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Printing Outside the Box: Additive Manufacturing Processes for Fabrication of Large Aerospace Structures

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Sponsoring Program(s)

Marshall Space Flight Center/Center Management and Operations
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Project Description

To achieve NASA's mission of space exploration, innovative manufacturing processes are being applied to the fabrication of propulsion elements. Liquid rocket engines (LREs) are comprised of a thrust chamber and nozzle extension as illustrated in figure 1 for the J2X upper stage engine. Development of the J2X engine, designed for the Ares I launch vehicle, is currently being incorporated on the Space Launch System. A nozzle extension is attached to the combustion chamber to obtain the expansion ratio needed to increase specific impulse. If the nozzle extension could be printed as one piece using free-form additive manufacturing (AM) processes, rather than the current method of forming welded parts, a considerable time savings could be realized. Not only would this provide a more homogenous microstructure than a welded structure, but could also greatly shorten the overall fabrication time.

The main objective of this study is to fabricate test specimens using a pulsed arc source and solid wire as shown in figure 2. The mechanical properties of these specimens will be compared with those fabricated using the powder bed, selective laser melting technology at NASA Marshall Space Flight Center. As printed components become larger, maintaining a constant temperature during the build process becomes critical. This predictive capability will require modeling of the moving heat source as illustrated in figure 3. Predictive understanding of the heat profile will allow a constant temperature to be maintained as a function of height from substrate while printing complex shapes. In addition, to avoid slumping, this will also allow better control of the microstructural development and hence the properties. Figure 4 shows a preliminary comparison of the mechanical properties obtained.

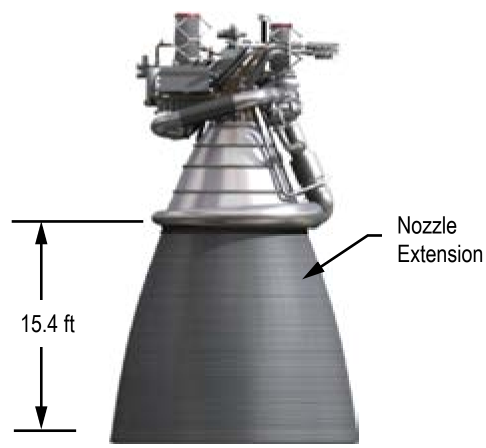

Figure 1: Nozzle extension for the J2X LRE.

Figure 2: Preliminary build of Inconel 718 for mechanical property testing.

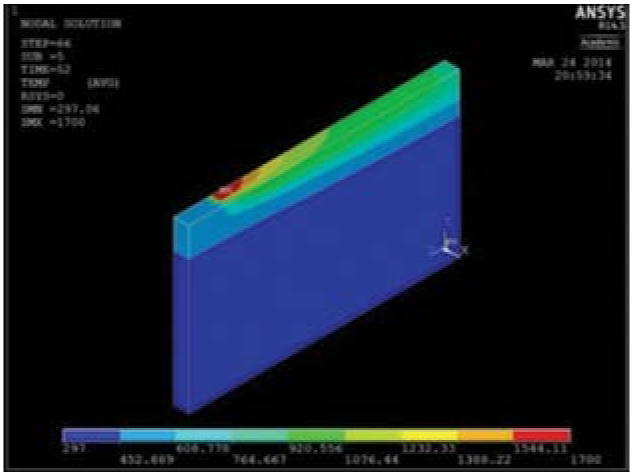

Figure 3: ANSYS transient heat analysis for specimen shown in figure 2 (temperature = °C).

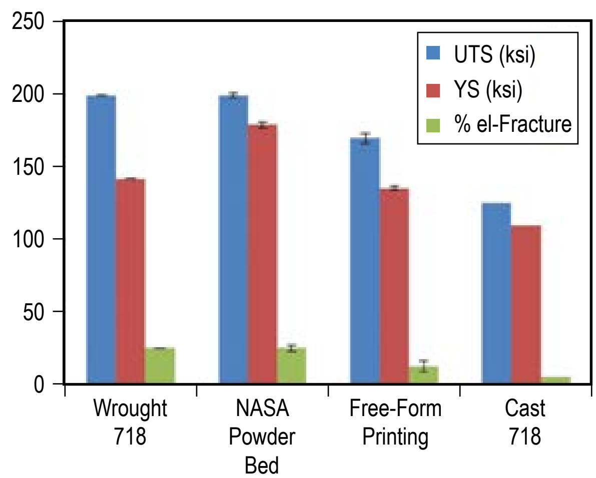

Figure 4: Comparison of properties obtained using powder bed process versus the free-form printing.

Anticipated Benefits

As the technology developed under this proposed effort is of interest to NASA as well as industrial partners, it is anticipated that teaming agreements could be made between manufacturers of robotic equipment for spin-off technologies. Validated thermal modeling of the build process conducted under this proposed effort will be made available to NASA. It is anticipated that this thermal model will be modular in design and can be readily implemented into the robotic controls.

Key to developing spin-off technology will be establishing the property-microstructure relationships for the pulsed arc source to advance its usage. While the margin of safety for components and systems may vary depending on requirements for cyclic life and impact resistance, a constant requirement among different applications is a basic knowledge of the constituent material capabilities as influenced by the manufacturing process. Without this, no designer can arrive at a safe, robust, and reliable design. It is expected that the enhanced control capability and predictive features of this proposed effort will enable a better selection of process parameters.

Potential Applications

Potential NASA applications for the free-form AM technologies developed under this effort include large structures such as solid and liquid rocket motor casings, liquid rocket nozzle extensions, and liquid rocket combustion chambers in addition to other demanding applications for complex designs and their repair.

Notable Accomplishments

The preliminary properties shown in figure 4 are comparable with the referenced standards.[1] Variation in properties may result from a slight difference in the NASA heat treatment that used a (°F solutionizing temperature versus that of the 1750 °F[2] for the powder bed specimens.[2]

References

1. MatWeb Material Property Data, <www.matweb.com>, assessed 11/15/14.

2. "Nickel Alloy, Corrosion and Heat Resistant, Bars, Forgings, and Rings 52.5Ni 19Cr 3.0Mo 5.1Cb 0.90Ti 0.50Al 19Fe, Consumable Electrode or Vacuum Induction Melted 1775°F (968°C) Solution and Precipitation Heat Treated," AMS 5663, 1965–09–01.