in the container is not essential; however, some manufacturers buy only a single type aerosol can, which is then used to package penetrant, solvent remover, or nonaqueous developer. Whether the can does or does not contain a mixing ball, it is good practice to shake the can thoroughly before spraying to ensure an even distribution of penetrant and propellant.

2.4.5.2.2.3.4 Applying Aerosol Penetrants. When applying penetrant from an aerosol container, the nozzle should be held 3 to 6-inches from the part surface and the can moved in a line to completely cover the area to be inspected. A thin, even coating with no breaks or non-wetted area is necessary. Excessive penetrant is not desirable as it tends to run or drain off the area and complicates removal. Holding the can motionless or moving it too slowly while spraying will result in an excessive layer of penetrant. Short distances between the can nozzle and the part reduce the size of the spray pattern, and produce a thick layer of penetrant in a small area. Long distances between the nozzle and part increase the size of the spray pattern, and reduce the penetrant layer thickness. There is also an increase in overspray and the possibility of uncovered areas.

2.4.5.2.3 Brush or Swab Application.

CAUTION

Care must be taken to avoid spilling the penetrant while on or in an aircraft or other sensitive locations.

NOTE

Synthetic sponges may dissolve in penetrant.

Penetrant may be applied to large parts by brushing, wiping, or even pouring from a container. The brush or swab method is most frequently used to coat a small area of a large structure. Brushing or swabbing provides control over the placement of penetrant on the desired area, improves the ability to regulate the quantity or thickness of the penetrant layer, and eliminates overspray. Any brush, swab, rag, or even sponge may be used provided the applicator material will not react with the penetrant. The size of the brush may vary from large paint brushes down to small acid or artist brushes, depending on the size of the area to be covered. Any type of clean container may be used to hold the penetrant.

2.4.6 Temperature Limitations.

NOTE

Penetrants may be applied over a range of ambient temperatures; however, certain limits must not be exceeded as the inspection process may be degraded. The operating range for conventional penetrants is 40°F (4°C) to 125°F (52°C). There are special penetrants formulated for hot applications exceeding these limits. Special purpose penetrants are discussed in (paragraph 2.7).

2.4.6.1 Low Temperature Limitations.

NOTE

Penetrant inspection SHALL NOT be performed when the test part temperature is less than 40°F (4°C). Reasons for this restriction are:

2.4.6.1.1 At 32°F (0°C) or less, any moisture, even from the inspector’s breath, will form ice crystals on the part, which will interfere with the penetration process.

2.4.6.1.2 The propellant pressure in aerosol containers is affected by temperature. The gas pressure decreases with lower temperatures. When the temperature drops below 60°F (15.6°C), the reduced pressure can result in an erratic spray pattern.

2.4.6.1.3 The evaporation rate of solvent cleaners and nonaqueous developers is reduced at lower temperatures. The evaporation or drying time for two types of nonaqueous developers at various temperatures is shown in Figure 2-17. The graph shows a ten-fold increase in drying time between the temperatures of 60°F (15.6°C) and 0°F (-18°C).

2.4.6.1.4 Viscosities of penetrants increase as the temperature decreases. When temperatures are between 40°F (4°C) and 60°F (15.6°C), the penetration dwell time SHALL be increased in accordance with (paragraph 2.4.7.4.2, Table 2-2) due to the increased viscosity. The increase in solvent cleaner evaporation time, penetrant dwell time, and developer drying time required at temperatures lower than 40°F (4°C), makes the total inspection time far too long to be practical.

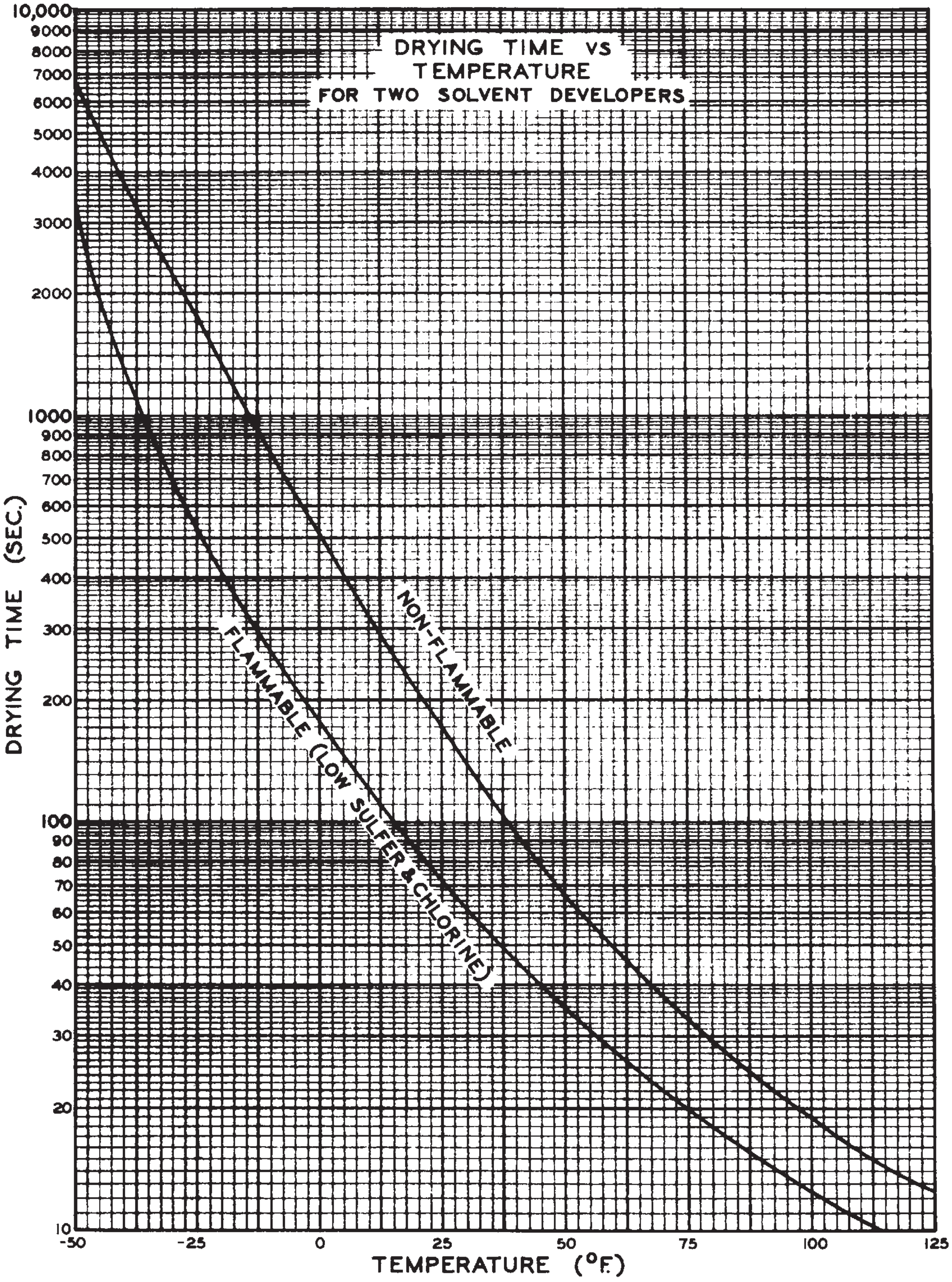

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Figure 2-17. Graph Showing the Approximate Drying Times for Two Types of Nonaqueous Developers at Various Temperatures

2.4.6.2 High Temperature Limitations.

WARNING

> The disadvantages of elevated temperatures outweigh the advantages. Penetrant application and dwell SHALL NOT be initiated on parts where temperatures exceed 125°F (52°C), unless special high temperature penetrants are used.

Sensitivity is improved slightly when test part temperatures are 125°F (52°C) to 150°F (65.5°C). The higher temperature evaporates some of the liquid, which increases the dye concentration and improves the visibility of indications. The elevated temperature also reduces viscosity, which speeds penetration. At temperatures of 125°F (52°C), the volatile components of penetrants are rapidly evaporated. During penetrant dwell, the layer of penetrant is very thin and with a part temperature of more than 125°F (52°C), the loss of volatile components will drastically change the penetrants composition. Elevated temperatures also reduce visible dye color and fluorescence (heat fade), making indications less visible. In general if a part is too hot to handle, it is too hot for penetrant testing.

2.4.7 Penetrant Dwell.

2.4.7.1 Definition of Penetrant Dwell. Penetrant dwell is the total length of time the penetrant is allowed to remain on the part before removal of the penetrant. This includes immersion, soak, and drain times. The purpose of dwell is to allow the penetrant to seep into and fill any surface openings.

2.4.7.2 Factors Influencing Penetrant Dwell Time. There are a number of interacting factors that influence the length of time required for penetrant to enter and fill a surface void. Some of the factors are listed below with a description of each following: void size (geometry and volume), penetrant sensitivity, part material and form, discontinuity type, discontinuity contamination, insoluble soil contamination, and soluble soil contamination.

2.4.7.2.1 Void Size. The dwell time required for a penetrant to enter and fill a surface void depends mainly on the width of the surface opening and depth of the void. Penetrant enters and fills voids with wide openings more rapidly than those with narrow openings. Very narrow or tight flaws, such as those associated with fatigue cracking, may require 2 to 5 times the length of dwell time compared to a wider flaw such as a crack caused by over-stressing. The larger void depth requires more time to fill because there is more volume within the void.

2.4.7.2.2 Penetrant Sensitivity. The sensitivity of penetrants is affected by the length of penetrant dwell time. The differences in dwell times are due to the differences in surface tension, contact angle, and viscosity of the various penetrant types and sensitivities. While material viscosity between manufacturers of the same type and sensitivity level vary, the combination of factors tends to stabilize dwell time for each type and sensitivity. This allows penetrants within each of the sensitivity levels to have equivalent dwell times.

2.4.7.2.2.1 Sensitivity Selection. Selection of the sensitivity level to be used depends on a number of factors: potential flaw size, width of opening, volume of the discontinuity, part size, part shape, surface finish, residual stress, allowable flaw size, and intended service of the part. The rule-of-thumb is to use the highest sensitivity possible to reveal critical discontinuities while at the same time ensuring complete removal of all surface penetrant to reduce or eliminate background. Difficulties can be experienced if the sensitivity level is either too low or too high. Low sensitivity levels may not reveal critical flaws, while excessive sensitivity can result in an excessive residual background that would obscure any discontinuity indications or produce nonrelevant indications.

2.4.7.2.3 Part Material and Form. The effect of part material (steel, magnesium, aluminum, etc.) and form (castings, forgings, welds, etc.) on penetrant dwell relates to the type of flaw typically found. For example, cold shuts in steel casting tend to have tighter openings than cold shuts in magnesium castings. Therefore, the dwell times for cold shuts in steel castings are typically longer than the dwell times in magnesium and aluminum castings. Discontinuities occurring in forgings are typically tighter than in castings and require longer dwell time.

2.4.7.2.4 Discontinuity Type. The various types of discontinuities differ in the width of the opening. Laps are tighter than porosity, and fatigue cracks are tighter than either laps or porosity. The required length of penetrant dwell increases as the discontinuity width decreases (surface opening becomes tighter or narrower).

2.4.7.2.5 Discontinuity Contamination. Penetrant dwell times are based on clean parts without entrapped contaminants. Inspection of parts that have been in service can be complicated by the difficulty of removing all of the entrapped soil from the discontinuities. The effect of the entrapped soil on the penetrant dwell time depends upon the type and amount of soil involved.

2.4.7.2.6 Insoluble Soil Contamination. If the discontinuity is full of soil, is not soluble in penetrant, penetration cannot occur. A change in penetrant sensitivity or dwell time will not help since penetrant cannot enter such flaws. A discontinuity only partially filled with insoluble soil will produce a smaller and less visible indication. Increasing the dwell time will not improve the indication; however, a more sensitive penetrant with its higher dye content will produce a more visible indication.

2.4.7.2.7 Soluble Soil Contamination. When discontinuities contain soils soluble in penetrants, such as un-pigmented grease, oils, cleaning solutions and other soluble organic materials, penetration of the inspection fluid into the discontinuity can occur. The penetrant will fill any vacant space in the discontinuity and then stop. Diffusion then begins between the penetrant and soluble soil. In a short time, the penetrant and soil become mixed; however, this mixture will fluoresce much less and may not give a useful indication. An increase in dwell time will improve the visibility of the indication. With increased dwell time some of the soil diffuses out of the discontinuity and is replaced with pure penetrant. Using a more sensitive penetrant will improve the visibility of the indication since the higher dye content can withstand more dilution.

2.4.7.3 Affects of Temperature and Viscosity on Dwell Time.

2.4.7.3.1 Penetrant Viscosity Vs. Temperature Change. Viscosity of oils, which includes penetrants, changes drastically with temperature. Oils become thin (less viscous) at high temperatures and thick (more viscous) at low temperatures. How the viscosities of a number of penetrants change with temperature is illustrated in (Figure 2-18). The horizontal and vertical scales are spaced to show the viscosity changes as a straight-line function. This chart also shows that the viscosity of a high sensitivity, postemulsifiable (PE) penetrant is about 3 centistokes (cs) at 120°F (49°C) and about 75 cs at -10°F (-23°C), or becomes about 25 times thicker. The same chart shows the viscosity of visible dye is about 2 cs at 120°F (49°C) and 22 cs at -10°F (-23°C), which is an eleven times increase in viscosity. The required part temperature range for applying penetrants is 40°F (4°C) to 120°F (49°C). Most penetrants are applied at or near a part temperature of 70°F (21°C). Therefore, nearly all operating instructions or procedures specifying dwell times are based on applying penetrant to a part at or near a temperature of 70°F (21°C). The viscosity of a typical high sensitivity postemulsified penetrant (7 cs) at 70°F (21°C) is twice the viscosity (14 cs) at 40°F (4°C) and about half the viscosity (3 cs) at 120°F (49°C). Other penetrants show a similar range of viscosity change with temperature. These viscosity changes are significant enough to require the adjustment of dwell times for temperature extremes.

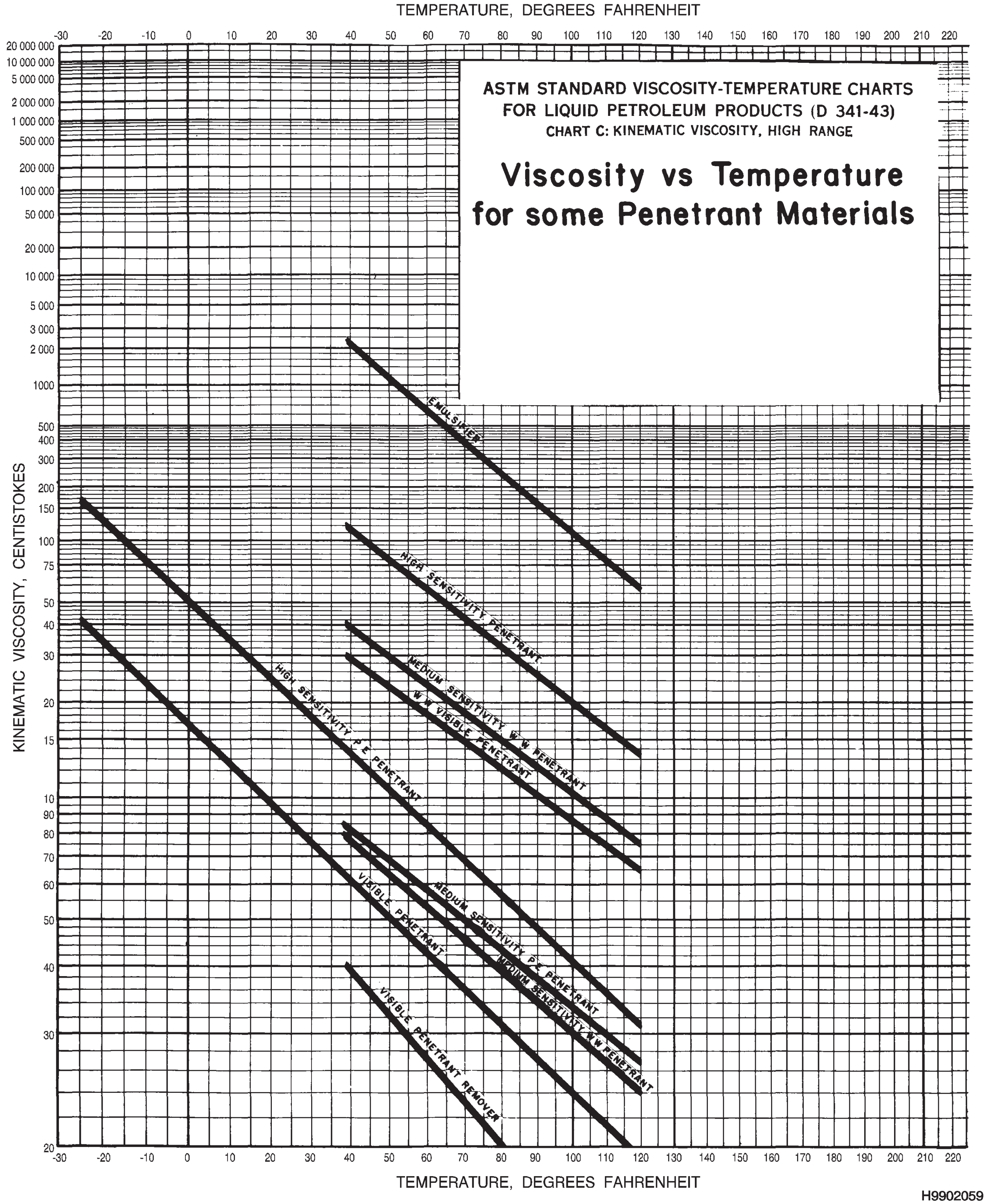

Figure 2-18. Graph Showing the Viscosities of Several Quality Parts Listing (QPL) Penetrants at Various Temperatures

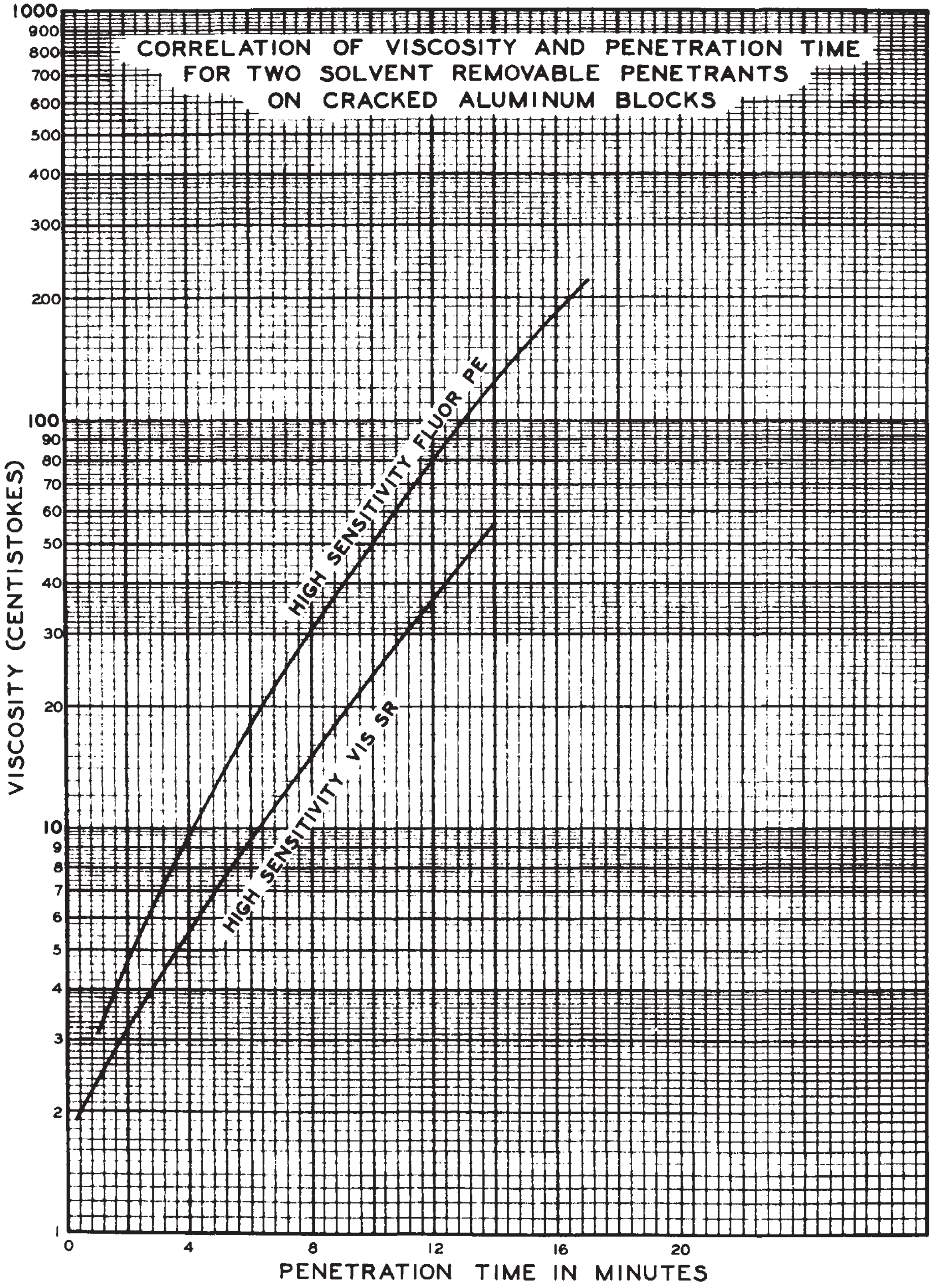

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Figure 2-19. Graph Showing the Comparison of Dwell Time Vs. Viscosity for Two Types of Penetrants

2.4.7.3.2 Dwell Time Vs. Temperature and Viscosity.

NOTE

> The evaporation rate of penetrant is increased at temperatures above 100°F (37.2°C). Care SHALL be taken to prevent the penetrant from drying.

Laboratory experiments have demonstrated penetrant dwell time does not have to be changed in the same ratio as the viscosity changes. The minimum dwell times for the penetrants previously discussed is compared in (Figure 2-19). The high sensitivity PE penetrant, with a viscosity of 7 cs at 70°F (21.1°C), required a penetrating time of 3 minutes. At 40°F (4°C), the viscosity doubled to 14 cs, while the dwell time increased by 1.75 to 5.5 minutes. At 120°F (49°C), viscosity of penetrant drops to less than one-half (3 cs) and the dwell time decreases by two-thirds (1 minute). The thinner visible-dye penetrant, with a viscosity of 3.6 cs at 70°F (21.1°C), required a penetrant dwell time of 2.4 minutes. At 120°F (49°C), the viscosity was reduced by almost one-half (2.0 cs), while the required dwell was reduced to one-fifth of the time (0.5 minutes).

2.4.7.4 Penetrant Dwell Characteristics.

2.4.7.4.1 Dwell Modes. There are two basic penetrant dwell modes, "immersion" and "drain."

2.4.7.4.1.1 Immersion Dwell Mode. In this mode the part remains submerged in a tank of liquid penetrant for the entire dwell period. Immersion dwell can also be performed by continuously brushing with fresh penetrant throughout the dwell period.

2.4.7.4.1.2 Drain Dwell Mode.

NOTE

> Drain dwell is the preferred mode and SHALL be used unless the inspection instruction specifies immersion dwell.

With drain dwell, the part is first covered with penetrant by spraying, brushing, or immersion. Once coated, the part is placed on a rack or rest and allowed to drain during the dwell period. Comparison tests with aluminum crack blocks and nickel-chrome penetrant panels have demonstrated the improved performance of drain dwell mode compared to immersion dwell mode. This improved performance is due to the changes in penetrant composition that occurs during the dwell period. The penetrant vehicle is a mixture of heavy oils that dissolve and hold the dye materials in solution; and thin or lightweight solvents or oils that reduce the viscosity of a penetrant. During the drain dwell period, the lighter weight liquids evaporate, which increases the concentration of the dye material entrapped in discontinuities. The increased dye concentration enhances the visibility of the indication. The drain dwell mode is also more economical than immersion dwell mode since the excess penetrant drains from the part and is recovered. The savings with drain dwell are two-fold, since the drained penetrant is recovered and the remaining penetrant layer is much thinner than an immersion dwell layer. The thinner penetrant layer requires less emulsifier during the removal process. Generally, the immersion is momentary, but at most, it should be no longer than half the total dwell period.

2.4.7.4.2 Minimum Penetrant Dwell Times.

CAUTION

> The minimum dwell time for service-induced defects SHALL NOT be less than 30-minutes, unless otherwise specified by a specific part procedure.

NOTE

> Selection of a penetrant dwell time is complex and depends upon a large number of factors. A thorough knowledge of the penetrant capabilities and limitations of the penetrant system used for the type of discontinuity to be detected is required. Whenever possible, the decision of dwell time should be based upon experience of the responsible engineering support. Documents governing dwell time SHALL specify the mode and time of dwell. The number of factors influencing the entry of penetrant into a discontinuity complicates setting uniform minimum penetrant dwell times.

Most dwell times are based on past experience with similar parts, materials and potential flaws. The minimum penetrant dwell time that SHALL be used is provided in (Table 2-2). These dwell times are based on the expected flaw condition and ambient temperature conditions. Minimum penetrant dwell times for manufacturing induced defects SHALL be as specified by ASTM E 1417 or as specified by specific technical directive or procedures. Minimum penetrant dwell times SHOULD be specified in the technical directives or part specific procedures mandating the inspection.

Table 2-2. Minimum Penetrant Dwell Times

Temperature 40º - 60ºF	Minimum
Service Damage/Fatigue Cracks	60 minutes
Stress Corrosion Cracks	240 minutes
Temperature 60º - 125ºF	Minimum
Service Damage/Fatigue Cracks	30 minutes
Stress Corrosion Cracks	240 minutes

2.4.7.4.3 Effects of Insufficient Dwell. When the dwell time is too short to allow the penetrant to completely fill the discontinuity, the visibility of the resulting indication will be reduced. A thermally cracked, aluminum block with one half receiving an adequate dwell, and the other half an insufficient dwell is shown in (Figure 2-20). The differences in dwell times have different effects depending on the flaw size. The very small flaws are not indicated, the visibility of indications from medium size flaws is greatly reduced, and there is a slight reduction in the visibility of larger size flaw indications. If it is suspected a part has not had an adequate dwell, the part SHALL be completely cleaned and then reprocessed through the entire inspection process.

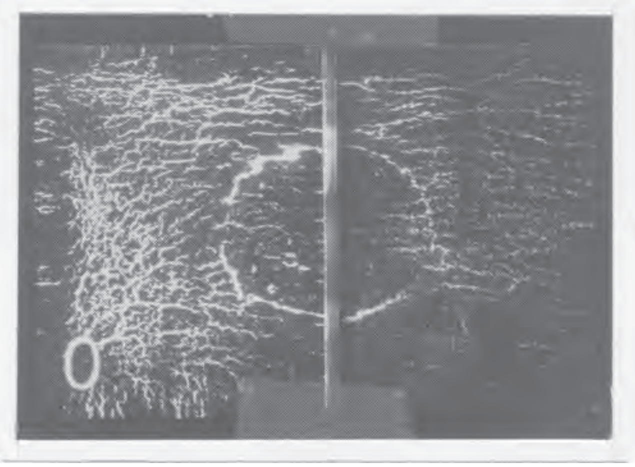


Figure 2-20. Comparison of Adequate Dwell Vs. Insufficient Dwell on a Thermally Cracked Aluminum Block

2.4.7.4.4 Effects of Excessive Dwell.

NOTE

> Fresh penetrant SHALL be applied at 60-minute intervals when dwell time exceeds 60 minutes or when the penetrant appears to be drying on the part. The penetrant SHALL NOT be allowed to evaporate to the tacky or dry state while on the part. If, for some reason, the penetrant is allowed to become tacky, the part SHALL be subjected to a complete reprocessing through the pre-cleaning and penetrant inspection cycle.

Once the penetrant has completely filled a void, extending the dwell time will not improve the indication; except for the case of the contaminated flaw. Application of fresh penetrant improves the rate of penetration and makes it easier to remove the excess surface penetrant at the end of the dwell period. Evaporation is accelerated by temperatures above 100°F (38°C) or by rapid air movement. When inspections require excessively long penetrant dwell times, another inspection method, such as eddy current, may be considered to reduce inspection time.

2.4.8 Penetrant Removal. This section provides basic, intermediate, and advanced information on the methods and procedures used in removing excess surface penetrant. The first portion of the section contains general information applicable to all removal methods. The second portion is devoted to the water washable penetrant processes and water washing or spray rinsing. The remaining portion covers the methods and procedures used in the postemulsifiable lipophilic, postemulsifiable hydrophilic, and solvent removable penetrant processes.

2.4.8.1 After the penetrant has been applied and has filled any open discontinuities, the excess penetrant on the surface SHALL be removed. Removal of the excess surface penetrant is a critical step in the inspection process. Improper removal can lead to misinterpretation and erroneous results. Excessive or over-removal will reduce the quantity of penetrant entrapped in a flaw, resulting in either a failure to produce an indication or an indication with greatly reduced visibility. Incomplete or insufficient removal will leave a residual background that may interfere with the detection of flaw indications. The term “removability” applies to the ease of removing the excess surface penetrant. “Washability” is sometimes used interchangeably in commercial application; however, the materials specification and this manual will use “washability” only in the case of water-washable penetrants.

2.4.8.2 Factors Influencing Penetrant Removal.

2.4.8.2.1 Part Surface Condition. The surface condition of the part has a direct effect on removability. Smooth, polished surfaces such as chromium-plated panels can be easily processed by any of the removal methods with no residual background. As the surfaces become rougher, such as chemically etched or sand blasted parts, the removal of surface penetrant becomes more difficult. Rough surfaces reduce removability in two ways 1) The roughness restricts the mechanical force of the spray rinse in the indentations or low points and 2) the roughness prevents the emulsifier from evenly combining with the surface penetrant. It is not always possible to produce a background-free surface on rough parts. The wash or emulsification time required for a completely clean surface may result in removal of some of the penetrant entrapped in flaws. In this case, the wash or emulsification time may be shortened, leaving some residual background. The amount of residual background SHALL be limited to allow any flaw indications to be visible through the background.

2.4.8.2.2 Part Shape or Geometry. The part shape and geometry may indirectly affect removability by causing a thicker layer of penetrant to accumulate during the dwell period and restrict accessibility to the test surface by the spray rinse. One of the factors involved in removing excess surface penetrant is the mechanical action or force of the spray rinse. When parts contain surfaces where the spray cannot directly strike the surface, such as concave or recessed areas, holes, and screw threads, the removal time is increased in these local areas. Also, the thickness of the penetrant layer in these inaccessible areas is usually greater than on the adjacent surfaces. This is due to the tendency of the penetrant to drain and collect in these areas. For example, during the dwell period the penetrant will drain from the top or crown of a thread and will flow into the thread root area. The increased layer thickness in the thread root requires a longer removal time than the thin layer at the thread crown. The inaccessible surfaces usually have thicker layers of penetrant and require additional removal time. Care SHALL be exercised to prevent over-removal on the accessible surfaces with thinner penetrant layers, while trying to adequately clean the thicker penetrant layer from an adjacent inaccessible surface.

2.4.8.2.3 Narrow Deep Flaws. Flaw size and shape may complicate the removal process. Narrow, deep flaws, while requiring long penetrant dwell times, provide a relatively large reservoir to hold entrapped penetrant. The narrow surface opening reduces both the diffusion rate of emulsifier into the flaw and the effect of mechanical force of the spray rinse on the entrapped penetrant. The result, narrow, deep flaws produce highly visible indications with a minimum of removal problems.

2.4.8.2.3.1 Narrow, Shallow Flaws. The removal process becomes slightly more critical when narrow, shallow flaws are present. Narrow, shallow flaws do not have a large reservoir to hold entrapped penetrant. The visibility of an indication depends on the amount of penetrant that exits from the flaw. If the flaw is shallow, only a small amount of penetrant is available, and the indication may be faint. Over-removal of any entrapped penetrant will reduce the visibility of an already faint indication. In addition, a small amount of residual background (insufficient removal) will obscure faint indications.

2.4.8.2.3.2 Broad, Shallow Flaws. Broad, shallow flaws are defined as those with the surface opening equal to or greater than the depth. They present the most critical case for penetrant removal. The opening does not reduce the force of the spray rinse, nor does it restrict the emulsification rate, and entrapped penetrant is easily removed. Extreme care must be used during penetrant removal if broad, shallow flaws are likely to be present.

2.4.8.3 Removability Properties of Penetrant. Penetrant materials vary widely in their ease of removal. There are differences in removability between the various penetrant types, classes, and sensitivity levels. Also, similar penetrants provided by different manufacturers vary in removability. One penetrant characteristic affecting removability is the viscosity. High viscosity (thick) penetrants are more difficult or more slowly removed than low viscosity (thin) penetrants. The penetrant system sensitivity level also affects removability. Higher system sensitivity level penetrants contain more dye per unit volume, and trace quantities of residual penetrant will produce a higher background than the same quantity of a penetrant system with a lower sensitivity level. It is necessary to remove more of the residual high sensitivity penetrant to produce an equivalent background.

2.4.8.4 Removal of Water Washable (Method "A") Penetrants.

CAUTION

> Water washable (Method A) penetrants are prohibited for use on all flight critical aircraft components, and on all engine components. Water washable penetrants SHALL NOT be used on these components without specific written authority from the responsible engineering authority.

NOTE

> Water washing of fluorescent penetrant SHALL be accomplished under UV-A illumination. The wash station should be in subdued light, if possible (less than 20 lumens).

Water washable penetrant is removed after penetrant dwell by subjecting the part to a water spray wash. The spray wash may be a hand-held nozzle, a semi-automatic system, or a fully automated system. Care SHALL be exercised to prevent over-removal since the penetrant entrapped in discontinuities contains an emulsifying agent and is easily removed. Removal is controlled by length of wash time and the wash SHALL be stopped when an acceptable background is reached. Cracked-chrome panels, following different wash times is shown (Figure 2-21). Insufficient wash, optimum wash, and excessive wash are shown. The smooth surface of the chrome-plated panel is deceptive. If the surface were rougher, some residual background may have been retained on the optimum-wash sample. See Section 2.4.9 for proper rinse procedures.

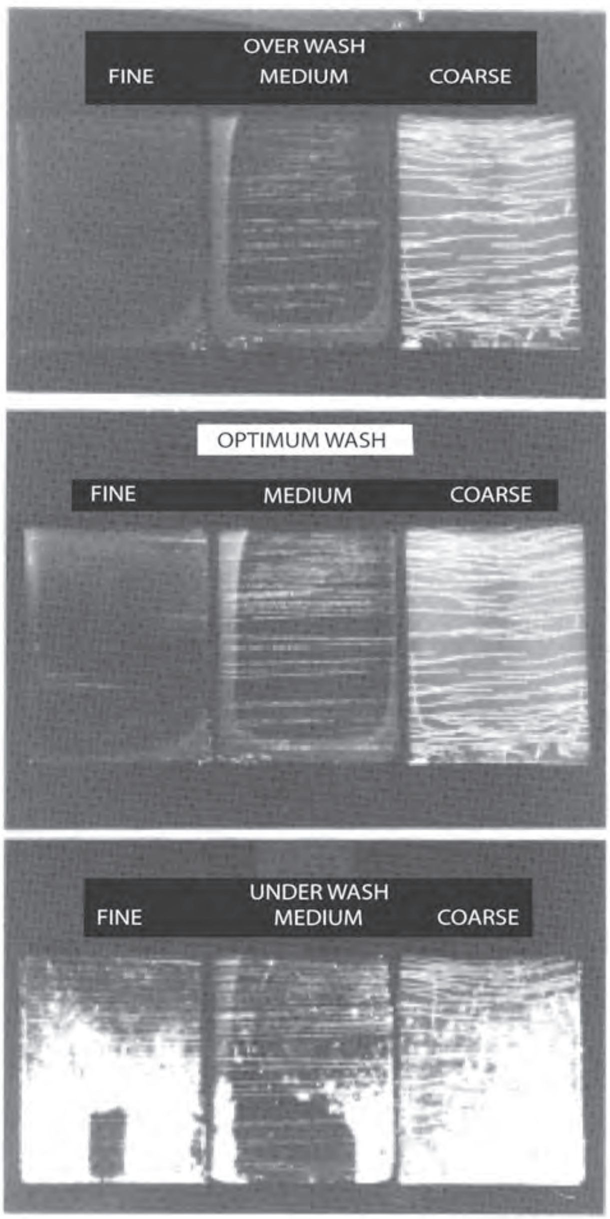


Figure 2-21. Cracked-Chrome Panels Showing Effects of Insufficient Wash, Optimum Wash, and Excessive Wash

2.4.8.4.1 Advantages of Water Washable, (Method "A") Penetrant. Water Washable, Method "A", penetrants have several advantages over other methods:

- Elimination of the separate emulsification process step results in cost savings:
    - The cost of the combined penetrant emulsifying agent is less than the total cost of separate penetrant and separate emulsifier.
    - A separate tank or station for emulsifier is not required.

  - Cost of automating is reduced.
  - Process flow time, especially on volume is reduced.

- The emulsifiable mixture is easily removed from complex shaped parts, making it advantageous for use on threads and keyways.
- The variables associated with controlling emulsifier dwell time are eliminated.

2.4.8.4.2 Disadvantages of Water Washable, (Method “A”) Penetrant. Water Washable, Method “A”, penetrants also have disadvantages:

- There is no control over the diffusion or emulsified layer. Penetrant entrapped in flaws contains emulsifying agent, making it susceptible to removal by over-washing. It is also easily removed from broad, shallow flaws.
- Water rinse time is critical and SHALL be carefully controlled.
- Residual background is higher than from the same sensitivity level postemulsifiable penetrant system.
- The penetrant emulsifying agent mixture is susceptible to water contamination.
- Treatment or disposal of large quantities of rinse water contaminated with water washable penetrant is required.

2.4.8.5 Comparison of Lipophilic, Method "B" and Hydrophilic, Method "D" Penetrants.

CAUTION

> Post-emulsifiable lipophilic (Method "B") penetrants are prohibited for use on all rotating engine components without specific authorization from the responsible engineering authority.

The main difference between methods "B" and "D" is not in the penetrant material, but in the process used to remove the penetrant. Unlike Method "A" penetrant materials, which have a built-in remover action, the removability action is aided by emulsifier or remover. Close attention SHALL be given to knowing which method you are using and the advantages and disadvantages to using both.

Both Method "B" (Lipophilic) and Method "D" (Hydrophilic) penetrants are oil-based vehicles containing highly visible colored or fluorescent dyes. They are formulated to optimize their penetration and visibility capabilities. They differ from water washable penetrant in they resist removal by water washing since they do not contain an emulsifier. A separate process step of emulsification is required for removal.

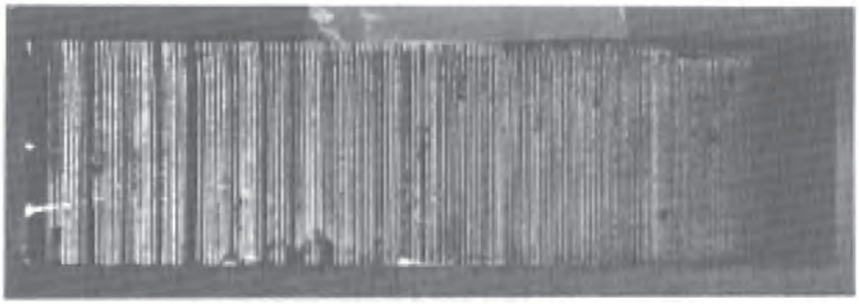
2.4.8.5.1 Lipophilic Emulsifier Versus Hydrophilic Remover Processes. Differences between the lipophilic and hydrophilic processes are summarized as follows:

- Lipophilic emulsifier is supplied as a ready to use liquid, whereas hydrophilic remover is supplied as a liquid concentrate, which must be diluted with water before use.
- The hydrophilic process requires an additional pre-rinse step immediately following the penetrant dwell period.
- The methods of applying the emulsifier and remover differ. Parts are dipped into lipophilic emulsifier and then immediately removed to drain. Parts either are immersed into hydrophilic remover for the entire removal time or are subjected to a spray of remover for the specified time.
- The modes of action by which the lipophilic emulsifier and hydrophilic remover remove the excess penetrant differ.

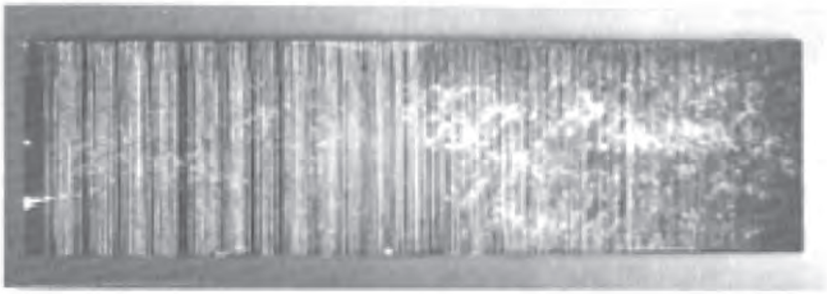
2.4.8.5.2 Advantages of Using Hydrophilic Removers Over Lipophilic Emulsifiers. A comparison of the physical, chemical, and application differences between the hydrophilic and lipophilic techniques is provided in (Table 2-3). There are several benefits to using the hydrophilic method over the lipophilic method. The hydrophilic process has the ability to remove surface penetrant with reduced effect on penetrant entrapped in a crack. Another major advantage of hydrophilic removers is the increased process tolerance (e.g., hydrophilic removal time is not as critical as lipophilic emulsification dwell). Hydrophilic removal times of 1 or 2-minutes have little effect on penetrant entrapped in a discontinuity, while exceeding the maximum lipophilic emulsification times by as little as 10 or 15-seconds can seriously degrade a flaw indication. A cracked-chrome plated panel processed to show the effects of optimum, insufficient, and excessive hydrophilic removal (Figure 2-22). The cracks in the panel are progressively smaller from left to right in the figure. Another advantage to using hydrophilic remover is the relative insensitivity to removal of penetrant entrapped in a discontinuity. This permits complete removal of fluorescent background in most cases. In contrast, when using lipophilic emulsifier on slightly rough surfaces, it is desirable to leave a faint residual background when maximum sensitivity is required. The reduction of background fluorescence with the hydrophilic remover improves the contrast, making faint indications easier to see. The hydrophilic method also allows spot touch-up removal on local areas during the final clear water rinse. Spot touch-ups cannot be done with the lipophilic method, since the oil base emulsifier will not tolerate water. Hydrophilic removers also provide better control, handling, and recycling of the process materials. This can significantly decrease wastewater treatment costs and minimize water pollution.

Table 2-3. Comparison of Hydrophilic Vs. Lipophilic Methods

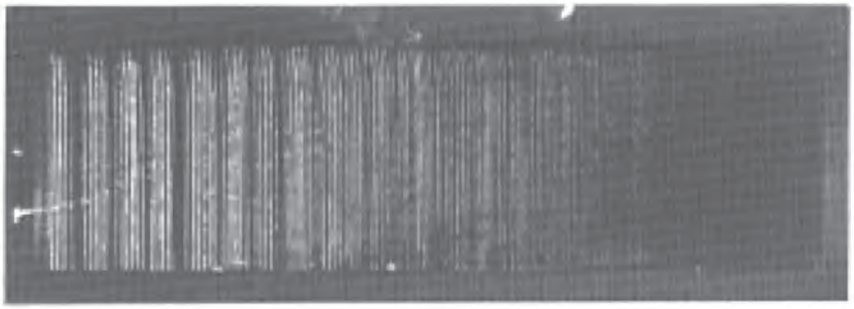
Hydrophilic	Lipophilic
1. Supplied as a concentrate	1. Supplied as a ready to use fluid
2. Water base when mixed	2. Oil base
3. Low viscosity 9 to 12 cs	3. High viscosity 35 to 120 cs
4. Limited penetrant tolerance	4. Miscible with penetrant in all concentrations
5. Miscible with water in all concentrations	5. Limited water tolerance
6. Applied as dip or spray	6. Applied as a dip
7. Action: Dip-detergent with scrubbing wash	7. Action: Diffusion activated by scrubbing
8. Reduced drag-out	8. Critical emulsion time



OPTIMUM REMOVAL



UNDER REMOVAL



OVER REMOVAL

Figure 2-22. Effects of Optimum, Insufficient, and Excessive Hydrophilic Removal Dwell Time

2.4.8.6 Removal of (Method “B”) Penetrants with Lipophilic Emulsifier.

2.4.8.6.1 Using Lipophilic Emulsifier (Method “B”) (Figure 2-14).

NOTE

> When the part surface has been coated with emulsifier, the part SHALL be removed from the liquid and allowed to drain. The part SHALL NOT remain in the emulsifier during the dwell period.

Lipophilic emulsifier is applied, after a sufficient penetrant dwell time, by dipping or immersing the part in a tank of emulsifier. Lipophilic emulsifier is used as supplied by the manufacturer. Application of the material SHALL NOT be accomplished by spraying, flowing, brushing, or wiping onto the part. The two major problems with spraying and flowing are the difficulty in applying a uniform thickness and the difficulty of applying enough emulsifier without the mechanical force of the spray scrubbing the penetrant layer. Brushing or wiping on material produces an uncontrolled and uneven mixing action. There are a few automated systems where the emulsifier is applied as a fog.

2.4.8.6.2 Lipophilic Emulsifier Dwell.

CAUTION

> Dwell time is critical in this process and SHALL be monitored closely to avoid over-emulsification.

After the emulsifier has been applied and the part is draining, a period of time is allowed for diffusion of the materials. During diffusion, a water removable colloidal mixture is being formed. This is the emulsifier dwell time and is one of the most critical factors in the lipophilic process. A timing device is required to control this process. The objective is to stop the diffusion when the emulsifier has just reached the part surface and before it diffuses into any penetrant entrapped in a discontinuity. Penetrant without emulsifier resists removal. If the dwell time is too long, the emulsifier will diffuse into entrapped penetrant easily removed causing loss of sensitivity and missed flaws. If the time is too short, the thin layer of surface penetrant not emulsified will cause an excessive background that can obscure a discontinuity indication. A number of factors which influence the dwell times are discussed in the following paragraphs.

2.4.8.6.3 Factors Influencing Lipophilic Emulsifier Dwell Time.

2.4.8.6.3.1 Part Surface. Very smooth polished surfaces retain only a thin layer of penetrant and require a relatively short emulsifier dwell period. On the other hand, longer emulsifier dwell times are required for rough surfaces, which retain a thicker layer of penetrant. Inspections of components with rough surfaces, such as sand castings, dictate a longer time for the emulsifier to diffuse to the bottom of the surface indentations.

2.4.8.6.3.2 Flaw Type. Tight flaws, with significant depth relative to flaw width, are more tolerant to longer emulsification dwell time than are wide, shallow flaws. The diffusion rate of even the more active emulsifiers is slowed down when diffusing into constricted or narrow openings. The diffusion rate on wide, shallow flaws can be rapid and it is easy to over-emulsify. Some over emulsification can be tolerated with deep flaws, which provide large reservoirs for entrapped penetrant. A degree of under-emulsification (or residual background) may be required when detection of shallow flaws in parts with rough surfaces is required.

2.4.8.6.3.3 Penetrant Dwell Time. Long penetrant dwell times permit more penetrant to drain from the part, resulting in a thinner surface layer. Since diffusion rate for a given emulsifier is constant, the emulsifier dwell time required is proportional to the thickness of the penetrant layer (e.g., thicker layers require more emulsification dwell time, and thinner layers require less time).

2.4.8.6.3.4 Emulsifier Contamination. As parts are processed, the emulsifier becomes contaminated with penetrant from both the initial immersion and the drain cycle. While penetrant and emulsifier are soluble in all combinations, the gradual increase of penetrant in the emulsifier slows the emulsification action. With combined build-up, the mixture will eventually stop functioning as an emulsifier. The slowing action due to penetrant contamination is very gradual, and at concentrations of less than 25-percent (penetrant in emulsifier) the performance of the emulsifier is generally not affected.

2.4.8.6.4 Determining Lipophilic Emulsification Dwell Time.

CAUTION

- The lipophilic emulsion step does not tolerate deviation from the optimum dwell time. A relatively short over-emulsification time of 10-seconds on a 1-minute dwell period can result in failure to indicate small flaws.
- Emulsifier dwell time SHALL NOT exceed 5-minutes.

Although emulsifier dwell time is critical for most defects, the large number of influencing factors make it impossible to develop a general dwell timetable. Optimum emulsifier dwell time must be determined on each part by experiment, even here, dwell times may require adjustment to compensate for local conditions. At the extreme, dwell times may range from 10-seconds to 5-minutes; however, typical dwell times of less than 1-minute are adequate. Cracked-chrome plate panels and the effects of insufficient, optimum, and excessive emulsifier dwell are shown in (Figure 2-23).

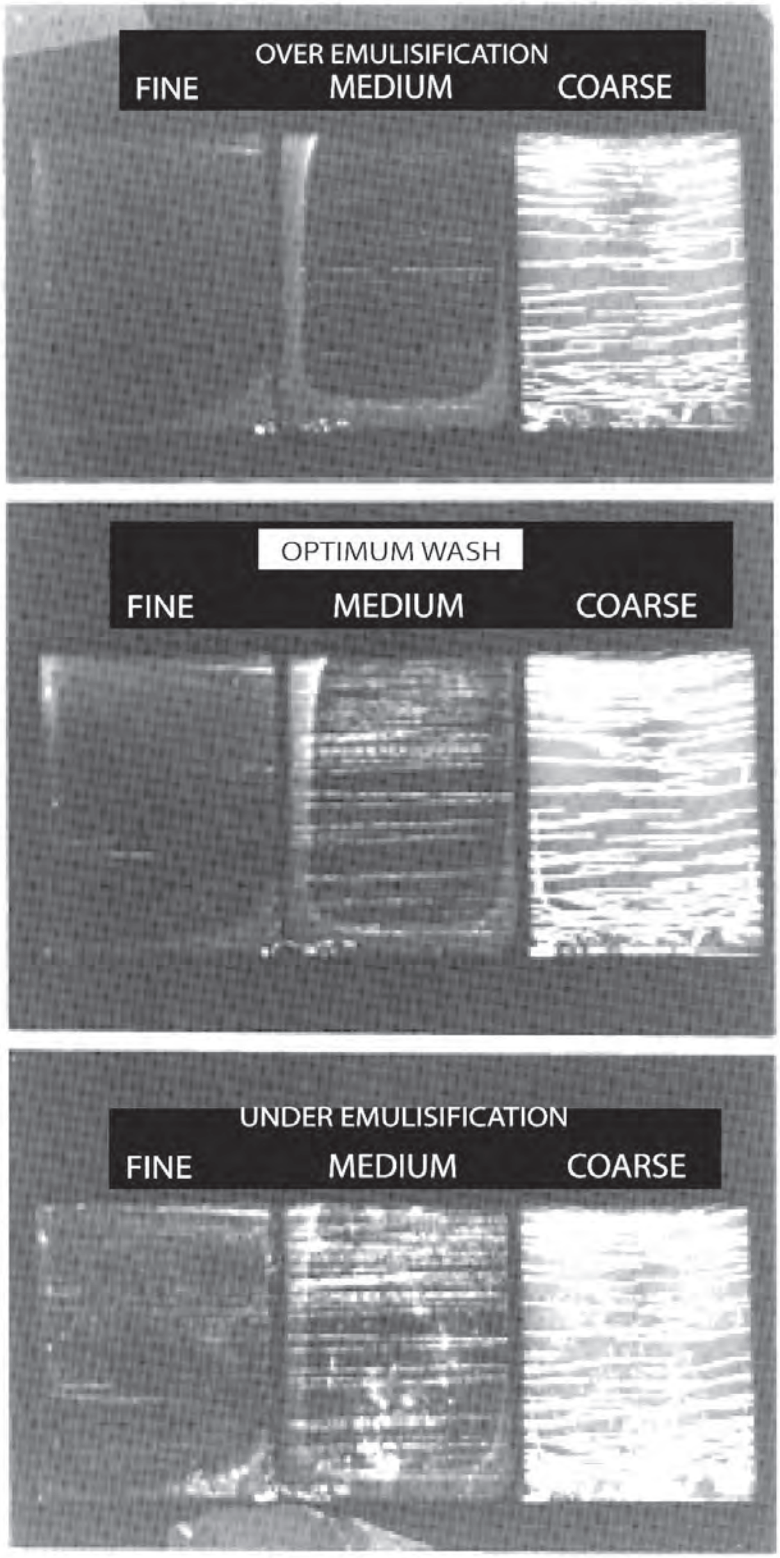


Figure 2-23. Effects of Optimum, Insufficient, and Excessive Emulsifier Dwell Time

2.4.8.6.5 Rinse - Stopping the Emulsification Action.

CAUTION

- Postemulsifiable penetrant entrapped in flaws and not diffused with emulsifier is relatively resistant to water spray and rinse time is not critical, however, excessive spray pressure or hot water can remove entrapped penetrant and SHALL be avoided.
- For an agitated immersion rinse, the dwell time SHALL be the minimum required to remove the emulsified penetrant. Examine the components under appropriate illumination after rinsing. Clean and reprocess those parts exhibiting excessive background.
- The air nozzle SHALL be held at a sufficient distance from the part to ensure the developing indication is not smeared by the air blast.

After the appropriate dwell time, emulsification SHALL be stopped by agitated immersion or water rinse. If rinsing is used an initial light water spray over the entire surface of the part SHALL be performed. This initial rinse stops the diffusion process and eliminates excessive emulsifier dwell on any surface. Further water spraying to remove the excess emulsified surface layer is performed only after the entire surface has been wetted and the diffusion process has been stopped. After rinsing, allow the water to drain from the component. Utilize repositioning, suction, blotting with clean absorbent materials or filtered shop air at less than 30 psi to prevent pooling of water. See Section 2.4.9 for proper rinse technique.

2.4.8.6.6 Batch Processing Using Lipophilic Emulsifier.

CAUTION

When a number of parts are being inspected, they SHALL be processed one at a time through the emulsifier, emulsifier dwell, and wash steps unless they are small enough to be batch processed.

Because emulsification time is critical for the Method B process, the dwell time for each part SHALL be closely monitored. Excessive dwell will occur when emulsifier is applied to a number of individual parts and they are then individually washed. Batch processing of parts is the preferred method for the inspection of multiple components provided the parts are small enough they can be processed simultaneously without touching one another.

2.4.8.6.7 Insufficient and Excessive Emulsification.

CAUTION

The part SHALL be completely reprocessed if, during or after the rinse step, it is suspected to be too short (insufficient emulsification) or too long (excessive emulsification) a dwell time has occurred.

Correction of dwell time cannot be achieved by immersing in penetrant or emulsifier. The part must be cleaned to remove all residual penetrant and reprocessed through the entire process. A good indicator of over-wash or over-removal of the surface penetrant is evidenced by a total lack of residue that may occur on all or specific areas of the part.

2.4.8.7 Removal of (Method "D") Penetrants with Hydrophilic Remover.

2.4.8.7.1 Hydrophilic Remover Concentration.

CAUTION

Penetrant and remover are qualified as a system to be used together and SHALL NOT be interchanged.

Each penetrant manufacturer has its own formulation that varies in aggressiveness. The concentrations of hydrophilic remover (in water) can range from 5 to 35-percent. The concentrations used for qualification are identified in the Qualified Products List (QPL SAE AMS 2644) and should not be exceeded without approval from the responsible engineering authority. Caution SHALL be exercised when changes in suppliers are involved because the required concentration may change.

2.4.8.7.2 Using Hydrophilic Remover, (Method "D") (Figure 2-16).

2.4.8.7.2.1 Hydrophilic Remover Pre-Rinse. The hydrophilic remover method differs from the lipophilic emulsifier in two ways: hydrophilic remover baths require mild agitation and pre-rinse is performed before parts are placed in the remover bath. The hydrophilic method requires spraying the part with clean water immediately following the penetrant dwell. The mechanical action of the water spray removes over 80-percent of the excess surface penetrant, leaving only a very thin uniform layer of surface penetrant on the part. The post penetrant dwell spray helps optimize the removal process by reducing the amount of remover consumed, and in immersion setups, minimizes contamination of remover due to penetrant carry-over. It also reduces remover contact time by approximately 50-percent compared to when no pre-rinse step is used. A pre-rinse step cannot be used in the lipophilic process, as the oil base emulsifier does not tolerate water. Slight agitation of the remover bath or movement of the part in the bath is regularly required to maintain fresh remover on the part surface while the part is submerged.

2.4.8.7.2.1.1 Pre-Rinse Procedure. The pre-rinse step SHALL be used since it improves the efficiency of the process and minimizes hazardous waste. Where possible, the spray nozzle SHALL be held a minimum of 12 inches from the part surface. The pre-rinse cycle SHALL be a coarse spray of clean water at a maximum pressure of 40 psi (275 kPa) for 30 to 120 seconds. The water temperature SHALL be between 50°F (10°C) and 100°F (38°C). The water pre-rinse SHALL be applied for the minimum amount of time required to achieve removal of the bulk surface penetrant. The objective is to reduce the amount of surface penetrant, while leaving only a thin layer remaining on the part. See Section 2.4.9 for proper rinse technique.

2.4.8.7.2.2 Different Hydrophilic Remover Application Techniques. Hydrophilic remover is typically applied by immersion, spraying or a combination of both. Brushing or swabbing shall not be used. Each technique offers certain advantages as well as disadvantages discussed in the following paragraphs.

2.4.8.7.2.2.1 Hydrophilic Remover Immersion.

NOTE

Excessive agitation as evidenced by foaming SHALL be avoided.

The primary advantage of the hydrophilic immersion technique compared to the spray technique is its effectiveness on hollow or complex geometry parts where the configuration interferes with the spray impinging on the part surface. In use, the part or parts are immersed in the remover tank while still wet from the pre-rinse. A slight agitation is necessary to bring fresh solution in contact with the surface. Agitation can be movement of the part through the solution, but is most usually produced by an air manifold in the bottom of the tank. Time of immersion depends on a large number of factors and will vary between 30-seconds up to 2-minutes and SHOULD be no more than necessary. The maximum time of 2-minutes is seldom required, except on very rough surfaces or when remover is depleted. Remover immersion time SHALL NOT exceed 2-minutes.

2.4.8.7.2.2.1.1 Remover Appearance. A freshly mixed remover bath is a transparent or clear, pink solution. During use, as penetrant is removed from the parts and retained, the bath becomes turbid or cloudy with distinct color change. As additional parts are processed and the penetrant tolerance point is approached, globules of penetrant will rise to the surface, and then slowly disperse back into the mixture. This effect is not usually noticed in an agitated bath, but is visible when the agitation is shut off. When the penetrant tolerance point is reached, the penetrant will remain floating on the surface. A characteristic of the bath is that the excess penetrant does not spread across the surface, but collects at the sides. The remover will continue to function in this condition, but at a reduced rate. In addition to the longer removal time, another problem with using remover after the penetrant reaches its tolerance point, is the tendency of the floating penetrant to deposit on the part as it is withdrawn from the solution, resulting in an objectionable background. If the bath is to be used after the tolerance point is reached, the majority of the floating penetrant SHALL be removed. Do this by wiping the tank edges with absorbent newspaper, paper towel, or rags. To learn more about Process Control for penetrants, (paragraph 2.6).

2.4.8.7.2.2.1.2 Penetrant Tolerance. One of the disadvantages of the hydrophilic immersion technique is the remover's limited tolerance to penetrant contamination. As parts are processed, the amount of penetrant in the remover gradually increases. If the removal process is closely monitored, penetrant contamination will reach a point where a distinct performance change occurs. The amount of penetrant causing this performance change is called the "remover's penetrant tolerance point". The amount of penetrant tolerated is directly related to the concentration of the remover and sensitivity level of the penetrant. Typical tolerance levels for a remover concentration of 33-percent is 5 to 6-percent for a Sensitivity Level 3 penetrant, and 3 to 4-percent for a Sensitivity Level 2 penetrant.

2.4.8.7.2.2.2 Hydrophilic Remover Spray Technique.

2.4.8.7.2.2.2.1 Hydrophilic Remover Spray Mechanism. The modes of action are the same in both hydrophilic immersion and spray remover techniques; however, the relation between the chemical and mechanical action complicates the mechanism during the spray removal technique. As the spray water pressure is increased, the rate of removal also increases. A common misconception is the increased rate of removal is due solely to the greater mechanical action. The higher water pressure actually increases both mechanical and chemical action. As the water pressure increases, more solution contacts the surface per unit of time, thereby increasing the chemical action.

2.4.8.7.2.2.2.2 Hydrophilic Remover Spray Equipment. A practical and efficient way of handling the low remover concentrations is by continuously metering the remover directly into the stream of water. This can be done with an aspirator device that employs the water flow to create a vacuum (Bernoulli Effect), drawing up the concentrate directly from the container. The method is inexpensive and only requires a minimum of equipment and provides intermittent, on/off operation. A disadvantage of this system is the variation in concentration with water pressure. This requires the careful control of water pressure as well as the mixing ratio. The most commonly used system is the installation of a three-way valve on the water rinse or wash line. The aspirator is connected to one side, fresh or plain water to the second, while the third position is off. This allows the existing wash tank to be used for both spray removal and fresh water rinsing. For portable applications, a simple garden sprayer may also be used, provided the maximum 5-percent concentration is not exceeded.

2.4.8.7.2.2.2.3 Hydrophilic Remover Spray Technique. Hydrophilic remover can be applied by spraying the part with a mixture of water and remover. This method of application has several advantages: it does not require a separate tank; it works well on simple contoured parts; and it can be easily automated. The procedures, and equipment, and parameters are identical with those used in spray rinsing. The usual concentration range is 1 to 5-percent remover to water by volume. The concentration of remover SHALL NOT exceed 5-percent.

2.4.8.7.2.3 Hydrophilic Remover Final Water Post-Rinse. A clean water rinse SHALL be performed after the immersion or spray hydrophilic removal steps. The purpose is to remove any remover residues that could contaminate the developer or interfere with the development process. The rinse step is a water spray in the station or tank used for the pre-rinse. The process step is not critical and requires very few controls. The cycle SHALL be a clean water spray of up to a maximum of 120-seconds duration using a pressure of not greater than 40 psi (172 kPa) and the water temperature SHALL be between 50°F (10°C) to 100°F (38°C). Where possible, the spray nozzle SHALL be held a minimum of 12 inches from the part surface. Rinsing of fluorescent penetrants SHALL be accomplished under UV-A illumination. See Section 2.4.9 for proper rinse technique.

2.4.8.7.2.3.1 Hydrophilic Remover Touch-Up. One of the advantages of the hydrophilic technique is the ability to do touch-up removal on local areas after the initial application of the water rinse. Hydrophilic remover touch-up can be performed provided the combined remover dwell time of the first and second remover applications does not exceed 120-

seconds (2-minutes). The hydrophilic remover touch-up, SHALL be applied using remover at or below the concentration of the initial remover step using either immersion or spray. If spray application is used, the remover concentration SHALL NOT exceed 5-percent. After touch-up, the part SHALL be fresh water rinsed. A check of the hydrophilic remover touch-up spray concentration SHALL be accomplished by one of the methods explained in (see paragraph 2.6.10.4). See Section 2.4.9 for proper rinse technique.

2.4.8.8 Removal of (Method “C”) Penetrant With Solvent (Figure 2-15).

2.4.8.8.1 General. All oil-based penetrants are soluble in a large number of organic liquids; however, postemulsifiable penetrants are most frequently used in Method C processes. The majority of solvent removers are Class 2 (non-halogenated), and they can be further subdivided on the basis of their flash points or boiling points. For almost all solvent removers, removal of the excess surface penetrant is accomplished through dissolving and dilution. The exception to this is when an aqueous based detergent mixture is used as a solvent remover. Furthermore, when higher boiling point solvents are used care must be taken to control the amount of solvent applied to the surface. Excess solvent can strip penetrant from defects or dilute the penetrant in a defect with the result of producing dim, fuzzy indications.

2.4.8.8.2 Factors Influencing Solvent Remover Selection. The selection of a suitable solvent remover depends on a number of factors. The most significant factors are the evaporation rate (boiling point), flammability, and cost. Solvency is a factor but becomes significant only when the removal process allows excess solvent to remain on the surface of the part, thus diluting penetrant trapped in defects. For smooth surfaces, high boiling point solvents can be used with minimal concern since residual solvent can be easily wiped from the surface with a dry cloth. The higher boiling point solvents are also less flammable than lower boiling point solvents. For rougher surfaces, caution is required with the use of the higher boiling point materials; the lower boiling point solvents may be more appropriate since any residual solvent would evaporate before it could dilute the penetrant in a flaw. With the lower boiling point solvents, however, safety (flammability) may be a concern.

2.4.8.8.3 Solvent, (Method "C") Removal Procedure.

CAUTION

- The solvent cleaner SHALL NOT be applied directly onto the inspection area to remove excess penetrant.
- Only solvents appearing on QPL SAE AMS 2644 or technical grade Isopropyl Alcohol (TT-I-735, Grade A) SHALL be used for Method C removal of excess penetrant.
- All solvent residues must be removed from the inspection surface by a final dry cloth wipe before developer application.

The use of high sensitivity, postemulsifiable penetrant with the solvent removal method will produce indications from small, tight flaws, however, improper application procedures will seriously degrade the indications. The use of excess solvent will remove or dilute entrapped penetrant resulting in a failure to produce a visible indication. The following outlines the recommended practice for the Method C process:

a. Following the penetrant dwell period, the surface SHALL be wiped with a clean, dry lint-free rag or paper towel to remove the major portion of surface penetrant. The proper procedure, which SHALL be followed, is to make only a single pass and then fold the rag or towel over to provide a fresh surface for each succeeding wipe.

b. When the surface penetrant has been reduced to a minimum, any remaining residual penetrant is removed with a fresh lint-free rag or towel moistened with solvent. The amount of solvent applied to the rag or towel is critical. The cloth or towel SHALL only be lightly moistened with the application of a fine spray of solvent to the cloth. The cloth SHALL NOT be saturated either by pouring, immersion or excessive spraying.

c. A UV-A lamp SHALL be used to examine the part surface during the intermediate and final wiping stages. The surface of the rag SHALL also be examined with the UV-A lamp after the final solvent wipe. If the rag shows more than a trace of penetrant, it SHALL be folded to expose a clean surface, remoisten with solvent, and again wiped across the part.

d. This procedure SHALL be repeated until the rag shows little or no trace of penetrant.

e. Finally the part SHALL be wiped with a clean, dry rag to remove any residual solvent on the surface.

2.4.9 Water Washing/Rinsing Technique. Water washing or spray rinsing is usually accomplished in a stationary rinse tank, which is provided with a hose, nozzle, drain, and in the case of fluorescent penetrant, UV-A illumination. Rinsing procedures used for removal of water-washable penetrant, Method "A", and postemulsifiable penetrant, Method "B" (after emulsification), and Method "D" (after remover application) are nearly identical. The difference is in controlling the rinse time. Rinse times for Method "A" penetrants are very critical as the entrapped water-washable penetrant can be removed from discontinuities if the time is not controlled. Entrapped postemulsifiable penetrants not diffused with emulsifier resist removal, and rinse times are not as critical. The conditions and procedures described in the following paragraphs are applicable to both water-washable and postemulsifiable penetrants.

2.4.9.1 Factors Influencing Effectiveness of Wash/Rinse.

2.4.9.1.1 Size of Water Droplets. Removal of excess surface penetrant depends upon the mechanical force of the water impacting the part surface. The impact force consists of the droplet mass and velocity at impact. The two factors are related, and increasing either will produce a higher mechanical force. There are limits on both size and velocity; the latter is derived from the water pressure. If the droplet is small or if the pressure is too high, the result will be a fog or mist with little removal ability. On the other hand, a solid stream of water is not desirable either because it covers only a small area at one time or is actually one large continuous drop.

2.4.9.1.2 Water Pressure. Increased water pressure increases the speed of removal; however, excessive pressure can atomize the water into a fog that is useless for removal. Normal line pressure, approximately 10 to 40 psig, is acceptable and is generally used. Water pressures in excess of 40 psig SHALL NOT be used. If hydro-air nozzles are used, air pressure shall not exceed 25 psi.

2.4.9.1.3 Water Temperature. The temperature of the rinse water will affect the washability. Some penetrant-emulsifier combinations may form a gel with water temperatures of 50°F (10°C) or less. This gel can be removed but requires longer wash times. Other penetrant emulsifier combinations have reduced removability at elevated temperatures, above 110°F (43°C). The effect of temperature on washability depends upon the penetrant formulation, which varies between suppliers. Penetrant-emulsifier combinations meeting specification requirements are washable in the temperature range of 50°F (10°C) to 100°F (38°C). Therefore, the rinse water temperature SHALL be maintained between 50°F (10°C) to 100°F (38°C).

2.4.9.1.4 Spray Angle.

CAUTION

Water nozzles capable of producing spray patterns such as solid streams or a fine mist SHALL NOT be used. Rinsing dye penetrant from the surfaces of parts SHALL be accomplished with a fan-shaped, coarse spray.

The angle of spray may be varied over a wide range with only slight effects on the removal time. When the angle is close to perpendicular (80 to 90 degrees), the droplets will rebound into the oncoming water, diverting the fresh droplets, which reduces the scrubbing action. The scrubbing action is also reduced when the spray is close to parallel with the part surface (10 to 20 degrees), since there is little energy transfer at the point of impact. Generally, an angle of 45 to 70 degrees is most effective.

2.4.9.1.4.1 Recommended Spray Rinse Procedure. Washing is best accomplished with a fan shaped, coarse spray. Where possible, the spray nozzle SHALL be held a minimum of 12 inches from the part surface. The water temperature SHALL be in the range of 50°F (10°C) to 100°F (38°C), and line water pressure SHALL NOT exceed 40 psig. The wash time will depend upon the surface roughness of the part. Water-washable penetrant can easily be over-washed and wash time SHALL be closely controlled. Washing of fluorescent penetrant SHALL be performed under UV-A black light illumination in a semi-darkened area. The washing SHALL be stopped when a low background level is reached. If small defects must be detected in parts with rough surfaces, some residual background may be necessary. The total rinse time SHALL NOT exceed 120-seconds.

2.4.10 Drying. After removal of excess surface penetrant, the part SHALL be dried prior to applying nonaqueous or dry developer. When aqueous developers are used, part drying before developer application is not required. Drying can be accomplished in a number of ways:

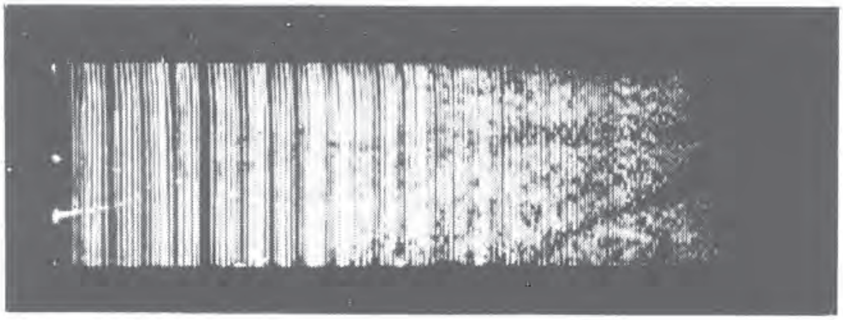
- Allow the parts to set at room temperature in still air. The length of time required for this method depends upon temperature and humidity of the air and is usually too long to be used for drying wet developer.
- Warm air blowers are often used on large parts that cannot be oven dried. This method may not uniformly dry wet developers.
- The most frequently used method of drying parts is with a recirculating hot air oven. It provides a rapid means of properly drying parts and wet developer, is adaptable to production, and permits control of the temperature.

2.4.10.1 Time and Temperature Effects on Drying.

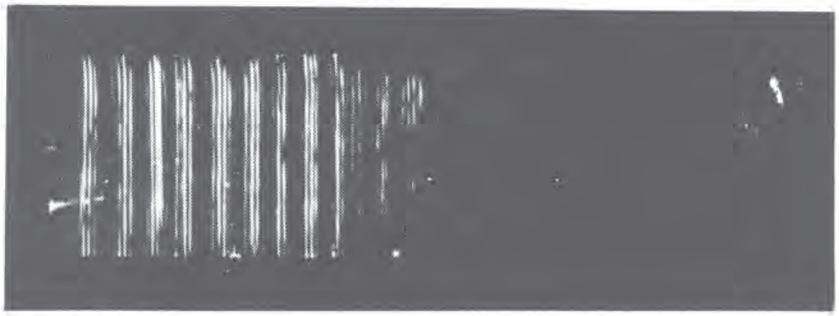
NOTE

- Depots with automated and semi-automated penetrant inspection systems may exceed the 140°F (60°C) drying oven temperature while performing inspections with these systems. The part temperature SHALL NOT exceed 140°F (60°C). All parts remaining at 140°F (60°C) for longer than ten minutes or exceeding 140°F (60°C) SHALL be reprocessed (cleaned and reinspected).

- When drying test parts in a recirculating oven, both time of exposure and dryer temperature SHALL be carefully monitored. The smallest quantity of penetrant entrapped in discontinuities can be subject to dye degradation and/or large evaporation losses. Fluorescent dyes experience heat fade or permanent loss of fluorescence at elevated temperatures. Heat fading of the penetrant starts at about 140°F (60°C) and increases rapidly with increased temperatures and time. Evaporation loss can decrease the small amount of penetrant entrapped in a discontinuity to such a low level it will not contact the developer on the surface and an indication will not form. The effects of drying temperature and time are more severe when a dry developer is used. Aqueous or wet developers are applied before application of heat in a drying oven and may retain contact with the penetrant during the drying cycle. The base vehicle (water) of the developer tends to mix with the penetrant in the defect. The evaporating action of the base vehicle helps to draw the penetrant from the defect to form the indication. For comparisons of proper versus excessive drying for Sensitivity Level 3 penetrant prior to applying dry developer (Figure 2-24). Proper drying was performed at 120°F (49°C) for five minutes. Excessive drying was at 150°F (66°C) for ten minutes. The fine indications are the first to disappear.



PROPER DRYING



OVER DRYING

Figure 2-24. Effects of Proper vs. Excessive Drying

2.4.10.2 Procedure for Determining Pre-Developer Drying Parameters.

CAUTION

> Parts SHALL be separated with an air space between them. If the part temperature reaches and remains at 140°F (60°C) for over ten minutes, the inspection sensitivity can be reduced. As a guideline remove the parts before they become too hot to handle with bare hands. This is a temperature of about 120-125°F (49-52°C).

It is easy to monitor and control oven temperature, but almost impossible to monitor test part temperatures. Another complicating factor is the rate at which the part undergoing the test, heats. Thin sections will reach oven temperature and dry before thick sections become warm. The recommended procedure is to set the oven temperature between 120 and 140°F (49 -60°C), and check the part every 5-10 minutes. Remove the part as soon as it is dry.

2.4.11 Application of Developers.

2.4.11.1 (Form a) - Dry Developer.

2.4.11.1.1 Description.

CAUTION

Dry developers SHALL NOT be used with visible-dye penetrants since they do not provide adequate contrast.

Dry developer is characterized by their fluffy nature and low bulk density, i.e., one pound of dry developer occupies 2 or 3 times the volume required for wet developer powders in the dry form. Dry developer is loosely held on the part surface by adhesion and the coating layer is very thin and uniform. In fact, dry developers leave very little visible trace, but their presence becomes readily obvious when a finger or rag is wiped across the surface. Dry developers can be used with any method of fluorescent penetrant, but not with visible-dye penetrant.

2.4.11.1.2 Advantages of (Form a) - Dry Developer.

- Does not require a liquid bath.
- Easier to transport than liquid bath.

2.4.11.1.3 Disadvantages of (Form a) - Dry Developer.

- Air cleaners, facemasks, or respirators may be required.
- Part must be completely dry prior to application.

2.4.11.1.4 Using (Form a) - Dry Developer.

2.4.11.1.4.1 Preparation of (Form a) - Dry Developer. There is no preparation short of having a container that will help to keep moisture out of the developer.

2.4.11.1.4.2 Application of (Form a) - Dry Developer.

WARNING

Dry developer particles are not toxic materials; however, like any solid foreign matter; they SHALL NOT be inhaled. Air cleaners, facemasks, or respirators may be required. The Installation Bioenvironmental Engineer SHALL be consulted if the process generates airborne particles.

NOTE

> Dry developers SHALL NOT be applied to a part until the surface and any discontinuities are thoroughly free of moisture. The presence of even a little moisture will interfere with the developer action and small flaws may be missed.

Dry developers can be applied in a number of ways:

- Blowing the powder with a bulb type blower.
- Immersing the part in a container of dry particle powder.
- Pouring the powder over the parts.
- Using a dust or fog chamber where the particles are blown into an air suspension.
- Spraying with an electrostatic system or a low-pressure flock gun.

2.4.11.1.4.2.1 After application, the excess developer SHALL be shaken off or removed with a hand air bulb or squeeze blower. The developer particles are not loosely held, but care SHALL be taken to not remove them during handling. Wiping, brushing, or compressed air in excess of 5 psig SHALL NOT be used. Care SHALL be taken to prevent contamination of the dry developer. The two most frequent contaminants are water (or moisture) and penetrant. Water in dry developer comes from parts that have not been completely dried or from careless splashing during the wash step. Water or moisture contamination will cause the dry developer to form lumps or to cake, thus reducing its effectiveness. Penetrant contamination occurs when particles of penetrant soaked developer fall from poorly washed parts or heavy indications. Penetrant contamination will cause false indications either on the part being processed or on subsequent parts.

2.4.11.2 (Form b) - Water-Soluble (Wet Aqueous) Developer.

2.4.11.2.1 Description. Water-soluble developers are developer particles dissolved in a water solution. Water-soluble developers contain wetting agents, corrosion inhibitors, and biocides. They differ from wet suspended developer since the particles dissolve in water to form a clear, lightly tinted solution. During the drying process, the developer particles crystallize out of solution as the water evaporates. The resulting coating is thick, bright white and readily visible. The dry layer is thicker than wet suspended developer coating, and much thicker than a dry developer coating.

2.4.11.2.2 Advantages of (Form b) - Water-Soluble Developers.

- The primary advantage of water-soluble compared to water-suspended developer is the elimination of the need for agitation to keep the particles in suspension.
- The coating does not produce streaks or runs that often occur with wet suspended developers.
- The developer particles, being soluble in water, are very easy to remove during post-cleaning.

2.4.11.2.3 Disadvantages of (Form b) - Water-Soluble Developers.

CAUTION

> Water-soluble developers SHALL NOT be used on parts processed with water-washable penetrant or visible-dye penetrants.

NOTE

Water-soluble developers are subject to bacterial growth. The susceptibility is dependent on the geographical area and the type of local water. The first indication can be a foul odor or visible growth.

- Water-soluble developers contain wetting agents that can act as penetrant removers and SHALL be used very carefully. This removal action is accelerated with water washable penetrants and is the reason water-soluble developers SHALL NOT be used with water washable penetrants.
- Even though a thick, white coating is produced, water-soluble developers do not function well with visible-dye penetrants.
- Like the wet suspendible developers, the biocides in water-soluble developers only delay growth. The water-soluble developers SHALL be discarded when bacterial growth is noticed and the tank or container SHALL be completely disinfected prior to mixing a new solution.

2.4.11.2.4 Using (Form b) - Water-Soluble Developer.

2.4.11.2.4.1 Preparation of (Form b) - Water-Soluble Developer. Water-soluble developers are supplied as dry-powders and SHALL be completely dissolved in water before use. The proportions of dry-powder to water depend upon the type of developer and the manufacturer. The manufacturer’s recommendations on concentration SHALL be followed. In making up the bath, the dry-powder SHALL be stirred into the water until it has completely dissolved. Since the developer particles are dissolved in the solution, agitation is not required after the developer has been initially mixed with water.

2.4.11.2.4.2 Application of (Form b) - Water-Soluble Developer.

CAUTION

Water-soluble developers SHALL NOT be used on parts processed with water-washable, Method A, fluorescent penetrants or any visible-dye penetrants.

NOTE

Water-soluble developer in open immersion tanks is subject to evaporation. As the water evaporates, the developer concentration increases. A solution concentration level SHALL be established and maintained by the addition of water or dry-powder. For process checks and methods for measuring solution concentration (paragraph 2.6).

The inspector may apply developer with spraying, flowing, or immersion techniques. If the immersion process is used, the part SHALL not remain in the solution any longer than required to provide complete coverage. The developer may be applied to parts while they are still wet from the water wash after penetrant removal. Care SHALL be exercised to prevent entrapment of soluble developer in the part cavities or concave surfaces (pooling). The developer should wet the part surface with no water break areas after application. After the developer is applied, the parts SHALL be oven dried, since room temperature evaporation is too slow. The developing action, and thus the developing time, does not start until the developer is dry.

2.4.11.3 (Form c) - Water-Suspended (Wet Aqueous) Developer.

2.4.11.3.1 Description.

NOTE

> Developing action in wet suspended developers will not start until all the absorbed and adsorbed water has been driven off. Developer dwell time SHALL NOT begin until the part is completely free of moisture.

Water-suspended developers consist of inert particles in a water suspension. The developers are supplied as either concentrated liquid or as a bulk, dry-powder that must be mixed with water prior to use. In addition they contain chemical dispersing agents to reduce the tendency of the developer particles to stick together or form clumps. Wetting agents are added to provide complete and thorough coverage of the parts. Corrosion inhibitors are added to protect the part from corrosive attack. Finally, biocides are added to provide a reasonable tank life by delaying bacterial growth. When applied, water-suspended developers evaporate very slowly at room temperature and require a hot air oven for proper drying.

2.4.11.3.2 Advantages of (Form c) - Water-Suspended Developer.

- The particles are insoluble in water and when dry, are highly adsorptive and absorptive.
- It can be used with Method A - Water-Washable Penetrants.

2.4.11.3.3 Disadvantages of (Form c) - Water-Suspended Developer.

- Agitation is required to keep the particles in suspension.
- Water-suspended developers may produce streaks or runs.

2.4.11.3.4 Using (Form c) - Water-Suspended Developer.

2.4.11.3.4.1 Preparation of (Form c) - Water-Suspended Developer. Use of wet suspended (Form c) developer requires the use of a drying oven therefore it is always used in stationary penetrant systems. Wet developer concentrates SHALL be mixed with water in the proportions recommended by the manufacturer. The concentrations vary between types and manufacturers. The measured quantity of powder or liquid concentrate is added to the water, while stirring constantly until a smoothly mixed suspension is obtained. A newly mixed batch of suspended developer SHALL stand for 4 or 5–hours before use to allow the developer particles to wet.

2.4.11.3.4.2 Application of (Form c) - Water-Suspended Developer.

CAUTION

- Water-suspended developers must either be constantly agitated to keep the particles from settling out of the suspension or the suspension SHALL be thoroughly agitated prior to use.

- The drain time for water-suspended developers SHALL NOT exceed 30-seconds.

Water-suspended developers may be applied by spraying, flowing or immersion. Wet developer, since it has a water base, can be applied to parts still wet from penetrant removal. When the part has been thoroughly covered with the developer solution, it SHALL be immediately removed from the solution and allowed to drain for a short time. Care must be exercised to prevent entrapment of soluble developer in the part cavities or concave surfaces (pooling). The developer SHALL wet the part surface with no water break areas after application. After the developer is applied, the parts SHALL be oven dried, since room temperature evaporation is too slow.

NOTE

> The developing action, and thus the development time does not start until the developer is dry.

2.4.11.4 (Form d and Form e) - Nonaqueous Solvent- Based Developer.

2.4.11.4.1 Description. Nonaqueous solvent- based developers are composed of particles of developer suspended in a mixture of volatile solvents. These developers are typically packaged in ready-to-use aerosol cans. The penetrant materials specification QPL SAE AMS 2644 classifies nonaqueous solvent-based developers into two categories; (Form d), formulated for Type I fluorescent penetrant systems and (Form e), formulated for Type II visible penetrant systems. Many nonaqueous developers are formulated to perform as both (Form d and Form e) developers. The suspending solvents of these developers are carefully selected for their compatibility with penetrants. Solvent developers also contain surfactants and dispersants whose functions are to coat the particles and reduce their tendency to clump or collect together. Solvent developers are the most sensitive forms of developers due to the solvent action contributing to the adsorption and absorption mechanisms. In many cases where tight, small flaws occur, the dry and aqueous developers do not contact the entrapped penetrant. This results in the failure of the developer to create the necessary capillary and surface tension forces that serve to pull the penetrant from the flaw. The nonaqueous developer solvents enter the flaw and dissolve into the penetrant. This action increases the volume and reduces the viscosity of the penetrant. Developer manufacturers must carefully select and compound the solvent mixture. Either excessive or inadequate volatility or solubility will adversely affect the performance of the developing action. High volatility reduces the time for the developer to function before it evaporates, while low volatility increases the drying time. Low solubility reduces the penetrant dissolving action, so the extraction of the penetrant from the flaw will not be enhanced.

2.4.11.4.2 Advantages of (Form d and Form e) - Nonaqueous Developers.

- Nonaqueous solvent-based developers are packaged in portable aerosol containers.
- Nonaqueous solvent-based developers are volatile and fast drying in air, thus eliminating the need for a drying oven.
- Nonaqueous solvent-based developers are sealed in their containers and are not recovered after their initial use, which eliminates any degradation by contamination.
- When proper techniques are used, nonaqueous-solvent-based developers provide a smooth, even layer of developer whose thickness can be controlled by the operator.
- Nonaqueous solvent-based developers can be used with both fluorescent and visible-dye penetrants.
- Nonaqueous solvent-based developers are capable of producing the highest level of sensitivity of any of the developer forms due to their solvent action.

2.4.11.4.3 Disadvantages of (Form d and Form e) - Nonaqueous Developers.

WARNING

Nonaqueous solvent-based developers contain solvents that can be flammable, and when used in confined locations, present a health hazard. Caution SHALL be exercised to prevent ignition and to avoid inhalation of the vapors.

- The developer particles are suspended in the solvent and tend to rapidly settle out. Agitation of the container prior to and during application is required.
- The portable aerosol containers have a small spray coverage that makes coating of a large surface very time consuming. The aerosols are best limited to small, local areas.
- Aerosol cans exhibit a gradual loss of pressure over a period of time and occasionally there are leaks due to improper sealing. When the pressure is lost, the can and its remaining contents must be properly discarded.
- If the nozzle is not free of dried developer particles, spray patterns can be very erratic. It is necessary to clean the nozzle after every use by inverting the can and pressing the spray nozzle until only propellant escapes.

2.4.11.4.4 Using (Form d and Form e) - Nonaqueous Developer.

2.4.11.4.4.1 Preparation of (Form d and Form e) - Nonaqueous Developer.

CAUTION

> The presence of any moisture will interfere with the developer action and small flaws may be missed. Like dry-powder developers, solvent developers SHALL NOT be applied to a part until the surface and any discontinuities are thoroughly free of moisture or solvent residues.

Since these developers are self-contained in a pressurized spray can, the only preparation required is shaking the can in order to thoroughly mix the developer, carrier solvent, and propellant.

2.4.11.4.5 Application of (Form d and Form e) - Nonaqueous Solvent-Based Developers.

NOTE

> Excessive thickness of developer SHALL NOT occur. Parts that have received excessive developer SHALL be completely reprocessed. Liquid flow on the part surface SHALL be avoided.

Nonaqueous solvent-based developers are always applied by spraying. Proper spraying produces a thin, uniform layer very sensitive in producing indications. Dipping, pouring, or brushing is not suitable for applying solvent-based developer. Dipping and pouring increases the time the solvent is dissolving and diluting the entrapped penetrant so much of it ends up in the unevaporated liquid developer layer. During the drain, the penetrant will flow from the flaw site, and any indications that do form will be weak and badly distorted. Application of solvent developer by brushing will also leave streaks and distort and smear flaw indications into unrecognizable forms.

Nonaqueous solvent-based developer SHALL be applied only as a fine spray or mist. Spraying of nonaqueous developer is most often done with pressurized, aerosol containers. There are a few production lines that use pressure pots and spray guns. Electrostatic spraying is possible, but is seldom used due to the poor throwing power of the spray.

Prior to spray application, the container SHALL be agitated. Nonaqueous solvent-based developer is usually a suspension and the particles settle out in a matter of minutes. The spray can or gun SHALL be held far enough from the surface to produce a light, moist film. The recommended technique is to apply a very thin, dry layer and build up the thickness with several passes rather than applying a single, wet pass.

The optimum coating thickness depends on the penetrant system type (i.e., visible or fluorescent dye) and must be judged from its appearance, based upon training and prior experience. When using Type I penetrant systems, the luster or surface texture of the part surface SHALL NOT be completely hidden. If the metallic luster cannot be seen, the developer layer is too thick, and small indications may be masked or too widely spread or blurred. Developer coatings that are too thin may not extract a sufficient amount of entrapped penetrant to form an indication. Also, too thin of a coat does not allow the penetrant to spread and magnify the indication. For Type II penetrant systems, a slightly thicker coating is required to provide a solid white background to contrast with the visible indication. The metallic luster will still be visible under bright white light in most cases.

Observe the comparison of a cracked aluminum panel with optimum developer thickness for a Type II (visible) penetrant system, to one where an excessive developer layer has been applied is reflected in (Figure 2-25).

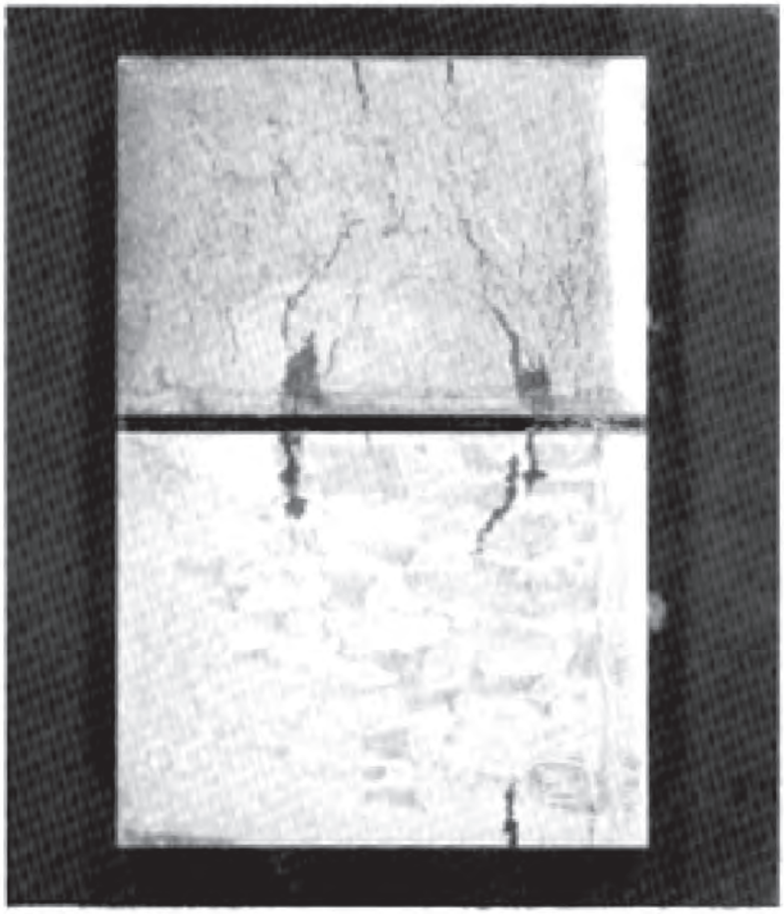


Figure 2-25. Cracked, Aluminum Panel Comparing Results of an Optimum Thickness Layer of Developer (Top) to an Excessive Thickness Layer of Developer (Bottom)

2.4.11.5 Developer Dwell (Development Time).

NOTE

- The developer dwell time SHALL NOT start until part is completely free of moisture or solvent. The dwell time for form a (dry developers) begins immediately after developer application. The dwell time for form b, c, d and e developers begins immediately after the developer is completely dry.

- The maximum developer dwell time SHALL NOT be exceeded.

- The dwell times specified are based on small discontinuities.

- Extraction of the penetrant entrapped in a flaw is a function of time and volume of available penetrant. Sufficient time SHALL be allowed for the developer to draw the entrapped penetrant from the flaw and spread it on the part surface to form the indication. The length of developing time varies widely with a number of influencing factors.

- Indications from small discontinuities may not form if the minimum dwell time is not met or may exhibit a very diffuse indication if the maximum dwell time is exceeded. In either case, these discontinuities may be missed. The minimum and maximum developer dwell time SHALL be followed: (Table 2-4).

- Medium or large discontinuities, which develop faster, will be blurred at the maximum dwell times; however, medium or large discontinuities contain enough penetrant to form an observable indication even though it is blurred. The lateral diffusion of penetrant over a period of time can be so great that the indications may become indistinct, even for medium and large discontinuities.

- To increase penetrant system capability, parts should be viewed periodically during developing; however, the minimum dwell time SHALL be met. Developer action starts when the developer is completely dry and continues until all of the available penetrant is extracted. An indication will gradually form, reach a maximum resolution point (bright and sharp), and then begin to degrade.

2.4.11.5.1 Minimum and Maximum Developer Dwell Times. The minimum and maximum developer dwell times SHOULD be specified in the technical directives or part specific procedures mandating the inspection. Both the minimum and maximum developer dwell times that SHALL be used in the absence of specific technical directives or procedures are listed in (Table 2-4). These dwell times are based on the developer form, the ambient temperature, and the expected flaw condition.

Table 2-4. Developer Dwell Times

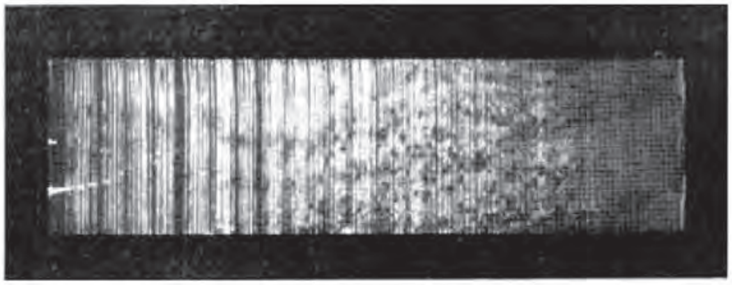
Temperature 40° - 60°F		
Nonaqueous Developer	**Minimum**	**Maximum**
Service Damage/Fatigue Cracks	20 minutes	60 minutes
Stress-Corrosion Crack	60 minutes	120 minutes
Aqueous Developer		
Service Damage/Fatigue Cracks	30 minutes	120 minutes
Stress-Corrosion Crack	60 minutes	120 minutes
Dry Developer		
Service Damage/Fatigue Cracks	30 minutes	240 minutes
Stress-Corrosion Crack	60 minutes	240 minutes
Temperature 60° - 125°F		
Nonaqueous Developer	**Minimum**	**Maximum**
Service Damage/Fatigue Cracks	10 minutes	30 minutes
Stress-Corrosion Crack	30 minutes	60 minutes
Aqueous Developer		
Service Damage/Fatigue Cracks	15 minutes	60 minutes
Stress-Corrosion Crack	30 minutes	120 minutes
Dry Developer		
Service Damage/Fatigue Cracks	15 minutes	120 minutes
Stress-Corrosion Crack	30 minutes	240 minutes

To increase penetrant system capability, parts should be viewed periodically during developing. Over-development (i.e., too long a development time), is possible and SHALL be avoided. Developer action starts when the developer is completely dry and continues until all of the available penetrant is extracted. An indication will gradually form, reach a maximum resolution point (bright and sharp), and then begin to degrade. The lateral diffusion of penetrant over a period of time can be so great the indication becomes indistinct. Medium size or large discontinuities will appear as a smear or blob of penetrant. Small indications are especially critical, since the small amount of penetrant may not be observed when it diffuses.

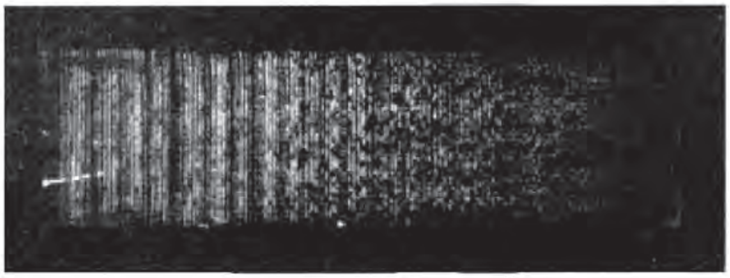
2.4.11.6 Comparison of Developers. The relative sensitivities of penetrant inspection with various forms of developer are influenced by a number of factors. The method of applying the developer produces a range of sensitivities for each of the developer forms. Some of the common forms of developer, plus the application method, arranged in order of decreasing sensitivity are listed (Table 2-5). This is the sensitivity order most generally accepted. It is recognized that solvent-suspended developers applied by spraying produce a highly sensitive penetrant system. Industry agreement on the developer sensitivity order ends at this point. The type of test sample, type of flaw, flaw size and shape, type of penetrant, method of removal, and drying procedures will affect the sensitivity of the penetrant system. The number of variables involved has resulted in conflicting reports on the relative performance of dry versus water-based (suspended and soluble) developers. When properly applied, it is agreed the water-based developers form a coating with a finer matrix of developer particles that are in more intimate contact with the part surface when compared to dry developers. The opposing argument is that an uneven coating of water-based developers can mask indications. There is agreement that water-soluble developers SHALL NOT be used on water washable penetrant. Photographs of a single cracked-chrome plated panel, that has been processed with four forms of developer using application methods available to base level NDI laboratories are contained in (Figure 2-26).

Table 2-5. Developer Forms and Application Methods in a Decreasing Sensitivity Order

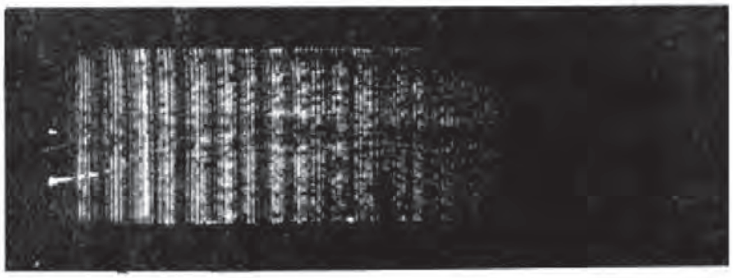
Developer Form	Application Method	Sensitivity
Nonaqueous-Wet (Solvent Suspended)	Spray	Highly Sensitive
Water-Soluble	Spray	Highly Sensitive
Water- Suspended	Spray	Highly Sensitive
Water-Suspended	Immersion	Highly Sensitive
Water-Soluble	Immersion	Highly Sensitive
Dry-Powder	Electrostatic Spray	Decreasing Sensitivity
Dry-Powder	Fluidized Bed	Decreasing Sensitivity
Dry-Powder	Air Agitated Dust Cloud	Decreasing Sensitivity
Dry-Powder	Dip and Pour	Least Sensitive



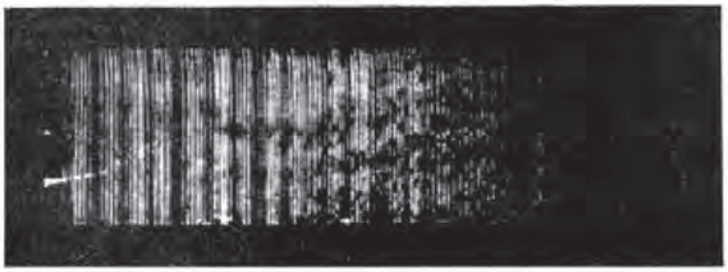
a. SOLVENT DEVELOPER, SPRAY



b. WATER SOLUBLE DEVELOPER, IMMERSION



c. WATER SUSPENDED DEVELOPER, IMMERSION



d. DRY DEVELOPER, IMMERSION

H0400341

Figure 2-26. Comparison of Four Forms of Developer on a Cracked Chrome Panel

2.4.11.7 Self-Development.

CAUTION

Self-development SHALL NOT be used in aircraft and engine maintenance inspection where service-induced flaws must be detected. Self-development SHALL NOT be used for aircraft and engine component inspection unless specifically approved by the responsible NDI engineering authority.

Self-development is the formation of an indication without the application of a developer material. All penetrants are capable of some degree of self-development since they will exude from a discontinuity and spread over the surface. The critical factors are the size and volume of the discontinuities that must be detected. A relatively large volume of entrapped penetrant is required, and self-development is not reliable in detecting small, tight flaws.

2.4.12 Post-Cleaning After Penetrant Inspection.

2.4.12.1 Effects of Inspection Residues on Subsequent Service.

WARNING

Parts that will contact liquid oxygen SHALL be given special attention. Traces of oil can cause an explosion when contacted by liquid oxygen.

Penetrant inspection residues can have several adverse effects on subsequent processing and service. Developer and penetrant residues left on the test part, have detrimental effects on the application of surface finishes such a painting, plating, and anodizing. Penetrant residues left in the discontinuities can seriously affect the weld quality if not removed prior to repair welding. Developer residues can interfere with the functioning of the part if they involve a moving or wear surface. In addition, developer materials can absorb and retain moisture resulting in corrosion of the part.

2.4.12.2 Removal of Inspection Residues. Chemicals used in the penetrant inspection process could present problems to the inspection and/or the part after the inspection. Care SHALL be taken to ensure the part is free of all residues, which could present problems to the inspection process or the parts usability.

2.4.12.2.1 Developer Residue Removal. Developers are the last material applied in the penetrant process and may be one of several forms. The form of developer applied (dry-powder, nonaqueous, water suspendible, or water-soluble) greatly influences the method and difficulties of removal. One point common to most developers is the increase in adherence with time on the part. The longer a developer remains on a part, the more difficult it is to remove. Removal of the developer coating SHALL be accomplished as soon as possible after completing the penetrant inspection.

2.4.12.2.1.1 Removal of Dry-Powder Developer. Dry-powder developer adheres to all areas where applied. Some dry-powder may lodge in recessed areas, faying surface joints, or crevices. Dry-powder particles can be removed with a water-soluble detergent wash followed by a water rinse. Dry-developer particles adhering to penetrant bleed-out SHALL be removed during the “Removal of Penetrant Residues” described below (see paragraph 2.4.12.2.2).

2.4.12.2.1.2 Removal of Nonaqueous Developer.

NOTE

> To avoid spreading developer particles over a larger area, aerosol solvent SHALL NOT be directly sprayed on the developer without first hand-wiping.

Aerosol solvent spraying may be used as a final step to remove residual or trace amounts of developer when it is not practical to use water. Nonaqueous developer is usually applied by spraying from an aerosol can. The majority of applications involve a relatively small area. This makes it advantageous to initially remove the developer by hand-wiping the surface with a dry cloth or paper towel. The remaining traces of developer can then be removed with water or alcohol moistened rag or paper towel. The inspected area may contain threads, crevices, and surface recesses where wiping will not remove all of the developer particles. These areas should be pressure sprayed with a water and detergent solution after the initial wipe. Solvent spraying is not particularly effective, as the developer is usually insoluble. A vapor degreaser SHALL NOT be used because the elevated temperature bakes or hardens the developer coating.

2.4.12.2.1.3 Removal of Water-Soluble Developer. Water-soluble developer is the easiest form to remove since the developer coating readily re-dissolves in water. Immersion or pressure spraying with water SHALL be performed to remove water-soluble developer.

2.4.12.2.1.4 Removal of Water Suspendible Developer. The removal characteristics of water suspendible developer are very similar to non-aqueous developer. The best method of removal is immersion and pressure spraying with a hot detergent solution. It can also be removed with a plain water spray and hand scrubbing with a fiber bristle brush.

2.4.12.2.2 Removal of Penetrant Residues. Removal of residual penetrant is almost always required. This step usually follows the developer removal. The amount of residual penetrant is small, consisting of penetrant retained in discontinuities, crevices, and part surface irregularities. Penetrant residues generally can be removed with liquid solvents and detergent or alkaline cleaning.

2.4.13 Protection of Parts Following Penetrant Inspection. The penetrant inspection process and subsequent removal of inspection residues leave the parts with a chemically clean surface. These surfaces, especially ferrous materials, are highly reactive and may corrode from the moisture in air. Such parts should receive a corrosion protection treatment as soon after the inspection and subsequent cleaning as required.

SECTION V INTERPRETATION OF LIQUID PENETRANT INSPECTION

2.5 INTERPRETATION OF INDICATIONS.

2.5.1 General. Successful detection of flaws by the penetrant inspection method depends upon many factors, chiefly, among which are the selection of the appropriate materials and process, the proper application of the chosen process, the quality of lighting during the examination and the ability of a technician to detect flaw indications. Interpretation is the process of determining whether an indication is relevant, non-relevant, or false. Evaluation involves assessing a relevant indication to determine its cause and type and reporting its category, location, and approximate size.

2.5.2 Importance of Understanding the Interpretation Process. The purpose of the penetrant inspection process is to detect flaws that will affect the integrity of a part. Many of these flaws may be very small. All of the penetrant materials, procedures, and process controls are oriented to producing valid indications from surface discontinuities. The inspection or examination step is one of the most important and frequently the least controlled of all the process steps. Marginally controlled inspection or examination conditions will degrade the entire penetrant process. Maximum benefits can only be obtained when all aspects of the process (e.g., personnel training and qualification, lighting, and inspection environment) receive equal management emphasis.

2.5.2.1 The apparent simplicity of the penetrant process is misleading. While the penetrant process is relatively straightforward, a successful inspection depends upon following very carefully prepared step-by-step procedures, from initial part cleaning to part examination and indication interpretation. An improper or marginal process step may not be recognizable in the inspection booth. As a result, a serious flaw may not be indicated. Many times, the first indicator of process degradation occurs during an individual process step. For example, an excessive emulsification time or an improper water-spray pattern can be identified at the time of the respective process steps, but the consequent removal of penetrant from a defect would go unnoticed.

2.5.3 Personnel Requirements.

CAUTION

All personnel performing any of the penetrant process steps SHALL be qualified in accordance with (paragraph 1.2).

Personnel, responsible for processing of part through one or more of the penetrant process steps, but do not inspect or interpret indications, SHALL have a basic knowledge of the process theory, practical aspects, and equipment operation. They SHALL be aware of the process control requirements and of the effects of improper procedures or degraded materials on the formation of indications.

2.5.3.1 Personnel, responsible for processing of part through one or more of the penetrant process steps, and for interpreting and evaluating penetrant indications SHALL have a detailed knowledge of the theory, practical aspects, and application procedures for the major penetrant processes. They SHALL be capable of performing all of the process steps, performing materials, and process control tests, and providing technical guidance to operators and trainees. In addition, they SHALL have knowledge of the potential types of discontinuities peculiar to the part being inspected, be familiar with the appearance of penetrant indications of those discontinuities, and have experience in interpretation and evaluation of indications. It is essential for an inspector to gain experience by working with other individuals who possess the required skill before being assigned interpretation responsibilities.

2.5.4 Lighting.

2.5.4.1 Ultraviolet (UV-) Light Illumination.

2.5.4.1.1 Characteristics. Ultraviolet (UV-) light is electromagnetic radiation with a wavelength ranging between X-rays and visible light, but is not visible to the human eye. The ultraviolet range is usually divided into three bands:

2.5.4.1.1.1 UV-A - Soft ultraviolet or long wavelength (320 to 400 nm), commonly called "UV-A" has the smallest bandwidth of the ultraviolet range and is just below visible wavelength range of 400 to 760 nm. The electromagnetic spectrum showing the relatively small band of ultraviolet radiation used in fluorescent penetrant inspection (Figure 2-27). UV-A is near the violet end of the visible light range (near 400 nm).

2.5.4.1.1.2 UV-B - Medium wavelength (280 to 320 nm), used for examining minerals and in suntan lamps.

2.5.4.1.1.3 UV-C - Hard ultraviolet or short wavelength (180 to 280 nm), used in germicidal or sterilizing lamps.

WAVELENGTH MEASUREMENT UNITS

PM = PICOMETER = 1 X 10^{-12} M
μM = MICROMETER = 1 X 10^{-6} M
NM = NANOMETER = 1 X 10^{-9} M
MM = MILLIMETER = 1 X 10^{-3} M
M = METER = 1M
KM = KILOMETER = 1 X 10^{-3} M

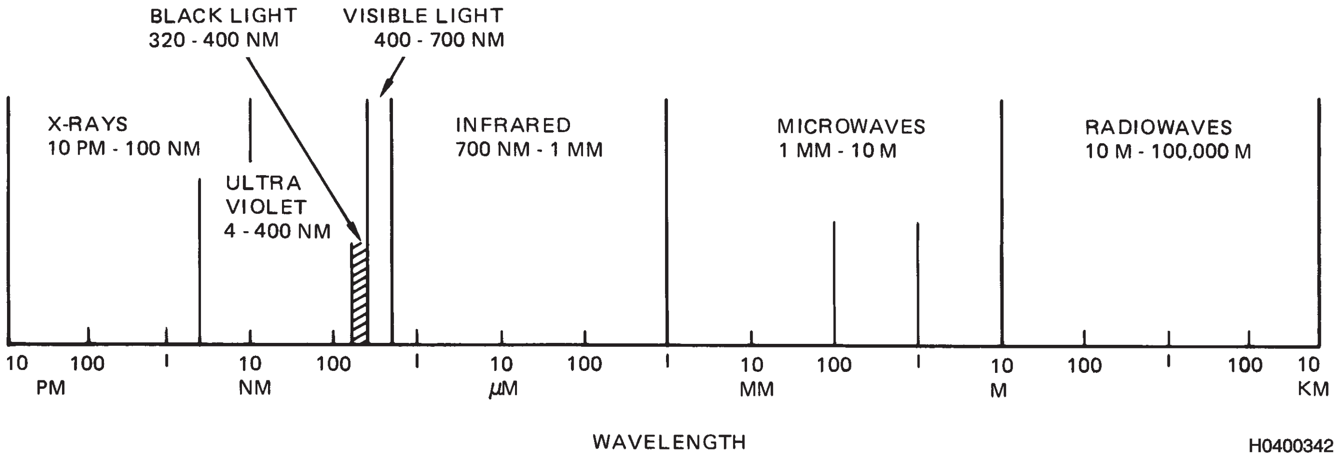


Figure 2-27. Electromagnetic Spectrum Shows the Relatively Narrow Band of UV-A

2.5.4.1.2 The Interaction of UV-A Radiation and Fluorescent Materials.

CAUTION

> Some optical plastics used in eyeglass lenses can fluoresce, causing a loss of eye sensitivity when exposed to ultraviolet light. UV filtering safety glasses, goggles, or face shields SHALL be worn over such glasses to block the UV-A.

Fluorescence is the ability of some chemical compounds to emit visible light when exposed to near ultraviolet radiation. When fluorescent materials are energized by ultraviolet radiation, visible light is emitted. The color of the emitted light depends upon the material. Each type emits a specific wavelength ranging from violet (400 nm) to red (700 nm). Factors in selecting a fluorescent dye are a) the color emitted, and b) the intensity of emitted fluorescent light. The most frequently used dyes emit a yellow-green light in the wavelength band of 510 to 560 nm. This color is chosen since the human eye has its highest response to wavelengths in the 550 nm range. The relative response of a typical human eye compared to various wavelengths of visible light using two different lighting conditions are shown (Figure 2-28). Curve A at 100 lumens (100-foot-candles) is typical of a well-lighted inspection bench. Curve B at 2 lumens (2-foot candles) is the maximum white light level allowed in a fluorescent penetrant inspection booth. Under the darkened condition, the sensitivity of the eye increases about 30 times and shifts slightly to the blue region. At a light level of 2 lumens, it is possible for the eye to see some light wavelengths below 400 nm and above 700 nm.

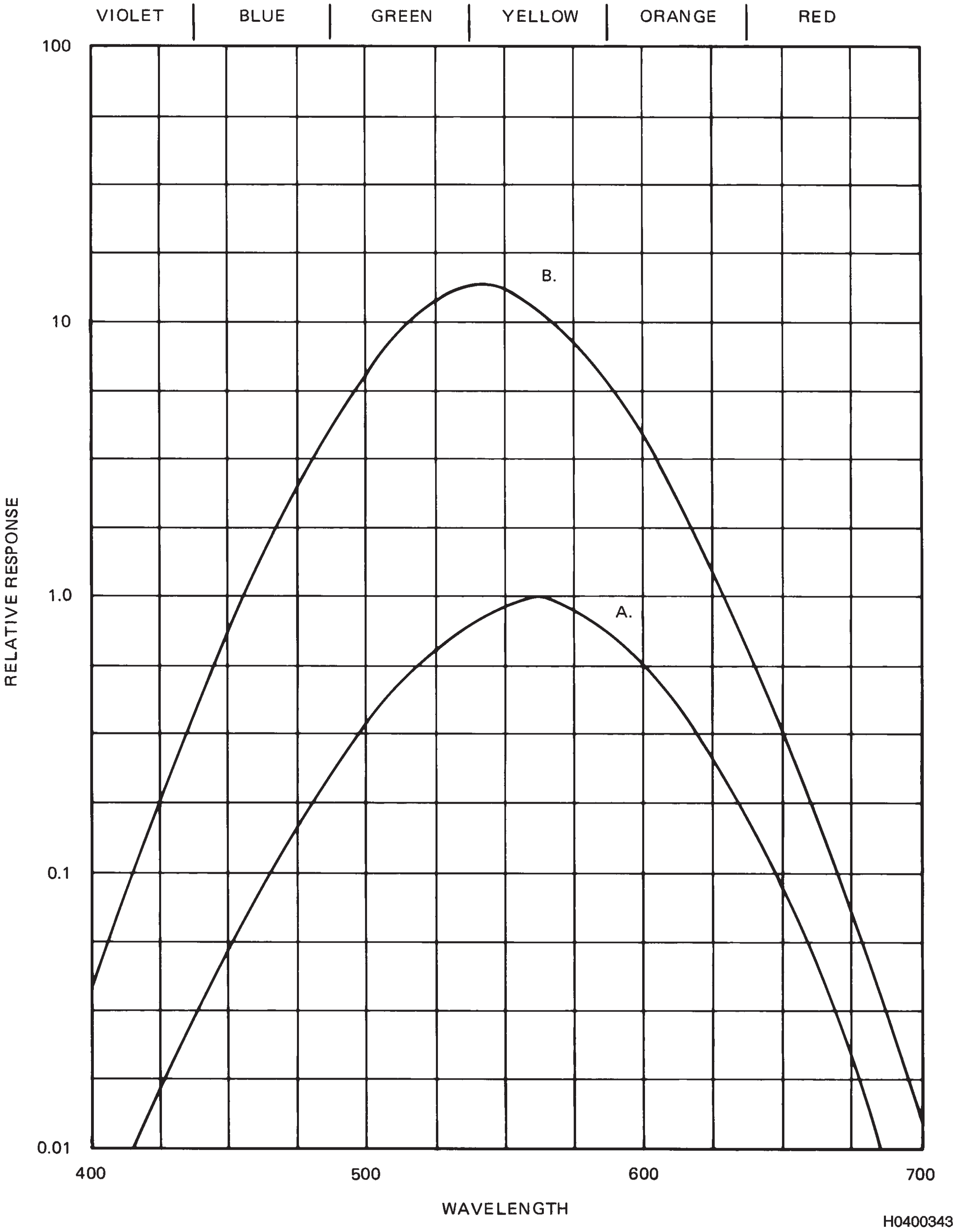


Figure 2-28. Relative Response of a Typical Human Eye to Visible Light at Two Different Light Levels, (A) 100 Lumens, and (B) 2.0 Lumens

2.5.4.1.3 UV-A Intensity and Ambient Light Requirements.

CAUTION

> When performing portable fluorescent penetrant inspection, a dark colored canvas or photographers black cloth SHALL be used to darken the area during the examination. Every effort should be made to reduce ambient light conditions to below 2 foot-candles.

The adequacy of a UV-A lamp for fluorescent penetrant inspection is determined by measuring the intensity of the UV-A with a UV-A radiometer placed at a distance of 15-inches from the front or outside surface of the UV-A source filter. UV-A lamps used in the rinse stations are NOT required to meet these requirements since they are not used to inspect for cracks in parts.

The ambient white light at the inspection surface SHALL NOT exceed 2-foot-candles. Ambient white light SHALL be measured with a white light meter with the UV-A lamps on.

2.5.4.1.4 Measurement of Intensity (Irradiance).

2.5.4.1.4.1 Measurement Devices. Ultraviolet light is electromagnetic radiation and is measured in units of energy per time, namely the unit of watt (W). Digital UV-A radiometers are currently the most commonly used instrument for conducting this measurement. Radiometers typically measure the energy of ultraviolet light in units of energy per time per area, i.e. watts per square meter or microwatts per square centimeter where one watt per square meter (W/m^2) equals 100 micro-watts per square centimeter ($\mu W/cm^2$). Care SHALL be exercised to assure the instrument used for this measurement is designed for the UV-A range with the peak at 365-nm.

2.5.4.1.4.2 Guidelines for UV-A Intensity Measurement. There are a few precautions to be observed when using UV-A intensity measuring instruments.

2.5.4.1.4.2.1 Some instruments have selectable ranges, and the proper range for the intensity being measured SHALL be used. The range selector may be changed while under the UV-A lamp.

2.5.4.1.4.2.1.1 The minimum UV-A output for a UV-A lamp SHALL be 1000 mW/cm^2 over a 5-inch diameter circle (minimum) for mercury vapor, gas-discharge lamps and Type A and B LED lamps when measured at a distance of 15-inches from the outside face of the filter. Type C LED lamps (single LED torch lamps) SHALL have a minimum UV-A output of 1000 mW/cm^2 over a 3-inch diameter circle when measured at a distance of 15-inches from the outside face of the filter.

2.5.4.1.4.2.2 The sensing element should be at the location and orientation of the part surface to be inspected. Some instruments have detachable sensors that may be placed directly on the part surface.

2.5.4.1.4.2.3 White light does not affect the reading of the instrument.

2.5.4.1.5 Variables in UV-A Sources. Mercury vapor arc lamps that will be used periodically during the day SHOULD be allowed to remain on until their last use of the day. This practice will extend the useful bulb life. This does not apply to Micro Gas Discharge (MGD) or Light Emitting Diode (LED) lamps.

2.5.4.1.5.1 Manufacturing Variations - UV-A bulbs are manufactured for other industrial applications. Non-destructive inspection (NDI) uses only a small portion of this production. The primary users do not require a specific output or consistency between bulbs. Consequently, new bulbs may vary by as much as 50-percent in their initial output. This means that of two new bulbs, one may have an intensity that is double that of the other without either being defective.

2.5.4.1.5.2 Line Voltage Variations -UV-A intensity varies almost linearly with line voltage. A common misconception is the bulb ballast or transformer will regulate line variations. Below approximately 90-volts, the lamps will not sustain the mercury arc and the lamp will extinguish, and will not restart until it has cooled. Lamps should be connected to stable power sources. If none are available and line voltage fluctuates, a constant potential transformer should be used.

2.5.4.1.5.3 Service and Aging Variations -During use, dust and dirt will collect on both the bulb face and filter. Even small amounts will reduce the intensity and, if allowed to build up, can result in as much as a 50-percent decrease in ultraviolet radiation output. The bulb face and filter SHALL be kept clean. The output of UV-A bulbs will also vary due to changes in operating characteristics, as the operating hours add up and the bulb ages, the intensity will gradually decrease and will decrease the bulbs output. Of greater significance is the number of bulb starts. A single start can equate to 2 or 3-hours of continuous use on operating life.

2.5.4.1.6 UV-A Lamp Safety. Ultraviolet radiation below 320 nm can be hazardous and may cause permanent effects. The output of a UV-A bulb is principally at 365 nm and the amount of radiation at shorter wavelengths rapidly falls off. The amount of radiation emitted at or below 320 nm is typically less than 1-percent; however, this quantity is enough to require a filter. Germicidal, sun tanning, and mineral light bulbs that emit short and medium wavelength ultraviolet light SHALL NOT be used for penetrant inspection. Ultraviolet light filtering safety eyewear and gloves shall be used to minimize potential detrimental health effects.

2.5.4.1.6.1 Eyeball Fluorescence under Ultraviolet Radiation. The fluid in the eye will fluoresce when exposed to ultraviolet radiation. An operator may experience this phenomenon as a clouding of the vision when the ultraviolet radiation is reflected into the operator’s eyeball or if ultraviolet radiation is reflected from highly reflective surfaces. This phenomenon, often referred to as veiling glare, can usually be corrected by positioning the lamp so the radiation is not directed or reflected into the inspector’s eye. The use of eyewear designed to protect the eyes from UV-A and UV-B will reduce this effect.

2.5.4.1.6.2 Restrictions on Eyeglasses.

CAUTION

Contact lenses, sunglasses, and glasses with photochromic lens that darken when exposed to sunlight SHALL NOT be worn when performing fluorescent penetrant inspection.

Sunglasses reduce the amount of visible light radiating from a fluorescing indication and faint indications may not be seen. Photochromic lens will darken when exposed to UV-A and reduce the ability to see small indications. Furthermore, eyeglass frames that fluoresce under UV-A can cause glare or unnecessary fluorescent background illumination and should not be used in the inspection booth.

2.5.4.2 Ambient Visible Light.

2.5.4.2.1 Requirements. Inspection of a part for fluorescent penetrant indications with UV-A lamps SHALL always be performed under the lowest possible level of ambient light. This increases the contrast between the light emitted from the indication and the background. A low level of visible ambient light is critical for maintaining the sensitivity of the inspection. Ambient light in stationary inspection system booths SHALL NOT exceed 2 foot-candles. If a stationary inspection booth is not adequate or appropriate, other provisions SHALL be made.

2.5.4.2.2 Measurement of Ambient Visible Light. Visible light is measured using photometers or light meters. The light meter responds to electromagnetic energy with wavelengths of approximately 380 to 750 nm. This range extends into the longer wavelength ultraviolet and shorter wavelength infrared ranges. Precise measurement is possible with filters excluding black light and infrared radiation. The unit of measurement is the foot-candle. Another term often used to measure light intensity is the lux, which equals 1-lumen per square meter of surface area. One foot-candle equals approximately 10 lux. Measurement of ambient white light SHALL be performed in stationary inspection booths at the required intervals defined in (paragraph 2.5.4.1.3).Ambient white light SHALL also be performed prior to portable inspection. Ambient light measurements SHALL be performed in accordance with (paragraph 2.6.6) and SHALL be performed with the overhead UV-A lamps on. Due to the response curve of silicon photodiodes and variability in filters used in meter construction, visible light meters are not suitable for measuring the emission of visible light from UV-A sources.

2.5.4.2.3 White Light Requirements for Type II Penetrant Inspection. For inspecting parts that have been processed with visible-dye penetrant (Type II), the lighting system in the viewing area SHALL provide at least 100-foot-candles (1000 lux) of visible white light at the examination surface.

2.5.5 Inspection Conditions.

2.5.5.1 Dark Adaptation.

CAUTION

> An inspector entering a darkened area SHALL allow at least 5-minutes for dark adaptation before examining parts. Furthermore, wearing clothing which fluorescences under ultraviolet light SHALL NOT be permitted during the performance of fluorescent penetrant inspection as it may raise the ambient white light in the inspection area to an unacceptable level.

The human eye becomes approximately 30-times more sensitive to light under dark conditions. This increased sensitivity gradually occurs when the light conditions change from light to dark. When first entering a dark area from a lighted area, little or nothing can be seen. During dark adaptation the human eye begins to adjust to the lower light levels in two ways. First, the pupil of the eye must widen to admit additional light. Second, the retina of the eye becomes more sensitive during dark adaptation as the retina switches from the cone to the rod receptors. Full sensitivity or dark adaptation requires about 20-minutes. A dark adaptation time of 5-minutes is usually sufficient for fluorescent penetrant inspection with UV-A lamps. The human eye contains a protective mechanism that further complicates dark adaptation. The pupil of the eye responds very rapidly to bright light. A very short, bright light exposure cancels the slowly acquired dark adaptation. Time for dark adaptation SHALL be allowed whenever an inspector enters the darkened station or is exposed to bright ambient light. A timer capable of measuring this time period SHALL be visibly or audibly available within the darkened area.

2.5.5.2 Cleanliness. The inspection area and the hands/gloves and clothing of the inspector SHALL be clean and free of extraneous penetrant material. Non-relevant indications may be formed when parts contact extraneous penetrants. In addition, the fluorescence from the penetrant will raise the ambient light level, thus reducing sensitivity.

2.5.6 Evaluating Indications.

2.5.6.1 Evaluating and Interpreting Relevant and Non-relevant Indications. A distinction must be made between relevant indications, non-relevant indications, discontinuities, and flaws or defects. A relevant indication is one resulting from a discontinuity. A non-relevant indication can result from an intentional change in part shape such as threads or small radii, or may be caused by improper or careless processing procedures. Non-relevant indications are of concern because they may mask or cover a true discontinuity indication. A discontinuity is an unintentional change in part surface or physical condition such as tooling marks, scratches or gouges, cracks, seams, laps, and porosity. A discontinuity may or may not affect the serviceability of the part. If the discontinuity reduces or interferes with the serviceability, it is classified as a flaw or defect. It is possible for a part to contain multiple indications that may be any combination of non-relevant discontinuities not affecting serviceability and defects requiring corrective action.

2.5.6.2 Inspectors Interpretation Responsibility. NDI personnel SHALL be capable of interpreting indications and evaluating discontinuities in accordance with the specifications and procedures for the inspection process in use. They are not normally responsible for disposition decisions on flawed parts, but they must report the type, location, and approximate size of any flaws present. Acceptance, rework or repair, and rejection limits are contained in the repair manuals and are the responsibility of the applicable work center.

2.5.6.3 Appearance of Indications. The size and shape of the discontinuity, the type of penetrant system, processing technique, type of developer, and the length of developer dwell influence the appearance of penetrant indications. These factors hold true for all types and forms of material and apply to both large and small parts.

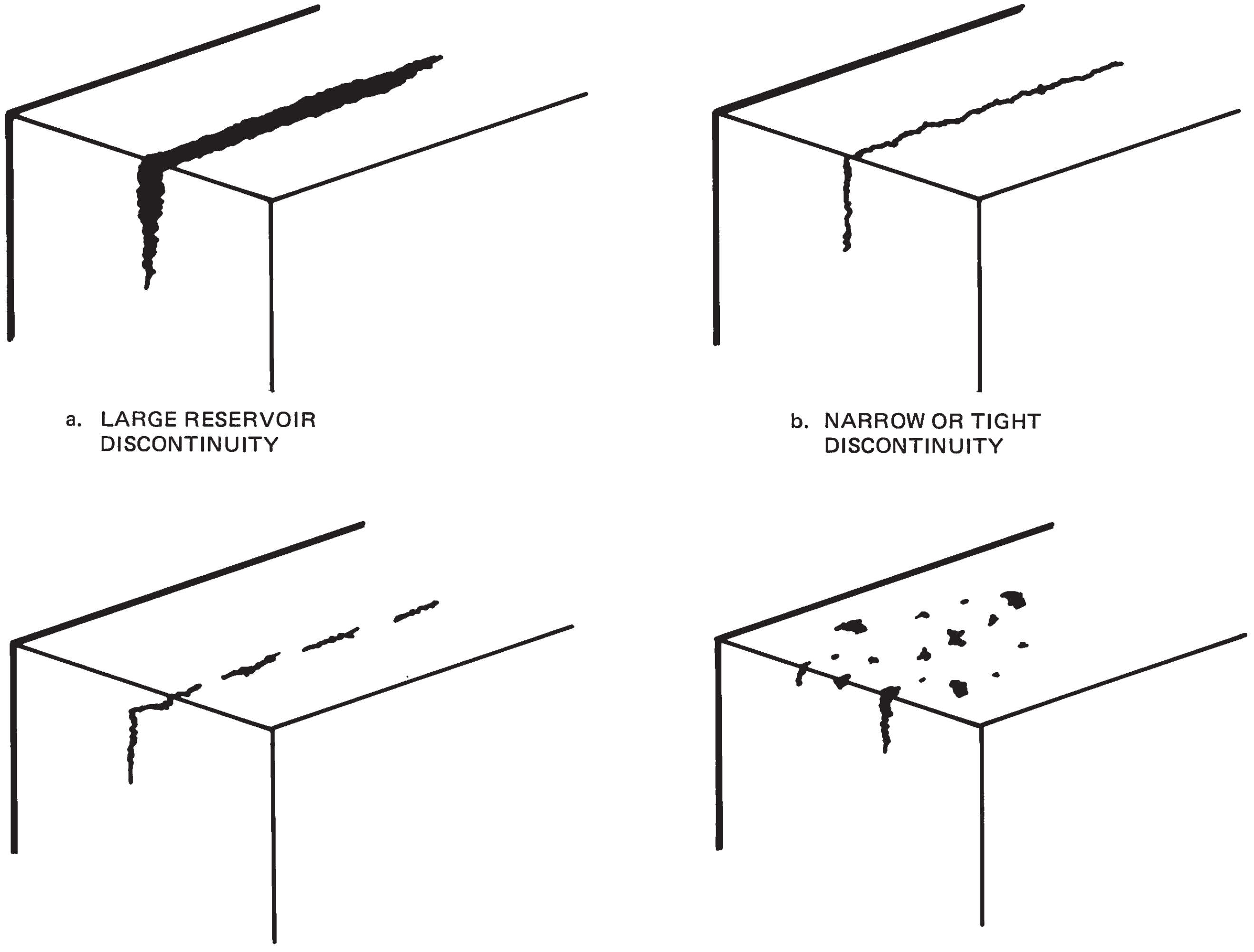
2.5.6.4 Classification of Discontinuity Indications.

NOTE

Remember, although an indication may signify a discontinuity in the test part, an indication is not always a sign of a defect. The responsible engineering authority SHALL make a determination if a discontinuity will be classified as a defect.

There are a number of ways of classifying discontinuities, such as appearance of the indication, its cause, material, and service conditions. The method of classification used depends upon the test method, the use of the parts, and the original designer. Many of the NDI application manuals, which are usually prepared by the original manufacturer, contain several discontinuity classifications in the same manual. Some of the indication types are discussed in the following paragraphs.

2.5.6.4.1 Continuous Linear Indications. Linear penetrant indications are caused by discontinuities such as cracks, seams, or laps. The width and brightness of the indication depend upon the volume of entrapped penetrant. The indication may be fairly straight or may have some curvature depending on how the discontinuity was formed. Also, the edges may be jagged or smooth, where the discontinuity meets the part surface. The surface appearance and a cross-section through a linear discontinuity with a large reservoir is shown (Figure 2-29, (a)). A narrow or tight linear discontinuity is also shown (Figure 2-29, (b)).



a. LARGE RESERVOIR DISCONTINUITY

b. NARROW OR TIGHT DISCONTINUITY

c. PARTIALLY WELDED LINEAR DISCONTINUITY

d. ROUNDED (LARGE & SMALL) DISCONTINUITIES

Figure 2-29. Typical Penetrant Indications (a, b, c, d)

2.5.6.4.2 Intermittent Linear Indications. Intermittent linear indications are caused by the same discontinuities that form continuous linear indications; however, either a subsequent process or service use has partially sealed the surface opening. This occurs in forging laps or where the part has been subjected to a mechanical smearing action. A sub-surface discontinuity that intermittently breaks the surface for its entire length or a partially filled seam will also produce an intermittent linear indication as shown in (Figure 2-29, (c)).

2.5.6.4.3 Round or Dot Indications. Round indications are characterized as having a length and width of approximately equal dimensions. Porosity or relatively small areas of unsoundness in metal components usually form rounded indications; however, the actual surface opening may be irregular in shape. Deep discontinuities, such as weld crater cracks, may appear rounded due to the large volume of entrapped penetrant. The appearance of large and small rounded indications is reflected in (Figure 2-29, (d)).

2.5.6.4.4 Manufacturing Discontinuities. Many discontinuities result from manufacturing and repair processes. These will probably be detected each time the part is reinspected. The NDI inspector must, therefore, be familiar with their appearance and cause, in order to make valid interpretations of inspection results. Some of the common types of manufacturing discontinuities are described in the following paragraphs.

2.5.6.4.4.1 Porosity. Porosity is common to all cast parts, particularly aluminum and magnesium. Porosity occurs when gases are entrapped in the molten metal during pouring and solidification and may also occur during welding. It does not always break the surface, and internal porosity is not detected by penetrant inspection. Porosity can be very small and distributed throughout the material, in which case, it is called microporosity or you may see larger pores, which are called macroporosity. Microporosity may or may not cause a penetrant indication. In castings, porosity is usually not considered a defect, unless it is extensive enough to cause a structural weakness or allow the leakage of a fluid intended to be contained by the casting.

2.5.6.4.4.2 Inclusions. Inclusions are particles of foreign material, usually slag, oxides, sulfides, or silicates trapped in the metal during solidification. If the material is mechanically worked into plate, sheet, or bar, the inclusions will be elongated by the forming operations. They are not usually at the part surface but may become exposed by subsequent machining. Since inclusions are solid foreign matter, they will not form penetrant indications unless the foreign material is porous. Inclusions are usually considered defects only when they are open to the surface, have a measurable length, and are located in a critical area.

2.5.6.4.4.3 Seams. Seams occur in rolled bar stock or parts machined from bar stock. They are inclusions, porosity, or more commonly, metal folds that have been elongated by the rolling process during fabrication. They are long, straight discontinuities running parallel to the direction of mechanical working. If the seams contain foreign material, they may produce no indications, or very faint indications. They may be classified as defects depending on size and location.

2.5.6.4.4.4 Forging Laps. Forging laps are formed when a portion of the metal is creased and folded over during the forging operation. They produce a wavy, irregular, linear indication, which may be faint or intermittent, since the lap breaks the surface at an angle and the edges may be partially welded. They may or may not be considered a defect, depending on size and location.

2.5.6.4.4.5 Flash-Line Cracking. Forging flash is the line of excess metal extruded into the space at the junction between the top and bottom dies. Cracking can occur when this excess metal is removed causing the linear type of indications. The cracking always occurs along and within the trimming marks.

2.5.6.4.4.6 Extrusion Tears. Extrusion involves forcing a metal through a die to produce a desired shape. This process is similar to squeezing toothpaste out of a tube. If the die lip has a nick, burr or lump of oxide, the die can produce tears in the extruded part. Extrusion tears are usually short linear defects perpendicular to the extrusion direction.

2.5.6.4.4.7 Thermal Cracks. When metals are subjected to a high temperature, localized stresses can occur due to unequal heating or cooling, restricted movement within the part, or unequal cross-section. Cracking will occur when the stresses exceed the tensile strength of the material. There are several types of thermal cracking depending upon the heating process.

2.5.6.4.4.7.1 Grinding Cracks. Grinding of hardened surfaces frequently introduces surface cracks. Localized overheating due to insufficient or poor coolant, improper grinding wheel, too rapid feed or too heavy a cut causes these thermal cracks. The cracks are shallow and sharp at the root, generally occur at right angles to the direction of grinding, and usually but not always, occur in multiples. Grinding cracks are considered defects since they reduce the fatigue strength.

2.5.6.4.4.7.2 Heat Treat Cracks. Heat-treat or quench cracks form as a result of unequal heating or cooling within a part. The cracks are deep, usually forked, and seldom form a pattern. These cracks are considered defects.

2.5.6.4.4.7.3 Weld Cracks. Welds can contain a number of discontinuities detectable by penetrant. They may be due to lack of penetration, lack of fusion, heating or quenching cracks in the weld bead and heat affected zone, and grinding cracks occurring during removal of the weld crown. Crack-like discontinuities are considered defects. Two typical examples are, weld grinding cracks; and, shrinkage or quench crack.

2.5.6.4.5 Service Induced Discontinuities. The most frequently encountered service discontinuities detected by penetrant inspection are fatigue cracks. Stress corrosion and overload cracking are also common. Overload fractures occur when the stress exceeds the tensile strength of the part. This is greater than the yield point, and the fracture is accompanied by some distortion. Cracks caused by overloading are relatively large and are further magnified by distortion, making them easy to detect visually without penetrant inspection.

2.5.6.4.5.1 Fatigue Cracking. Repeated or cyclic loading below the yield strength of the metal causes fatigue cracks. They initiate after a large number of load cycles usually at a surface imperfection such as a pit, scratch, tool mark, or at sharp change in cross-section. The initial crack is very small and forms a quarter or half-arc around the initiation point and then stops. After an additional number of load cycles, the crack grows slightly. This growth-arrest cycle produces a characteristic pattern on the fracture face, termed clamshell or beach mark pattern. Fatigue cracks have many common features. They occur in regions of high stress, are perpendicular to the direction of principal stress at their origin, and are transgranular. A good example of a fatigue crack is seen in Figure 2-30). Transgranular means the cracking progresses through or across the grains of metal rather than around them. Fatigue cracking occurs on a wide variety of parts and is considered a defect. It will continue to grow in-service, and the rate of growth increases as it becomes larger.

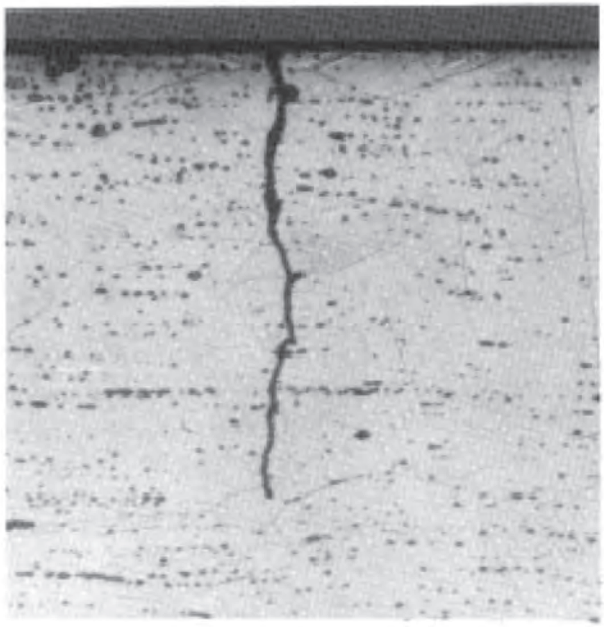


Figure 2-30. Micrograph of a Cross-Section Through a Fatigue Crack Showing the Transgranular Progression of the Crack

2.5.6.4.5.2 Stress-Corrosion Cracking. Stress-corrosion cracking is caused by a combination of stress and corrosion action. The stress may be either from service loads or a residual stress in the part. The residual stress can cause cracking of a part never in service. Stress-corrosion cracks have many of the characteristics of fatigue cracks. They occur in high stress areas at right angles to the stress and will grow in-service. Stress corrosion cracking may form a network of fine spider web-like cracks on the part surface. Penetrant indications of stress-corrosion cracks can also appear identical to indications of fatigue cracks. It is not always possible to distinguish between fatigue cracks and stress corrosion cracks from their surface appearance. Metallurgical examination is required to identify stress corrosion from fatigue cracks, since cross-sectioning will show stress-corrosion cracks are intergranular (meaning they propagate between the metal grains) whereas fatigue cracks are transgranular (they propagate through the metal grains). A micrograph of a stress-corrosion crack is shown (Figure 2-31). As with fatigue cracks, it is important to know the history or circumstances associated with the occurrence of the stress-corrosion cracking. Depending upon the service of the part, fatigue cracks may be free of contamination and may be easily detected with penetrant testing or they may be filled with contamination or under such high residual compressive stress they are impossible to detect with penetrant. Stress-corrosion cracks may have very little or a lot of corrosion products trapped in the cracks. The amount of corrosion product present significantly affects the detectability of this type of cracking. As with fatigue cracks, certain types of stress-corrosion cracking may not be detectable with penetrant methods. Extended dwell times may also be required to detect stress-corrosion cracking.

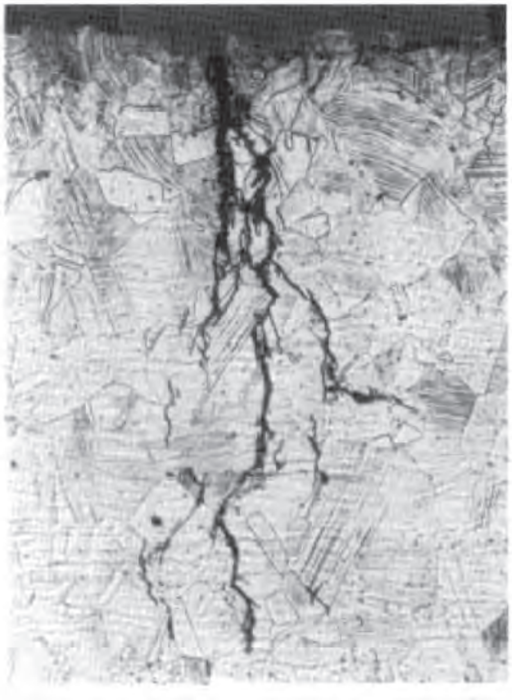


Figure 2-31. Micrograph of a Cross-Section Through a Stress-Corrosion Crack

2.5.6.4.5.3 Corrosion. The penetrant inspection method is occasionally used to detect corrosion. Corrosion usually attacks the material at the grain boundaries faster than at the interior of the grains and forms a network of very fine cracks. Corrosion may also be found as pitting on part surfaces. In the early stages, the crack or pitting are visible only under 10X or greater magnification. Penetrant indications of intergranular corrosion or surface pitting appear as a residual background that can only be resolved under magnification. Developer is not used when evaluating a penetrant indication using a magnifying glass. Penetrant inspection is often used to monitor the surface for adequacy of corrosion removal by grinding. Caution SHALL be exercised, since the mechanical removal causes smearing, which may obscure indications of remaining corrosion. In monitoring corrosion grind-out areas, a developer SHALL not be used. Following removal of excess surface penetrant, the area is examined using a low-power magnifying glass (3X to 5X). The examination SHALL be repeated after a minimum 5-minute dwell in lieu of developer. When the corrosion is no longer detected, the inspection process SHALL be repeated using nonaqueous developer.

2.5.6.5 Evaluation of Indications (Bleed-Back Method). Indications can be indistinct and blurred while still being highly visible. The following method may be used to verify and evaluate the type of indication. Lightly dampen a clean rag or cotton swab with an approved fast drying solvent, such as Isopropyl Alcohol. Carefully wipe the indication area only once with the solvent dampened rag or swab. After the solvent has evaporated, examine the bare surface with a 3X to 5X magnifying glass and watch the indication as it begins and continues to develop without developer applied. Evaluation of penetrant indications with a magnifying glass SHALL be accomplished with the developer removed. The developer will blur and enlarge the indication. The initial evaluation SHALL be done at low magnification (3X to 5X), with higher magnification (10X) used only after the indication has been located. If the indication cannot be located, spray a very light layer of nonaqueous developer over the area and watch the indication as it begins and continues to develop. If no penetrant bleed-out or surface imperfection can be seen, the original indication could have been non-relevant, possibly due to improper processing.

2.5.6.6 Photography of Indications.

2.5.6.6.1 General. Photography can be a good method of producing a permanent record of penetrant indications. Photography film and digital, can provide a very descriptive record since they show both the indication size and location on the part. They are permanent, reproducible, and the required equipment is available. Digital photography allows for rapid reproducibility and transportability of the imagery data, provides for very rapid optimization of exposure parameters and is much faster in terms of processing time. Photographs made at different times will vary due to a number of factors, such as changes in part position, camera position, UV-A intensity and filters used.

2.5.6.6.2 Camera Equipment. When photographing penetrant indications, which are generally very small, the camera must be held close to the object. This requires, at a minimum, a set of close-up (macro) lenses. Tripod or other means of holding the camera steady, and a cable release shutter are recommended methods to reduce blurring caused by camera motion.

2.5.6.6.2.1 Filters. When compared to the human eye digital camera sensors have a higher response to ultraviolet light. When photographing fluorescent indications, the ultraviolet light must be removed or filtered to obtain a usable photograph. The basic filter used is a No. 2B. (The name Wratten is often associated with the filter numbers, after the man who devised the numbering system.) The 2B filter will absorb the invisible ultraviolet while passing the visible blue light. This approach provides a photograph representative of what the eye sees. Color balance will be normal and the part will appear as a blue outline with the fluorescent indication appearing as bright yellow-green as normally seen. With black and white film or digital images, the part will be outlined and the indication will appear as a white line or dots. Some developers that form a bright background decrease the contrast between the part and indication, which may be compensated for by using a 2E filter. The 2E filter reduces the background brightness without reducing the indication brightness. To provide an image of the part, the part may be illuminated with a very subdued white light while illuminating the indication with a UV-A lamp.

2.5.6.6.3 Camera Positioning. Penetrant indications are usually small. On large parts, it may not be possible to include the entire part in the photograph and still get acceptable detail on the indication. The camera must be moved in close to the indication, showing just enough of the part to adequately identify the location of the indication. When photographing penetrant indications, a through-the-lens viewing system is preferred. Cameras with a separate viewing lens will not include the exact area when making close-up photographs. Compensate for this by shifting the viewer aiming spot, the distance between the lens and viewer opening.

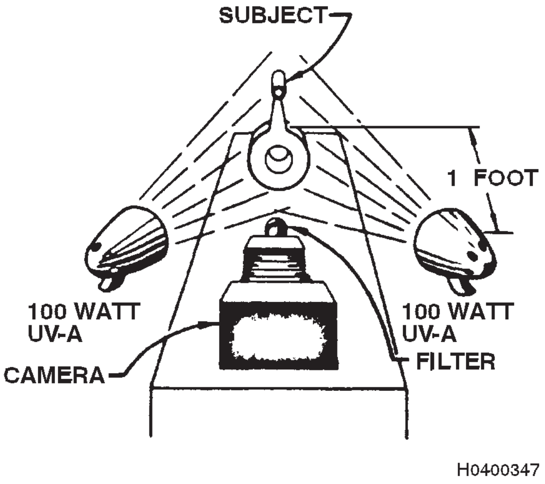


Figure 2-32. Location of Camera and Lights for Photographing Fluorescent Indications

2.5.6.6.4 Photographic Lighting. The maximum possible amount of UV-A energy SHALL be used to enhance the indication. The usual procedure is to use two UV-A lamps placed at equal distances on each side of the indication and position the camera in the middle Figure 2-32). This procedure provides equal light intensity across the length of the indication. The UV-A lamps SHALL be positioned so neither the direct beams, nor reflections from them, enter the camera.

Tubular (fluorescent) UV-A bulbs, and many ultraviolet-light guide sources emit more visible blue light than high pressure, mercury bulbs. Therefore, a No. 2E filter will produce a more natural photograph when fluorescent UV-A are used.

2.5.6.6.4.1 Lens Opening, Exposure, and Bracketing.

CAUTION

> Always use the smallest lens opening (largest F-stop number) possible to get an acceptable depth of field to keep the entire part in focus.

Close-up photography requires care in selecting the lens opening to obtain an acceptable depth of field. Depth of field is the distance range that is in focus. Lens openings are called F-stops with larger numbers indicating a smaller lens opening, as the lens opening increases, (smaller F-stop numbers), the depth of field decreases. The lens opening number should be higher than F5.6 for most close photography of this type as stated. Stop numbers of F6 or smaller will result in portions of the picture being out of focus. Close-up photography of fluorescent indications may require a number of exposures to obtain optimum results. Therefore three exposures should be made: the first at the meter indicated F-stop number; the second at two F-stop numbers under the meter reading; and the third at two F-stop numbers over the meter indicated number. A fourth exposure may be required at an intermediate setting. With very large or very small indications, the optimum lens opening may be three or four F-stop numbers off the indicated value.

SECTION VI PROCESS CONTROL OF LIQUID PENETRANT INSPECTION

2.6 LIQUID PENETRANT PROCESS CONTROL.

2.6.1 General. This section provides basic level information necessary to assure a high quality performance from the penetrant inspection system. Specific procedures to accomplish process control of the penetrant system are published in TO 33B-1-2 WP 102 00.

2.6.2 Need for Process Quality.

CAUTION

> The process materials and equipment SHALL be periodically tested and inspected to be sure they are all functioning properly.

Materials and process deficiencies are not always obvious. It is not easily determined if a penetrant has lost its ability to penetrate into a given flaw. Penetrant inspection, as well as all other nondestructive inspection processes, is not a perfect process. Flaws can be present and not be indicated for a number of reasons. The two main reasons for discrepancies in inspection results are:

- Substandard inspection materials due to either receipt of bad material from the manufacturer or degradation in storage or service.
- Process deviations in equipment, procedures, or operating conditions.

2.6.3 Why Test New Materials. Penetrant materials are subjected to extensive testing during their formulation to assure their proper composition. However, materials not performing satisfactorily can still be received. In a number of instances, the discrepancies in performance have not been detected until a number of parts have been processed. Considerable effort must then be expended to locate and reinspect the suspect parts. Unsatisfactory materials can result from a number of causes. The penetrant supplier may inadvertently omit an ingredient or a process. An ingredient with similar characteristics may be substituted if the original material is unavailable. The substitution of ingredients may occur at the penetrant formulator’s supplier.

2.6.4 Why Test In-Use Materials. Some inspection processes use the penetrant materials one time with no attempt to recover the excess. The materials are usually applied by spraying, and only enough material is applied to perform the test. The materials are stored in closed containers until they are used. These processes minimize the possibility of material contamination or degradation during use. More often, however, the materials are used in open tanks or open containers. When the immersion method is used, the surplus materials are allowed to drain from the part back into the tank. When penetrants are applied by brushing, the brush is alternately stroking the part surface and being immersed in the container. Both methods provide numerous opportunities for contamination and deterioration. Materials handled in this manner SHALL be checked periodically to be sure they are functioning properly.

2.6.5 Causes of Material Degradation.

2.6.5.1 Materials Contamination. Materials contamination is a primary source of penetrant system performance degradation. There are a number of contaminating materials and their effect on performance depends upon the contaminant type. Some of the common contaminants frequently encountered are:

- Water - Probably the most common type of contaminant. This can occur by careless or improper rinsing or carry over from other parts.
- Organic materials - Paint, lubricants, oils, greases, and sealant are other sources of contamination. If not removed from parts during precleaning, these materials can dissolve in the penetrant and react with or dilute it so it loses some or all of its ability to function.
- Organic solvents - Degreaser fluid, cleaning solvent, gasoline, and antifreeze solution are common types of solvent contaminants. These materials dissolve in the penetrant and reduce its effectiveness in proportion to the amount present.

A small change in performance is usually not noticeable (5-percent or less of the total volume). The method of entry into penetrant is usually carry-over on the interior cavities of the part.

- Dirt, soil, other insoluble solids - Soil/solid contamination can be carried into the penetrant, emulsifier, and developer as a result of improper pre-cleaning and carry-over from other parts. Another common source of soil contamination occurs when the dwell stations are used to store parts. Most dwell stations have drain pans, which return the effluent back to the immersion tanks. Any soil falling from unclean parts into the drain pan will be washed into the tank with the drain effluent.
- Acid and alkaline materials - Acid and alkaline contamination is extremely serious. They react with the penetrant to destroy fluorescence brightness even when present in fairly small quantities. They are usually residues from etching, plating or the cleaning processes.
- Penetrant - Penetrant is a normal contaminant of emulsifier in the postemulsifiable process. It can be carried in on penetrant covered parts during the penetrant dwell step. As the penetrant builds up in volume, it will gradually slow the emulsifying action, and if the level becomes high enough, the emulsification process will stop.

2.6.5.2 Evaporation Losses. Penetrant materials used in open tanks are continuously undergoing evaporation. The rate of evaporation is increased with warmer temperatures and large tank surface areas. Evaporation losses of penetrant result in an increase in viscosity, thus slowing penetration and emulsification. Evaporation of water washable penetrant may slow or speed washability, depending on the penetrant formula. Evaporation losses in developer solutions increase the concentration, which produces a heavier coating that may mask smaller indications. Since evaporation losses take place gradually, performance change may become significant before it is noticed.

2.6.5.3 Heat Degradation. Penetrants, especially fluorescent penetrants, are sensitive to elevated temperatures. Exposing penetrants to temperatures over 140°F (60°C) can reduce the fluorescence; and temperatures over 250°F (121°C) may destroy the penetrant completely. High temperatures also speed evaporation of the volatile components of penetrants, causing undesired performance changes. High temperature exposure of penetrants can occur from the following:

- Immersion of heated or hot parts.
- Inspection of hot surfaces resulting from exposure to the sun, such as flight-line aircraft.
- Improper storage of penetrant materials (such as in direct sunlight and high temperature storage) before being placed in use.
- Excessive exposure to heat in drying ovens.

2.6.5.4 Process Degradation. Not only do materials degrade, but equipment and procedures (other elements of the process) can deteriorate as well. UV-A bulbs and LEDs age, degrade, and also become dirty, reducing their output. Drying oven thermostats can be improperly set or may malfunction, resulting in excessive temperatures causing critical procedures to be performed incorrectly. Materials, equipment, and procedures SHALL be periodically audited during their service life to assure satisfactory process performance.

2.6.6 Establishing Work Center Process Control Intervals.

CAUTION

> The MAXIMUM allowed process control intervals are established in TO 33B-1-2 WP 102 00. Each activity SHALL set inspection intervals based on their workloads. Laboratories SHALL use the guidelines listed below to establish their process control requirements and intervals. The inspection intervals SHALL be documented as discussed in paragraph 1.5.5.

One of the factors influencing the degradation of a penetrant process (materials, equipment, and procedures) is the volume of parts being processed. The opportunities for materials contamination, drag-out, equipment malfunction, and procedure deviation are directly proportional to the number of parts being inspected. Equipment and process control inspection intervals vary depending upon the specific item to be checked. Many items will degrade on a time rather than a use basis. Since there is no uniformity in workload between activities, a single calendar schedule cannot be established. The process and equipment SHALL be inspected at established intervals in accordance with TO 33B-1-2.

2.6.7 Process Control Equipment. The performance of liquid penetrant systems depends on processing material quality, including the pre-cleaning chemicals, liquid penetrant, emulsifier and developer, plus the continued proper functioning of the several processing stages. A sudden undetected deterioration of one of the processing chemicals or malfunction in one of the stages may result in a defect escape and the acceptance of a defect containing part. The penetrant operator must be alerted to the sudden change or deterioration in materials and in equipment (paragraph 2.3.7) as soon as possible and certainly before processing a substantial quantity of parts. The following paragraphs describe the various configurations of process monitoring devices available that are often used in determining the performance of the penetrant system.

2.6.7.1 Penetrant System Monitor (PSM).

CAUTION

> The PSM panel SHALL NOT be used as a substitute for the cracked-chrome plate panels. The PSM panels are authorized for use with automatic and semi-automatic spray systems used in some depot laboratories when directed by the Depot NDI Manager.

One example of a process-monitoring device is the Penetrant System Monitor (PSM), also known as the “star burst” panel. The PSM is alternatively specified as Pratt and Whitney TAM Panel 146040, Sherwin Company P/N PSM-5 and Magnaflux Company P/N 198055. The PSM is especially suitable for high volume, semi-automated, and fully automated depot systems. It is intended for use as a daily or weekly monitor of the entire penetrant process. When properly used, the PSM will signal sudden changes affecting the integrity of a penetrant inspection process, changes that may have occurred in the materials, equipment, or procedures.

2.6.7.1.1 PSM Configuration. The PSM is a stainless steel panel measuring 4-inches wide by 6-inches long. A chrome-plated strip runs the length while the other side is a medium roughness, grit blasted surface. The chrome-plated strip contains five, evenly spaced, crack centers (Figure 2-33 and Figure 2-34) . The crack centers are in circular patterns varying in size from about 1/4-inch diameter down to about 1/32-inch diameter, and are arranged in order magnitude. The cracks radiate from the center in a star or sunburst pattern. No two panels are completely identical and crack patterns and sizes vary from panel to panel. Furthermore, the design of these panels has changed over time. In previous designs, the starburst cracks were formed by indenting the back side of the panel. In more recent designs, the starburst cracks are formed by laser ablation.

CAUTION

> Careful and thorough ultrasonic cleaning of the PSM panels between uses is mandatory (TO 33B-1-2 WP 102 00). Use extreme care in handling and storing the panels. Do not drop, hit, or place undue mechanical stress on the test panels. Do not attempt to bend or straighten the test panels. Do not expose the test panels to temperatures above 212°F (100°C). Careful and thorough ultrasonic cleaning of all panels after each use is mandatory. Handle the panels with care. The panels are easily damaged by rough handling or when dropped. Panels indicating or showing evidence of damage SHALL be immediately replaced.

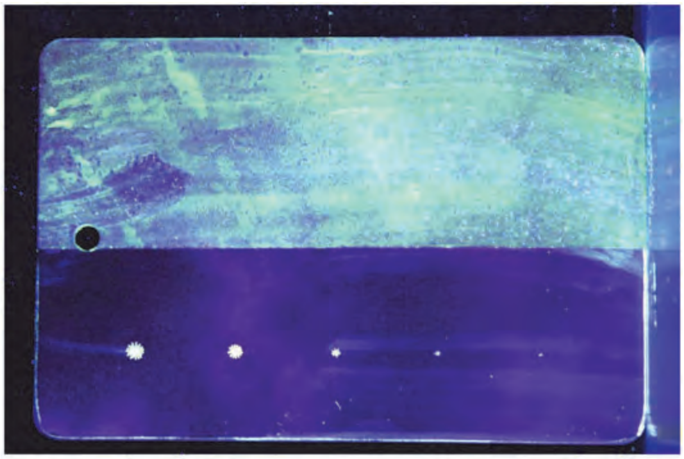


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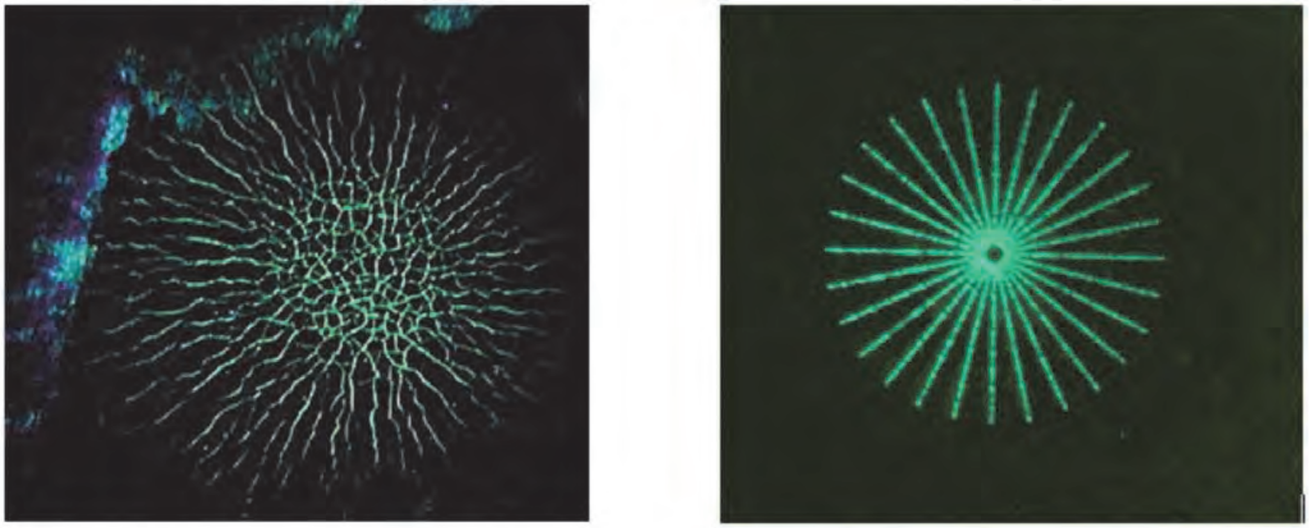
Figure 2-33. Processed Starburst (PSM) Panel With Indications



Starburst Cracks Formed by Indentation

Starburst Cracks Formed by Laser Ablation

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Figure 2-34. Magnified View of Largest Manufactured Indication

2.6.7.1.2 Monitoring of Sensitivity and Removability Using the PSM (Starburst) Panel. The PSM can monitor the entire process because it can be processed directly in the working tanks along with production parts. In addition, the grit blasted strip will separately indicate the effectiveness of the removal process steps. One disadvantage is that small or gradual changes are not readily noticed. Furthermore, as with cracked chrome plate panels, the PSM indications deteriorate with handling and repeated use. Also, the PSM panel can retain large amounts of residual penetrant, so careful and thorough cleaning is mandatory.

2.6.7.2 Cracked-Chrome Panels. The cracked-chrome panel is used for the evaluation of a liquid penetrant system's discontinuity detection performance. They are typically used to provide a qualitative side-by-side comparison of liquid penetrant performance. Their primary advantage is that small or gradual changes are readily noticed. Generally, tests made with cracked-chrome panels do not provide useful information on the background color or fluorescence caused by surface roughness of test parts or on the ability of a liquid penetrant to reveal micro-cracks in the presence of severe background porosity indications. Cracked-chrome panel indications will deteriorate with handling and repeated use. The panels are supplied in sets of two, with the supplier matching the panels as closely as possible. One panel is reserved for use as a "reference" or "transfer" standard while the other is the "working" panel.

The cracked-chrome panel is made by burnishing a 2.80-inch wide brass or copper plate to a mirror finish, then electroplating a thin layer of chrome on this surface. The chrome layer is brittle and cracks can be generated in it by bending the panel over a curved form. Crack depth is controlled by the thickness of the chrome plating. Crack width is determined by the degree of deformation of the panel during bending and straightening and is not controlled. After the plate is chrome plated and cracked, it is cut in half, lengthwise to produce two panels containing symmetrical crack patterns in each panel. Since the cracks extend across the original panel, the two panels are provided as a set with each panel measuring 3.94-inches (100 mm) long and 1.38-inches (35 mm) wide. Panels are typically available with cracks of 10, 20, 30, and 50 microns. The 30 and 50-micron panels are most often used with low and medium sensitivity penetrants. The 10 and 20-micron panels are usually used with high and ultra-high sensitivity penetrants. The standard panel is the 20-micron panel.

2.6.7.3 Cleaning and Storage of PSM and Cracked-Chrome Panels.

CAUTION

Careful and thorough ultrasonic cleaning of cracked-chrome panels is mandatory.

See TO 33B-1-2 WP 102 00 for cleaning and storage requirements for PSM and Cracked-Chrome panels.

2.6.8 Process Checks. The capability and reliability of penetrant inspections depend upon the 1) materials, 2) equipment, and 3) procedures. Degradation in any of the three areas will reduce the effectiveness of the process. Table 2-6 is for self-assessment only, and does not replace the required periodic process control requirements. The NDI supervisor SHALL perform an assessment of the penetrant process periodically. The interval of the assessment is at the NDI supervisor's discretion and does not require documentation. It is recommended that the process checklist be performed and documented whenever a unit self-assessment is accomplished. The process checks are presented in checklist format including a criticality identification system used in most Air Force checklists. The criticality is relevant to the penetrant process alone and should not be used by outside inspection agencies during assessments of the NDI Laboratory to determine the severity of an inspection finding. The criticality identifiers are as follows:

2.6.8.1 Critical Compliance Objectives (CCO). Items identified as key result areas for a successful mission accomplishment including, but not limited to, items where non-compliance could result in injury, excessive cost, or litigation. CCOs are shown in “BOLD AND ALL CAPS FORMAT.”

2.6.8.2 Core Compliance Items (CCI). Areas that require special vigilance and are important to the over-all performance of the unit, but are not deemed “Critical.” Non-compliance would result in some negative impact on mission performance or could result in injury, unnecessary cost, or possible litigation. CCIs are shown in “ALL CAPS FORMAT.”

2.6.8.3 General Compliance Items (GCI). Areas deemed fundamental to successful overall performance of the unit, but non-compliance would result in minimal impact on mission accomplishment or would be unlikely to result in injury, increased cost, or possible litigation. GCIs are shown in “sentence case format.”

2.6.8.4 General Data Information (GDI). Information required to validate equipment care and requisition priorities. GDIs are shown in “*italic sentence case format.*”

Table 2-6. Process Checks PT

CCO.1	**PART PREPARATION CHECKS - CLEANING/PRE-CLEANING. PRIOR TO APPLICATION OF PENETRANT, EXAMINE THE PRE-CLEANED PARTS FOR THE FOLLOWING:**	**YES or NO**
CCI.1.a	ARE COATINGS, SOIL, AND CONTAMINANTS COMPLETELY REMOVED?	
GCI.1.b	Have all cleaning process residues been removed?	
GCI.1.c	Are test parts dried, especially in recessed areas?	
CCI.2	ARE NEW AND IN-USE MATERIALS CHECKED TO DETERMINE THEY MEET OR EXCEED THE MANUFACTURES SPECIFICATIONS?	
GCI.3	Are tests on new materials are being properly performed and documented?	
CCO.4	**ARE TESTS ON IN-USE MATERIALS PROPERLY PERFORMED AND DOCUMENTED USING THE MAXIMUM PROCESS CONTROL INTERVALS ESTABLISHED IN TO 33B-1-2 WP 102 00?**	
GCI.5	Process Control of Penetrant. Observe the application of penetrant paying attention to the following:	
CCI.5.a.	DO PART TEMPERATURES EXCEED 125°F PRIOR TO PENETRANT APPLICATION?	
GCI.5.b.	Is the penetrant applied properly for the method being used?	
GCI.5.c.	Is the entire part surface or area to be inspected completely and evenly covered?	
GCI.5.d.	When using the immersion method are parts with concave or complex surfaces rotated in the penetrant to assure no air pockets remain?	
GCI.5.e.	Is drain and dwell accomplished in a satisfactory manner including the removal of any pooled penetrant?	
CCI.5.f.	DO PENETRANT DWELL TIMES COMPLY WITH THE SPECIFIC PROCEDURE REQUIREMENTS?	
GCI.6	Emulsifier and Remover Process Checks. Are the application, dwell and removal steps for lipophilic emulsifiers and hydrophilic removers closely monitored?	
GCI.7	Lipophilic Emulsifier Process Checks. Is the lipophilic emulsifier process observed and checked periodically to verify the following:	
GCI.7.a.	Are in-process Method B removability tests being properly performed and documented at intervals established in TO 33B-1-2 WP 102 00?	
GCI.7.b.	Is the test part rapidly and completely covered with emulsifier? Is their minimum mechanical action and no air pockets or uncoated surfaces?	
GCI.7.c.	Are test parts rotated to avoid pooling during the drain and dwell?	
CCI.7.d.	IS EMULSIFIER DWELL CLOSELY TIMED AND COMPLIES WITH SPECIFIC PROCEDURE REQUIREMENTS?	
CCI.7.e.	IS TEST PART PRODUCTION TIMED AND SPACED SO THAT NO DELAY OCCURS WHEN MOVING PARTS FROM EMULSIFIER DWELL STATION INTO THE RINSE STATION?	

	Table 2-6. Process Checks PT - Continued	
GCI.8	Hydrophilic Remover Process Checks. When the hydrophilic remover method is used, are the following applicable steps periodically observed and checked?	
GCI.9	Hydrophilic Remover Process Checks – Pre-Rinse Step. Is the pre-rinse step periodically observed and checked to verify the following:	
CCI.9.a.	DOES THE WATER PRESSURE, WATERS TEMPERATURE, DROPLET SIZE, SPRAY PATTERN MEET SPECIFICATIONS OF THE SPECIFIC PROCEDURE, TO 33B-1-1 OR 33B-1-2?	
GCI.9.b.	Are all surfaces adequately rinsed?	
GCI.10	Hydrophilic Remover Process Checks – Immersion Application. When hydrophilic remover is applied by the immersion method is the process observed and checked to verify the following:	
CCO.10.a.	**ARE IN-USE PERFORMANCE TESTS PROPERLY PERFORMED AT INTERVALS ESTABLISHED IN TO 33B-1-2 WP 102 00?**	
GCI.10.b.	Is the surface of the remover examined with a UV-A lamp for any signs of fluorescence?	
GCI.10.c.	Is there no odor or evidence of algae, fungi, or other growth?	
GCI.10.d.	Is agitation sufficient to move fresh remover in and around test parts but not excessive?	
GCI.10.e.	Are test parts completely immersed and when necessary rotated to eliminate air pockets?	
GCI.10.f	Are complex shaped parts rotated after removal to reduce pooling?	
CCI.10.g.	IS DRAIN TIME AFTER REMOVAL FROM BATH LESS THAN 30-SECONDS BEFORE RINSING IS STARTED?	
GCI.11	Hydrophilic Remover Process Checks-Spray Application. When hydrophilic remover is applied by the spray application method, is the process observed and checked to verify the following:	
CCO.11.a.	**ARE SPRAY REMOVER CONCENTRATION TESTS BEING PROPERLY PERFORMED USING THE PROCESS CONTROL INTERVALS ESTABLISHED IN TO 33B-1-2 WP 102 00?**	
GCI.11.b.	Is spraying done under UV-A illumination and in a shaded area?	
GCI.11.c.	Does the water pressure, temperature, droplet size, and spray pattern meet criteria established in the specific procedure, TO 33B-1-1, or TO 33B-1-2?	
GCI.11d.	Is the test part rinsed with fresh water following the spray removal?	
GCI.12	Post-Rinse Process Checks. Is the rinse step periodically observed and checked to verify the following:	
GCI.12.a.	Is the rinse station is adequately shaded?	
CCI.12.b.	IS RINSING ACCOMPLISHED UNDER UV-A illumination?	
CCI.12.c.	DOES THE WATER PRESSURE, TEMPERATURE, DROPLET SIZE, AND SPRAY PATTERN MEET CRITERIA ESTABLISHED IN THE SPECIFIC PROCEDURE, TO 33B-1-1, OR TO 33B-1-2?	
GCI.12.d.	On parts processed with lipophilic emulsifier, is the entire surface rapidly wetted to stop the emulsification process before attempting removal?	

Table 2-6. Process Checks PT - Continued

GCI.12.e.	On parts processed with hydrophilic remover, is the entire part rinsed to remove all traces of remover?	
GCI.12.f.	Is the test part free of pockets or splashes of penetrant after rinse?	
GCI.12.g.	Are test parts showing evidence of excessive residual penetrant (lipophilic process) completely cleaned and reprocessed through penetrant and emulsifier?	
GCI.13	Drying Process Checks. Is the drying process observed and checked periodically using the process control intervals established in Table 1, TO 33B-1-2 WP 102 00?	
CCI.13.a.	IS THE OVEN THERMOSTAT CALIBRATED FOR ACCURACY AT INTERVALS DETERMINED BY AF Metrology and Calibration (AFMETCAL)? IS THE CALIBRATION ACCOMPLISHED PER MANUFACTURER'S INSTRUCTIONS? NAVY: IS THERMOSTAT CALIBRATION DONE AT MANUFACTURER'S RECOMMENDED INTERVALS, OR AT 6 MONTH INTERVALS IF MANUFACTURER'S RECOMMENDED INTERVAL IS UNKNOWN?	
GCI.13.b.	Is the oven area inspected with a black light to ensure it is clean and without fluorescent penetrant contamination?	
GCI.13.c.	Are fans working properly and airflow not restricted?	
GCI.13.d.	Is all pooled rinse water removed?	
CCI.13.e.	IS THE DRYER OVEN TEMPERATURE SETTINGS AT 140°F OR LESS? (FOR AUTOMATED OR SEMIAUTOMATIC SYSTEMS USED IN SOME DEPOTS REFER TO EQUIPMENT OR PART SPECIFIC PROCESS ORDER)	
CCI.13.f.	DO TEST PARTS REMAIN IN OVEN ONLY UNTIL DRY?	
GCI.14	Developer Process Checks.	
GCI.14.a.	Is the developer area inspected with a UV-A lamp to ensure it is clean and without fluorescent penetrant contamination? Is it also free of any other contaminant, which may adversely affect penetrant inspection results (i.e., liquids, grease, excess developer, overspray, and extraneous parts and materials)? Is the area expose to UV-A and visually examined for any signs of fluorescence?	
GCI.14.b.	Are test parts in suitable condition (e.g., dry or wet) for the developer involved?	
CCI.14.c.	DO TEST PARTS DWELL THE REQUIRED TIME AFTER THE PART IS DRY (WATER OR SOLVENT DEVELOPERS)?	
GCI.15	Dry-Powder Developer Process Checks.	
GCI.15.a.	Is the developer dry with no clumping or fluorescent contamination?	
GCI.15.b.	Is the dry developer loose, fluffy, and pours easily?	
GCI.16	Dry-Powder Process Checks - Dip and Pour Method.	
GCI.16.a.	Is the developer dwell area clean and is there adequate room for the parts being processed?	
GCI.16.b.	Is the entire part surface is covered	
GCI.16.c.	Is excess developer powder removed without brushing or rubbing?	
GCI.17	Dry-Powder Process Checks - Fog Chamber Method.	

Table 2-6. Process Checks PT - Continued

GCI.17.a.	Are work and dwell areas adequate with controls accessible for adjustment?	
GCI.17.b.	Does the system have an adequate reservoir with positive feed and no caking or uncovered pressure tubes?	
GCI.17.c.	Is a good fog cloud produced with controlled air pressure?	
GCI.17.d.	Does the chamber or tank create excessive air pollution?	
GCI.18	Water-Suspended Developer Process Checks.	
CCI.18.a.	ARE PERFORMANCE COMPARISON TESTS PERFORMED ON SCHEDULE AND RECORDED?	
CCO.18.b.	**ARE CONCENTRATION CHECKS CORRECTLY PERFORMED ON SCHEDULE IN ACCORDANCE WITH THE PROCESS CONTROL INTERVALS ESTABLISHED IN TO 33B-1-2 WP 102 00?**	
GCI.18.c.	Is the solution clean with no penetrant on the surface?	
GCI.18.d.	Does agitation produce a uniform suspension with no caking on the bottom or in the corners of the tank?	
GCI.18.e.	Is the entire part covered with no water breaks or air pockets?	
GCI.18.f.	Is the test part drained over the tank or recovery tray to reduce drag-out losses?	
GCI.18.g.	Are complex test parts rotated during drain to reduce pooling?	
GCI.18.h.	Is the developer coating light and even after drying, with no retracted areas of beading or poor wetting?	
GCI.18.i.	Does the developer dwell time start when the part is free of moisture?	
GCI.19	Water-Soluble Developer Process Checks.	
CCI.19.a.	ARE PERFORMANCE COMPARISON TESTS PERFORMED ON SCHEDULE AND RECORDED?	
GCO.19.b.	ARE THE CONCENTRATION CHECKS PROPERLY PERFORMED ON SCHEDULE AND DOCUMENTED?	
GCI.19.c.	Are surfaces free of floating penetrant?	
GCI.19.e.	Is there no odor or evidence of algae, fungi, or other growth?	
GCI.19.f.	Does the developer wet the part surface; with no water break areas after spray or immersion?	
GCI.19.g.	Are test parts drained over the tank or recovery tray to reduce drag-out losses?	
GCI.19.h.	Are complex shaped parts turned over or rotated during draining to remove any pools?	
GCI.19.i.	Is the correct developer dwell time used; with dwell time beginning after the coating has dried?	
GCI.19.j.	Is the coating transparent and relatively even after drying?	
GCI.20	Inspection Booth Checks.	
GCI.20.a.	Is the inspection booth area clean?	
GCI.20.b.	Is the booth used to store parts or other items that could cause penetrant contamination to test surfaces?	
GCI.20.c.	Is the area free of spilled penetrant and does not fluoresce excessively when exposed to UV-A?	

Table 2-6. Process Checks PT - Continued

CCI.20.d.	IS THE AREA DARKENED TO 2-FOOT-CANDLES OR LESS AND PERIODICALLY CHECKED WITH AN ACCURATE VISIBLE LIGHT METER? IS THE CHECK DOCUMENTED AT INTERVALS STATED IN TO 33B-1-2 WP 102 00.	
GCI.20.e.	Are UV-A lamp bulbs and filters kept clean?	
CCI.20.f.	IS THE INTENSITY OF UV-A CHECKED AND DOCUMENTED AT LEAST ONCE EACH DAY OR PRIOR TO USE?	
GCI.20.g.	Are filters inspected for fit and are they crack free?	
GCI.20.h.	Are UV-A lamps positioned so they do not shine into the technician’s eyes?	
GCI.20.i.	Do technicians observe the 5-minute dark adaptation period?	
GCI.21	Portable Inspection Part Preparation - Cleaning/Pre-cleaning.	
GCI.21.b.	Has the surface been damaged by mechanical paint removal methods?	
GCI.21.c.	Has paint stripping residues or other inorganic contaminants been removed?	
GCI.21.d.	Is aerosol spray cleaner-remover suitable for pre-cleaning?	
GCI.21.e.	Has sufficient time been allowed for the pre-cleaning solvent to evaporate?	
GCI.22	Portable Inspection Penetrant Application Checks.	
GCI.22.a.	Are spray nozzles clean and free of dried or tacky penetrant?	
GCI.22.b.	Are aerosol cans shaken to thoroughly mix solvents prior to spraying?	
GCI.22.c.	Is a good spray technique used, with the can moving smoothly at the proper distance from the part?	
GCI.22.d.	Are brushes, swabs, and small containers used to apply penetrant clean and free of contaminates?	
GCI.22.e.	Is penetrant applied in an even layer, not excessively thick, and is free of runs?	
GCI.23	Portable Inspection Penetrant Removal Checks.	
GCI.23.a.	Is initial penetrant removal done with clean, dry cloth, folded between wipes to provide a fresh surface during each wipe?	
GCI.23.b.	Is final removal accomplished with a clean cloth, moistened (not saturated) with solvent? The cloth must be folded over with each wipe.	
CCI.23.c.	IS SOLVENT SPRAYED OR POURED DIRECTLY ON THE INSPECTION AREA?	
GCI.23.d.	Is a UV-A lamp used to check for traces of residual penetrant during penetrant removal?	
GCI.24	Portable Inspection Developer Application Checks.	
GCI.24.a.	Are can nozzles clean and free of caked developer?	
GCI.24.b.	Is the can agitated (mixing ball is loose) until all developer is in suspension?	
GCI.24.c.	Is the developer coating not excessively thick and applied in multiple thin layer passes, rather than a single layer?	
CCI.24.d.	IS THE REQUIRED DWELL TIME ALLOWED AFTER THE SOLVENT HAS EVAPORATED?	
GCI.24.e.	Is the developer spray pattern uniform?	

Table 2-6. Process Checks PT - Continued

GCI.25	Portable Inspection Area Checks.	
CCI.25.a.	IS THE INSPECTION AREA SHADED OR SHIELDED TO REDUCE AMBIENT LIGHT TO ACCEPTABLE LEVELS? THE USE OF A PORTABLE CLOTH MAY BE REQUIRED TO ACCOMPLISH THIS.	
CCI.25.b.	ARE BLACK AND AMBIENT LIGHT INTENSITIES WITHIN ACCEPTABLE LIMITS? (see paragraph 2.5.4.1.3)	
GCI.26	Post Cleaning Checks.	
GCI.26.a.	Are developer residues removed in a satisfactory manner?	
GCI.26.b.	Are penetrant residues removed in a satisfactory manner?	

2.6.9 Control of New Materials.

2.6.9.1 Approved Materials. With the exception of solvent removers only penetrant materials listed on the latest version of qualified products database (QPD) for SAE AMS 2644, may be procured and used. QPD can be found on website http://quicksearch.dla.mil/. Search for QPL-AMS2644, then select "Qualification" to gain access.

2.6.9.2 Provisions for Procurement of New Materials. Penetrant system material procurement SHALL meet the following requirements:

- Materials SHALL comply with the current version of SAE AMS 2644.
- Except for solvent removers, bidders SHALL have material listed (or approved for listing) on the most current revision of QPD SAE AMS 2644.
- Contract and special purchase orders for procurement of materials SHALL require a certified test report from the manufacturer as required by SAE AMS 2644.
- Materials listed on QPD SAE AMS 2644 and centrally procured using generic national stock numbers (NSNs) need not comply with the certified test report and quality conformance sampling requirement.
- All penetrant materials shall be tested for sensitivity and removability performance in accordance with paragraph 2.6.10 and TO 33B-1-2 WP 102 prior to introduction into the inspection process. Depot facilities may use alternate defect specimens (e.g., fatigue crack specimens) instead of cracked chrome panels to evaluate material performance.
- Aerosol (penetrant and developer) products shall also require sensitivity and removability testing in accordance with the requirements of paragraph 2.6.10 and TO 33B-1-2 WP 102 prior to introduction into the inspection process.

2.6.9.3 Sampling of Newly Received Materials.

2.6.9.3.1 General. Two samples are required from each batch or lot of penetrant, emulsifier or remover, and/or wet and dry developer when received. Only one additional sample will be required if the supplier has submitted a quality conformance sample. Either one or two samples SHALL be taken from each batch or lot of penetrant, emulsifier and remover, and wet and dry developer, when received and prior to use. One sample, either from the supplier or locally taken, will be used to verify the Quality Conformance. The second sample, which may be larger than the first, will be retained by the using activities as a reference standard for periodic process performance tests.

NOTE

> For aerosol products, a spray can of retained, in-use material shall be used as the reference for comparison to the newly received material.

2.6.9.3.2 Sample Size.

2.6.9.3.2.1 Quality Conformance Sample. For all items except developer solids, one sample of not less than 1-quart or no more than 1-gallon SHALL be taken from each batch or lot of each material. For each batch or lot of wet developers in the dry condition, a 2-pound sample SHALL be retained, and from each batch or lot of dry developer solids a 1-pound sample SHALL be retained.

2.6.9.3.2.2 Process Control Reference Sample. These samples SHALL also be retained for use as reference or master standards in comparing the performance of the in-use material. The sample size will depend upon the workload, which determines the frequency of process control testing. A suggested sample size for high volume workload systems is 1 to 2-gallons (for all items except developer solids) from each batch or lot of materials. The suggested quantity of wet developers in the dry condition is 2-pounds. A 2-pound sample is recommended for dry developer solid. Each depot and base SHALL be responsible for determining the sample size required for its workload. The reference sample SHALL be large enough to permit the required process control checks during the life of the material and still have a quantity of reference sample to run a comparison check against the new materials when the old solution is finally discarded.

2.6.9.4 Handling and Storage of New Samples. Care SHALL be exercised in obtaining, handling, and storage of the reference samples to prevent contamination or degradation. The containers SHALL be metal or glass since the penetrant oils and solvents attack many plastics. The same restriction applies to the seals or washers in the container lids. The sample containers SHALL be clean, dry, and have tight fitting lids or covers. The devices used for obtaining the sample SHALL NOT contain traces of other batch or lot materials. The samples SHALL be stored in a cool area and not exposed to sunlight, UV-A lamps, or high intensity white lights.

2.6.9.5 Quality Conformance Testing of New Materials. Depots with the appropriate analytical equipment and competent technicians to perform the required tests may test the following properties for compliance with SAE AMS 2644 in accordance with applicable procedures referenced in the material’s specification:

- Flash point (penetrants and lipophilic emulsifiers).
- Viscosity (penetrants and emulsifiers).
- Fluorescent brightness (penetrants).
- Thermal stability (penetrants).
- Water tolerance (water washable penetrants and lipophilic emulsifiers).
- Redispersibility (nonaqueous-wet and aqueous suspended developers).
- Fluorescence (developer).
- Removability (penetrant).
- Water content (hydrophilic remover concentrate).

2.6.9.6 Reporting Unsatisfactory Materials.

NOTE

Reporting problems, even relatively minor items, is essential for improvement in the NDI program, the materials specifications, and qualification testing. Information copies of written correspondence concerning unsatisfactory penetrant materials SHALL be furnished to AFRL/RXS, 2179 Twelfth Street, Bldg 651, Rm R59, Wright-Patterson Air Force Base, OH 45433-7718.

Unsatisfactory materials SHALL be reported in accordance with TO 00-35D-54 (Air Force) or AR 735-11-2 (Army). A copy of the quality conformance test report SHALL be included as substantiating data. The Air Force NDI Program Office, aflcmc-ezpt-ndio@us.af.mil, is the focal point collecting material deficiency reports relative to NDI materials. They may be contacted for assistance when preparing a material deficiency report. (For the Navy: Commanding Officer Naval Aviation Maintenance Office, Attn.: NDI PM, Patuxent River, MD 20670;) for the Army: AMCOM Corrosion Protection Office - NDT, RDMR-WDP-A, Bldg. 7631, Redstone Arsenal, AL 35898; DSN 897-0211.

2.6.10 Testing In-Use Materials.

NOTE

Penetrant materials that are provided ready-for-use and do not require mixing to a concentration, and are not recovered, or reused, or both, (such as materials packaged in aerosol containers, closed drums or materials poured into containers for one-time use) are not subject to the in-use penetrant requirements unless the shelf life has been exceeded or if storage temperatures above 120°F are suspected. Expired penetrant materials in closed containers, including aerosols, SHALL be tested every 12 months. Penetrant materials that are suspected to have been exposed to high temperature storage SHALL be tested just prior to use. Depot facilities using these closed systems SHALL develop a method to monitor system performance and appropriate interval as well as gain approval by the Depot NDI Level 3 Manager.

2.6.10.1 Monitoring the System Performance of the Stationary Penetrant Line. In-use materials SHALL be periodically tested to assure they are capable of acceptable performance. Frequency of in-process testing SHALL be based on the guidelines provided in TO 33B-1-2 WP 102 00 and documented in accordance with paragraph 1.5. Some in-process checks can be performed in the process tanks, while others are more conveniently performed on small samples taken from the tanks.

2.6.10.1.1 Monitoring of Sensitivity and Removability Using the PSM (Starburst) Panel. The PSM is used to monitor the entire process because it can be processed directly in the working tanks along with production parts. In addition, the grit blasted strip will indicate the effectiveness of the removal process steps. One disadvantage is small or gradual changes are not readily noticed. Furthermore, as with cracked chrome panels, the PSM indications deteriorate with handling and repeated use. Also, the PSM panel can retain large amounts of residual penetrant, so careful and thorough cleaning is mandatory. ARMY ONLY– A PSM panel SHALL be processed prior to the start of any FPI (Methods A, B, C or D) in order to identify process variation attributed to operator processing differences, i.e. penetrant removal and/or developer application and etc.

2.6.10.1.2 Use of PSM Panels. When used in depot inspection facilities the PSM panel SHALL be used to verify the penetrant system performance at the beginning of each shift. Because the PSM panel is a qualitative indication of the penetrant system performance, the inspector must be able to “discern” a difference in the panels appearance from one test to another; such as increased background fluorescence or decreased flaw indications or brightness of indications.

2.6.10.1.2.1 Reading PSM Starburst Indications. The inspector SHALL examine the starburst crack centers for the number of starburst indications as well as the brightness and size of the indications. For example, if the developer component is malfunctioning, crack centers may still be indicated but they may not be as bright as normal. Photographs of the indications can be useful to aid recognition of substantial change. Furthermore, when using aqueous developers, the developer SHALL provide a uniform coating over the chrome surface. Failure of the aqueous developer to wet the chrome may mean the solution strength is low or the wetting agent has biodegraded. If a performance problem is noted, additional testing is required to determine the cause.

2.6.10.1.2.2 Reading PSM Fluorescent Background. Washability and background fluorescence must also be interpreted. The grit blasted side of the PSM panel is used for this purpose. Some penetrant systems, especially high and ultrahigh sensitivity systems, leave a fluorescent background on the panel's grit blasted area. Other systems may leave no background. Neither condition is alarming unless it represents a change from the normal system performance. For example, with a hydrophilic remover system, higher than normal background fluorescence might indicate over dilution of the remover, shortened remover dwell times, absence of an effective pre-wash, etc. Lower background fluorescence might indicate failure to dilute the remover, over-extended remover dwell, inadequate developer application, etc. If a problem is noted, additional testing is required to determine the cause.

2.6.10.1.2.3 Cleaning PSM Panels. PSM Panels SHALL be thoroughly cleaned prior to use and immediately after use in accordance with procedure published in TO 33B-1-2 WP 102 00.

2.6.10.2 System Performance Test Procedure - Cracked-Chrome Panels.

CAUTION

> Use extreme care in handling and storing the panels. Do not drop, hit, or place undue mechanical stress on the test panels. Do not attempt to bend or straighten the test panels. Do not expose the test panels to temperatures above 212°F (100°C). Careful and thorough ultrasonic cleaning of cracked-chrome panels after each use is mandatory. Handle the panels with care. The panels are easily damaged by rough handling or when dropped. Panels indicating or show evidence of damage SHALL be immediately replaced.

The cracked-chrome panel (Figure 2-35) is used for the evaluation of a liquid penetrant system's discontinuity detection performance. They are typically used to provide a qualitative side-by-side comparison of liquid penetrant small or gradual changes are more information on the background color or fluorescence caused by surface roughness of test parts or on the ability of a liquid penetrant to reveal micro-cracks in the presence of severe background porosity indications. Furthermore, the chrome plated panel's mirror surface finish and flaw shape are not representative of normal aircraft parts. This requires special procedures when using the test panels. The main difference is the extreme care that SHALL be taken during the surface penetrant removal step. It is very easy to remove entrapped penetrant from the test panel cracks. Panels are cracked on one face only. When the penetrant materials are applied to the cracked face, surplus penetrant materials often get on the back of the panel. Penetrant materials on the back SHALL be removed to keep from contaminating the cracked panel face. Specific procedures for performing this test are located in TO 33B-1-2 WP 102 00.

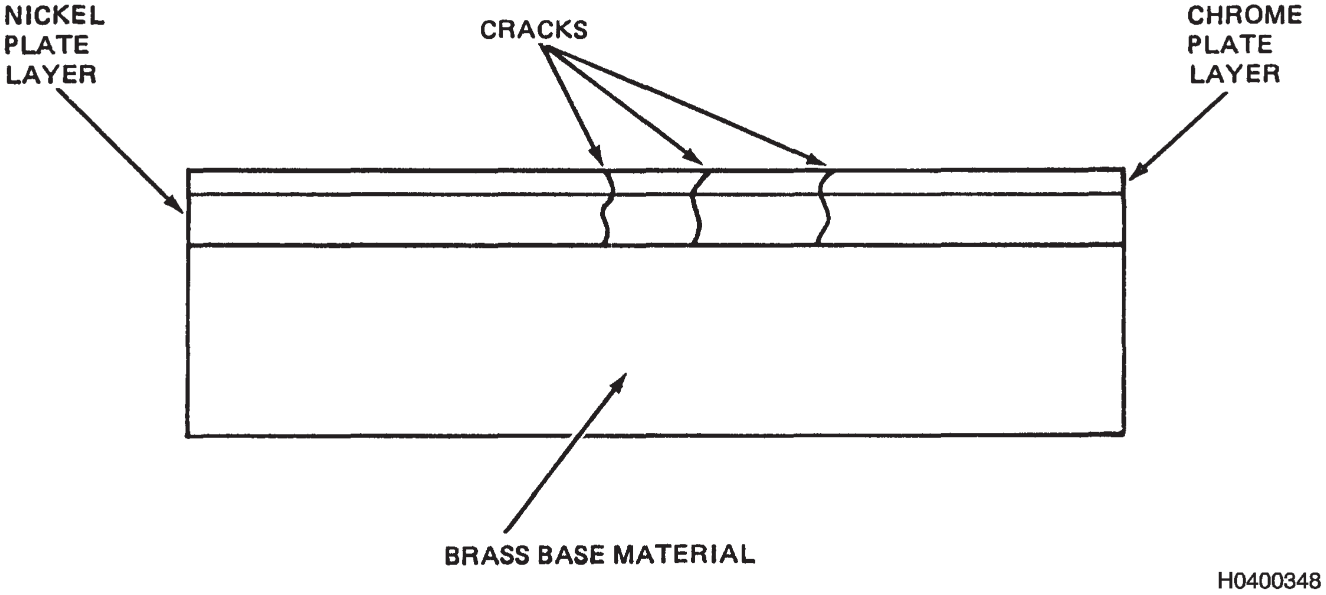

Figure 2-35. Illustration of Crack Depth in Cracked-Chrome Panel

2.6.10.3 Storage of Process Control Panels. All process control panels (cracked-chrome panels, PSM panels, gritblast panels) SHALL be stored in a clean environment to retard degradation. The cracked-chrome panels and PSM panels do not have an indefinite life. Penetrant and developer residues plus oxides retained in the cracks will gradually clog or fill the cracks, thus reducing the apparent size of the indications.

2.6.10.4 Additional Testing of Penetrant Material. Additional tests to determine the total working conditions of the penetrant include:

- Surface Wetting Test
- Penetrant Brightness Test
- Concentration of Water Based (Method A) Test
- Lipophilic (Method B) Emulsifier Removability Test
- Hydrophilic Remover Refractometer Test
- Hydrophilic Remover Hydrometer Test
- Hydrophilic Remover Performance Check
- Hydrophilic Remover Background Fluorescence Check
- Hydrophilic Remover Spray Solution Test
- Water-Suspended Developer Concentration Test
- Water-Suspended (or Soluble) Developer Coating Uniformity Test
- Water-Suspended (or Soluble) Developer Penetrant Contamination Test
- Water-Soluble Developer Concentration Test
- Dry Developer Contamination Test

2.6.10.4.1 Completing Intervals and Procedures. The intervals and procedures for completing the tests listed above are published in TO 33B-1-2 WP 102 00.

2.6.10.4.2 Surface Wetting Test. This test ensures the penetrant readily wets the surface and the penetrant film does not retract or form beads.

2.6.10.4.3 Penetrant Brightness Test. This test method compares the in-use penetrant with the reference penetrant. A comparison of the brightness is done between the two samples.

2.6.10.4.4 Testing Concentration of Water Based (Method "A") Penetrants. There are a small number of approved Method "A" penetrants currently containing water as a major constituent. These penetrants have been formulated to provide similar sensitivity performance to penetrants within the same sensitivity level while at the same time providing more environmentally friendly characteristics. Because water is a main constituent and evaporation losses may affect the penetrant performance, a periodic water concentration check is required. The water content of water-based method "A" penetrant shall be checked using a refractometer. The water content must be maintained according to the manufacturer's recommendation.

2.6.10.4.5 Testing Lipophilic Emulsifier (Method "B"). Penetrant is an unavoidable contaminant of lipophilic emulsifier. It is carried into the emulsifier on the surface of parts where it dissolves and is washed off during immersion and drain process. Since emulsifier and penetrant are capable of being mixed in all concentrations, even small quantities of fluorescent dye will cause the emulsifier to fluoresce. The fluorescent brightness increases with increasing dye content, but it is impossible to visually estimate penetrant contamination by observation of the tank surface. Emulsifier will continue to function when contaminated with penetrant; however, when the penetrant concentration reaches a certain level, the emulsification action slows and eventually stops. The penetrant material specification (SAE-AMS-2644) requires a 4-to-1 mixture of emulsifier to penetrant to leave no more residual background than the uncontaminated emulsifier.

2.6.10.4.6 Hydrophilic Remover Bath Concentration Test.

2.6.10.4.6.1 Hydrophilic Remover Immersion Bath Test. Freshly mixed (new) hydrophilic remover is characterized by a pinkish-red color that varies in intensity with the water content. The following three methods are used to verify initial remover concentration.

2.6.10.4.6.1.1 Hydrophilic Remover Refractometery Test.

NOTE

> The refractometery test is the preferred method for measuring the concentration of hydrophilic remover baths. Since the refractive index and light transmission properties of removers vary from batch to batch (even with the same type and manufacturer), each NDI lab SHALL verify the value obtained from both with the graph provided by manufacturer showing concentration versus refractive index value reading for each batch or lot of remover when it is prepared.

Refractometery is a test method by which the refractive index (Snell's Law) of a material is measured using a simple device called a refractometer. A refractometer measures the refractive index using the refractive index scale, which ranges from 0 to 320, with water having a refractive index of 0. A refractometer is supplied in the penetrant process control kit and is the recommended method to use in determining the initial water content concentration. Refractometery is also an acceptable method for testing in-use hydrophilic remover concentration provided that penetrant contamination is not excessive. A hydrophilic remover performance check will usually indicate excessive penetrant contamination before the refractive index is affected by penetrant contamination.

2.6.10.4.6.1.1.1 Creating a Hydrophilic Remover Concentration versus Refractive Index Graph. Upon completion of the graph, maintain on hand and use to determine accurate readings from the refractometer when performing your Hydrophilic Remover Refractometer Test.

a. Using a Graduated Cylinder: Mix a 10% Concentration of Hydrophilic remover to water (Ex. 10 ML Hydrophilic Remover concentrate to 90 ML Water). Mix the concentration within the graduated cylinder thoroughly to ensure consistency of the mixture.

b. Perform the refractometer test on the mixture and record Refractive Index Value.

c. Plot the refractometer reading onto your grid using the Y axis as your refractometer reading and the X axis as your samples known solution concentration.

d. Clean the Graduated Cylinder and make sure it is completely dry and free of any water or left over remover.

e. Repeat steps a thru d to record your values for 20% and 30% concentrations.

f. Using a ruler, starting at the zero between the X and Y axis, draw a line through the points plotted on the graph.

g. Highlighting your allowable range (per manufacturer of emulsifier) makes it easier when performing the hydrophilic refractometer test (shaded area) you can highlight the area by using the line from the plot graph (Figure 2-36).

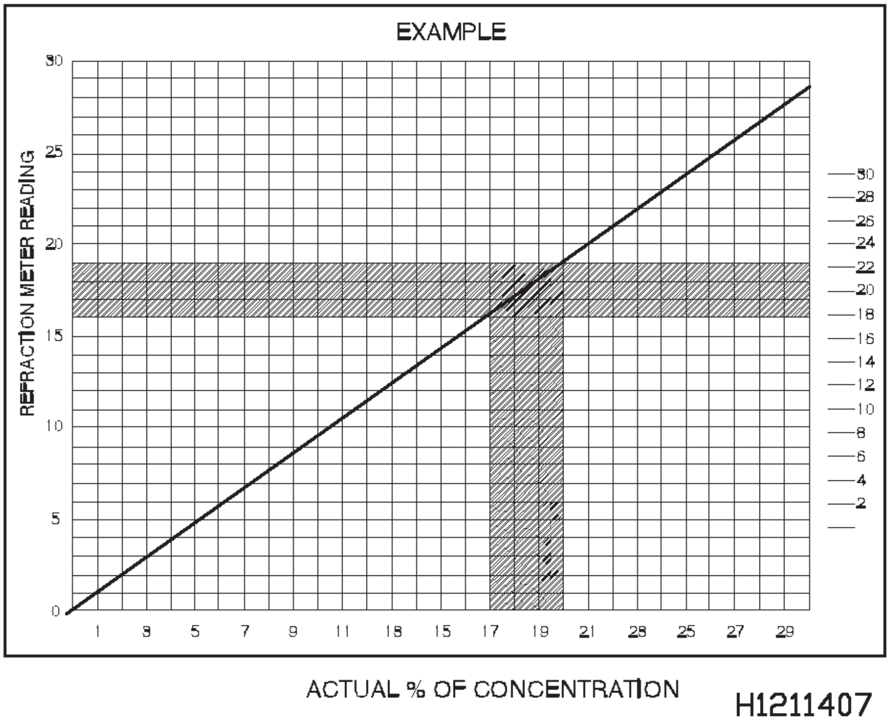

Figure 2-36. Remover Concentration vs Refractive Index Graph

2.6.10.4.6.1.2 Hydrophilic Remover Visual Colorimetery Test.

NOTE

There is no requirement at this time to perform this test.

Visual Colorimetery is an alternate method for measuring the concentration of hydrophilic remover solutions. It is a method which utilizes the measurement of the light absorption by colored solutions. The fundamental principles of visual colorimetery state that the amount of light absorbed by a given substance in a solution is proportional to the intensity of incident light and to the concentration of absorbing material. Colorimetery is a simple method and is fairly precise. It matches the color of a standard solution with an unknown; when they become identical they must contain the same amount of colored substance. The instrument used to perform this task is known as a colorimeter. This method may be performed by depots with the appropriate equipment.

2.6.10.4.6.1.3 Hydrophilic Remover Hydrometery Test

NOTE

The refractometery method is the preferred method for measuring the concentration of hydrophilic emulsifiers. Hydrometery may be used if recommended by the manufacturer of the hydrophilic remover.

The hydrometery test involves the use of a hydrometer to determine the concentration of a solution by specific gravity.

2.6.10.4.6.2 Testing Water-Suspended Developer.

CAUTION

Prior to using a new solution, a working level SHALL be established by measuring the distance from the top of the tank to the solution itself. This working level SHALL be maintained by the addition of water to replace evaporation losses.

2.6.10.4.6.2.1 Why Test Water-Suspended Developer. There are a number of service factors affecting the performance of water-suspended developers. Most significant of these are changes in concentration and contamination problems.

2.6.10.4.6.2.2 Water-Suspended Developer Concentration Level. Reduced concentration results in thin coatings, which decrease the sensitivity of the system. Developer concentration may vary for a number of reasons:

- Evaporation - As water evaporates, the concentration levels increase, causing excessive coating thickness on the part.
- Drag-out - As parts are processed, developer is removed due to the film adhering to the part surface, or entrapped in recesses of the part. This loss of developer is termed drag-out and, unless concentrate is added, will result in reduced developer concentration.
- Inadequate agitation - Allows some of the developer particles to settle out, which also reduces concentration.
- Caking - It is also possible for the developer particles to cake on the bottom or in the corners of the tank preventing them from being suspended.

2.6.10.4.6.2.3 Contamination of Water-Suspended Developer. Developer contamination takes a close second to concentration problems. Fluorescent dye contamination can be caused by the wetting agents inherent in the developer, which can remove penetrant entrapped in the part.

CAUTION

Prior to obtaining the hydrometer reading, the working solution SHALL be filled to the proper working level (as previously measured and marked), thoroughly agitated, and the tank checked for caked particles on the bottom or in the corners. Newly prepared solutions SHALL NOT be used or checked for concentration until 4-hours after mixing. This aging period allows the developer particles to become wetted or saturated. The solution SHALL be stirred after the 4 hour aging period.

2.6.10.4.6.2.4 Water-Suspended Developer Concentration Test. A specific gravity vs. concentration graph SHALL be used when checking the developer concentration. An example of such a specific gravity vs. concentration graph for two water-suspended developers is illustrated in Figure 2-37). This graph illustrates the variation that can occur in the specific gravities of different water-suspended developers, even from the same manufacturer. The reading from the hydrometer is then compared to an accurate graph/conversion chart, which may be obtained from the supplier for the specific developer. This graph/chart SHALL be used when checking the developer concentration, an example is shown in (Figure 2-38). A specific gravity vs. concentration graph is needed for each developer since variations can exist between different developers, even when they are made by the same manufacture.

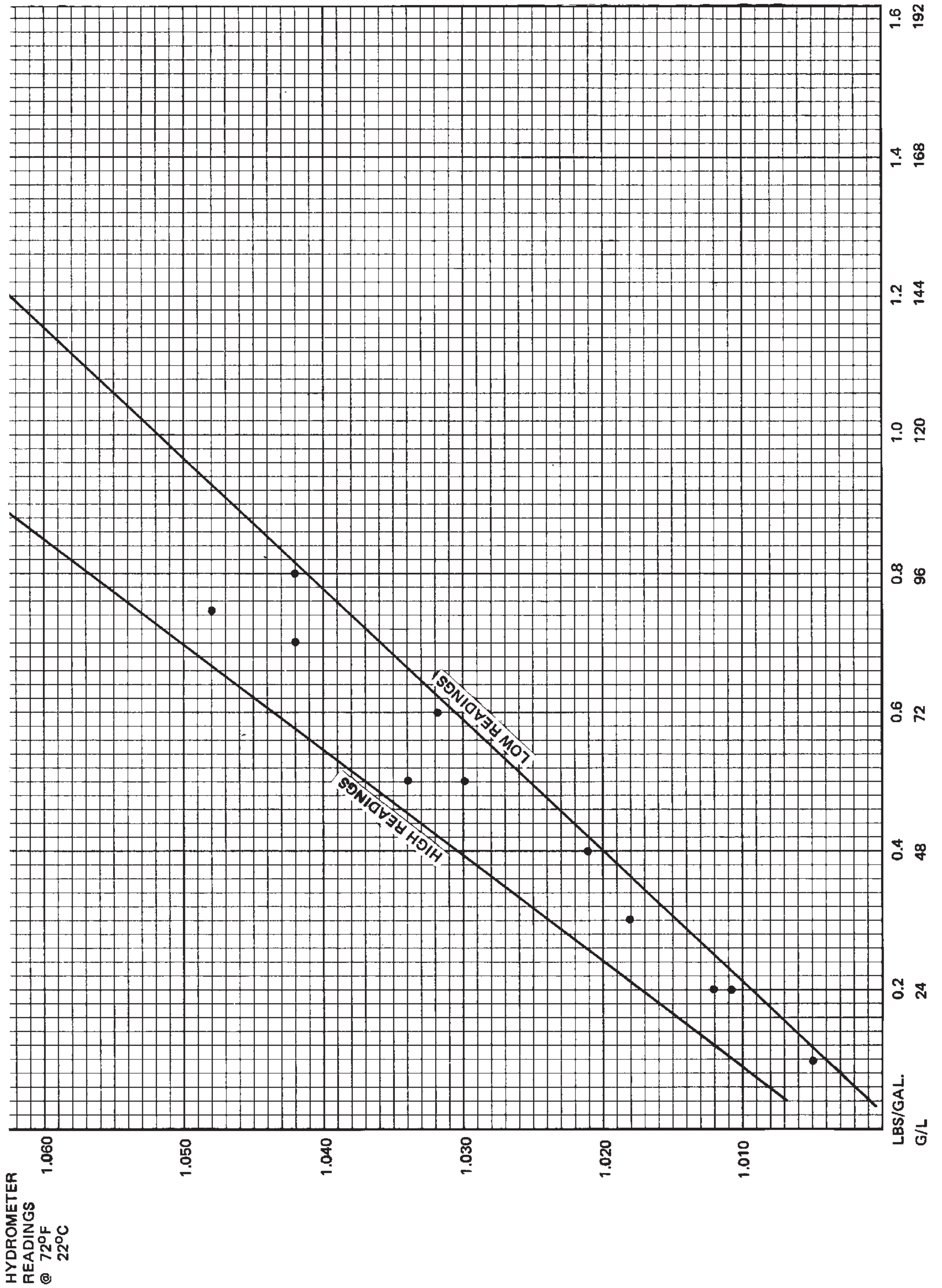

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Figure 2-37. Specific Gravity Hydrometer Readings for Two Water-Suspended Developers

2.6.10.4.6.2.5 Water-Suspended Developer Penetrant Contamination Test. Water-suspended developer may also become contaminated with penetrant. Check for fluorescent penetrant dye contamination via visual examination of the bath surface by passing a UV-A lamp over it. Uncontaminated developer appears dull white while fluorescent dye contamination will show up as specks of yellow-green, floating on the top of the bath. Low-levels of contamination can be skimmed off the developer liquid surface. Baths that exhibit significant amounts of surface penetrant that cannot be completely separated must be replaced.

2.6.10.4.6.2.6 Testing Water-Soluble Developer

NOTE

Water-soluble developer SHALL NOT be stirred or agitated after its initial mixing or for this test.

Water-soluble developers reduce the number of in-service problems encountered with suspended developers since agitation is not required and the particles do not settle out. However, there are still concentration and contamination problems to be aware of. As stated with water-suspended developers, evaporation and drag-out still factor in concentration changes, and the wetting agents can still remove entrapped penetrant resulting in contamination. Due to these factors, water-soluble developers SHALL be periodically tested to ensure acceptable performance is maintained.

2.6.10.4.6.2.7 Water-Soluble Developer Concentration Test.

NOTE

There are a wide variety of materials available to formulate water-soluble developers; therefore, the specific gravity hydrometer readings versus concentration will vary more than they will for the water-suspended developers. Generally, the manufacturer's recommended concentration level is used in standard penetrant systems. Poor water quality can cause situations where water-soluble developer does not completely dissolve in the concentration recommend by the manufacturer. Using warm distilled or filtered water may increase the amount of developer dissolved in the solution. Generally, concentrations lower than 0.5 lbs per gallon are not recommended because the solution may not contain enough chemical additives to prevent algae growth or poor wetting qualities.

The concentration range (between the lines) for several water-soluble developers of one manufacturer is shown in (Figure 2-38). The supplier can provide an accurate conversion chart for its particular developer, which SHALL be used when checking the developer concentration.

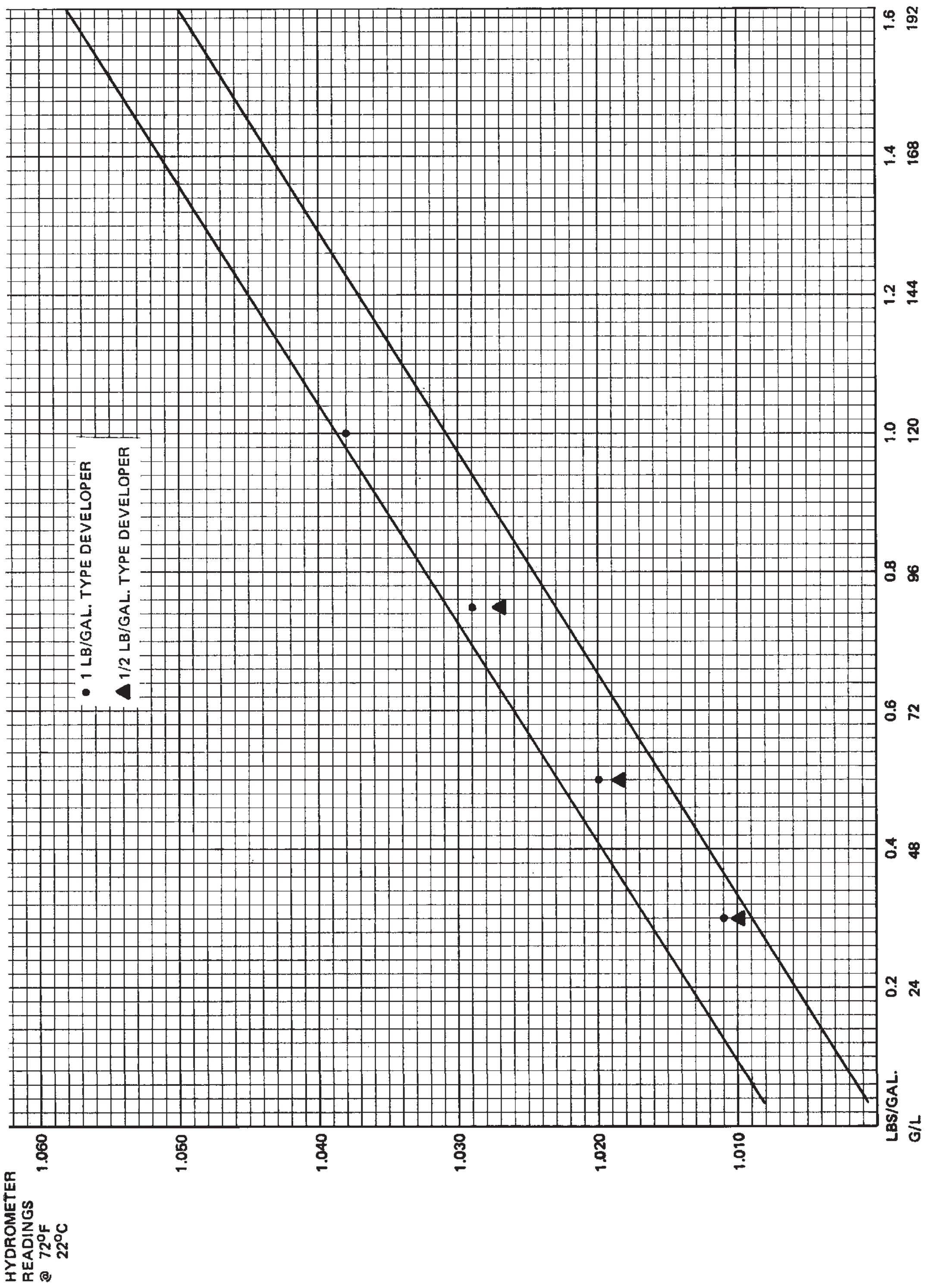

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Figure 2-38. Specific Gravity Hydrometer Readings vs Concentration for One Manufacturer's Water-Soluble Developers

2.6.10.4.6.2.8 Water-Soluble Developer Penetrant Contamination Test. Water-soluble developer may also become contaminated with penetrant. Uncontaminated developer appears dull white while fluorescent dye contamination will show up as specks of yellow-green, floating on the top of the bath. Low-levels of contamination can be skimmed off the developer liquid surface.

2.6.10.4.6.3 Testing Dry Developer.

2.6.10.4.6.3.1 Why Test Dry Developer. Dry developers, unlike water-based developers, do not have problems with concentration changes, however they do become contaminated. This contamination comes from moisture condensation; water from inadequately dried parts or splashed into nearby containers by careless rinsing. Dry developers may also become contaminated by penetrant transported by improperly rinsed parts. This forms lumps of penetrant-soaked developer and may fall off during developer application.

SECTION VII SPECIAL PURPOSE LIQUID PENETRANTS

2.7 SPECIAL PURPOSE LIQUID PENETRANT.

2.7.1 General.

NOTE

> The materials described in this section are not covered in QPL SAE AMS 2644. There are a number of penetrant materials that differ from the materials described in the previous sections. These materials are formulated for special applications and purposes. These materials SHALL NOT be used without specific guidance from the responsible engineering authority.

This section describes these special purpose materials and discusses the reasons for their use. The application procedures vary widely between materials and manufacturers; therefore procedures are intentionally not covered. Each of the manufacturers provides detailed application procedures for the particular material when it is procured.

2.7.2 Liquid Oxygen (LOX) Compatible Penetrants. Liquid oxygen (LOX) has a high degree of chemical reactivity. It will explosively react or combine with a large number of materials. This includes traces or residues from normal penetrant inspection materials. There are special cleaning procedures to be used on parts and components that will be contacting gaseous or liquid oxygen. Disassembled parts may be penetrant inspected in the lab, but SHALL be sent to the cleaning shop for complete removal of residual inspection materials. Difficulties are encountered with assembled parts (on or off of aircraft) and complex shaped parts containing crevices, recessed areas, or faying surfaces where inspection materials become trapped and are not easily removed by cleaning. Such items SHALL be inspected using another nondestructive test method, or special penetrant materials SHALL be used which do not react with oxygen. There are LOX compatible materials available by special order. These materials are mainly intended for use on space vehicles and can be used on aircraft when required.

2.7.2.1 Requirements for LOX Compatible Materials. Testing for LOX compatible materials involves dropping a weight on the material in a LOX environment. If the material is not compatible (e.g., will readily burn in an oxygen rich atmosphere), it will cause an audible explosion, a visible flash in a darkened room, discolor the impact surface, or leave evidence of charring. There are two ways of avoiding a LOX reaction from penetrant materials:

a. Completely remove all conventional inspection material residues. NDI inspectors are not properly trained in these cleaning processes.

b. Use only materials inert in an oxygen environment. This is not simple, since the penetrant system is specifically formulated to detect very small flaws. These penetrants are designed to resist removal from cracks and crevices and the organic dyes are oxygen reactive.

2.7.2.1.1 Choosing LOX Compatible Penetrants. There are three approaches used in choosing LOX compatible penetrant systems:

a. Use materials soluble in water and lending themselves to complete removal during post cleaning. These penetrants have dyes and developer materials soluble in water. Water-soluble penetrants, if their water content is high, are LOX insensitive, however, when the water evaporates, the residues can become LOX sensitive. Water-soluble penetrant systems have been approved for some LOX related applications since their residues are water-soluble surface agents similar to detergents. Approval for LOX applications is based on their ease of removal from surfaces and flaw entrapment using plain water.

b. Use materials that are completely volatile and evaporate from the parts without leaving a residue. These penetrants have a class of dyes that sublimes at room or up to temperatures in the range of 130° to 200°F (54° to 93°C). These and other materials will fluoresce from a discontinuity and will dissipate entirely from the flaw on setting or when the part is slightly heated. The materials have been used in formulating volatile penetrant systems. The problems to be considered are:

- Even though the materials evaporate from the surface or a flaw, there is still the possibility of it re-depositing at another location.

- Determination of 100-percent dissipation as judged by the disappearance of an indication does not mean a residual-free surface or crack.

c. Use non-reactive liquids that maintain the dyes in solution and are completely wetted by the liquid at all times. Another method of formulating penetrants not LOX-reactive is to dissolve the dye in a non-reactive, non-volatile liquid or vehicle. The liquid serves to quench the reactivity of the dye and, since it is non-volatile, does not produce a reactive residue. Water based penetrants do not meet this criteria, since they evaporate, leaving a reactive residue. There are some useful fluorinated hydrocarbon liquids, commonly called fluorocarbon or fluorolube oils that may be employed as penetrants. Fluorolube oils are quite non-volatile and are non-reactive with LOX. They also act to quench any LOX reactivity of dye that is dissolved in or wetted by the fluorolube oil. Unfortunately, they are not good solvents for fluorescent dye.

2.7.3 Low Sulfur, Low Chlorine Penetrant Systems.

NOTE

Low sulfur and low halogen penetrant material requirements are not covered in QPL SAE AMS 2644.

There is considerable concern over the effects of small quantities of sulfur and halogens present in penetrant materials. This concern is due to the increased use of high temperature alloys such as nickel and cobalt-base alloys, austenitic stainless steel, and titanium in aircraft and engines. These alloys are susceptible to hydrogen embrittlement, intergranular corrosion, and stress corrosion. Small amounts of sulfur and halogens, principally chloride, remaining on the alloys during service will increase their susceptibility to attack. Sulfur and halogens are not essential compounds in penetrant materials, nor are they deliberately added. They are usually introduced as contaminants in the raw materials. There is considerable difference of opinion as to the allowable limits of these contaminants. Nuclear and boiler codes specify from 0.5% to 1% by weight as the maximums. Many of the QPL materials will meet at least the upper limit. The position is similar to that for LOX compatible materials, namely, there is no requirement for special penetrants if the part to be inspected is disassembled and can be sent to the cleaning shop for the removal of all inspection residues. The aircraft or engine manufacturer’s recommendations SHALL be followed for on-aircraft and assemblies.

2.7.4 High Temperature Penetrant Materials. Standard penetrant materials are limited to temperatures of 125°F (52°C). There are special penetrant systems formulated for use above 125°F (52°C). These special high-temperature penetrants contain visible and fluorescent dyes that resist heat degradation. The vehicles and solvents are carefully chosen to remain liquid and resist evaporation at the operating temperature. The nonaqueous-wet developer must be modified since standard developer will peel or curl on hot surfaces. The upper temperature limits are in the range of 350°F (177°C) to 400°F (204°C). Typical applications for high temperature penetrant systems are the inspection of live steam valves and lines and intermediate weld beads prior to laying down a covering bead.

2.7.5 Dye Precipitation Penetrant Systems.

NOTE

Dye precipitation penetrant systems are not covered by penetrant material specification SAE AMS 2644.

Dye precipitation penetrant systems are commonly referred to as high-resolution penetrants. The penetrant contains a high concentration of either visible or fluorescent dye dissolved in a highly penetrating, volatile solvent. The penetrant is usually applied by brushing on the surface to be inspected. The penetrant will enter any discontinuities, and during the dwell period, the solvent evaporates, precipitating the dye as a solid, which fills the discontinuity. A very thin layer of solvent developer is sprayed onto the surface after removal of the excess surface penetrant and while using a two-step development process. The developer re-dissolves the solid penetrant dye entrapped in the flaw, expands its volume, and extracts it from the flaw. It is possible to build the indication to any desired size and resolution by applying additional thin coats of solvent developer. When the indication reaches the desired size, it is fixed by applying a layer of plastic developer. The plastic developer allows the developer coating with the embedded indication to be removed or stripped from the part. There is also a one-step developer that provides the same result. Dye precipitation penetrant systems are extremely sensitive.

2.7.6 Reversed Fluorescence Method. The reversed fluorescence method is similar to a photographic negative of the standard fluorescent penetrant inspection. A standard visible-dye penetrant is applied to the surface to be inspected and after the dwell; the excess is removed in the normal manner. A special developer, containing a low intensity fluorescing dye and a relatively small amount of developer powder, is applied by spraying under a UV-A lamp. The entire surface will fluoresce, except for the flaw, which appears as a dark line where the penetrant has quenched the fluorescent dye.

2.7.7 Thixotropic Penetrant. A thixotropic material is one that changes form or structure as a function of time or shear stress. Thixotropic penetrants are applied as a solid or gel and then change to a liquid after application. They are used when it is difficult to apply the penetrant as a liquid. One example is a high temperature penetrant in the form of a crayon or stick used to inspect welds before they have cooled.

2.7.8 Dilution Expansion Developers. Dilution expansion developers differ from the conventional powder type developers in they do not utilize the absorption-adsorption action of powder particles. In fact, powder particles are not required and may even interfere with the action of dilution-expansion developers. The action of dilution-expansion developer is to dissolve the exuded and exposed layer of entrapped penetrant and disperse it in the thicker layer of developer. Dilution-expansion developers have a layer thickness equivalent to that of conventional powder developers.

2.7.9 Plastic-Film Developers. Plastic-film developers form a dry, flexible layer that can be peeled or stripped to provide a record of indications on test surfaces. The most frequently used plastic-film developers are two-part systems. The first part provides developer action while forming a white, reflecting background. The second part forms a clear layer that freezes the indication and provides film strength and some flexibility. The layers combine and can be removed from the part as a thin film and maintained as a record of the indication.

SECTION VIII LIQUID PENETRANT INSPECTION SAFETY

2.8 LIQUID PENETRANT INSPECTION SAFETY.

2.8.1 Safety Requirements. Safety requirements SHALL be reviewed by the laboratory supervisor on a continuing basis to ensure compliance with provisions contained in AFI 91-203 or appropriate directive as well as provisions of this technical order and applicable weapons systems technical orders. The material safety data sheet (MSDS or SDS) for each penetrant material SHALL be reviewed by the shop supervisor before the material is first put into use. Recommendations of the Base Bioenvironmental Engineer and the manufacturer regarding necessary personnel protective equipment SHALL be followed.

NOTE

Air Force Instruction 91-203 or appropriate service directive SHALL be consulted for additional safety requirements.

2.8.2 General Precautions. Precautions to be exercised when performing penetrant inspection include consideration of ventilation, skin irritation, fire, electrical, and use of UV-A lamps. The following minimum safety requirements SHALL be observed when performing penetrant inspections.

2.8.3 Personal Protection Equipment. Penetrants, emulsifiers, and some types of developers have very good wetting and detergent properties, and can act as solvents for fats and oils. If they are allowed to remain in contact with body surfaces for extended periods, they MAY cause skin irritation. Personal protective equipment SHALL be supplied and worn when handling penetrant materials. Wear eye protection, an apron, and gloves while processing parts and changing chemicals.

2.8.3.1 Protective Gloves. Neoprene gloves are an excellent choice when handling penetrant materials, and SHOULD be worn unless another suitable substitute is identified and approved by the Base Bioenvironmental Office. The insides of gloves SHALL always be kept clean. Wash exposed areas of body with soap and water, continual contact with penetrant materials MAY cause skin irritation and a removal of natural body oils.

2.8.3.2 Eye Protection. Wear eye protection (e.g., goggles, face shield, safety glasses) while using penetrant inspection material. Protect the eyes from all possible hazards associated with the penetrant process. At different stages of the process different eye protection may be required. For ultraviolet light, UV filtering safety glass are sufficient. UV filtering safety goggles or face shields are more appropriate for combination chemical splash and UV protection.

2.8.4 Ventilation.

WARNING

Penetrant inspection materials MAY be harmful when vapors are inhaled when exposed to skin for an extended period of time. Proper safeguards and personnel protective equipment (PPE) SHALL be used as recommended by the local Base Bioenvironmental Office and product manufacturer.

CAUTION

Many penetrant materials are combustible, but most have relatively high flash points. They are not considered a serious fire hazard in open tanks, however, when sprayed as a fine mist, they are easy to ignite and open ignition sources SHALL be avoided when spraying is used.

Some penetrant materials contain volatile solvents that can be nauseating. This is especially true of the vehicles in aerosol or pressure spray containers. Provide adequate ventilation when penetrant inspection is being performed. When recommended by the base bioenvironmental engineer, wear an approved respirator working in areas where adequate ventilation cannot practically be provided. Dry developer materials are a fine dust. A protective device SHALL be worn over the nose and mouth during this process.

2.8.5 Matting. Use rubber insulating floor matting in front of penetrant lines. This matting is required to reduce electrical and slipping hazards. This matting SHALL be replaced when it is worn to one-half the original thickness (approximately 1/8-inch). Use only one continuous length of matting and ensure it continues beyond the ends of the equipment for at least 24-inches. If facility construction or safety walkways prevent extension beyond equipment, local safety office may approve deviation IAW AFI 91-203 or appropriate service directive.

2.8.6 UV-A Hazards.

WARNING

Unfiltered ultraviolet radiation can be harmful to the eyes and skin. UV-A lamps SHALL NOT be operated without filters. Cracked, chipped, or ill-fitting filters SHALL be replaced before using the lamp.

Prolonged direct exposure of hands to the filtered UV-A lamp main beam MAY be harmful. Suitable gloves SHALL be worn, during inspections, when exposing hands to the main beam for extended periods.

- The temperature of some operating UV-A lamp bulbs reaches 750°F (399°C) or more during operation. This is above the ignition or flash point of fuel vapors. These vapors will burst into flame if they contact the bulb. UV-A lamps SHALL NOT be operated when flammable vapors are present.
- Exercise care when using hot mercury vapor or gas discharge lamps so as to not burn hands, arms, face, or other exposed body areas. Do not lay hot UV-A lamps on combustible surfaces. The bulb temperature also heats the external surfaces of the lamp housing. The temperature is not high enough to be visually apparent, but is high enough to cause severe burns with even momentary contact of exposed body surfaces. Extreme care SHALL be exercised to prevent contacting the housing with any part of the body. Consult your local bioenvironmental office for specific guidance.
- Ensure workers do not handle UV-A lamps at the penetrant rinse station when washing parts, because of electrical hazard present.
- UV-A filtering safety glasses are specifically designed for penetrant and magnetic particle inspections and are recommended as they will filter out glare and reduce eyestrain. Install ultraviolet filters on all mercury vapor lamps used for penetrant inspection. Replace cracked, chipped, or broken filters before using the light. Injury to eyes and skin will occur if the light from the mercury vapor bulbs is not filtered. UV-A filtering safety glasses, goggles, or face shields SHALL be worn and precautions SHALL be taken to cover exposed skin that is exposed to the direct beam of any UV-A lamp.

2.8.7 Hazards of Aerosol Cans. Aerosol cans are a convenient method of packaging a wide variety of materials. Their wide use, both in industry and the home, has led to complacency and mishandling.

2.8.7.1 Aerosol cans are gas pressured vessels, when heated to temperatures above 120°F (49°C) the resulting gas pressure may potentially burst the container. Any combustible material, regardless of flash point, can ignite with explosive force when it is finely divided and dispersed in air. Penetrant materials SHALL be stored in a cool dry area, protected from direct sunlight.

2.8.7.2 Penetrant materials (penetrant, cleaner/remover and developer) MAY contain petroleum distillates and aliphatic (kerosene, mineral spirits, etc.) or aromatic (benzene type hydrocarbon) solvents. These chemicals SHALL be carefully used in the aerosol form to avoid health hazards.