Analysis of mechanical properties of stainless steel 316 L printed via selective laser melting (SLM)

Z A Zakaria[*a], J M Bryce [b], Evyan Y.C.Y [c], W Y Woo [a],

[a] Department of Mechanical Engineering, Faculty of Engineering, Science and Technology, Nilai University, Negeri Sembilan, Malaysia.
[b] Centre of Liberal Arts and Languages (COLAL), INTI International University, Negeri Sembilan, Malaysia.
[c] School of Applied Sciences, Faculty of Engineering, Science and Technology, Nilai University, Negeri Sembilan, Malaysia.

[*]Corresponding author and e-mail: Z A Zakaria, zairul@nilai.edu.my

Abstract

Additive Manufacturing (AM) or 3-Dimensional (3D) Printing is a means of production by building up material, layer upon layer. AM offers a high level of customisation and avoids expensive tooling costs or lengthy programming time as well as offering a significantly faster method of production. Within AM, Powder Bed Fusion (PBF) is a commonly used system owing to the wide range of material availability, ability to integrate technology into small scale to office sized machines, and the capability to create functional components having mechanical properties comparable to those properties of bulk materials. Selective Laser Melting (SLM) is a system under the PBF category, where a high-power-density laser is used to melt and fuse metallic powders together. The process, however, is characterized by high temperature gradients and a densification ratio that in turn may have significant impact on the microstructure and properties of SLM parts. The objective of this paper is to compare the mechanical properties between Stainless Steel 316 produced by conventional manufacturing processes and that produced by SLM. This article also presents an overview of both AM and SLM, and aims at understanding the potential of AM through SLM in contributing to Industry 4.0. This paper demonstrates the mechanical properties of Stainless Steel 316 L components that were manufactured using SLM. After undertaking various tests, the results of the mechanical properties of the printed parts are as follows: i) Tensile Strength is 307 MPa; ii) Compressive Strength is 204 MPa and iii) Hardness is 272 HV. The data shows that, despite components printed by SLM resulting in functional parts, further research is required in order to achieve the desirable grain structure and properties.

Keywords: *Additive manufacturing (AM); Powder Bed Fusion (PBF); Selective Laser Melting (SLM).*

1. INTRODUCTION

Additive Manufacturing (AM) or 3-Dimensional (3D) Printing is a process that enables parts to be manufactured directly from Computer Aided Design (CAD) data via the additive deposition of individual cross-sectional layers of the part (Qatawwi et al., 2017). As opposed to traditional subtracting manufacturing methods, this process reduces waste during manufacturing and can be separated into several categories by their input materials and the forming process

(Yagnik, 2014). Under the ISO/ASTM 52900:2015 partnership, AM is defined as the *"process of joining to make parts; (clause of 2.6.1 of this standard defines parts as joined material forming a functional element that could constitute all of a section of intended product), from 3D model data, usually layer upon layer (under clause 2.3.10 of this standard, a layer is defined as material laid out, or spread, to create surface), as opposed to subtractive manufacturing and formative manufacturing methodologies"* (ASTM International, 2017). One of the most popular process under the 3D Printing is Powder Bed Fusion (PBF) at 54% market share in 2019 whilst Selective Laser Melting (SLM) is the most common technology under the PBF process owing to the extensive range of metal alloys availability (Prashanth, 2020)

1.1 Selective Laser Melting (SLM)

Under the AM process categories, there are many processes which vary in terms of material, internal shape, process itself, surface finish and geometrical shape required. ASTM F42 and ISO/TC 261 formulated terminology defining the range of AM processes into seven categories, being Sheet Lamination (SL), Direct Energy Deposition (DED), Powder Bed Fusion (PBF), Material Extrusion, Material Jetting, Binder Jetting and VAT Photopolymerisation. Powder bed fusion is a process that produces parts by using thermal energy to fuse selected areas of a powder bed. The process includes SLM, Direct Metal Laser Sintering (DMLS) and Electron Beam Melting (EBM) with metal, polymer and ceramic being the materials available for use (Yagnik, 2014).

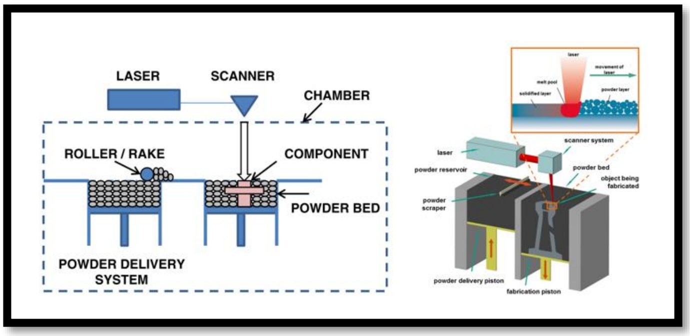


Fig. 1. Working principle of Selective Laser Melting (SLM) (Prashanth, 2020).

In the SLM process, complete melting of the material in powder form takes place. To create the part, the powdered material is distributed in a layer, typically to a depth of 0.1 mm, which is then melted by laser beam. The localised laser causes the powder to melt forming micro pools of high temperature, molten metal as shown in Figure 1. The component part is formed by building up layer upon fine layer to give the part its eventual shape. The structure of the part is determined by different factors, such as the properties of the material used, the parameters of the process, the design strategy and the geometry of the part. This versatility of this process renders it eminently suitable for use within the aerospace industry where additive manufacturing overcomes the limitations of conventional, subtractive processes in the manufacture of intricate and complex parts, with the additional benefit of significantly reducing material waste and component weight. SLM technology is also applied within the medical field for the creation of prostheses due to the ease of scanning, modelling and manufacturing process, thereby lending itself to customisation to the patient's anatomy (Kempen et al., 2012).

1.2 Mechanical properties of material

Mechanical properties of components are important to ensure that the produced part fulfils the requirements of its application (Tymrak, 2014). The mechanical properties characterise the behaviour and reaction of the material to an applied load or force. The specific mechanical properties of a component can be determined via various tests of deforming the material such as elongating, twisting and compressing (Pelleg, 2012). The mechanical properties of any given object will vary depending on the shape and size of the specimen undergoing test (Petrone, 2016). Among the various mechanical properties of material are strength, ductility, hardness, toughness and impact resistance.

2. METHODOLOGY

Three (3) tests were conducted to determine the mechanical properties of the part that would be printed via SLM, those three (3) tests being Tensile Test, Compression Test and Hardness Test. In order to print the parts, the parts had to be modelled in any 3D software and for this research, Solidworks was used. The 3D model information stored in a STereoLithography (STL) file was converted into geometry consisting of multiple layers using specific software. The specimens were designed according to the ASTM standard for testing of metallic materials as shown on Figure 2 before being printed via SLM using 316 L Stainless Steel powder.

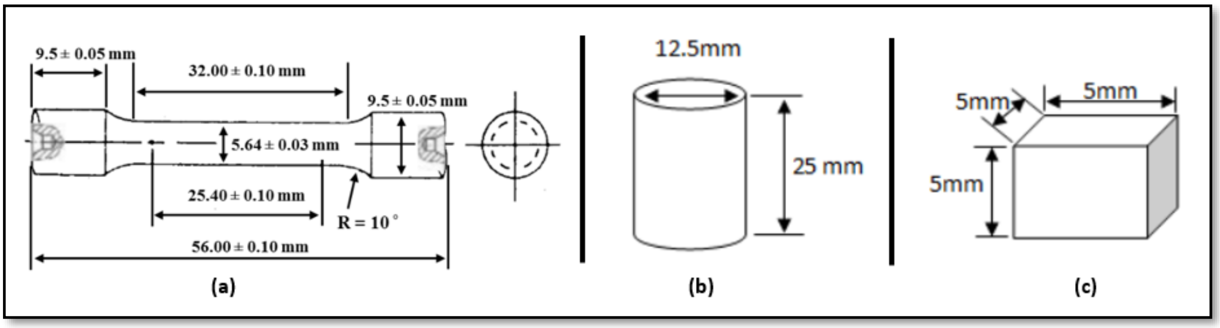
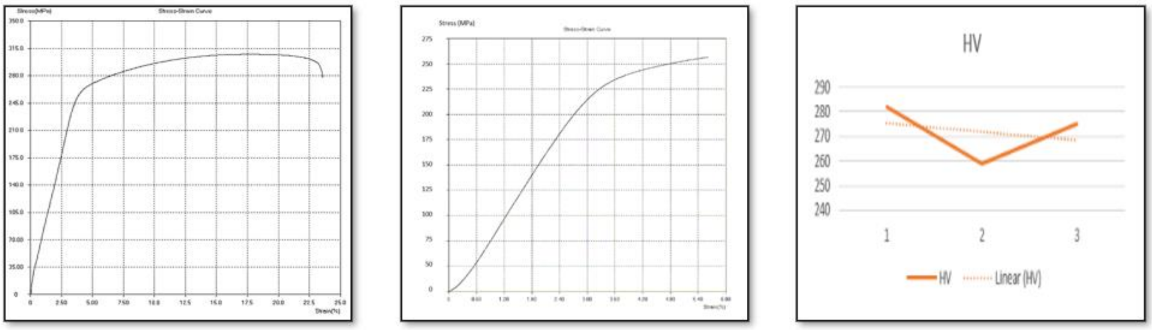


Fig. 2. (a) Tensile Test Specimen (b) Compressive Test Specimen (c) Hardness Test Specimen (Pelleg, J. 2012).

3. RESULT

3.1 Tensile Test

The first experiment was the tensile test, the dog bone plate was gripped at the tool of the Universal Testing Machine (UTM) by the two ends of the part. After setting the tool and setting the dimension of part and speed of force to 10 mm/s, the machine applied the tensile force at the two ends of the part. The force increased gradually until the part broke. The ultimate tensile strength result was 307 MPa as shown on Figure 3 (a).



(a) (b) (c)

Fig. 3. (a) Tensile Test Result (b) Compressive Test Result (c) Hardness Test Result

3.2 Compressive Test

A hollow rectangular block was used in the compressive test experiment and the same UTM machine was used but with a different tool. The part was positioned at the centre of the tool and fixed by adjusting the tool to zero distance, making contact with the surface of part. The speed of compression was set to 1mm/min, below which deformation of the part would be too slow. The compressive strength result was 260 MPa as shown on Figure 3 (b).

3.2 Hardness Test

A square piece as shown in Figure 2 (c) was tested using a Vickers hardness test machine. The tooling was adjusted to a distance of 15 microns from the surface of the part and the load of the diamond tool set to 30 kgf in order to conduct the experiment. The result is shown in Figure 3 (c) and the average HV from 3 points was 272 HV.

4. DISCUSSION

The data in Figure 3 only represents the data of components produced though SLM and data of conventional machining were obtained from the standard mechanical properties figure (Pelleg, J. 2012). The comparison between the parts produced via conventional machining and SLM is shown in Table 1. The data shows that SLM has the capability to create functional components having mechanical properties comparable to those of bulk materials.

Table 1. Data of parts produced via Conventional Machining and Selective Laser Melting (SLM)

Mechanical Properties	**Stainless Steel 316 L Manufacturing Process**	
	Conventional Machining Process (Pelleg, J. 2012)	**Selective Laser Melting (SLM)**
Tensile Strength	345 – 1000 MPa	307 MPa
Compressive Strength	170 – 310 MPa	260 MPa
Hardness Vickers (30kgf)	170 – 220 HV	272 HV

5. CONCLUSION

Industry 4.0 represents a considerable, and perhaps the most significant, transitional change in manufacturing of the future, and AM is seen by many as a key technology offering enormous potential in overcoming current manufacturing limitations and opening revolutionary opportunities for intricate, cost-saving and progressive design and manufacturing. Furthermore, AM may improve sustainability in terms of the reduction of waste in manufacturing by additive manufacturing rather than reduction manufacturing techniques.

The role of the employee may be redefined in the future with increased use of AM as traditional labour forces move more towards design, management and analysis. Manufacturing could be performed on a Do-It-Yourself type platform whereby, with the addition of a relatively inexpensive 3D-printer, students can manufacture their own designs and small manufacturing businesses can produce complex products with minimal cost and investment

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