UROP Proposal

Quantitative Analysis and Comparison of Microstructure between Investment Cast and Additively Manufactured Open-Cell Aluminum Foam

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<u>Statement of the problem/topic of the research or creative work:</u>

The primary goal of my proposed research is to identify and visualize the underlying grain boundary structure of open cell aluminum foam (OAF) for two different forms of production. OAF is a multifunctional material capable of many applications in the engineering field, but as of yet it has not been accurately characterized at the crystalline level [1]. In order to optimize the performance of this material it is important to characterize the relationship between its microstructure and its micro/macro mechanical response. My portion of this research will attempt to analyze and model the different grain boundary structures achieved through investment cast and additively manufactured foam. Under the supervision of Dr. [redacted], I will organize the disassembly of a small sample of foam such that each ligament can be subject to nondestructive, high-energy X-ray diffraction microscopy (HEDM) to provide the tomography measurements necessary to reconstruct a 3D model of the structure's internal grain orientation. I am currently working through this process with Dr. [redacted] for a sample created through investment cast and have a timeline to be finished by the summer semester. The proposed research will focus on completing this analysis for an additively manufactured sample of identical structure, allowing a side by side comparison of structure-response relationship between the varied forms of manufacturing. The 3D grain map generated through this process may then be related to the measured responses of various typical loading conditions.

<u>Relevant background/literature review:</u>

Open cell metallic foams have recently become the focus of many engineers, in research as well as industry, as its unique design allows it to maintain a low density while retaining much of its strength. The foam has the ability to let fluid flow through it, coupled with its lightweight structure, acoustic properties and a high energy to impact ratio makes it a multifunctional material that has the potential to be used in many engineering applications [2]. Its porosity and pore size can be specified to attain specific densities and properties appropriate for the desired use. Current applications of this material include heat exchangers, filter elements, crash absorbers, energy storage, high-speed transportation, biomedical implants etc. [3].

The first step in analysis of this material will be to separate its individual ligaments. A dbFIB will be used at a high current to mill away material in specified locations operating as a cutting system. This device operates very similarly to a scanning electron microscope (SEM) but instead of using electrons to image the sample, the FIB fires focused ions which can be used to image, mill away material, and deposit material [4]. The FIB has a milling precision of 1 micron, making it a viable tool for accurate fabrication as well as minimizing the damage to the foam's microstructure. The FIB will also complete platinum deposition, used at a lower current, with the assistance of an Omniprobe©, to mount each ligament in the upright position needed to complete HEDM at the APS.

The first type of manufacturing to be investigated is investment casting. It involves pouring molten metal into an expendable mold and results in a part that may need minor machining to reach its finished state. This technique produces open cell aluminum foam by specifically using a polyurethane or salt mold in order to achieve desired porosities between 50% and 97% [2]. This variability matched with its cheap material and simple equipment makes this process increasingly desirable in the manufacturing industry. This method of production is what I am currently evaluating this semester.

The second type of foam to be analyzed is created using an additive manufacturing process known as direct metal laser sintering (DMLS). This process is similar to 3D printing in its capabilities but does not use an extrusion process. Instead, a metal powder is spread across its platform and a laser is then used to melt 20-40 micron layers at a time to create intricate metal parts [5]. This process is relatively new but is increasing in demand as it allows the formation of complex part geometry in a relative small window of time.

Specific activities to be undertaken and a timetable allotted for each activity:

The following activities will be completed for a DMLS produced sample of aluminum foam in order to accomplish the proposed research goals:

Activity 1: Generating a 3D model of investment cast foam to be reproduced using DMLS

Timeline: May 16th – June 6th

The first step in the preparation of the aluminum foam samples will include cutting the sample to the appropriate dimensions, generating a 3D model of the sample, mapping out the various dimensions for cuts that will result in the disassembly of the sample, and sending the CAD file to a manufacturer to be reproduced exactly through DMLS. The cutting of the foam will be done by using an electrical discharge machining tool. The tool uses a series of rapidly recurring current discharges between two electrodes to successfully cut the material to a desired size while minimizing damage to the surrounding areas [6]. The sample will be cut to a $4mm^3$ cube. This size was chosen because it is large enough for its mechanical response to be valid for larger sections of material yet small enough to accommodate the use of the dbFIB. Next the sample will be duplicated virtually using an X-ray CT scanning machine.

From there the model can be opened in SolidWorks©, where it can be accurately measured and used as a reference. Using this software I will plan and map out each cut to successfully disassemble the sample. Making virtual cuts ensures that the ligaments will not exceed the 1.5mm limit for the APS and also gives a reference angle for the mounting purposes described in “Activity 3”. SolidWorks© will also allow me to convert the part file into the appropriate STL format that will be sent to the manufacturer. A sacrificial sample will be generated simultaneously and used to practice performing virtual cuts on a physical sample.

Activity 2: <u>Use a dbFIB to prepare sample ligaments for HEDM</u>

Timeline: June 6th – July 18th

This spring semester I have been trained in the University of Utah’s Nanofab Laboratory to use their Helios NanoLabTM 650© [7]. I will use the FIB at the highest possible voltage and current to cut though each ligament. The high current and voltage decreases the time needed to cut. This will result in lower accuracy but the loss in accuracy is not significant. The advantage of using this machine is the precision and reduction in damage to the sample but the disadvantage is that each cut takes an upward of 6hrs making only two cuts possible per overnight run. This is the largest factor in the timeline of this stage of the research.

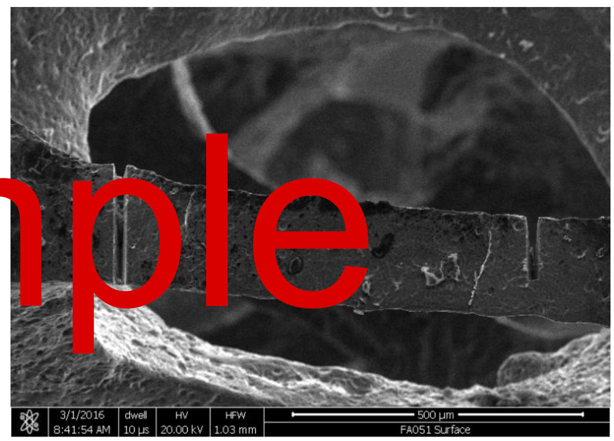

Figure 1 Aluminum foam ligament after preliminary cut using FIB “This work made use of University of Utah USTAR shared facilities support, in part, by the MRSEC Program of NSF under Award No. DMR-1121252.”

Once the ligament is cut entirely on one side and part way on the other (see figure 1) I will use a special extraction tool called the Omniprobe©. This probe consists of a tungsten needle that will be carefully moved to within a few microns of the sample surface [8]. Once in position the FIB will once again be used, but this time to deposit a small amount of platinum, making a superficial weld, securing the needle to the ligament. From there the FIB will be modified to finish the final cut, successfully removing the ligament from the sample without letting it fall and be damaged. The probe is then used to move the ligament across the platform to our mount. The mounts will be 3D printed using ABS plastic that will then be coated in a conductive paint, ensuring a path to ground while the FIB is in use. Once the ligament has been moved to near contact with the mount, the FIB will again use platinum deposition to make a connection between the ligament and the mount. The final step in this process involves using the FIB to mill away the first platinum deposit. Randy Polson is my current contact and trainee for the dbFIB and he will continue to assist me when needed throughout this process.

Activity 3: Analyze sample at the APS using HEDM to model 3D grain structure

Timeline: July 18th – August 5th

As each ligament is prepared, the ligament and its CAD model will be labeled. Each ligament will be individually scanned at the APS and must be able to fit inside the 1.5mm wide X-ray beamline. In order to meet this constraint I will position each ligament in a vertical orientation and attempt to reduce any slant that may result in wobbling during platform rotation. Dr. [redacted] has already submitted a proposal to access the APS and take the HEDM measurements. Once the readings have been taken they will be used, along with our solid 3D model to reconstruct a virtual model of the foam that indicates boundaries between varying grain orientation. This can then be compared the same model for the investment cast foam.

Relationship of the proposed work to the expertise of the faculty mentor:

Dr. [redacted] is the head of the Multiscale Mechanics and Materials Lab at the University of Utah and will serve as my mentor for this project. Recent work in her lab has included generating three dimensional models that display internal grain structure in an attempt to relate these features to crack propagation. Her lab has a primary focus on high-performance computing to characterize mechanical response of materials that directly relate to aerospace, defense, and manufacturing industries [10]. This makes Dr. [redacted] a perfect supervisor for my research work as her lab directly relates to my project and she has the expertise to adequately assist me in achieving my research goals. While in Dr. [redacted]'s ME 1300 Statics/Strengths class, I thoroughly enjoyed her teaching style and enthusiasm for mechanical engineering. During the proposed semester I will attend weekly group meetings to keep up to date on progress in other projects as well as update on my own work. Along with this Dr. [redacted] and I have arranged to meet once a week to go over questions, problems and progress in my project.

<u>Relationship of the proposed work to the student's future goals:</u>

As an undergraduate student I am pursuing a mechanical engineering degree with an emphasis in aerospace engineering. Once completed, I hope to obtain a career in the aerospace industry or possibly attend graduate school for a Master's in aerospace engineering. In either scenario my work in this research lab will be invaluable in providing hands on work experience as well as a broadening opportunity to expand my education. Open cell foams are currently being implicated in many aerospace applications including lightweight aircrafts and impact resistant shielding. This project will specifically assist my understanding and handling knowledge of materials that I will undoubtedly encounter in my future education and career. My desire to succeed in engineering drives my ambition for this research as it will be crucial in defining my career as an engineer as well as providing opportunities to move forward with my education. I have thoroughly enjoyed my current research with Dr. [redacted]'s group and I look forward to continuing through the summer.

Bibliography

[1] Spear, A. D., Suter, R. M., & Lind, J. F. (2016). 3D Grain Mapping of Open-Cell Aluminum Foam for a Novel Structure-Property-Performance Study. Salt Lake City, UT: University of Utah.

[2] Wang, L., Li, H., Wang, F., & Ren, J. (2005). Preparation of open-cell metal foams by investment cast. China Foundry, 2(1), 56-57. Retrieved March 24, 2016, from http://www.foundryworld.com/uploadfile/20094856237329.pdf

[3] http://www.azom.com/article.aspx?ArticleID=8097

[4] https://en.wikipedia.org/wiki/Focused_ion_beam

[5] http://gpiprototype.com/services/metal-3d-printing.html

[6] https://en.wikipedia.org/wiki/Electrical_discharge_machining

[7] http://www.fei.com/products/dualbeam/helios-nanolab/

[8] http://sal.nanofab.utah.edu/dual-beam-focused-ion-beam-microscope-dbfib/

[9] http://mmm.mech.utah.edu/

[10] A. Spear, personal communication, January 11th - March 13th, 2016