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Letters

Blown powder deposition of 4047 aluminum on 2024 aluminum substrates

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Abstract

Aluminum and its alloys are difficult to deposit with the aid of lasers owing to their high reflectivity to incident light. This research deposits aluminum 4047 powder on widely-used aluminum 2024. The research concluded with successful blown powder deposition of aluminum 4047 thin wall structures using fiber lasers thereby proving feasibility of deposition and the bonding of two dissimilar aluminum alloys. Metallographic analysis conducted on the thin wall structures shows a distinct lack of porosity which leads to favorable material characteristics. Micro-hardness estimation is used to support the argument. Finally, scanning electron microscopy was employed to ascertain material distribution.

Keywords: Blown powder deposition; Aluminum alloys; Micro-hardness; Functionally graded material; EDS analysis

1. Introduction

Additive manufacturing (AM) of metals with the aid of lasers is a versatile manufacturing technology that exhibits exceptional small lot manufacturing capabilities coupled with extra-ordinary design flexibility while reducing manufacturing complexity and lead times [1–3]. Aluminum and its alloys are used world over owing to their wide ranging properties and manufacturing versatility [4]. They also exhibit high reflectivity, conductivity and chemical reactivity which leads to their poor adaptability to additive manufacturing processes [5,6]. Aluminum 2024 (2024 Al) used in this research is an aluminum–copper alloy with high strength-to-weight ratios, and excellent fatigue resistance and thereby finds extensive use in aerospace structural components. 2024 Al also exhibits high reflectivity which limits its processing potential to certain conventional manufacturing processes like casting, and machining [7].

This research focuses on blown powder AM systems as compared to the more widely known powder bed AM systems. Blown powder systems have advantages over powder beds, including their ability to repair existing components and their capability to manufacture functionally graded materials. They also offer size flexibility toward the manufacture of large AM parts. Also, blown powder systems exhibit considerably different absorption and emissivity [8] characteristics as compared to powder-bed systems [9,10]. This indicates that blown powder systems achieve less energy density which in-turn makes the deposition of aluminum alloys significantly more challenging. This research though aims to propose solutions that can bring the benefits of lasers and blown powder systems to aluminum alloys. This methodology will provide a precision technique to economically repair legacy 2024 Al parts and benefit most industries.

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2. Research need

To adapt aluminum for use with AM systems some researchers are investigating the weld-ability of aluminum alloys [11,12], while others have developed hybrid weld-AM processes [13,14]. Many researchers have achieved deposition success using pulsed laser deposition [15–19], while others have achieved favorable results using selective laser melting [20,21]. While the development of hybrid processes and laser pulsing has provided beneficial results, they could also prove to be expensive and complex add-ons that could hinder the wide-spread adaptability of aluminum alloys. Also, new material development does little to address the repair needs of legacy 2024 Al components that are in existence today. The need of the hour is a technique that can economically repair 2024 Al components while being easy to adapt to other aluminum alloy systems. With the high cooling rates achievable using blown powder deposition (BPD) this research aims to achieve refined grain structures and correspondingly favorable mechanical properties.

3. Method

The experimental setup employed in this research includes a fiber laser from IPG Photonics, which has a peak power of 1 kW, an operating wavelength of 1 micron, and a spot size of diameter approximately 2 mm. The powder used for deposition was −100/+325 gas atomized 4047 Al powder acquired from Valimet Inc. The substrates employed in this research are samples of 2024 Al alloy prepared in-house. A FEI Helios NanoLab 600 FIB/FESEM with an Oxford energy dispersive spectrometer was used to estimate composition.

4. Approach/concept

The research team theorized solutions to solve the problems associated with BPD of aluminum, the first of which was the use of aluminum alloy powders that have improved laser absorptivity like the aluminum 4047 alloy (4047 Al). The 4047 Al alloy is an aluminum–silicon alloy which has improved laser absorption characteristics compared to 2024 Al. Irrespective of the approach used, creating and sustaining a melt-pool on the surface of a 2024 Al substrate is exceedingly difficult [22]. Fig. 1 shows unsuccessful attempts by the research team to deposit 4047 Al powder on a 2024 Al substrate.

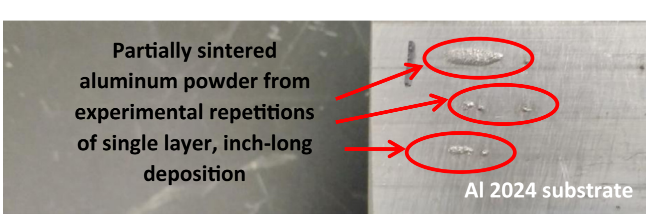

Fig. 1. Unsuccessful BPD of 4047 Al powder on a 2024 Al substrate. (Top view.)

On assessing the data from the unsuccessful deposits, the research team concluded that even with the employment of 4047 Al powder, the substrate was still not absorbing sufficient energy to create and sustain a melt-pool.

This results in a lack of a metallurgical bond between the dissimilar aluminum alloys which is indicated by the partially sintered 4047 Al powder attached to the 2024 Al substrate. This is better illustrated in Figs. 1 and 2(a).

The proposed concept was then revised to compensate for this phenomenon. Fig. 2 illustrates the revised concept wherein BPD is employed to deposit a uniform layer of partially sintered 4047 powder on the surface of the 2024 substrate (Fig. 2a). Owing to this sintered 4047 powder having significantly improved laser absorption, this layer now has the capability to create and sustain a melt-pool. BPD being a layer-by-layer deposition process is then used to melt and deposit the second layer of 4047 powder (Fig. 2b). This and subsequent deposition generate sufficient energy density to melt and re-crystallize any of the partially sintered 4047 powder thereby creating a metallurgical bond with the 2024 Al substrate (Fig. 2c).

5. Results and discussion

This research successfully implemented the proposed concept to deposit thin-wall deposits of 4047 Al on 2024 Al substrates using BPD. Multiple thin-wall deposits with differing process parameters were employed to prove repeatability and consistency. The images in Fig. 3 prove metallurgical bonding between the substrate and the deposit along with an interface zone (dilution region) that exhibits materials from both [23]. No delamination of the deposit from the substrate was noticed across any of the thin-wall structures. Micro-structure images in Figs. 3a and 4a indicate a distinct lack of porosity. Scanning electron microscopy (SEM), EDS analysis (shown in Fig. 3b) also justifies the material distribution and the lack of porosity. The significant material count variations in the dilution zone (Fig. 3b) are attributed to the transition from an aluminum–copper [24] system to an aluminum–silicon [25] system. As expected, the dilution zone consists of diminishing copper, and increasing silicon with aluminum as the primary element. The excessive variations in the EDS line-scan data of the dilution and 4047 Al zone can be attributed to the as deposited micro-structure. This is an effect of BPD whose high cooling rates lead to the formation of aluminum as the dendritic phase and aluminum–silicon solid solution as the matrix which is uncommon in conventional manufacturing processes. Fig. 4a represents the micro-structure of the 4047 Al deposits and clearly shows the dendrite growth (Al phase, Al–Si Matrix). BPD possesses exceptionally high cooling rates which the research team is currently investigating. The data obtained will be employed in the future to further increase the cooling rates and produce grain refinement.