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# SOME STUDIES ON SURFACE METALLURGY OF SS316L 3D PRINTED STENT USING SELECTIVE LASER MELTING

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**Abstract:**
This examination of the surface integrity of an SLM-printed powder stent made of SS316L is presented in this work. For the evaluation of surface roughness, four samples from various post-processing conditions, including electropolished, stress relieved, electropolished and stress relived, and without stress relived and without electropolish, was chosen. Various surface roughness parameters were examined in this paper in relation to the SLM procedure. The SS316L 3D-printed powder stent's grain size, grain orientation, local intergranular misorientation, and surface topography were further assessed using characterization techniques like SEM and EBSD. The result demonstrates that electropolished stents with less stress improve surface integrity.

***Keywords:*** *CHD, Stent, Selective Laser Melting, Surface Roughness,316L SSpowder, Metallurgical Aspects*

## 1. Introduction: -

Numerous cardiovascular diseases have become more prevalent recently, and an increasing number of people have early-stage heart disease. Each year, countless individuals need assistance in the fight against heart disease. Coronary artery bypass grafting, heart transplantation, and coronary angioplasty are among the treatments for cardiac disorders brought on by blocked arteries [1].One of history's most important medical advancements was the discovery of coronary angioplasty. Coronary angioplasty is a technique that frees up constrictions in the coronary arteries to allow blood to flow again to the heart. In 1977, Andreas Grunting performed the first angioplasty [2].In the middle of the 1980s, the stent developed [3].The passage of the arteries is protected from further narrowing or closure with a thin metal mesh tube known as a stent. 316 L Stainless Steel (316 L SS), Tantalum (Ta), Titanium (Ti), Nitinol (Ni-Ti), Cobalt-Chromium (Co-Cr), Platinum (Pr), Pure Iron, and Magnesium Alloy (WE43) are the common materials used to make stents. The raw materials most frequently used in the manufacturing of stents are 316L stainless steel. marine-grade, food, chemical, marine, aerospace, and biomedical industries all use 316L stainless steel, marine-grade steel.Because it has qualities that are simple to fabricate, biocompatible, have acceptable mechanical strength, and are corrosion-resistant. The surface topography of implants is crucial for the formation of the stent-artery interaction. The complexity of the process and the use of bioimplants define the value of surface roughness. As a result, to increase biocompatibility and performance, bioimplants such as cardiovascular, orthopedic, and dental implants need to have a Ra value in the range of 10 nm–100 mm [4-5].In the manufacturing of bio-implants using any conventional or unconventional procedure, surface properties are crucial. There is a need for comprehensive research in the investigation of the surface properties of bio-implants. In 3D printing, the material is added layer by layer to produce the finished object. It is therefore crucial to assess the surface produced by 3D printing in terms of its use in bioimplants. Additionally, no research has been published on the metallurgical elements of 3D-printed bioimplants. This study examines the metallurgical properties and surface roughness characteristics of an SLM-fabricated 316L stainless steel stent. In particular, the surface roughness was quantified, and then the grain size, grain orientation, and local intergranular misorientation were assessed using scanning electron microscopy (SEM) and electron backscatter diffraction (EBSD). Four samples were compared in order to examine the surface roughness characteristics and however the good surface quality exhibited stent, further considered in metallurgical aspect for overcoming the difficulties associated with using 3D printing to produce bioimplants.

## *2 Materials and Method*

### *2.1 Stent Design and Material*

The experimental study used 316L stainless steel powder because of its simplicity in production, biocompatibility, appropriate mechanical strength, and corrosion resistance qualities. A stent with the following dimensions: length 40 mm, exterior diameter 4 mm, inside diameter 3.5 mm, axial gap between neighboring stents 3.69 mm, and strut thickness 0.5 mm, was the subject of experiments. The stent in Fig. 1 was created using the CREO programme and served as an input for the SLM process used in 3D printing. To ensure that the part receives support while being printed, the stent's design is closed-structured.

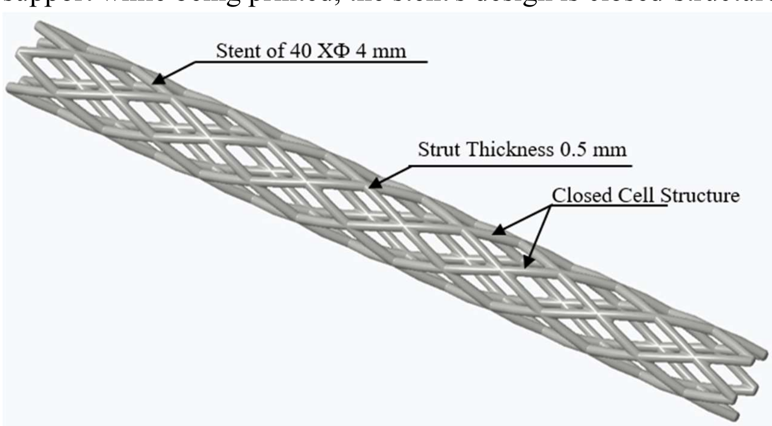


Fig.1 316L 316 L SS Stent Used in Experimentation

Table 1 lists the molecular composition of the 316L stainless steel powder used to create the experiment's stent. Manufacturer: OEM developed the powder through a gas atomizing process. The powder used has a particle size range of 10 to 45 m and a spherical particle shape. The powder had a bulk density of 7.95 g/cm3 and a thermal conductivity of 15 W/mK.

**Table 1** Material Characterization of 316L stainless steel.

| **Elements** | Fe | N | C | S | P | Si | Mn | Mo | Ni | Cr |
|---|---|---|---|---|---|---|---|---|---|---|
| **Wt.%** | bal. | 11.39 | 0.015 | 0.016 | 0.011 | 0.74 | 1.22 | 2.37 | 11.39 | 17.37 |

### *2.2 SLM Setup*

The industrial SLM system (SLM solutions SLM 280) was employed in the experimental of 3D printing of the stent, as illustrated in Fig.2. Optimized input process parameters were taken into account in this work. Pre-pilot trials, preliminary experimentation, and a literature review are used to finalize the parameters. The stents were printed with a constant layer thickness of 60 µm and a height aspect ratio of 1mm. The machine parameters were set up to produce the stent at a rate of up to 113 cm3/h. The procedure had an 80 µm beam focus, a scan speed of 10 m/s, and an average inert gas usage of 13 l/min.


Fig. 2 SLM 280 Setup (*Courtesy- 3D Product Development Pvt. Ltd.*)

Further sand blasting technique was used for cleaning the powder particles from the stent. These parameters were respect to supports as the part has a low thickness. Fig. 3 shows 316 L stainless steel powder stent manufactured on SLM 280 setup.

Fig. 33D Printed SS316L powder stent with SLM process

## 3. Results and Discussion

### 3.1 Surface Roughness

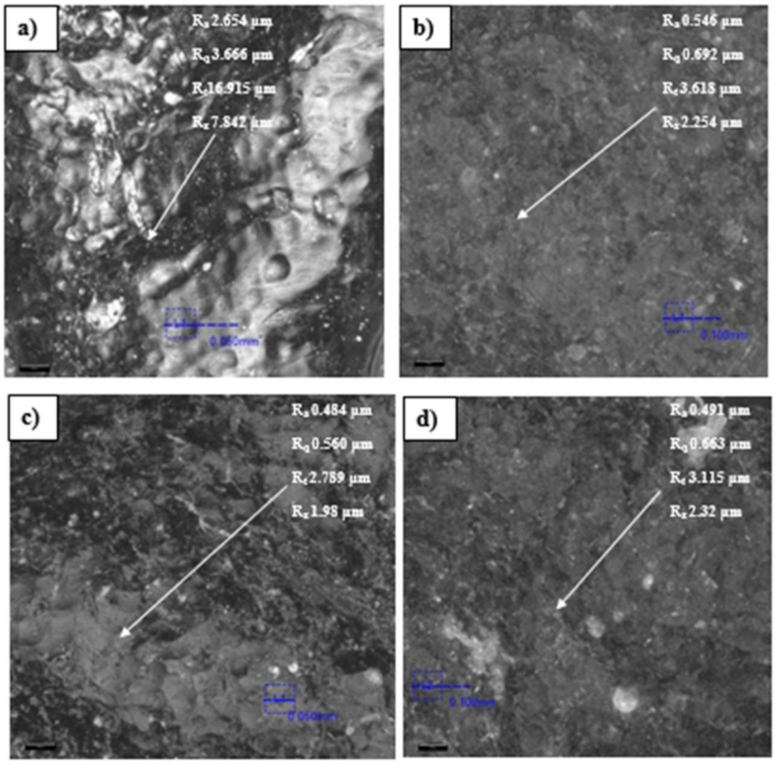


Fig. 4 Measured surface parametersa) stress relieved b) electropolished c) stress relivedand electropolished d) without stress relivedandwithout electropolished

Surface roughness is a crucial bioimplants characteristic because it affects how stents and arteries interact. In this work, the Bruker Alicona CMM was used to measure the average surface roughness of four samples with a sample profile length of 80 m and a lens set of 10x to 80x. From Fig. 4, the stress relived electropolished stent had an average surface roughness of 0.484 $\mu$m, root mean square of the profile of 0.560 $\mu$m, total height of the roughness profile of 2.789 $\mu$m and ten-point mean roughness of 1.98 $\mu$m, which were on lower side as compared to remaining three samples.The measured surface parameters for stress relived and electropolished stent were lower than that of the other three samples.

### 3.2 Surface Characterization

The surface morphology of the 316L stainless steel parts produced by the SLM process needs to be investigated because several instances have been noted, including deformation brought on by post-processing operations, warpage, porosity, and unmelted powder that causes microcracks in the 316L stainless steel powder produced by the SLM process.316L stainless steel powder stent surface morphology was investigated using scanning electron microscopy (SEM) examination on a ZEISS GeminiSEM 300. To examine the surface morphology at 1000x magnification, SEM was conducted along the length. Microcracks, unmelted powder, and porosity were seen in the stress-relieved, electropolished, and untreated stent samples, according to the scan results. In contrast, the smooth surface of the electropolished, stress-relieved stent sample is illustrated in Fig. 5.The surface morphology of the 3D-printed 316L stainless steel powder was studied using SEM analysis with a ZEISS Gemini. This was done to investigate the surface morphology of the 316L stainless steel parts manufactured by the SLM process, as there are several issues observed, such as deformation due to post-processing operations, warpage, porosity, and unmelted powder resulting in microcracks in the 316L stainless steel powder manufactured by SLM.316L stainless steel powder stent surface morphology was investigated using scanning electron microscopy (SEM) examination on a ZEISS GeminiSEM 300. Scanning electron microscopy was conducted along the length to examine the surface morphology at 1000x magnification. According to the scan results, microcracks, unmelted powder, and porosity were seen in the stress-relieved, electropolished, and untreated stent samples. In contrast, the smooth surface of the electropolished, stress-relieved stent sample is illustrated in Fig.5.

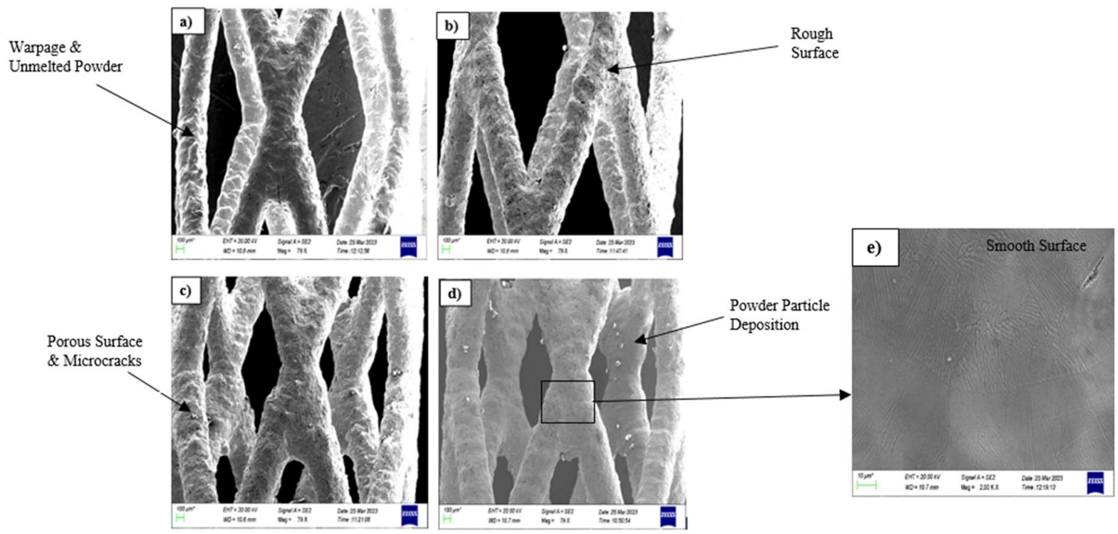


Fig 5. SEM images of a) stress relived b) electropolished c) without Stress relivedandwithout electropolished d) stress relived and electropolished e) uniform surface of stress relived and electropolished stent.

### *3.3 Grain Size, Grain Orientation and Misorientation Angle.*

The grain size and orientation of the surface metallurgy of 316L stainless steel powder significantly impact the SLM procedure. This study uses EBSD to assess surface metallurgy in terms of grain size, grain orientation, and local grain misorientation angle. Grain size, grain orientation, and local intergranular misorientation are all information that can be obtained using electron backscatter diffraction (EBSD) microscopy. EBSD images, which show the orientation of the grains through a colour change, are to be used to analyse how the grains are oriented about planes. ImageJ software is used to quantify the colour mapping of the grain orientation. The average grain size is obtained of 3D printed stent is 40 $\mu$m as shown in Fig 6.According to this, practically all grains are oriented in the (001) plane. While 19.91% and 15.53% of the grains have an orientation towards the (111) and (101) planes, respectively, 64.56% of the grains have a heading towards the (001) plane. Local grain misorientation has a significant impact on the SLM process. Local grain misorientation of the stress-relieved and electropolished stent is shown in Fig. 6(b). Local grain misorientation was used to comparatively analyse the effects of SLM procedures on surface roughness. The local grain misorientation of the electropolished and relieved stent stress is shown in Fig. 6(a). The largest grain area fraction was discovered to be below the 5° grain misorientation angle, and roughly 64 % of the grain area fraction was found below the 15° misorientation angle.

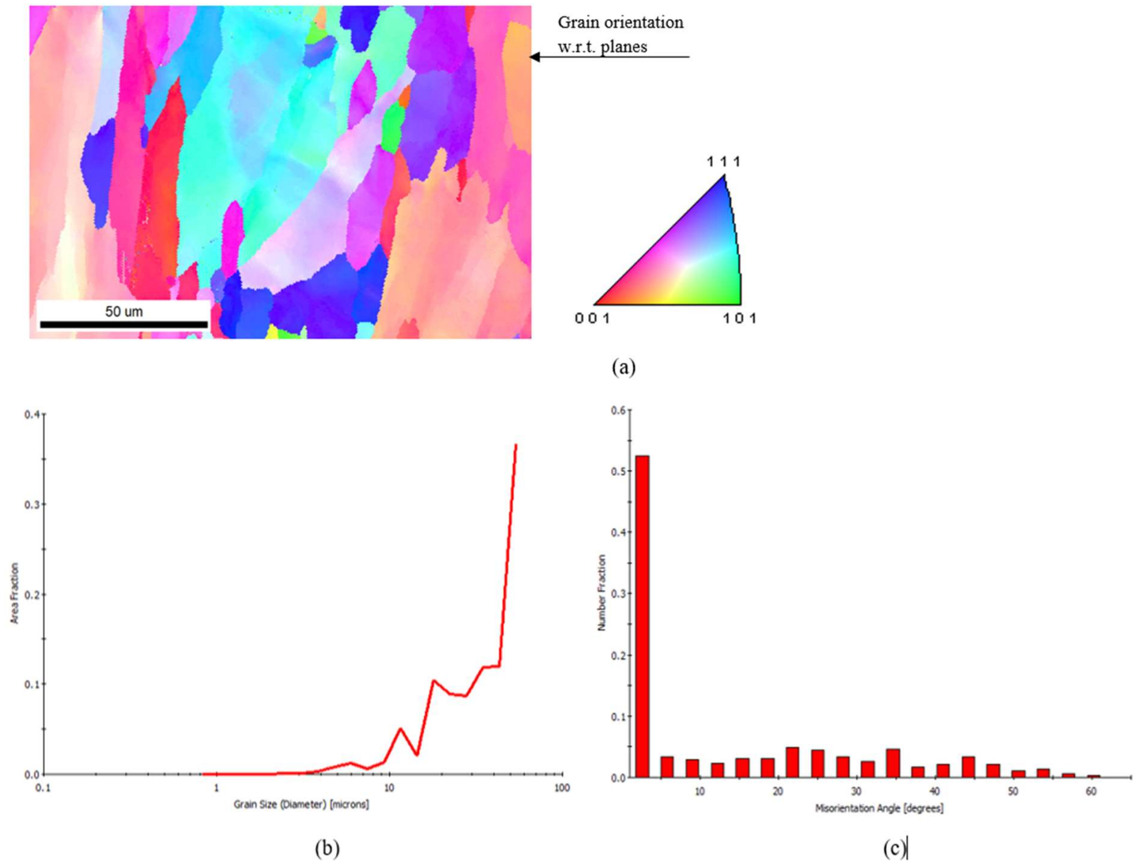


Fig 6. EBSD images of stent a) grain orientation b) grain area fraction c) misorientation angle

**Conclusion:-**

In this study, the influence of post processing techniques on surface roughness parameters were studied and in extension the optimized parameters are corroborated with metallurgical considerations such as grain size, grain orientation, local misorientation in suitability with bio medical applications. From this examinations following conclusions were drawn.

- The surface roughness parameters are more specific to exhibit surface quality. The surface parameters such as $R_a$ 0.484 $\mu$m, $R_q$ 0.560 $\mu$m, $R_t$ 2.789 $\mu$m and $R_z$1.98 $\mu$m for stress relived electropolished stent is found to be better. Whereas the surface roughness parameters as mentioned above are observed to be higher in the order of without stress relived and without electropolished, electropolished and stress relived, respectively.

- The evaluation of SEM images of surface topography of 3D printed stent surface is clearly corroborate the obtained surface parameters. The surface defects such as warpage, unmelted powder, metal deposition and microcracks are observed in SEM images of without stress relived and without electropolished, electropolished and stress relived, respectively.
- The SLM process has a significant impact on grain orientation and it exhibits the inverse relation with grain size. The average grain size is found to be 40 $\mu$m for electropolished stress relived stent. The grain misorientation is observed in electropolished stress relived stent with 64% grain area spreading in the range of 0° to 15°, whereas remaining 35 % spreads from 15° to 60°.

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