

Analysis of the Production of Complex Part Components of Stainless-Steel 316L by Selective Laser Melting

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Abstract—The current study focuses on the state-of-the-art review of Selective Laser Melting (SLM) process on SS316L stainless-steel to provide complete information to the readers on the 3D printability of this material. There has been a great demand of SS316L due to the wide range of applications and excellent mechanical and anti-corrosion properties. Whether it is an automobile sector or the sector of aerospace engineering, be the marine engineering sector or the field of medical-science, everywhere this material has found its application in fabricating the most complex part or components. The 3D printing of SS316L has become popular in these high risk sectors and gaining momentum day-by-day. This article will provide detailed information on the effect of SLM process parameters on the microstructure and quality of SS316L printed parts.

IndexTerms—Hatch-Spacing, Laser Power, Layer-Thickness, Scanning-Speed, SLM

I. INTRODUCTION

Selective Laser Melting is a fabrication technique used to melt the particles of any metallic powdered substrate and is a layer-by-layer process to build the desired 3D shape of part component. It is an effective or the constructive way of geometry and making of steel-parts. Low carbon stainless-steel with good quality features and credibility and security can be easily and produced by the SLM-process [1,2]. Very complex 3-D components or parts with critical inner structures can be easily produced by the Selective-Laser-Melting process. This process involves the local-melting of high-quality homogenized mixture of alloy-powder by employing a very high power laser beam. The benefit of this process is that a very lesser number of persons are involved in this [3,4]. The process of Selective-Laser-Melting is a process which generally consists of the melting of only that region or the selected area of a powdered-substrate which is marked by the laser-scanning action to get melted by the energy provided by the Laser [5]. Firstly, the 3-dimensional model of the product or the part component to be obtained for the desired purpose is being drawn on the computer-software and then the stored in the .STL file format in the computer then the powder of the given material is poured on the build-plate [6]. The build-plate prepared for the storage of the powdered material in the machine of SLM is now kept inside the SLM machine for the further action of melting by the laser [7]. After the powder has been kept inside the SLM machine, the most essential task is the optimization of process-parameters [8]. The optimization of the process-parameters is very important to maintain the proper melting of the powder, so that it is protected from the damage by excessive-burning [9,10].

II. THE PROCESS-PARAMETERS OF SELECTIVE LASER MELTING –

- Laser-power
- Laser-scanning Speed
- Hatch-spacing
- Layer-thickness
- Scanning-Strategy
- Laser Energy density

During the laser-scanning action, many times there is incomplete burning or the incomplete melting of the powder material taken on a build plate. Also there may be an excessive burning of the material taken [11,12]. The only reason is that, there is a shortage of good optimization of the process-parameters like maintaining the Laser-power, scanning-speed, hatch-spacing and layer-thickness upto a good range or proper limit, otherwise the material gets burned or remains incompletely fused, due to which there are lot of pores created in the specimen [13,14]. Defects like porosity, voids, balls and keyholes are created in the sample made. Those defects can reduce the strength of the material and the other physical properties of the sample made [15]. A very good scanning-strategy is always required to avoid such defects [16]. The material taken in this study is basically the SS316L stainless-steel. A diagram for the process of Selective Laser Melting is shown in the Fig.1(a) and Fig.1(b), in the next page.

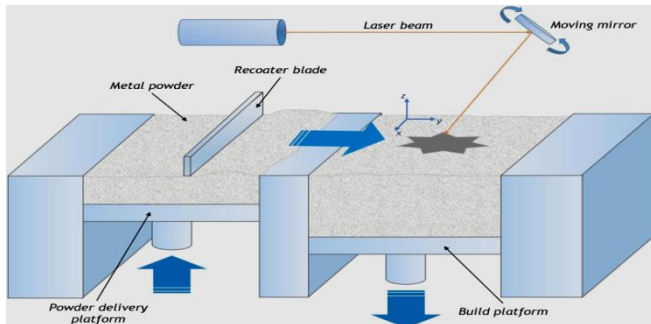


Fig. 1(a)- Selective Laser Melting Process

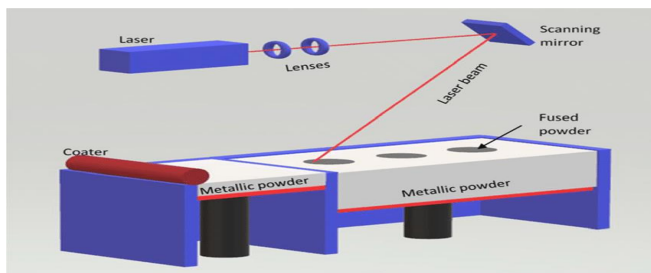


Fig. 1(b)- Selective Laser Melting Process

(i). Importance of Stainless-Steel 316L

- SS 316L is a very popularly used powdered material, because of its excellent mechanical features and anti-corrosion properties. SS316L steel can be used to prepare highly-dense part or components which have good-strength, [17].
- Reliability, durability and machine-ability and

weld-ability. SS 316L is widely used due to its excellent formability and impact, toughness and compatibility [18].

(ii). Importance of 3D Printed Stainless-Steel 316L

Stainless-steel 316L is widely used in the field of medical-science, like the implants in the orthopedics. Prosthesis is also prepared from the stainless-steel 316L [19]. Also there is a vast use of this material 316L stainless-steel in Aerospace-engineering [20]. Zeng et al used the stainless-steel material to construct the stainless-steel porous-structures from 316L [21]. Stainless-Steel 316L is considered ideal material to be used in Auto-motive industries for making the automobile components like the Car exhaust-filters, intake-manifolds, and hydraulic-manifolds by 3D printing technique [22]. The 3D-printed stainless-steel is used in making many marine engineering components by SS 316L [23]. Also 3D printed SS 316L is used in constructing chemical reactors, tanks and valves [24]. Due to its excellent features in marine industries, the SS 316L being 3D printed, is used in making pipes, underwater-equipments, food-processing equipments, water-treatment, heat exchangers and pipe fittings in kitchen appliances[25]. The 3D printed stainless-steel 316L is used in making the surgical instruments, fuel-injectors etc [26]. Having very excellent corrosion-resistant properties, the 3D printed SS 316L is mostly used in water treatment plants in the form of pipes [27].

III. LITERATURE REVIEW OF THE SELECTIVE LASER MELTING OF SS316L

REF.NO-	AUTHOR	MATERIAL	PARTICLE SIZE	PROCESS PARAMETER	RESULT
ma15217575, Page no-3/12, Topic no- 2, material s and methods,Art. [37].	DANIEL,RICARDO ALVES 28-OCT-2022	SS316L	22.2,32.4& 45.2µm	Laser power=260W, Scanning speed=1060mm/s, Hatch spacing =100µm, Layer thickness=30µm	Melt-pool beads were visible on the surfaces. Volumetric Energy Density has effect on the melt-pool width. Flow ability is also affected by these parameters

Vol.146/041004-1, Art. [21], Table 3- Response surface test design scheme and results. [18],[19, 20].	YALI WANG, ZHYONG LI, MAY-24	SS316L	100 μ m	Maximum power =210W, Maximum scan speed=750mm/s, Scanning spacing=800 μ m.	Increase in the surface roughness is observed with an increment in the Laser power and a reduction in the value of scanning speed. Fluidity of the melt pool is not very good, presence of un-melted powder particles around the melt channel are observed, reduction in the surface quality of the parts formed is also observed.
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1616-1629, Art [33-35], Art [36], Table 6, Results of SLM, Art [39].	C.HAKAN GUR, HAMID OMIDVAR 25-JAN-24	SS316L	33.81µm	Maximum Laser power=240, highest scan speed=2000mm/s	The SS316L powder contains 0.1wt % nitrogen, G as entrapmen t led to the formation of very small/min ute pores of spherical shape which are due to the entrapmen t of the gases and the absorption of nitrogen gas. Presence of powder porosity level is only due to the influence of process parameters of SLM.
415-434, KAMATH et al [10], SUN et al [15]	N.AHMED, RK ABU AL-RUB, I.BARSOUM 25 –SEP-23	SS316L	35µm	Max Laser Power=400W, Scanning speed=2000mm/s Layer thickness=25-40µm	Componen ts made with SLM have same mechanica l strength and fatigue life similar to the traditional methods.

061008-2 Vol. 145, Art [2.1-2.2].	YASH PARIKH,KUTTOMAND LAM 20-FEB-2022	SS316L	18-20µm, and 38-40µm	Max Laser power=150W and 250W, Scan speed=50mm/s-800m m/s, Hatch-spacing =110µm	Highest densificati on is achievable only due to higher energy density with higher process parameter optimizati on.
[12,21&23], Art. [2.1], DOE table no-2, Taguchi mixed level design].	GOLDEN KUMAR, SWETA HEMANT JAGDALE. 25 sept-2023	SS316L	22.7µm,32.4 µm and 45.2µm	Laser power =150W,185,220W,25 5W, Scan-speed=650, 675,710,770,800,830, 890 Hatch spacing=111,117,123 , 125,129µm	Hardness values found to be decreasing when laser power increased keeping scan and hatch spacing constant. Increase in the Surface roughness of samples is noticed.
J.Manufact.Mater.Process. 2024, 8,35. Art. [41].	GERMAN OMAN BARRIONUEVO, JORGE ANDRES 9-FEB-2024	SS316L	20-50µm	Laser Power=160W, Scanning speed=1100mm/s, Hatch spacing=40µm.	Clustering of the powder particle reduces the effective cross sectional area and reduces strength and hardness.

F.BARTOLOMEU et al A.M.,Pg-82, 2.Experimental procedure, 2.1.2, Selective Laser Melting.	F.BARTOLOMEU, N.ALVES, F.S.SILVA, E.PINTO 21-MAY-2017	SS316L	20µm-110µ m.	Laser Power=70W, Scan rate=417mm/s, Scan spacing=0.07, Layer thickness=0.03mm.	Part density of 99% is achieved only due to higher quality due to highly optimized parameters . Parts made by SLM possess good strength as compared to the other process.
Table no-3,Process parameters of AlSi10mg and 316L	HUAN MILAO, HAO ZHANG, 25-MAY-2023	SS316L	32.24µm	Laser power=230W, Scanning speed=960mm/s, Hatch spacing=0.11mm.	Scanning speed and volumetric energy density are the most important factors in controlling the porosity level.
Table 1. process parameters combination, Experimental methodology.	JIRI HAJNYS, MAREK PAGAC, JANA PETRU SS316L S	SS316L	15-50µm	Laser power=200W, 250W,300W & Scanning speed=650mm/s.	Scanning speed has the impact on the level of porosity included with not very good results of porosity rate.

2. (a)Effect of Laser Power on the Hardness of Stainless-Steel316L

When the Laser power in the process is increased and the scanning speed & hatch spacing are decreased, keeping the scan strategy constant throughout the process, then the hardness of the specimen sample is decreased according to a study by S.JAGDALE and S.THEEDA in 2022. The decrease in the hardness is only due to the fact that when the laser power is at higher levels, it can create very larger molten pools which results in the microstructures or coarse grains that are the main cause of producing the porosity in the

sample. Those porosity formations are the main cause of decrease in the hardness of the sample at initial level. But if the laser-power is maintained to a certain level there will not be any further reduction in hardness of the sample, rather it will be improved. This is shown in the figure given below as Fig.2.(a)

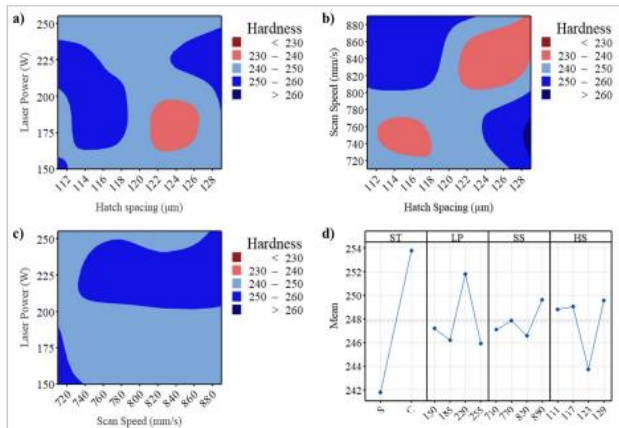


Fig-2.(a) Effect of Laser Power & Scanning-Speed on the Hardness of SS316L

[From, Figure 2, Contour plots showing the effect of (a) laser-power and hatch-spacing, (b)scan speed and hatch-spacing, c)Laser-power and scan-speed on micro-hardness, d)Main effect analysis of micro-hardness by SH Jagdale and S.THEEDA et al 2022].

2.(b) Effect of the Laser-Power on the Surface-Roughness of Stainless Steel

With an increase in the value of the laser-power and keeping the value of scanning-speed along with other parameters like hatch-spacing, layer thickness as it is, there is an increase in the value of surface-roughness as energy density of laser is increased due to an increase in the value of laser power while the remaining factors like scanning speeds, hatch-spacing and layer thickness are constant. But on the other hand when the laser-power is decreased with keeping the other factors like scanning-speed and hatch-spacing constant, then the surface-roughness of the specimen seems to be decreasing fact concluded by S.THEEDA in the year 2022, along with the scanning-strategy. The effect of the Laser-power and scanning speed both are shown in the Figure no-2.(b)

2.(c) Effect of Laser-Scanning-Speed on the Surface-Roughness of Stainless Steel316L

With density and surface-porosity values SHANMUGANATHAN in a study in the year 2023, discussed that when scanning-speed of laser is increased, then the laser energy density also increases, which then shows a rise in the relative-density. Then in this case the voids and pores are observed, which are the main reason of increase is or decrease in the roughness of the specimen of SS316L. Decreased energy-density is only due to the increased scanning-speed and the porosity is observed due to lower rate of energy-density. Surface-porosity is minimum when the scanning-speed is also at minimum level. [Art 17, SHANMUGANATHANin 2023].This is shown in the Figure no-2.(b), below for both laser-scanning-speed and the laser-power effect on the Surface roughness.

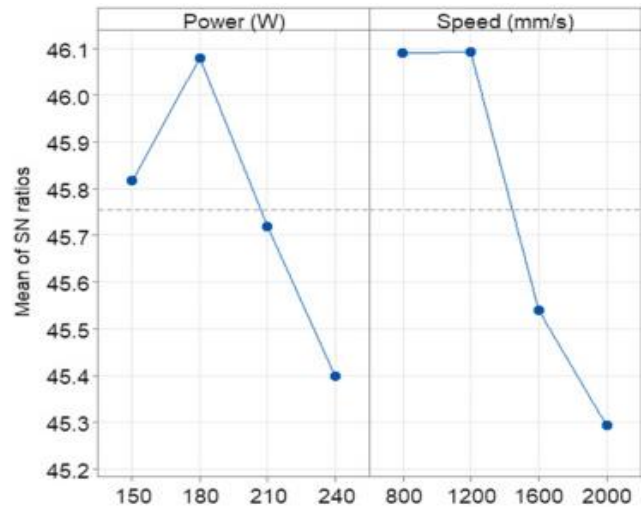


Fig-2.(b)Effect of the Laser-Power and Scanning-Speed on the Surface-Roughness of the Stainless-Steel 316L

3.(a) Effect of the Hatch-Spacing on the Surface-Roughness

The Hatch-spacing has a very important role and effect on the Surface-Roughness, that is when a proper hatch-spacing is applied, then it gradually affects the Surface-roughness. If an adequate hatch-spacing of 100μm is being used then it leads to very low surface roughness. Also a very higher-energy-density is obtained by using this rate of hatch-spacing. [ZHICHAO-DONG, YABO LIU, WEBIN WEN JINGRAN GE & JUN LIANG et al 2018]. This is shown in the figure given below as Fig-3.(a)effect of the Hatch spacing on the Surface-Roughness of Stainless-steel.

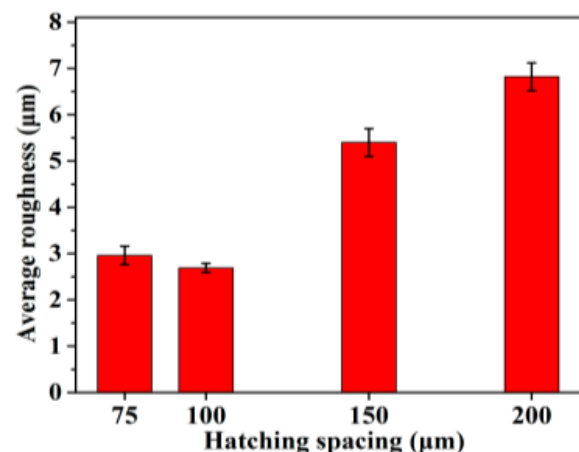


Fig-3.(a)Effect of the Hatch-Spacing on the Surface Roughness of Stainless-Steel 316L

[Fig-10. AVERAGE-ROUGHNESS OF THE TOP SURFACE-ROUGHNESS OF THE SAMPLES a=75,b=100,c=150 & d=200 in μm Hatching spacing byZHICHAN DONG, YABO, WEIBIN WEN, JINGRAN GE AND JUN LIANG et al 2018].

IV. SUMMARY

The study on the Selective Laser Melting of stainless-steel 316L gives analytical information on the importance of SLM on the formation of parts or the components made from the material SS316 powder. How the variation in the values of the process-parameters affect the mechanical properties of the material, how easily and in less-time and with very less persons, in the making of SLM printed part can be made with optimized process parameters, is studied here in the analysis. Changing one of the value of the process-parameters and then keeping the others unchanged, affects the properties of SLM printed-parts and damage of powdered material is also observed, for which the remedy is only to set them at a normal-level. The improvement in the features and performance of the stainless-steel 316L can only be observed, when a lot of defects are removed away from the samples made, and a very high quality laser-energy density is used for the melting of the powder and shielding of the atmosphere of the SLM is considered very much important to prevent the product from the oxidation and incomplete-formation. The energy-density more than the required quantity, can be proved harmful for the specimen as the powder of the material starts burning and due to which a lot of pores and voids are generated, which directly affects the Surface-quality of the SLMed samples. The different particles are used in different experiments which shows, that particle size of the powder material is very essential for the good formation of the product under the **powder bed fusion process**. When the melting of the powder material is good, then the chances of porosity formation is very less which directly affects the density of the product formed. The density is highly dependent upon the melting rate of the powdered material, because when the more number of particles are properly melted down by the laser, nothing remains to be burned and everything is completely burnt, which will be an essential factor for the complete and stronger formation of the part or component needed. The higher laser power is completely avoided to prevent the excessive burning of the material. A very lower or moderate laser power is considered ideal. The scanning-speed with other factors like hatch-spacing and layer-thickness when kept constant to some extent, need a moderate laser power for the absolute-scanning action by the laser. A better scanning action is responsible for the presence of cellular grains in the sample. Scanning-strategy plays an important role in the stress free texture of the material formed.

V. FUTURE SCOPE OF THE MATERIAL SS316L 3D-PRINTED

There is a vast scope for the usage of the material 3D printed stainless-steel 316L in the upcoming future, seeing its extensive applications in the manufacturing-sectors. Being both compatible for machining purposes and having an excellent weld-ability conditions whether it is in the

aerospace-sectors or the marine-engineering-sector, this material is best suited for the making of even the most complicated parts with possible ease of making and with less-environmental degradation. With its availability, the material used has the capability to resist corrosion upto a large-extent, so taking it into the concept of 3D-printing has a broader perspective in the coming era of additive-manufacturing. Material is very ductile also as compared to the other materials in this field. This material can fulfill the demands in the medical-science upto a long extent tackling the problem-of-corrosion. The parts made from this material SS316L can be used in large number in the automobile-sector for making the part-components which are very complex-designed and are to be used only due to their anti-corrosion properties. The most popular use of the Stainless-steel 316L can be seen in the upcoming future, the material is most suited for the making piping products like valves, ducts and pipes as it has the excellent corrosion-resistant property, which makes it the most unique material in the field of Additive-Manufacturing. The material also finds its utility in the food processing industry as due to its non-corrosive nature, where it may be proved a very good idea to make use of the SS316L for the storage of Vegetables and food materials, the food items may be kept fresh for a longer time and can be transported by it in any form like a container or box. Eatables can be stored freshly without any damage due to high-quality. This trend may be started by knowing the durability and clean-ability of the material where it is able to protect itself from the adverse or extreme conditions. This can protect itself from the attack of powerful-chemical substances used in the food-industries like sodium-benzoate, sodium-nitrite and synthetic-substances used for sweetening the food items. The material Stainless-steel 316L being 3D printed can be vastly used in the material handling and automation industries, taking its property of high-machinability, flexibility, weld ability and its lightweight/portability into consideration, will make a prospective way for it, become the highly sustainable material that will be produced with less-cost, less manufacturing process, less-noise and will give higher durability and with developed bio-compatibility enhanced-strength. The advanced type of equipments, used in the field of surgery can be smoothly manufactured using the 3D-printed SS316L material knowing its sustainability.

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