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Laser metal deposition of nickel coated Al 7050 alloy

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ABSTRACT

Al 7050 is not a friendly alloy for laser additive manufacturing because of the presence of low boiling point elements such as Mg and Zn in 7XXX alloys. This paper presents an alternate solution of laser metal deposition of Al 7050 alloy powder coated with nickel. Microstructural investigation using optical and electron microscopy revealed that the deposits are free from relevant defects such as porosity or lack of fusion. However, the added nickel was partially segregated in the inter-dendritic boundaries and formed brittle Al_3Ni intermetallics. As a result, as-deposited Ni coated Al 7050 alloy showed almost no tensile ductility. Laser deposited samples were friction stir processed to refine and uniformly distribute Al_3Ni particles in the α-Al matrix. Tensile test results revealed a good combination of yield strength (178 MPa), UTS (302 MPa), and 6% elongation of friction stir processed (FSP) samples. Post FSP heat treatment additionally improved both strength and elongation about 10%. Microstructural investigation revealed a systematic change of columnar to equiaxed dendrites from bottom to top of each deposited layer.

1. Introduction

Additive manufacturing (AM) is an innovative technique in which layer-by-layer material added to manufacture part. AM gives a lot of flexibility in terms of customization and repair technology especially for automotive and aerospace industries. Lightweight design combined the high strength is the one of the first priority in the current era of automotive and aerospace industry. This combination of low density (2.7 g/cm^3) with high strength makes 7xxx series aluminum alloys a potential candidate for light weight applications [1]. The ultimate tensile strength of Al 7050 alloy after heat treatment is 543 MPa [2] which is approximately twice that of 4xxx series aluminum alloys. Additive manufacturing of aluminum alloys always remained a challenge and specifically for 7xxx series aluminum alloys. However, the 4xxx series has been successfully additively manufactured [3–9] without major defects and mechanical properties are comparable to cast Al 4xxx components. Recently, Reschntnik et al. [10] and Hansong et al. [11] additively manufactured Al 7075 alloy using powder sintering and micro metal deposition technique respectively. Process induced cracks were found by Reschtnik et al. during AM of Al 7075 alloys using selective laser melting. Micro droplet deposition manufacturing (MMDM) technique involves melting of Al 7075 billets using induction furnace. To the best of our knowledge, no direct energy deposition technique-using laser as a heat source has been attempted so far for additive manufacturing Al 7xxx alloys. The major challenge in laser additive manufacturing of Al 7050 alloy is the low boiling point of alloying elements such as Zn and Mg as compared to aluminum, which evaporates during laser deposition. This evaporation decreases the quantity of strengthening elements and creates defects such as porosity and voids in the deposit. Moreover, Al is a highly reflective material. Consequently, deposition of Al alloys is challenging compares to Ni-, Fe-, Co-, and Ti-base alloys.

In the present investigation, Ni coated Al 7050 powder was additively manufactured using direct Laser Metal Deposition (LMD) to overcome the above stated challenges. There is a dire need of AM of 7xxx series aluminum alloys because of its endless applications in automotive and aviation industry. The objective of this study is to optimize the laser deposition parameters for manufacturing defect free Al 7050 alloy and to investigate the microstructure-property relationship in laser deposited samples. Solution heat treatment of the as nickel coated Al 7050 alloy was carried out for one hour followed by two-step aging to improve the mechanical properties. Heat treatment showed minimal effect on as-deposited nickel coated Al 7050 alloy sample. Ultimate tensile strength of additively manufactured and heat treated Al 7075 alloy using selective laser

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melting [10] found to be 203 MPa with elongation of 0.5%. One of the objectives of this study is to understand the effect of heat treatment of nickel coated Al 7050 alloy samples. Cottam et al. [12] reported laser cladded of 7075 aluminum alloy on Al 7075 T6 substrate using Nd:YAG laser. Cottam et al. reported hardness value of the laser cladded part lower than T6 plate. Precipitation mechanisms have been widely studied in spray forming, equal channel angular pressing, controlled diffusion solidification etc. [13–22]. Precipitation was also observed during laser metal deposition of Al 7050 alloy. However, there is limited literature available on precipitation kinetics during laser additive manufacturing of Al 7050.

2. Experimental procedures

Laser Metal Deposition (LMD) technology has been developed at Wayne State University based on a 1.2 KW Diode Laser, ABB IRB-1410 six-axis Robot, Coaxial Nozzle, Bay State 1200SP-1 Powder Feeder. LMD technology works on the principle of directed energy deposition process. Various other processes similar to LMD were developed with distinct names such as Direct Metal Deposition (DMD) [23] at University of Michigan, Laser Engineered Net Shaping (LENS) [24] at Sandia National Laboratories, Direct Light Fabrication (DLF) [25] at Los Alamos National Laboratories. The basic principles of these technologies are similar in that they use a high-power focused laser beam to create a melt pool on the substrate, to which metallic powder or wire is delivered to create a metal clad. LMD technology combines the rapid prototyping with laser cladding into solid freeform fabrication process as shown in Fig. 1. In the LMD process, a high-energy laser beam is focused onto the substrate or a previously deposited layer to form a melt pool; metal powders are simultaneously delivered into the melt pool by a specially designed coaxial nozzle. The nozzle is designed such that the powder streams converge at the same point on the focused laser beam. A robot is used to control the motion of the laser beam as per tool path generated from the CAD model of an object to create a 3D component layer-by-layer. Note that in the present investigation, argon was used as a powder delivery and shielding gas to prevent the oxidation of the melt pool during laser deposition.

Advanced Powder Solutions Inc. supplied the gas atomized nickel coated Al 7050 alloy powder. The range of powder particle size found to be from 5 to 50 μm and most powder particles found to be spherical. Fig. 2(a) exhibits the morphology of Ni coating on the Al 7050 powder particles. Note that the Ni coating was made by physical vapor deposition. Fig. 2(b) shows cross sectional view of Al 7050 powder in which coating is clearly visible around the periphery of Al 7050 particle. The Ni coating thickness was about 0.5 μm. It should be also pointed out that the morphology of the Ni coating is rather discontinues granular surface. The deposition was conducted on a 12.7 mm thick Al 6061 rolled plate. The first objective was to achieve defect free deposition of nickel coated Al 7050 alloy powder. Deposition parameters (laser power, powder feed rate, and scanning speed) were optimized to achieve high-density deposition, as each parameter has significant effect on the build quality of deposit. Process parameter window found to be rather small as all parameters are dependent on each other and cannot be varied much. Laser power had to be kept relatively high as aluminum has high thermal conductivity and consequently melt pool cooled down rapidly but if the laser power kept too high, than Mg and Zn would evaporate resulting in large porosity. Powder feed rate had to be optimized to make sure that required height is achieved. Powder feed rate if kept low, desired height might not achieved and if its more than optimum level, all powder particles might not melt which will create bonding error (lack of fusion) at the layer interface. Scanning speed was optimized accordingly with optimized powder flow rate and laser power. After various initial attempts, final optimized parameters were achieved as shown in Table 1. Samples were deposited with optimized parameters as shown in Fig. 3(a). For microstructural evolution and micro hardness study, coupons of 20 mm × 20 mm × 3.5 mm were made. In addition, a set of 100 mm × 20 mm × 3.5 mm block was made to prepare tensile test specimens. The hatched tool path pattern as shown in Fig. 3(b) followed for both coupon and block sample with bead overlap of 1 mm and layer thickness of 0.5 mm. Optical micrograph as shown in Fig. 3(c) of as-deposited nickel coated Al 7050 alloy revealed greater than 99.5% dense deposition. No major defects like cracks, deboning at layer interface was observed.

XRD analysis was carried out on the polished flat top surface of deposit using Bruker D8 analyzer to identify various phases in the as-deposited and heat-treated samples. Samples for SEM investigation were prepared by cutting half of as-deposited and heat-treated coupon. These half cut samples were mounted, polished

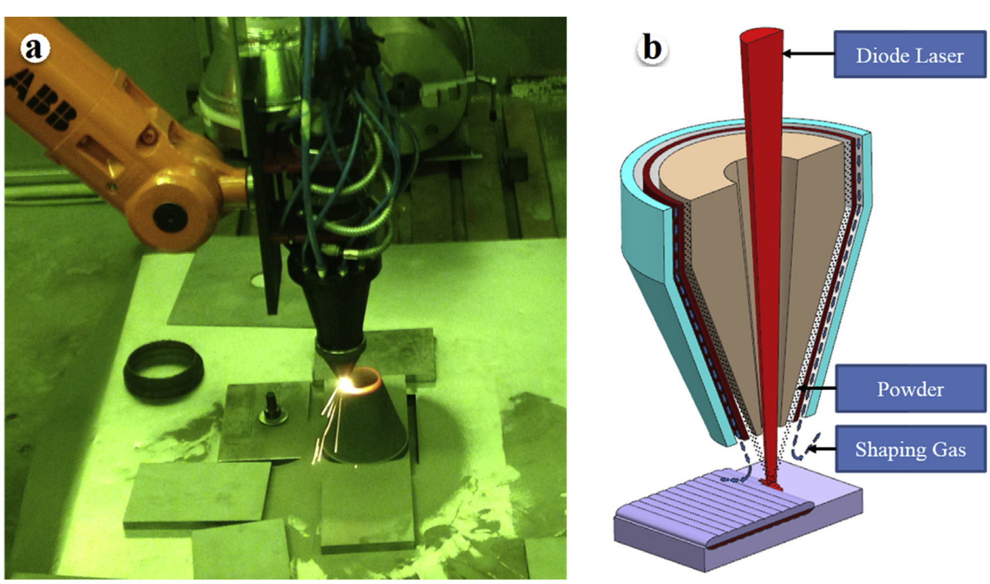

Fig. 1. (a) Coaxial nozzle connected at the end of robotic arm, (b) Schematic of LMD process.