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On the surface roughness of 316L stainless steel fabricated using L-PBF additive manufacturing

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ABSTRACT

Additive manufacturing (AM) offers numerous advantages over traditional fabrication methods such as manufacturing complex parts. However, a significant limitation lies in the restricted surface quality, hindering its widespread use. While parts produced through conventional manufacturing techniques such as milling and grinding typically have an average roughness (Ra) value of less than 1–2 µm, those manufactured using laser powder bed fusion (LPBF) AM usually fall within the range of 10 to 30 µm. Surface roughness plays a critical role in various applications, as certain uses necessitate superior surface quality to prevent premature failure due to surface-induced cracking. Subpar surface quality not only compromises the strength, wear resistance, and corrosion resistance of parts but also impacts the precision of the fabricated components. Therefore, it is imperative to optimize the fabrication process and enhance the surface quality of metal parts. Moreover, the surface quality of each layer dictates the bonding strength between adjacent layers and process stability, as a high-quality preceding surface is essential for ensuring the integrity of subsequent layers. Consequently, surface roughness significantly influences process stability and the properties of metal parts produced through LPBF. This work aims at evaluating surface roughness of as printed 316L stainless steel parts made using LPBF AM process and their effects on tensile properties of the produced samples. Microscopic analyses are done to evaluate the roughness (including Ra, Rq, and Sa parameters) at different locations to evaluate the effects of different printing parameters on their size distributions. In addition, the macro-mechanical behaviour of the as printed samples is compared with the ones with polished surface.

Keywords: Additive manufacturing, Metal, Surface roughness, Tensile characteristics, Surface finish

Introduction

Additive manufacturing (AM) of metallic materials builds 3D metal objects layer-by-layer from a digital input [1]. Additively manufactured stainless steel (SS) 316L finds use in oil and gas, automotive, energy and implants due to its excellent corrosion resistance and strength [2]. Numerous investigations have been carried out to examine the mechanical characteristics and microstructure of SS 316L alloy components produced by selective laser melting (SLM) AM in both as-built and different post-process heat-treated conditions [3-5]. As commonly known, scanning speed in AM plays a critical role, directly affecting the molten pool's temperature, size, solidification rate, and ultimately the final part's surface properties [6]. In the present investigation, the influence of scanning speed on the tribological properties and mechanical response of SLM printed SS 316L samples was experimentally investigated.

Material and Method

The TruForm 316 (FE-271) and Xact Metal XM200G were used in the current investigation to produce samples with the suggested spot size of 100 µm. For consistency, the powder utilized in each AM operation was fresh out of a sealed container and in its pristine state. The apparent density of the powder was 4.14 g/cm^3 and hall flow measurement was 14 seconds. Also, the distribution of the particle size was 19, 30 and 48 for d10, d50 and d90, respectively. The measurements of apparent density, hall flow, and microtrac were performed in compliance with ASTM B212, B213, and B822 test standards, correspondingly. The printing parameters were selected as the recommend parameters by the machine manufacturer. Three different scanning speeds were selected: 1400 (SS_1400), 1700 (SS_1700), and 2000 (SS_2000) mm/s. The layer thickness was set to 30 µm, build direction was selected vertical to the build plate and printing power was set to 350 W.

After the printing process, at least 3 samples for each batch were machined by using conventional end mill tool. Similarly, 3 samples for each batch were roughly polished by using Xebec rough brush. Lastly, remaining 3 samples for each batch were finely polished with Xebec fine brush. The surface properties of the as built, machined and

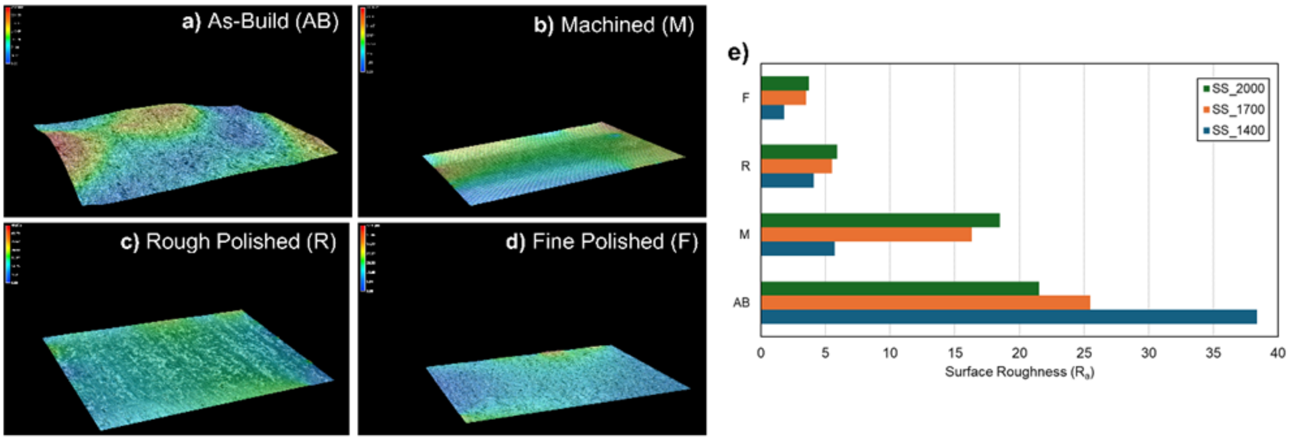

Fig. 1: Visualization of the surface for tensile testing samples produced at a scanning speed of 1400 mm/s a) As-build sample, b) Machined, c) Rough and d) Fine polished, and e) Surface roughness-Ra values for the inspected samples.

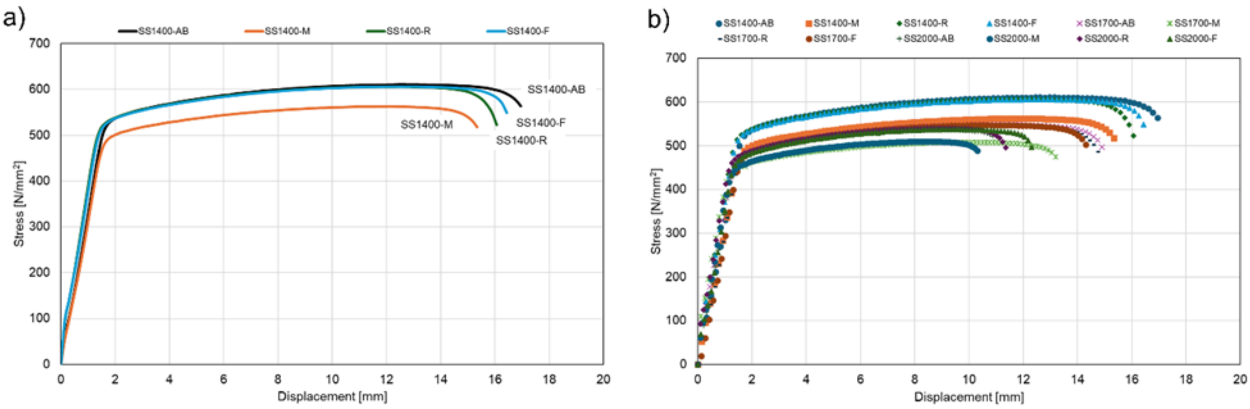

Fig. 2: Tensile testing results for the samples produced by different scanning speeds.

polished samples were investigated via Keyence 7000 VHX digital microscope. To determine the mechanical properties of the as-printed samples, tensile tests were performed using a Zwick Roell tensile tester with a capacity of 10 kN. During the tests, velocity of the moving gripper was set to 5 mm/s and the tests were conducted according to ASTM E8-22 standard.

Experimental Results

The topology information on the surface for the reduced sections of the tensile testing samples (Produced with a scanning speed of 1400 mm/s) are visualized in Fig 1a-d. When the samples produced by 1400 mm/s scanning speed were taken into consideration, the arithmetic average roughness Ra values were measured as 38.4 µm for the as-build sample. On the other hand, machining process reduced the average roughness to 5.7 µm. Also, when the polishing brushes were used instead of machining, the average roughness values were decreased to 4.1 µm and 1.8 µm for rough and fine polishing, respectively. A similar behaviour can be seen for different scanning speeds as shown in Fig 1e. It should be noted that average surface roughness values decreased as the printing speed increases for the as-build samples. Due to the fact that higher printing speeds reduces the area of remelting during the printing process, a lower average surface roughness values could be obtained.

The mechanical behaviour of as-build, rough polished and fine polished samples that were printed with 1400 mm/s scanning speed represented a similar behaviour. On the other hand, machining decreased both the strength and ductility of the alloy 10%, roughly. This could be explained with the distortions occurred on the material during the machining process. The feed rate could be decreased to reduce this effect with a cost of process time. Also, increasing scanning speed decreased both the strength and ductility of the alloy (Fig. 2b), as expected. Similar results were obtained regardless of scanning speed in terms of post-processing.

Conclusion

Machining after the additive manufacturing of 316L decreased the materials strength and ductility. To overcome this problem, rough or fine polishing with the brush could be applied. Fine polishing compromises the lowest average surface roughness without leading a decrease in the strength of material.

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