Additive Manufacturing – Engineering Considerations for Moving Beyond 3D Printing

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ABSTRACT
3D Printing technology has enjoyed considerable publicity and growth in the past few years with many successful prototype applications. Multiple projects at EWI that are focused on a specific metal AM technology known as laser powder bed fusion and several barriers to the adoption of this technology will be discussed. The paper will highlight three areas where EWI is working to fill technical gaps: (1) development of a methodology to generate material property data for additive manufacturing; (2) heat treatment of nickel alloys; and, (3) in process sensing during the production of components using commercially available laser powder bed fusion equipment such as the EOS Direct Metal Laser Sintering™ equipment. Results will be presented showing that conventional heat treatments may need to be altered for these materials, and process sensing technologies from the welding industry may be leveraged to help ensure part quality.

KEY WORDS: Laser powder bed fusion; 625; in-process sensing; mechanical property; direct metal laser sintering; additive manufacturing

INTRODUCTION
Additive Manufacturing (AM) affords the user great flexibility in producing near-net shapes with little or no machining required. Because AM is born out of Rapid Prototyping technology, form and fit of these components has historically been considered first over functional aspects. Because AM processes are creating volumes of material by joining multiple layers of material, consideration of the functional aspect is critical to the use of the technology. Figure 1(a) illustrates a common view of 3D Printing technology which uses a process to produce a part directly from a CAD file. Additive manufacturing is depicted in Figure 1(b), which illustrates, that like any other manufacturing process to produce functional components, material and quality aspects must be considered. EWI is addressing many of the technical gaps surrounding the manufacturing chain associated with additive manufacturing of metals. This paper will address some ongoing work at EWI in developing material property data, the response of these materials to conventional heat treatment, and finally in-process sensing. While there are several other viable AM processes being evaluated for production of metal parts across a range of desired feature size and overall dimensions the target AM process for this work (Harris, 2012; Herderick, Kapustka and Harris, 2011; Harris, 2011; Kapustka and Harris, 2014), and the major focus of work at EWI in metals AM, is Laser Powder Bed Fusion (L-PBF).

L-PBF is one subset of additive manufacturing processes that is rapidly growing for the production of metallic components in the aerospace and medical industries. The technology uses a rapidly scanned laser beam to melt metal powder that is preplaced one layer at a time in a powder bed, enabling complex three dimensional shapes in alloys such as nickel alloy 625 to be produced. Understanding of the performance of these alloys is important for adoption of these processes. A critical aspect of this performance is the response to heat treatment which serves to reduce residual stress and develop the necessary material properties. Another critical aspect is the effect of geometry on the material properties. From a process perspective, defining the methodology by which material property data is generated, and the in-process quality control and inspection will be discussed.

DEVELOPMENT OF A MATERIAL PROPERTY DATASET FOR NICKEL ALLOY 625
EWI and the Additive Manufacturing Consortium (AMC) have developed a standard methodology for the generation of mechanical property data for L-PBF processes, and is currently applying this to generate mechanical property data for nickel alloy 625. The methodology uses standard coupon geometry, and defines and records in excess of 50 process parameters that can affect the material produced. The rigor involved in this methodology is driven by the fact that additive manufacturing processes create material, by joining individual weld beads. The effect of geometry and heat flow on microstructure development can lead to significant variability in this microstructure and property development. In addition, variability in process conditions may also drive this variability in properties. Figure 2 shows data from several sources for L-PBF, Electron Beam Powder Bed Fusion, and Laser Directed Energy Deposition of nickel alloy 625 without the application of any heat treatment (Murr, 2011; Amato, 2012; Xue, 2007; EOS, 2011; Rombouts, 2011; Rombouts, 2012; Betts, 2011; AMS 5666G, 2013; Dutta, 2011; Yadroitsev, 2009; R. Grylls, personal communication, 21 October 2012). It should be noted that there is significant variability in the properties within a given process and between different AM processes. It is difficult to determine the underlying causes for variability due to the lack of detail in reporting. Though it is apparent that different coupon geometries, ranging from as-built specimens to producing coupons and removing specimens, is one cause for these differences.