Physical characterization of High Entropy Alloys (HEAs) through Differential Scanning Calorimetry (DSC)

Rene Pacheco Uribe, Harper College – CCI Intern

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Introduction

New discoveries and advancements in physics have always been linked with new materials development, be it to create the needed environment for an experiment, to be able to handle the experiment itself or even as an accidental discovery. Accelerator physics is no exception: high power beams require materials that can handle said power, pushing for the development of radiation resistant materials. The vast pool of possibilities that High Entropy Alloys (an alloy with more than 3 principal elements in its composition in equimolar or near equimolar ratios[1]) offer has claimed the attention for its use in accelerator environments. The novelty of these materials has in turn created the need for testing their properties and their performance under the stresses they would find in an accelerator.

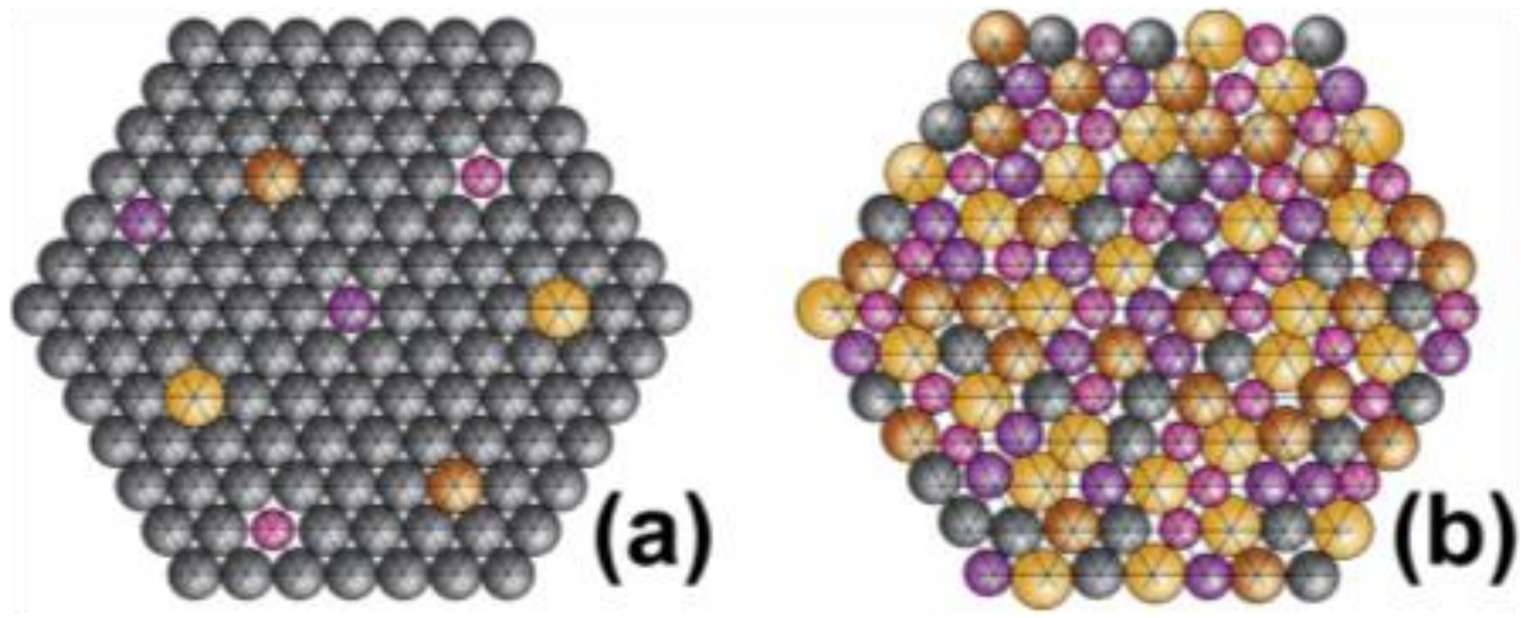

Figure 1. (a) Conventional Alloy, (b) High-entropy alloy [1]

Thermal shock induced damage is one of the mayor challenges in High Power Target systems, which is proportional to sudden changes in temperature and a material with high Cp can resist such changes, it is therefore important to test this property on the newly developed HEAs.

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Differential Scanning Calorimetry

One of the techniques used to characterize the HEAs is Differential Scanning Calorimetry (DSC); a thermal analysis procedure that consists of heating a sample and a reference (which is an empty sample carrier) following a temperature program, and measuring the energy flow of both the sample and the reference. This method allows for the determination of specific heat (Cp) and small or big changes in the phase of the sample[2]. The tests were performed using a Netzsch DSC 404 F3 Pegasus; the materials studied were the 12 different compositions of HEAs developed in collaboration with the University of Wisconsin-Madison. These materials were tested in order to determine their specific heat and its change under similar temperatures to the ones they would be exposed to in an accelerator (around 600C).

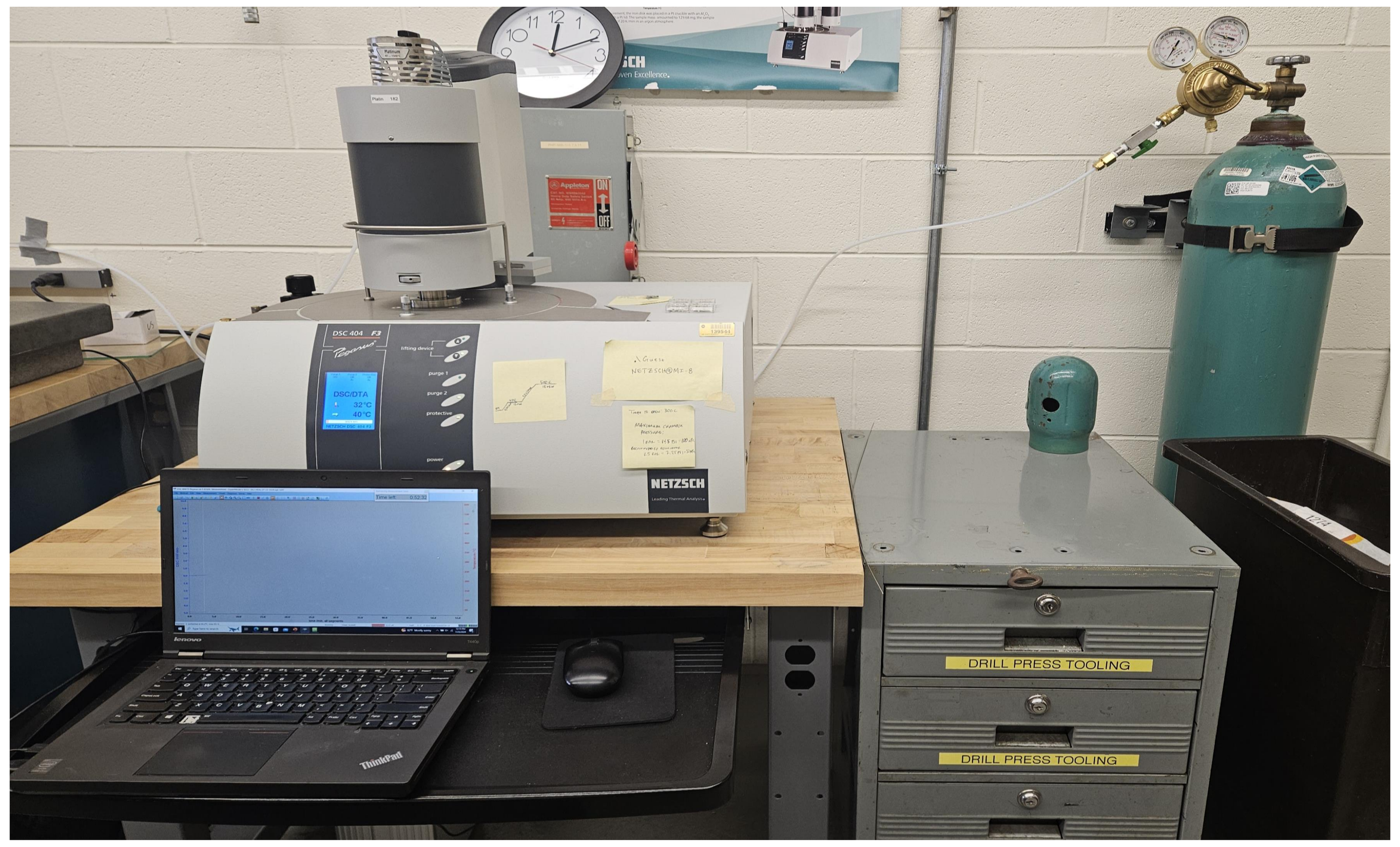

Figure 2. DSC 404 F3 Set up.

Challenges and Results

One of the main challenges of the study resided on its short timeline, a particularly tough constraint considering the relatively large amount of time needed to take a single measurement (around 8 hours per sample), the need for a recalibration of the device, and carrier contamination incidents.

The results for the first 3 compositions of the HEAs show a higher-than-predicted specific heat values, the greatest difference showed by the 3rd alloy (composition $Al_{15}Cr_{20}Mn_{20}Ti_{10}V_{35}$) with its experimental values being larger than the prediction by 25-50%; the other alloys in comparison were bigger by 7-16%.

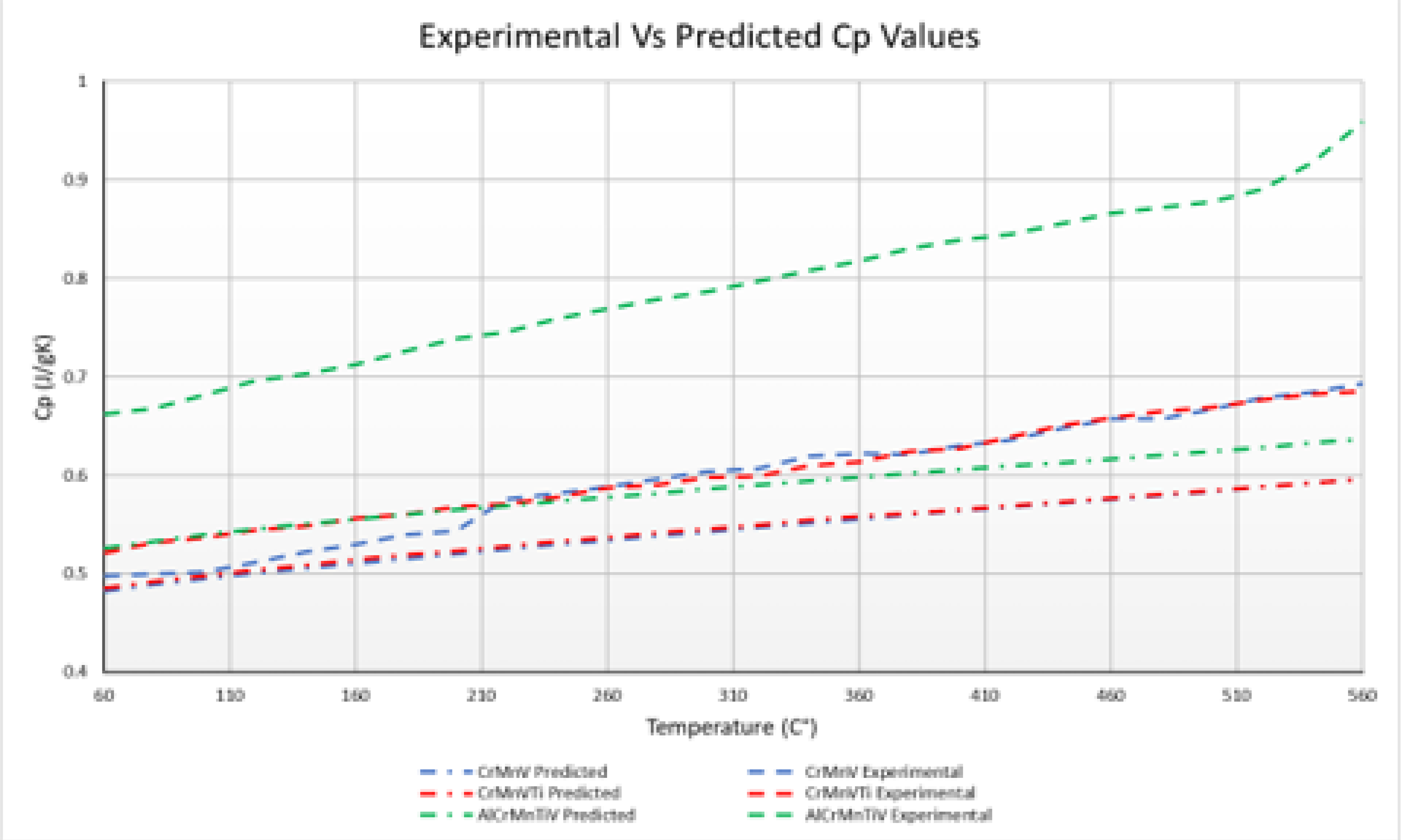

Figure 3. Experimental vs predicted values for the tested compositions. Average % difference for CrMnV is 9.55%, for CrMnTiV is 10.3% and for AlCrMnTiV is 33.49%.

Future Work and Conclusions

Due to the time constraints of the project only 3 of the 12 HEAs compositions were tested, leaving 9 HEAs for future experimentation. Furthermore, the characterization after irradiation is still pending.

The field of HEAs is vast and unexplored; it offers new solutions to current challenges and might be the answer to future problems as well, more research and development of these novel materials might lead to unexpected, more exciting outcomes.

References

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2) Gabbott, P. (2008). A Practical Introduction to Differential Scanning Calorimetry. In Principles and Applications of Thermal Analysis, P. Gabbott (Ed.). https://doi.org/10.1002/9780470697702.ch1