The 12th
International Conference on
Materials and Metallurgical Engineering
28 and 29 November 2023, Tehran

Mat 2023

دوازدهمین
کنفرانس بین‌المللی
مهندسی مواد و متالورژی ایران
۷ و ۸ آذر ماه ۱۴۰۲/ تهران

Anisotropy Assessment of 3D Printed 316L Alloy Produced by Selective Laser Melting

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Selective Laser Melting (SLM) is an innovative Additive Manufacturing (AM) technique with extensive applications in the medical industry. This study focuses on understanding the mechanical behavior of 3D-printed biomedical alloys in all directions. A comparison between a 316L sample produced through SLM and a conventionally manufactured one reveals the significant influence of imperfections, such as type, size, and distribution, on the anisotropic performance of fabricated parts. These findings underscore the need to investigate the relationship between mechanical properties and microstructural characteristics to enhance the quality of 3D-printed biomedical alloys.

Keywords - Additive Manufacturing, Anisotropy, Selective Laser Melting, 316L Alloy

I. INTRODUCTION

Additive manufacturing processes, particularly selective laser melting (SLM), are expected to drive the fourth industrial revolution due to their remarkable features. SLM enables the production of complex parts with high efficiency and desired mechanical properties. However, the SLM process can introduce defects and result in anisotropic behavior, affecting the mechanical properties of the fabricated parts.

Researchers have investigated the factors contributing to anisotropy in SLM-produced parts. Studies have identified shape variations in holes and defects at layer boundaries as significant contributors to anisotropy. Adjusting scanning parameters can reduce porosity and crack density, but the complete elimination of anisotropy is challenging due to the nature of the SLM process. Understanding anisotropy is crucial for enhancing the performance of fabricated items.

Experiments on 316L samples produced through SLM have shown strong anisotropy in mechanical properties, influenced by microstructures and processing parameters. However, based on authors' knowledge most studies exploring anisotropy in SLM-made parts have focused on comparing samples produced in different building directions. However, this approach may not be practical for items with significantly longer dimensions in one direction, such as a hip orthopedic implant. In such cases, it is more appropriate to examine the properties of horizontally produced samples in different directions, enabling efficient mechanical analysis and consideration of specific force tolerances in the design process.

The present article aims to investigate anisotropy in the mechanical properties of 316L alloy produced through SLM and compare it with a similar sample created by the conventional method. The focus is on evaluating compressive strength and hardness and exploring their relationship with microstructural characteristics. Since comprehensive and accurate information about the hardness and yield strength of SLM-produced 316L alloy in different directions is lacking, this research fills a critical knowledge gap in the field of orthopedic implant manufacturing.

II. MATERIALS AND METHODS

A cylindrical model with a diameter of 12 mm and a length of 60 mm was designed in SOLIDWORKS software and printed from 316L alloy using the Noura M100 P SLM machine. The density and porosity of the samples were determined using the Archimedes method. Optical microscopes were employed for microstructural investigations. Compression tests were conducted on samples prepared from both conventional and printed specimens, measuring yield stress, stiffness, and Young's modulus. Hardness measurements were performed using the Vickers microhardness method.

III. RESULTS, DISCUSSION AND CONCLUSION

The densities of conventional and SLM samples have been calculated (7.822 gr/cm^3 and 7.770 gr/cm^3, respectively). Considering the direct relationship between the percentage of voids and sample density, the percentage of voids was also determined (1.979 % and 2.631 %, respectively). In the SLM process, the scanning strategy has a significant impact on the density and percentage of voids. The best scanning angle is the angle in which less amount of heat is accumulated and adequate layers' overlap form. The relatively Low percent of voids in the SLM sample is proof that the scanning angle of 67° applied in the SLM manufacturing process reduces voids.

The microstructures of alloys are highly influenced by their production methods, resulting in different properties. Optical microscope images reveal distinct microstructures. In the conventional specimens, grains are mostly coaxial in one direction and elongated in the other. In contrast, the SLM specimens exhibit melted regions forming molten pools in a pattern perpendicular to the building direction. The printed samples also show random porosities and irregular defects. Analysis indicates a higher defect volume in the building direction due to unmelted powders and lack of re-melting. These irregular defects occur between successive layers due to weld pool instability and insufficient wetting caused by oxide films.

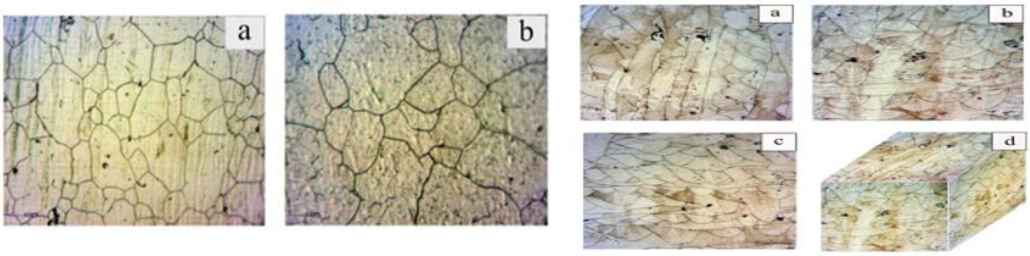
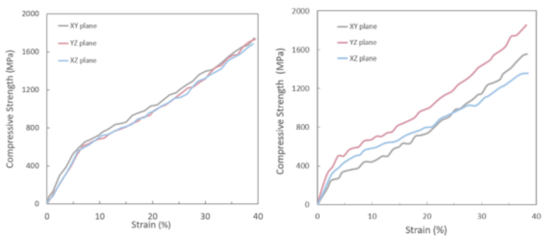


Fig.1: Optical microscope images in (a) longitudinal direction of conventional sample, (b) Transverse direction of conventional sample, (c) YZ direction of SLM sample, (b) XY direction of SLM sample, (c) XZ direction of SLM sample and (d) 3D form of SLM sample

The cooling rates differ significantly between the printed and conventional specimens, leading to fine subgrains and improved mechanical behavior in the printed samples. These subgrains which grow in the direction of the highest temperature gradient. The presence of cells with the same crystallographic orientation defines a grain. It was expected to observe less anisotropy in SLM samples due to the presence of subgrains, but according to Fig. 2 the conventional samples have less anisotropy in mechanical properties compared to the SLM samples. Mechanical properties of the conventional samples in directions normal to the rolling direction are close, with a slight strength increase (about 6%) in the rolling direction. The better strength of these samples in all directions are due to denser structure and work hardening during rolling. The printed specimens exhibit anisotropy in mechanical behavior. The results of hardness measurements are aligned with compression test. The conventional sample has an average hardness of 259.0 HV, 12% higher than the printed sample (231.2 HV). Anisotropy in SLM specimens is attributed to variation in defects; to reduce anisotropy in printed samples, focus on reducing defects, especially in the building direction which most defects were observed is essential.



a) b) z

Fig. 2: Compression test results related to (a) conventional and (b) SLM samples

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