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ENHANCEMENT OF SURFACE CHARACTERISTICS AND TRIBOLOGICAL PERFORMANCE OF WAAM AL6063 VIA LASER SHOCK PEENING

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ABSTRACT

The rising demand for Wire Arc Additive Manufacturing (WAAM) underscores its potential as an effective alternative to conventional subtractive manufacturing methods. However, WAAM faces challenges, notably uncontrolled grain size and tensile residual stresses in fabricated components, which can limit its applications. To address these challenges, this study explores Laser Shock Peening (LSP) as an advanced post-processing technique to enhance component durability through severe plastic deformation and improved surface properties. WAAM was employed to fabricate Al-6063 alloy components, which were subsequently treated with LSP to investigate its effects on surface characteristics and tribological behavior. The LSP treatment resulted in significant improvements, including grain refinement and the formation of a high density of dislocation lines on the shock-peened surface, leading to increased surface hardness. Moreover, LSP transformed the initial tensile residual stresses into a compressive state, further enhancing the material's performance. This study demonstrates the potential of LSP to improve the surface integrity and durability of WAAM-fabricated Al-6063 components.

Keywords: Wire Arc Additive Manufacturing (WAAM), Al-6063 Alloy, Surface Characteristics, Laser Shock Peening (LSP), Tribological Behavior

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1. INTRODUCTION

Additive Manufacturing (AM) has revolutionized production processes by enabling complex geometries and reducing material wastage compared to traditional subtractive methods. Among various AM technologies, Wire Arc Additive Manufacturing (WAAM) has gained considerable interest for its efficiency in fabricating large metallic structures. WAAM offers unique advantages, including reduced production time, minimal material wastage, and cost-effectiveness, especially for metals like aluminum, titanium, and steel. However, the technology faces challenges that can compromise the quality of components produced, particularly in terms of surface characteristics and tribological (friction and wear-related) performance. Al-6063, a popular aluminum alloy in structural applications due to its excellent corrosion resistance and mechanical properties, has been successfully used in WAAM processes. However, WAAM-fabricated Al-6063 components often exhibit limitations such as coarse grain structure, residual tensile stresses, and suboptimal surface hardness, all of which can impact their performance in demanding environments. These characteristics often require enhancement for WAAM components to be competitive with conventionally manufactured parts.

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To address these limitations, post-processing techniques like Laser Shock Peening (LSP) have been explored for WAAM components. LSP is a mechanical surface treatment that improves surface integrity and enhances mechanical properties by inducing severe plastic deformation, creating compressive residual stresses, and refining the surface microstructure. Previous studies have shown that LSP can significantly enhance fatigue life, hardness, and wear resistance in various alloys. Aluminum alloys, particularly Al-6063, are commonly used in WAAM for structural applications due to their lightweight properties, good corrosion resistance, and reasonable strength. However, WAAM fabrication often results in components with a coarse grain structure and high residual tensile stresses, which can reduce the mechanical properties and surface integrity of the final product (Bambach et al., 2020; Cunningham et al., 2018). The tribological performance of WAAM-produced components is a critical factor in determining their suitability for engineering applications. Al-6063 alloy, despite its favorable properties, tends to exhibit suboptimal tribological performance when fabricated via WAAM due to surface roughness, residual stresses, and porosity inherent to the process (Xu et al., 2019). Researchers have shown that post-processing techniques such as LSP can significantly enhance the wear resistance of Al-6063 by improving surface hardness and reducing surface defects (Liu et al., 2021).

The application of LSP to additively manufactured components has gained interest as it offers the potential to counteract the tensile residual stresses introduced by WAAM and other AM processes. Studies have demonstrated that LSP can transform tensile residual stresses into compressive stresses, leading to improved performance characteristics, particularly in fatigue and wear resistance (Sano et al., 2006; Chen et al., 2020). Specifically for aluminum alloys, LSP has been effective in refining grain size and improving hardness, leading to enhanced tribological properties and increased resistance to wear and abrasion (Hong et al., 2021). However, limited studies have focused on the application of LSP to WAAM-fabricated Al-6063 alloy components, particularly regarding its effects on surface characteristics and tribological performance. Therefore, this study aims to investigate the enhancement of surface characteristics and tribological performance of WAAM-produced Al-6063 alloy using LSP, with a focus on understanding the influence of grain refinement, surface hardness, and residual stress modification on the material's overall performance.

2. EXPERIMENTAL PROCEDURE

The WAAM system was composed of a Fronius Cold Metal Transfer (CMT) Advanced 4000 R nc MIG/MAG inverter power source, a VR1550 wire feeder, and a KUKA KR20 6-axis robot, and more details can be found in our previous studies from Chang et al. [27]. The wire feeding speed was 6.5 m/min, the travel speed was 0.18 m/min, and the flow rate of the shielding gas (100% Argon) was 25L/min. After the deposition of each layer, compressed air was employed to accelerate its cooling to below 50^{o}C. With these parameters, a 4.5 mm layer thickness was finally achieved. Wall-shaped components with simple geometry were built to avoid heterogeneously distributed defects caused by complex travel paths. As shown in Fig.2 and 3, after the WAAM process, the 3 mm thickness sheet and 6 mm-thickness block were used for subsequent mechanical properties measurements and microstructure characterization, respectively. These samples were all prepared by an electric discharge machine (EDM). To avoid performance differences caused by various surface qualities, all samples were polished before LSP.

Wire Arc Additive Manufactured (WAAMed) specimens, like a 10x10x5 dimensioned item, can be precisely shaped and refined by using wire electrical discharge machining (EDM). The WAAMed part is three dimensional, hence a method that can handle intricate geometries without compromising accuracy is needed. The non-contact cutting method of wire EDM ensures uniformity and consistency in the finished product by enabling exact cuts along all three axes. Because of its great precision, less material is wasted and fewer additional finishing steps are required. Furthermore, wire EDM is particularly well-suited for cutting WAAMed specimens due to its capacity to operate with difficult materials while preserving material integrity and dimensional stability. Intricate components made using additive manufacturing techniques can be manufactured with wire EDM as it is a valuable technique that guarantees high-quality outcomes and improves production efficiency. FIG: Image of wire cut pieces.

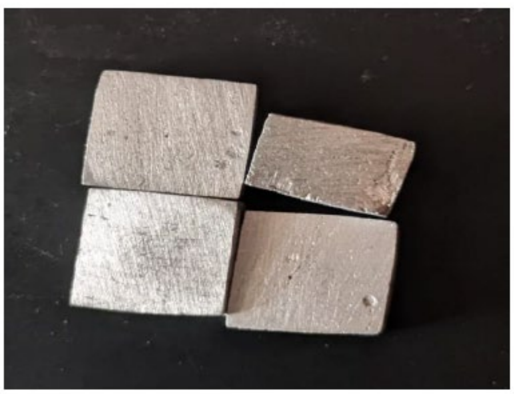


Fig.2

Fig.3

3. RESULTS AND DISCUSSION

Surface Electron Backscattered Diffraction (EBSD) maps of the specimens were taken prior to and following Laser Shock Peening (LSP) in order to visualize the grain refinement. These maps shed light on texture, inverse pole figure, and grain size distribution. For the inverted pole image in the study, the reference direction [100] was used. The orientations were indicated by colour coding, with red denoting [001], blue for [111], and green for [101]. In Figs. 5.1.a and b, a triangle in the upper right corner denoted this colour scheme. The coarse equiaxed grains were present in the first microstructure, as seen in Fig. 5.1.a. This might be explained by the thermal input that occurred during layer deposition; it functioned something like a low-temperature heat treatment, causing coarse granules to develop. On the other hand, as shown in Fig. 5.1.b, a refined microstructure was seen following LSP treatment. Area percent was displayed versus grain size both before and after LSP in the subsequent histograms. Only 24% of the grains after LSP breached the 60 μm size criterion, compared to 47% of the grains before LSP. Furthermore, the LSP procedure resulted in a considerable reduction in grain size, as evidenced by the average grain size falling by 22% from 59.7 μm to 46.7 μm

Both before and after Laser Shock Peening (LSP), the micro-hardness measured up to a depth of 1.5 mm in the uppermost and middle regions is shown. We find that LSP has a significant effect on micro-hardness. Before LSP, the specimen's initial micro-hardness was roughly 75 HV. Following peening, the surface microhardness in the middle and top parts increased to around 110 HV. Then, at a depth of about 1.2 mm, the micro-hardness steadily dropped to around 75 HV, where itstabilized, suggesting the development of a hardened layer that was 1.2 mm thick.

Similar improvements in micro-hardness were noted by Ding et al. [34] in an alloy

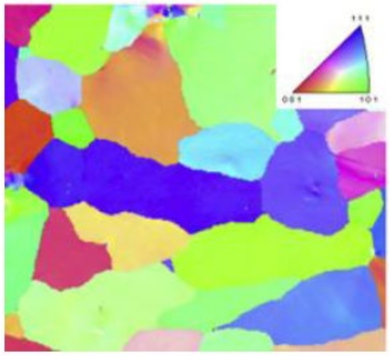


FIG 5.1.a: UN – PEENED SPECIMEN

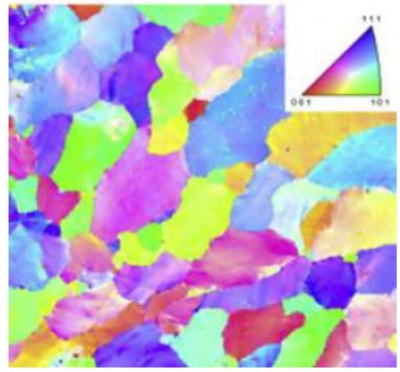


FIG 5.1.b: LASER SHOCK PEENED SPECIMEN

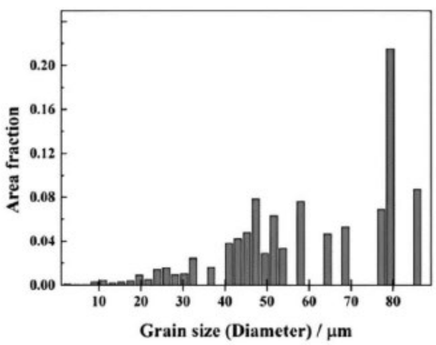


FIG 5.1.c: UN – PEENED SPECIMEN

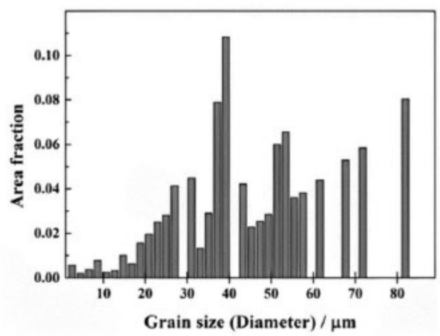
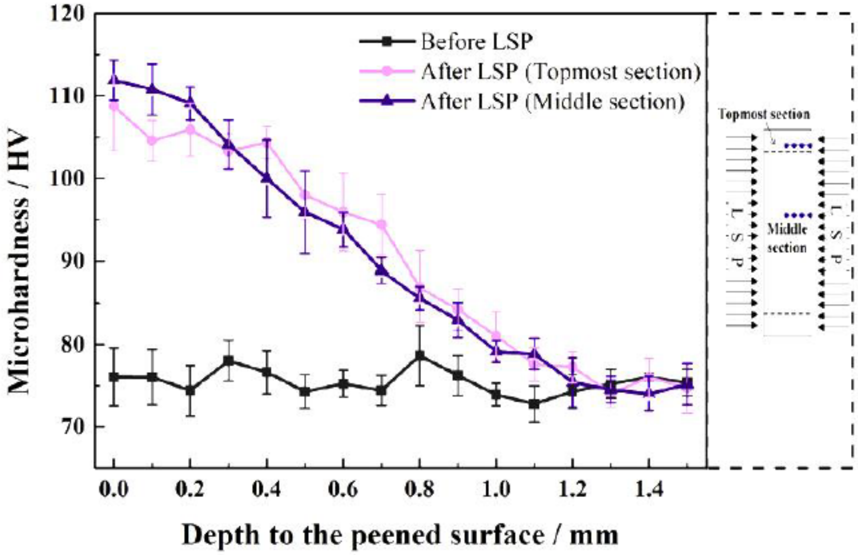


FIG 5.1.d: LASER SHOCK PEENED SPECIMEN

Both before and after Laser Shock Peening (LSP), the micro-hardness measured up to a depth of 1.5 mm in the uppermost and middle regions is shown. We find that LSP has a significant effect on micro-hardness. Before LSP, the specimen's initial micro-hardness was roughly 75 HV. Following peening, the surface microhardness in the middle and top parts increased to around 110 HV. Then, at a depth of about 1.2 mm, the micro-hardness steadily dropped to around 75 HV, where it stabilized, suggesting the development of a hardened layer that was 1.2 mm thick. Similar improvements in micro-hardness were noted by Ding et al. [34] in an alloy



4. CONCLUSIONS:

The Laser Shock Peening (LSP) treatment has shown a significant positive impact on the microstructure, grain size distribution, and mechanical properties of the treated material. Microstructural analysis revealed a marked refinement of grain size, resulting in a more homogeneous and finely grained structure. The LSP treatment successfully reduced the proportion of larger grains, from 47% to 24%, with a notable 22% decrease in average grain size, which dropped from 59.7 µm to 46.7 µm. This reduction in grain size, achieved through controlled plastic deformation, underscores LSP's effectiveness in altering the material's microstructure to enhance mechanical performance. These microstructural changes translate into substantial performance improvements, as finer grain structures are often associated with higher mechanical strength, improved fatigue resistance, and enhanced durability. By refining the microstructure, LSP enhances the material's intrinsic properties, making it more suitable for applications requiring high mechanical reliability and endurance. This refinement opens up broader possibilities for advanced materials in demanding applications, as LSP-treated materials demonstrate improved performance metrics and structural integrity.

CONFLICT OF INTEREST

None

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None

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