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Surface roughness variance on different levels of surface inclination of powder bed fused tool steel 1.2709

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Abstract. Evolution of additive manufacturing has allowed increased flexibility and complexity of designs over conventional manufacturing e.g. formative and subtractive manufacturing. Restricting factor of laser powder bed fusion of metals (PBF-LB/M) additive manufacturing is the as-built surface quality. To promote an understanding of the surface roughness and suitable surface measuring technologies octagon shaped tool steel 1.2709 samples was developed and manufactured. Different surface measuring technologies was also literary reviewed. Studied samples were manufactured with commercially available laser-based powder bed fusion system using standard parameter set provided by the system manufacturer. Surface roughness was measured from top and down skins from multiple different building angles in a way that process specific effects, such as direction of movement of the powder re-coater, was considered. Based on these measuring results of the samples the effect surface inclination are discussed. The results show that building angle strongly affects to surface roughness of laser-based powder bed fused parts. Surface roughness was measured to be more than five times worse in unsupported angle manufactured down facing surfaces when compared with vertical walls.

Keywords: Additive Manufacturing, Surface roughness, tool steel (1.2709), PBF-LB/M, L-PFB, SLM

1. Introduction

The driving force of ever grooving success of additive manufacturing is enabled allowed increased flexibility and complex geometry over conventional manufacturing e.g. formative and subtractive manufacturing. As-built surface quality is restricting factor of most popular additive manufacturing technique of metals, the laser-based powder bed fusion (PBF-LB/M) of metals using a laser based system. The quality or need of post processing is heavily involved by the use of support structure. The use of support structure automatically leads to poor surface quality and need of excessive post processing to finalize surface quality to application specific surface finish. The cost vice optimum would be to always manufacture so-called self-supporting shapes that do not need support structure. Unsupported down facing surfaces have partially fused particles which are lowering the surface quality comparing surface quality on the top up facing surfaces. Often when additive manufacturing surface roughness values are mentioned they are top surface and side surface quality values not the overall average quality values including also down facing surfaces. The factors affecting overall surface roughness in PBF-LB/M manufacturing process can be divided on process parameters, material properties and design aspects of the work piece. Effecting process parameters are layer thickness, spot overlap, energy density, laser beam velocity and spot angle. Material effects are powder grain size and chemical composition. Design effects are part building orientation, placement of the work piece, surfaces inclination angles. Overall process parameters for smoother surface have direct impact on additive manufactured part fatigue performance and need for further post processing steps. [1,2,3,4,5]

There are several physical phenomena in the surface formation of metal bodies produced by AM techniques that affect the surface shape as well as interfere with surface measurement. The laser, the powder layer, and the interaction between the layers beneath it significantly affect the surface details, i.e., the topography. Typical SLM printed part surface defects can be seen in Figure 1 [6]. The weld tracks are the most evident features, appearing as ridge-like formations indicating the path followed by the processing laser while traversing the powder bed. Smaller-scale ripples on the weld tracks are formed as a result of the cyclical process of liquefaction and solidification of the melt pool as the laser moves across the surface [7]. Partially melted powder particles as well as splashes cause unevenness on the surfaces of the body. The recesses on the surfaces may be due to discontinuity of the welding track, incompleteness of adjacent welds, and porosity due to gas adhesion [8].

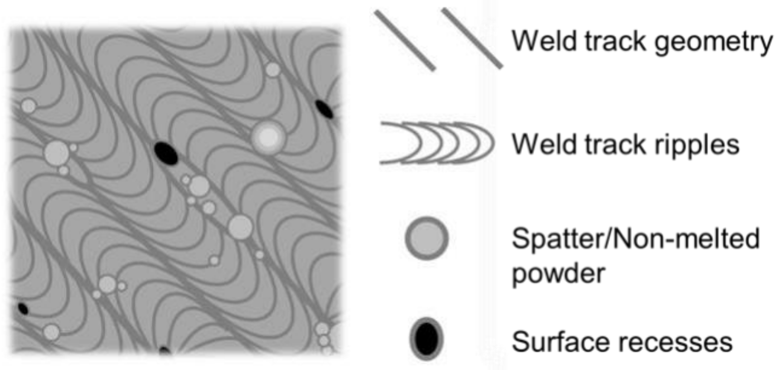

Figure 1 Topographic features relevant to investigation of surfaces, as they appear on a layer of an SLM metallic part. [6]

The purpose of this study is to promote an understanding of PBF-LB/M manufacturing process incline angel effect to surface roughness. Octagon shaped tool steel 1.2709 samples was designed and manufactured. Octagon shape was selected, because of prediction that shape would support itself and less support would be needed. Shape would also reveal if powder spreading (re-coater angle) has on effect on surface quality. Surface roughness was measured on samples rising and falling unsupported surfaces using optical profilometer and stylus profilometer. Different surface measuring technologies was also literary reviewed.

2. Surface measuring metrology

In general, surface metrology is defined as the measurement and characterization of a surface topology that broadly describes the shape and roughness of a surface. In this study, we are only interested in surface texture.

Lou et al. (2019) have specifically investigated methods for measuring the surface area of bodies made by additive manufacturing (AM) and the PBF (Powder Bed Fusion) method in comparison with conventionally made methods for measuring bodies. According to them, traditional measurement arrangements are not suitable for AM products due to its particularly different manufacturing method. In traditional manufacturing, regular patterns were formed on the machining surfaces, but with the AM technique, the surface formation is different. Partially melted particles and recesses in the surface distort the result and the results obtained do not sufficiently describe the functionality of the product. The surface of the print and even the shape of the surface change in the post-treatment, in which loose or partially melted particles can be removed. Prior to post-treatment, measuring the surface with a stylus-based device can be challenging if there are large partially melted particles on the surface. The stylus may not be able to measure surface depressions, particles will distort the result, the stylus may get stuck in the particles, or in the worst case the stylus will be damaged during measurement. [10]

ISO 4286 defined the surface structure parameters e.g. Ra and Rq values, while the surface texture parameters of the area are defined in ISO 25178-2 with e.g. Sa and Sq values. In industry, these values are mainly used to describe the texture of the surface, but these values do not provide enough information to control the production of additional manufacturing. [3]

Townsend et al. (2016), based on a review of surface roughness studies of AM products, the most commonly used surface roughness measurement method is a stylus-based tangential measurement. Optical measuring devices have also been used and their use is becoming more common. The optical measuring device gives a wider view of the surface by measuring the area at once. In this study, we have used a stylus device and an optical measuring device. [10]

3. Experimental setup

In order to get more surface quality data on powder bed fusion process, octagon shaped samples covering a range of surface angles were built with EOS M290 a laser powder bed fusion system. EOS Maraging Steel MS1 material and MS1 performance 2.0 parameter settings with 40 μm layer thickness was used on build processes. MS1 have a chemical composition corresponding to US classification 18% Ni Maraging 300, European 1.2709 and German X3NiCoMoTi 18-9-5. Figure 2 shows the detailed geometry of the total set of 6 octagon pieces has been made on our experimental setup. Octagons plane inclination angels vary from rising top surfaces 90°, 60°, 50°, 45°, 40°, 30° angles to falling unsupported down facing surfaces 60°, 50°, 45°, 40°, 30°, 20° angles. Octagon shape was selected, because of prediction that shape would support itself and less support would be needed. Shape would also reveal if powder spreading (re-coater angle) has on effect on surface quality. Placement of pieces on a powder bed is shown in Figure 3.

Surface quality was measured first with Keyence VX-3000 optical profilometer with surface area of 2 x 2 mm^2 rising surfaces and 4 x 4 mm^2 falling surface. Arithmetic mean surface roughness for surface value Sa and sum value Sz of largest peak height value and the largest pit depth value within measured surface area was measured. Second measuring method was stylus profilometer (contact measurement) MarSurf PS10 with 5 µm measuring stylus. With stylus profilometer, every octagon rising inclination plane surface quality was measured five times from different locations randomly over plane surface area. Final Ra and Rz results which is used in this study was average of these five measurements. Arithmetic mean surface roughness parameter Ra / Sa and sum value of highest peak to the lowest measurements Rz / Sz is used here as a representation of surface roughness.

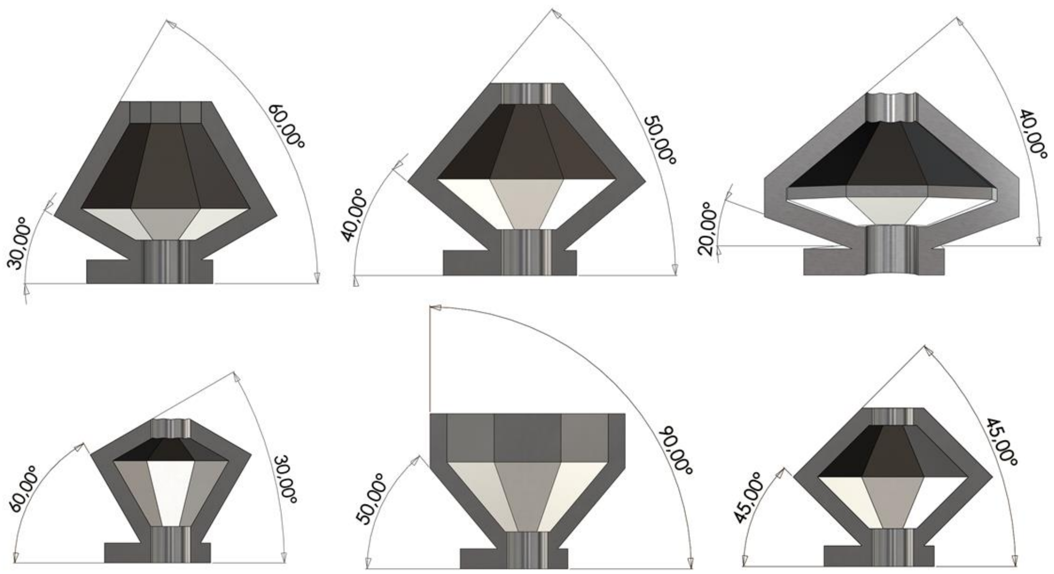

Figure 2. Detailed geometry of the total of 6 octagon pieces has been made on our experimental setup.

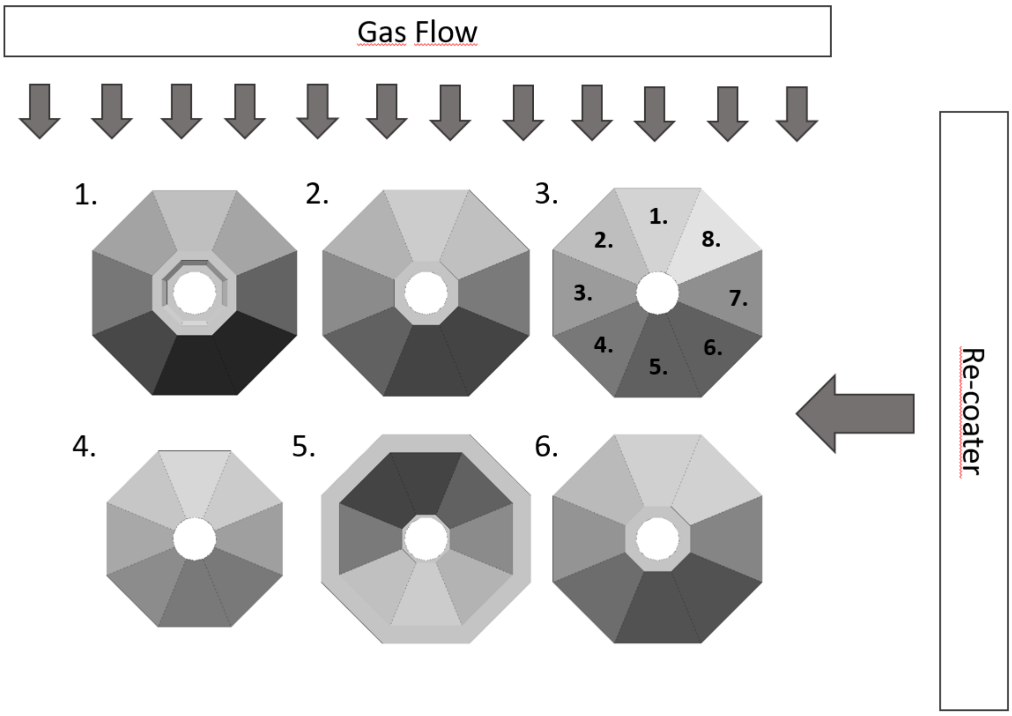

Figure 3. Detailed placement of 6 octagon pieces.

4. Results and discussion

Six octagon shape sample pieces was produced using PBF-LB/M additive manufacturing process. Octagon with 20 degrees falling surface fail on manufacturing without support structures. All other test pieces was possible to print without support structures. Due to poor surface quality on down facing surfaces stylus profilometer measuring tip was stuck on partially fused particles which result stylus profilometer to fail measure surface quality. On top facing surfaces measurements variance between optical and contact measuring methods was insignificant. One effect on small difference on values between measuring methods could be explained with measuring order where optical measurements was done first and contact stylus measurement second. Some of the partially fused particles could be fallen of between measuring.

The dependence of the surface roughness on the manufacturing inclination angle is illustrated on fig. 4 drawing and in line graph format on fig. 5 Sa and Ra - values and fig 6. Sz and Rz values. Values are average value of all eight top or down facing surfaces of one work piece. Top and down facing surface shown same trend on surface quality where surface quality deteriorated as the incline angle decreased toward the horizontal level. Top surface lowest surface roughness values on was measured on 90° angel (vertical side wall) Ra 6,7 µm and highest value Ra 11,0 µm on 30° angel. Down facing surface lowest surface roughness values on was measured on 30° angel Ra 17,9 µm and highest value Ra 58,0 µm on 60° angel. On average values shows that roughness values was three times higher on down facing surfaces comparing to top surface values. There is also significant difference of quality between down skin surfaces on 30° (Ra 58,0 µm) and 40° (Ra 36,0 µm) inclination angels. This information gives one more reason to consider not to design AM part overhangs smaller incline angels than 45° comparing to horizontal base. Values also show that ssurface roughness was measured to be more than five times worse in unsupported angle-manufactured down facing surfaces when compared with vertical walls.

The dependence of the surface roughness on the manufacturing re-coater angles is illustrated in in line graph format on fig. 7 and fig. 8. Octagon shape gives eight re-coater angles to investigate and given result values are average values from all work pieces with same re-coater angle. Re-coater angle 0° (surface 1, fig. 3) are towards gas flow and angle 270° (surface 7, fig. 3) are towards re-coater. Surface roughness measurements values variance on different re-coater angle was insignificant on incline surfaces. Top facing surface has slight increase in Rz surface roughness value between 180° to 315°, but same effect is not noticeable on other measurement values. Ra and Za top facing surface roughness values was between 7 – 11 µm on all re-coater angles and Sa surface roughness values for unsupported down facing surfaces was between 30 – 39 µm. Top facing Sz surface roughness values had biggest variance but there was no clear pattern for the variation. Calculating average value for all the surface roughness measurement values the calculation gives us Sa value 22,4 µm and Sz value 210,5 µm for overall surface quality to our test pieces outer surface.

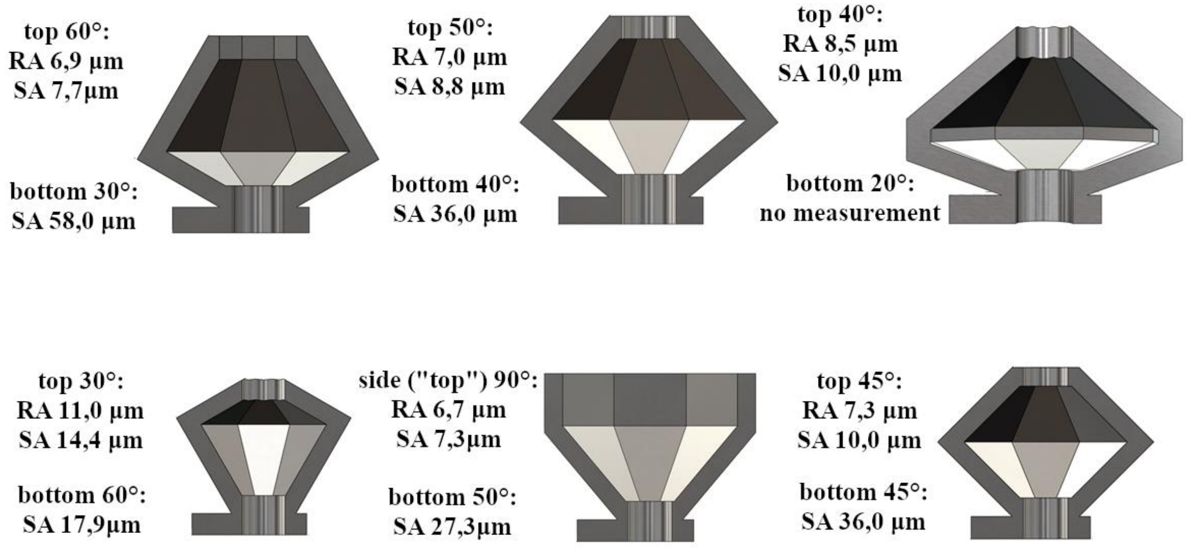

Figure 4. Surface roughness measurement results with different plane inclination angels, SA values are measured with optical profilometer and Ra values are measured with stylus profilometer. Values are average of all surfaces of one work piece.

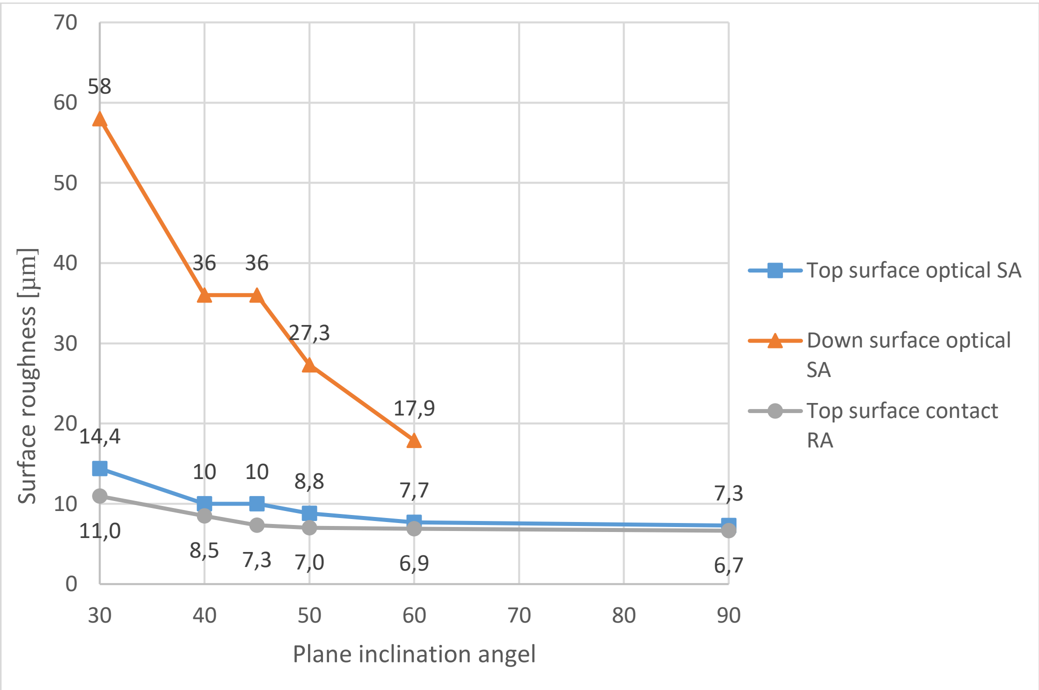

Figure 5. Line graph of surface roughness measurement results with different plane inclination angels, SA values are measured with optical profilometer and Ra values are measured with stylus profilometer. Values are average of all surfaces of one work piece.

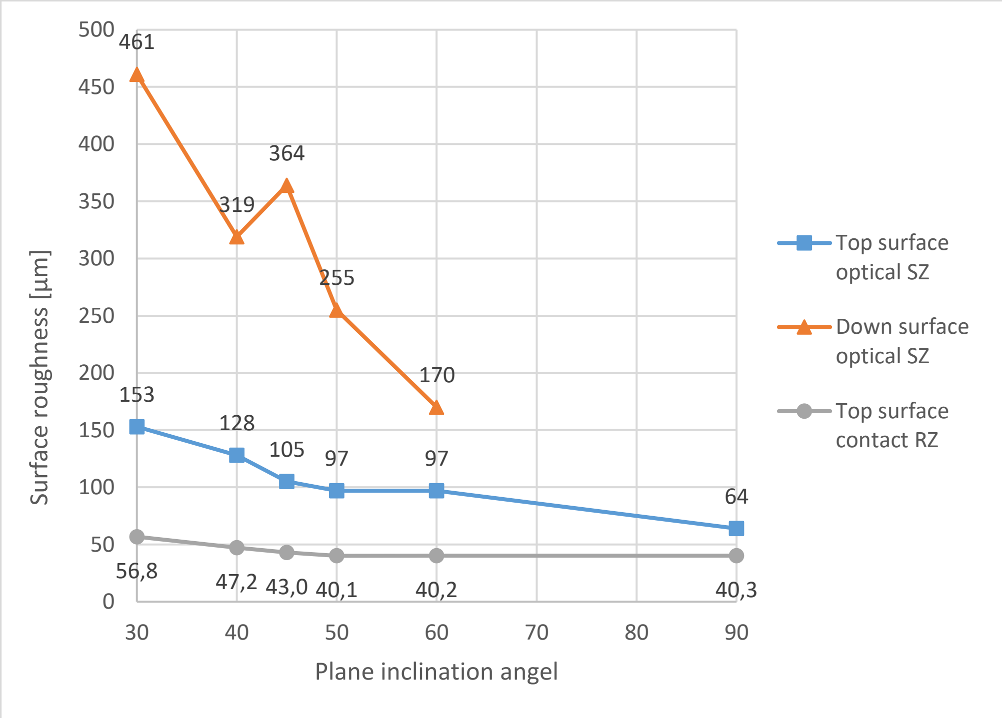

Figure 6. Line graph of surface roughness measurement results with different plane inclination angels, SZ values are measured with optical profilometer and Rz values are measured with stylus profilometer. Values are average of all surfaces of one work piece.

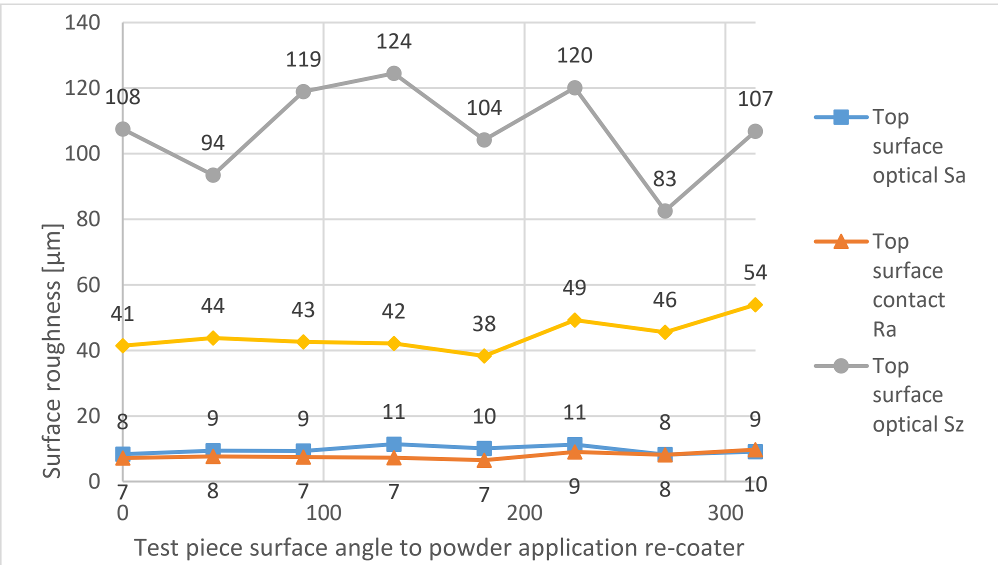

Figure 7. Line graph of top surface roughness measurements mean value from results of all test pieces with different re-coater angles, Sz / Sa values are measured with optical profilometer and Rz / Ra values are measured with stylus profilometer. Values are average of all work pieces.

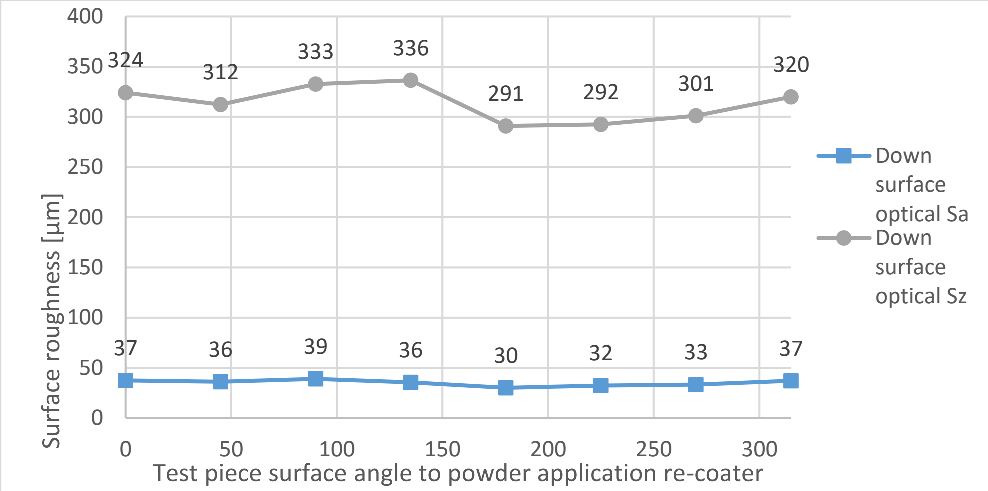

Figure 8. Line graph of down facing **s**urface roughness measurements mean value from results of all test pieces with different re-coater angles, Sz / Sa values are measured with optical profilometer. Values are average of all work pieces.

5. Conclusions

This study designed and investigated PBF-LB/M manufacturing process surface roughness quality for several incline angels and powder spreading angles. Octagon shaped tool steel 1.2709 samples were designed and additively manufactured using EOS M290 laser powder bed fusion system and commercial EOS parameter sets MS1 performance 2.0 parameter. The effect of the surface roughness was analysed multiple inclinations. Octagon shape of the samples gives eight re-coater angles to investigate. Main findings was concluded:

1. Surface roughness on unsupported down facing surfaces are so low quality that stylus profilometer with contact measuring tip was unapplied to measure surface quality.

2. Top and down facing surface shown same trend on surface quality where surface quality deteriorated as the incline angle decreased toward the horizontal level.

3. The surface roughness values show that roughness values was three times higher on down facing surfaces comparing to top surface values.

4. Surface roughness was measured to be more than five times worse in unsupported angles manufactured down facing surfaces when compared with vertical walls.

5. Surface roughness measurements values variance on different re-coater angle was insignificant on incline surfaces. Sample set was small and horizontal surfaces was not measured.

Further research and development is needed to find uniform standard ways measure and compare additive manufacture parts over all surface quality. Furthermore, considering issues could be the effect of post-manufacture polishing on uniformity of overall surface quality, part location and shielding gas effect on build plate and inner surfaces quality measuring technics.

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