MASS FINISHING OF LASER SINTERED PARTS

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Abstract

Selective laser sintered (SLS) part surfaces are quite rough textured by the layered structure and adherence of incomplete molten powder particles. Different post-treatments can help to smooth these surfaces. In this work we investigated the mass finishing method with a disc finishing machine. The aim was to quantify the influences of different process parameters on roughness values and rounding of edges. Therefore different geometries and material of abrasive media were used. Further the intensity was varied by changing the rotational speed and duration of the finishing process. Analysis was done with a 3D optical microscope to get profile and areal roughness parameters as well as radii of edges. SLS part surfaces with build angles from 0° to 180° in 15° steps were evaluated. The results show that depending on the used abrasive media roughness values can be reduced to about 15 % of its initial value in a few hours of finishing.

Introduction

Selective laser sintering is a technology to directly produce a real part out of a computer-aided design (CAD) file without the need of a tool. The CAD part has only to be saved as STL (standard triangulation language) file and sliced into layers of 60 µm to 180 µm. The assignment of the spatial position in the building chamber is done with Magics software of Materialise. This file contains now all the information, which is needed, to build up the part layer-by-layer. The raw materials that are used in SLS are powders of different materials like polymers, metals and ceramics. In general, reservoirs with powder provide the amount of material needed for one layer, which is then allocated by a counter-rotating roller or blades (depend on machine system). Then the powder is heated up, in the case of polymers, to a few degrees under the melting temperature of the material, so that a CO_2 laser scans and melts the required area of this specific layer to build up the part. The unmelted powder remains and functions as support. Finally, the building platform is lowered by the thickness of a layer and these steps are repeated until the part is complete [1, 2].

The layered structure of this process leads involuntarily to a stair-stepping effect on part surfaces which are tilted in respect to the building platform. Additionally the high temperature in the process entails the adherence of incomplete molten particles to the surface. These two effects cause rough part surfaces which hinders SLS parts to be used in visible applications [3, 4]. Therefore different post-processing methods like blasting, slide grinding and chemical treatment were investigated yet. As slide grinding is a low priced method with low manual effort that can also be used for part finish of other manufacturing processes we examined this process using the example of mass finishing with a disc finishing machine [5]. We varied the process parameters of the grinding process and measured and analyzed the surface topographies using a 3D optical microscope to evaluate the influence on part surfaces with build angles of 0° to 180° in 15° steps.

State of the art

Some work was done in evaluating methods to improve the surface quality of parts produced by Layered Manufacturing (LM). An early work by Spencer et al. addresses the vibratory finishing process for stereolithography parts [6]. They investigated two part material types and considered different geometric features with a special test part. The result was a 73 % reduced profile arithmetic mean R_a for the Ciba Geigy XB5143 material.

Especially vibratory grinding was investigated by Schmid et al. with SLS parts [5]. They used various grinding media and part geometries and processed the parts up to 12 hours. The analysis via a profilometer featured a great reduction of R_a from 10 µm to 2 µm concluding that the process parameters of the grinding process has to be refined to get even better results.

A new approach by Beaucamp et al. for titanium alloy parts exhibits a promising method for finishing metal parts [7]. Their shape adaptive grinding method uses a elastic membrane covered with nickel bonded or resin bonded diamond pellets which conforms to nearly any freeform surface. Several parameters can be actively controlled by a 7-axis CNC machine. Using three following process steps with different abrasive types they achieve a decrease of R_a from 5 µm to 10 nm.

Basics

A sample was designed (figure 1) which covers surfaces with build angles of 0° to 180° in 15° steps by building it in two different orientations, see figure 2. The left orientation where one surface is parallel to the building platform is the zero-orientation from now on, tilted-orientation the right one. Two surfaces abreast each other are parallel so that surfaces can be measured in a horizontal alignment. Moreover the part is built with a wall thickness of 4 mm as a solid build wouldn't be useful for this process.

The used disc finishing machine ECO 1x18 from OTEC GmbH operates by rotating the base plate disc of the round chamber and thereby creating a toroidal stream of the grinding media. The speed of rotation can be adjusted from 150 rpm to 319 rpm. Another big influence on the process has the grinding media where a lot of different materials, geometries and sizes are available [8].

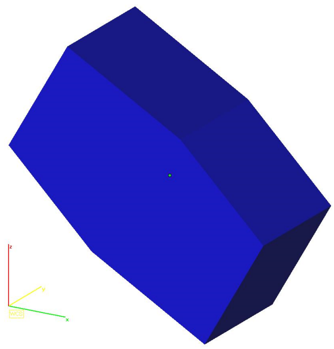

Figure 1: CAD model of the sample part, the edge length is 18 mm.

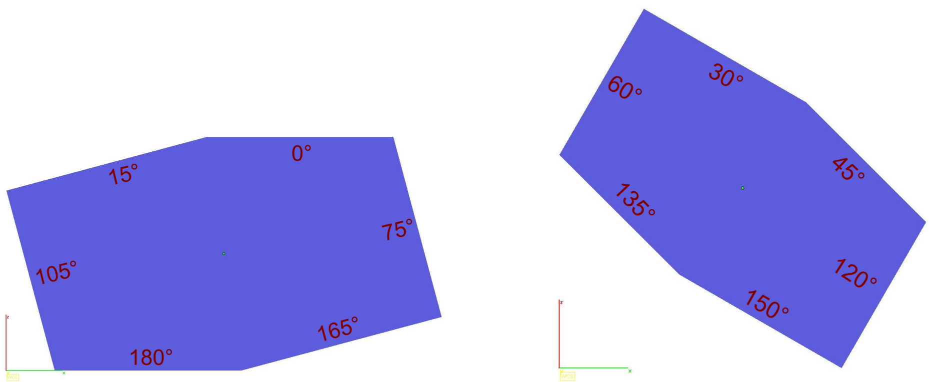

Figure 2: Front view of the sample with zero-orientation (left) and tilted-orientation (right) and their related build angles of the single surfaces. The large front and back sides are tilted 90°.

The analysis is done with a 3D optical microscope "VR-3100" by Keyence company. This measuring instrument uses fringe light projection to calculate the surface topography via triangulation. From the measured 3D data profile and areal surface roughness values according DIN4287 [9] and DIN 25178 [10] can be obtained as well as the radii of edges and comparisons between two 3D measurements.

Experimental conditions

The samples used in this work were manufactured in one build job on a EOSINT P 395 machine with mixed PA 2200 powder and PPP Balance (120 µm layer thickness) standard process parameters. Each orientation of the sample was built in one layer with sixty parts next to each other facing the largest surface to the x-z-plane.

For the process of grinding we wanted to obtained how different grinding media, the speed of rotation and the duration of grinding influences the surface quality of LS parts in respect to their building angles. Therefore we chose three different ceramic grinding media which are supplied by the disc finishing machine manufacturer, see figure 3. The geometry and material of the media are the main factors different media are classified. So we used two coarse finishing media made of the same material but one with a cylindrical diagonal cut and the other with a triangle geometry. The third media then has the same geometry as the second one but is made of a different material with a fine finish effect. The influence of rotation speed was evaluated by means of 150 rpm and 250 rpm. Finally the duration of the grinding process was investigated with times of 20, 60, 180 and 300 min while measuring the surface quality after each time step and continuing grinding the same samples to the next processing duration. For the sake of statistic statements each test series was done with three samples of each orientation.

Figure 3: Used grinding media: coarse finish media with cylindric diagonal cut shape and 3 mm and 5 mm edge length (left); coarse finish media with triangle shape and 6 *mm* edge length (middle); fine finish media with triangle shape and 6 mm edge length (right).

The topography of each surface of a sample was measured by stitching together an area of about 7.1 mm × 9.3 mm. From this area the roughness values R_a and R_z are calculated as the mean from ten profiles perpendicular to the steps on the surface. The roughness values S_a and S_z are calculated as the mean of nine subareas with the size of 2 mm × 2 mm. Individual measurements were done from the edges to determine the radii. This was done by taking the mean profile from sixty line scans across the edge and then measuring the radius of the edge.

Surface roughness results

First of all the results of the surface roughness evolution is presented by reference to profile and areal arithmetic mean (R_a and S_a) and mean roughness depth (R_Z and S_z) values. Figures 4 and 5 compare the profile and areal arithmetic mean values regarding the process duration for the three grinding media with the two rotation speeds. The same comparison is done in figures 6 and 7 with profile and areal roughness depth values. Both figures display the results with a B Spline fit using the example of the 15° tilted surface. These results are qualitatively representative for all surface orientations. The final surface roughness is more influenced by the choice of grinding media than the initial surface topography due to the build orientation. After 300 min of grinding the reduction of surface roughness figures in ascending order as follows. The ZSS media achieves the lowest reduction, even with a rotation speed of 250 rpm the reduction is similar and lower to the effect of the DS and DSF media with a rotation speed of 150 rpm, respectively. Hence, the modification of the geometry has a similar influence as the increased rotation speed. Increasing the rotation speed to 250 rpm with DS and DSF media the final roughness can reduced to another factor of up to 4. The different abrasiveness of these two media result in a little more reduction of the surface roughness with DSF media, which yields in a maximum reduction down to 16 % of the initial roughness values.

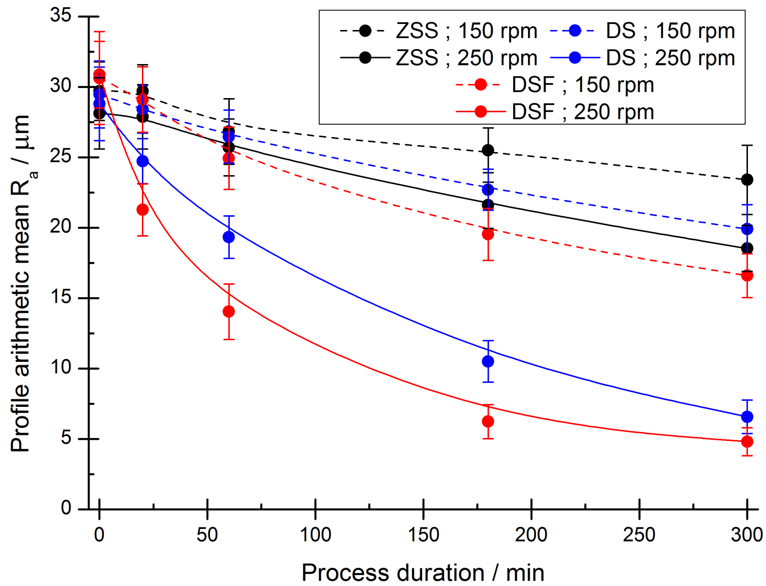

Figure 4: Diagram of profile arithmetic mean roughness depending on the process duration for the three grinding media with two rotation speeds for the 15° tilted surface.

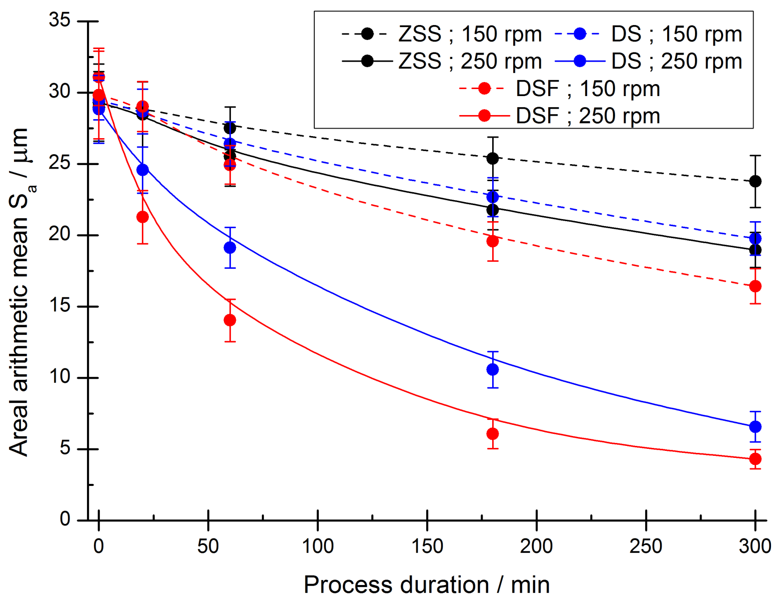

Figure 5: Diagram of areal arithmetic mean roughness depending on the process duration for the three grinding media with two rotation speeds for the 15° tilted surface.

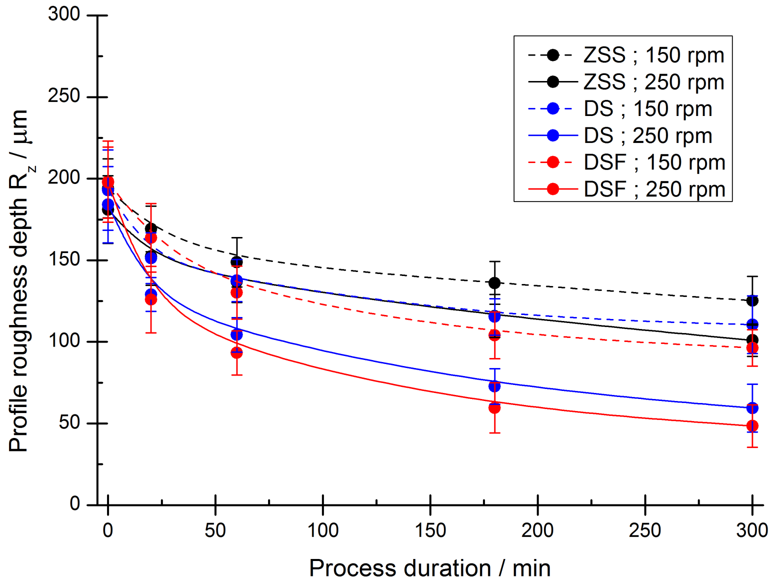

Figure 6: Diagram of profile roughness depth depending on the process duration for the three grinding media with two rotation speeds for the 15° tilted surface.

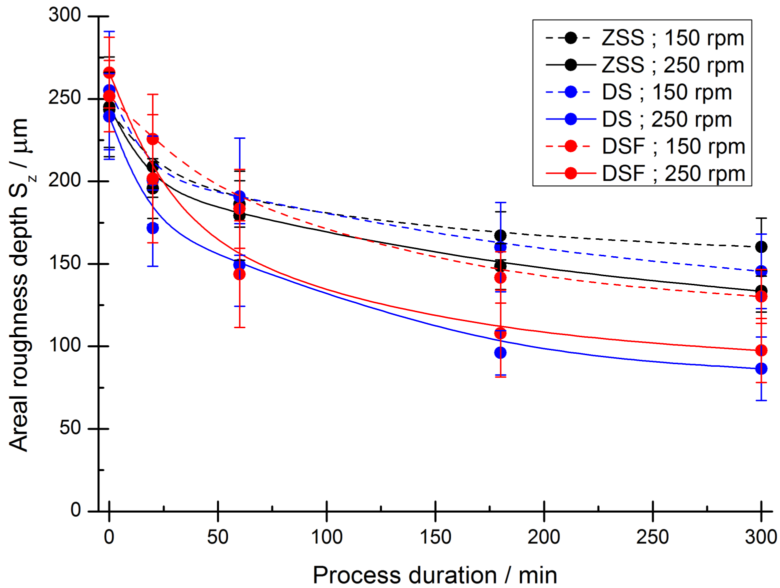

Figure 7: Diagram of areal roughness depth depending on the process duration for the three grinding media with two rotation speeds for the 15° tilted surface.

Comparison of 3D Topographies

Expanding to the determination of roughness values the 3D measurements of the surfaces depict the structure of the resulting topographies. Figure 8 shows the initial surface topography of the 15° tilted surface in comparison to the measurement of the same surface treated with DSF media for 300 min at 250 rpm in figure 9, which results in the lowest roughness values. In the initial topography stair-steps and incomplete molten particles are obvious. These adhered particles cannot be recognized after the grinding process whereas the stair-steps are still apparent because the peaks are ablated from the abrasive media but the valleys are not filled up with material of course. The amount of roughness reduction can clearly be seen by comparing profiles of both topographies. This is done by averaging sixty profiles perpendicular to the stair-steps per measurement and plotting in one diagram (figure 10).

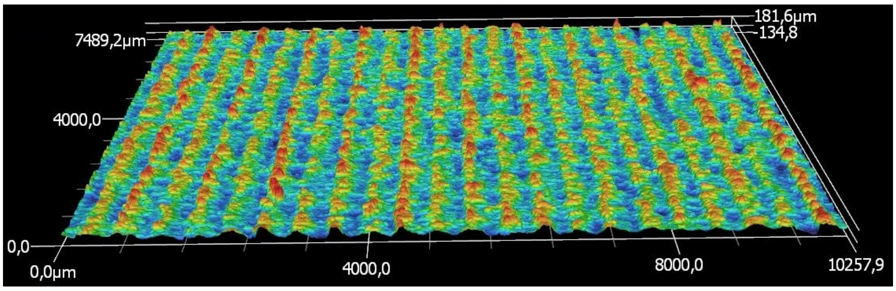

Figure 8: 3D measurement of the initial surface topography of the 15° tilted surface.

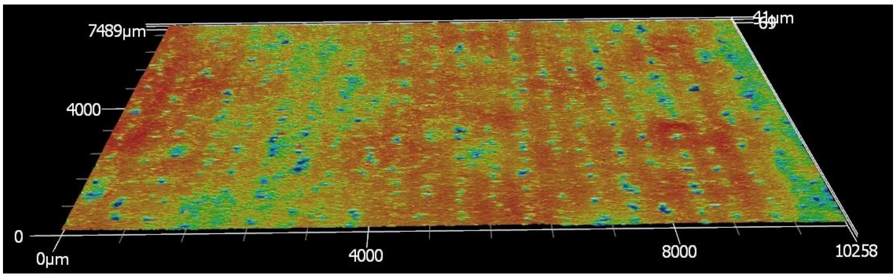

Figure 9: 3D measurement of the surface topography of the 15° tilted surface treated with DSF media for 300 min at 250 rpm.

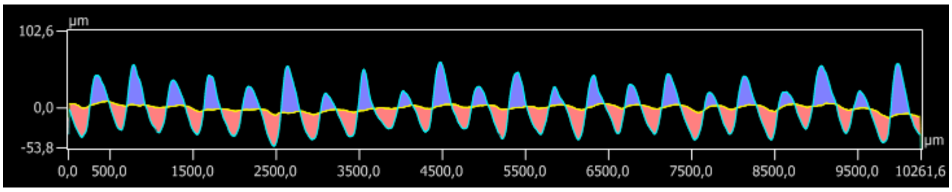

Figure 10: Comparison of averaged profiles perpendicular to the stair-steps from measurements of figures 8 (yellow profile) and 9 (blue profile).

Another interesting comparison is made between a fast and slow smoothing of the surface namely a treatment with DS grinding media for 60 min at 250 rpm on the one side and for 300 min at 150 rpm on the other side. These alternative processings result in surfaces with the same roughness values as can be seen above. Figures 11 and 12 show the measured topographies of both surfaces. At least the the depiction of the averaged profiles in figure 13 features the similarity of them. Taking these two parameter sets into account the product of intensity to the power of three and time ($f^3 \cdot t$) seams to be the relevant factor.

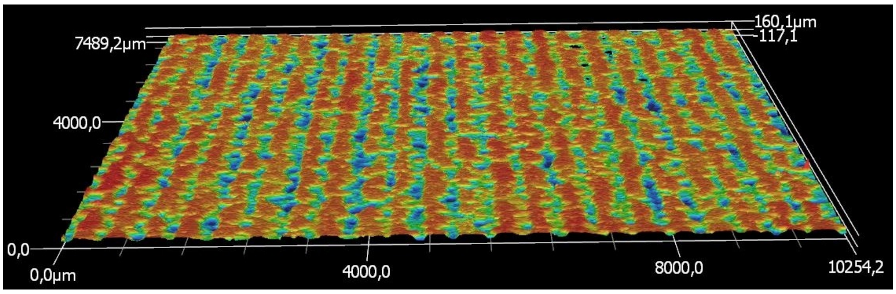

Figure 11: 3D measurement of the surface topography of the 15° tilted surface treated with DS media for 300 min at 150 rpm.

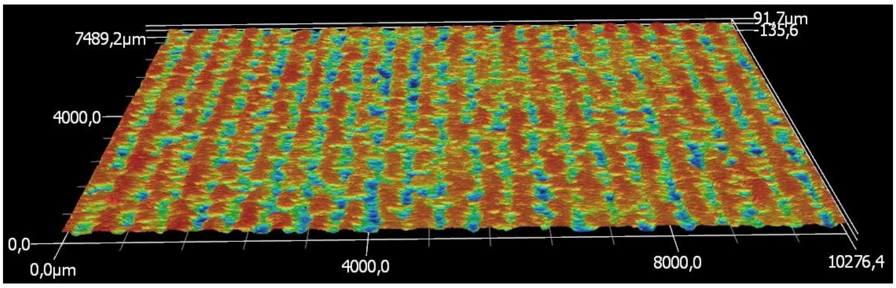

Figure 12: 3D measurement of the surface topography of the 15° tilted surface treated with DS media for 60 min at 250 rpm.

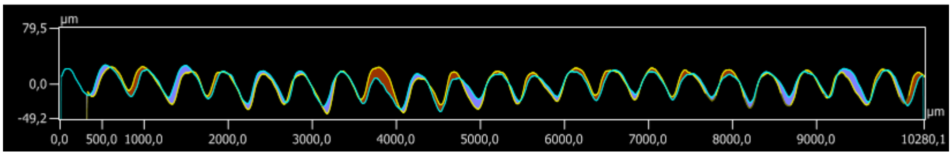

Figure 13: Comparison of averaged profiles perpendicular to the stair-steps from measurements of figures 11 and 12.

Analysis of edge rounding

Away from the surface quality part accuracy is an important topic in part finishing. Therefore we measured the edges, took the average profile from sixty profiles across the edges and determined the radius with it. In the following the focus is on the 90° edge which is for example the edge between the 30° and 60° surfaces of the tilted-orientation part as an upward directed edge.

In figure 14 the rounding off for the upward directed 90° edge from the samples with tilted-orientation after 300 min of treatment with the various grinding media is shown. The diagram is ordered from to right starting with the grinding media and rotation speed that results in highest roughness values. So it can be seen that a smoother surface finish implicate a higher rounding of edges whereas a processing with DSF grinding media at 150 rpm result in a quite low radius. Hence, the results give the indication that softer grinding process can degrade the rounding of edges, of course with the cost of longer process duration to get a specific surface roughness.

Another influence factor for part accuracy features the analysis of the orientation and direction of the edges. The edge radii for the 90° edges of the initial and most smoothed state are shown in figure 15. First, it can be seen that the downward directed edges have a three times larger radius as the same upward directed edges. Then, the orientation has a big influence, too, as a change from zero-orientation to tilted-orientation reduce the radius by half. Even after the strong treatment of the part the differences in orientation and direction of an edge is still obvious.

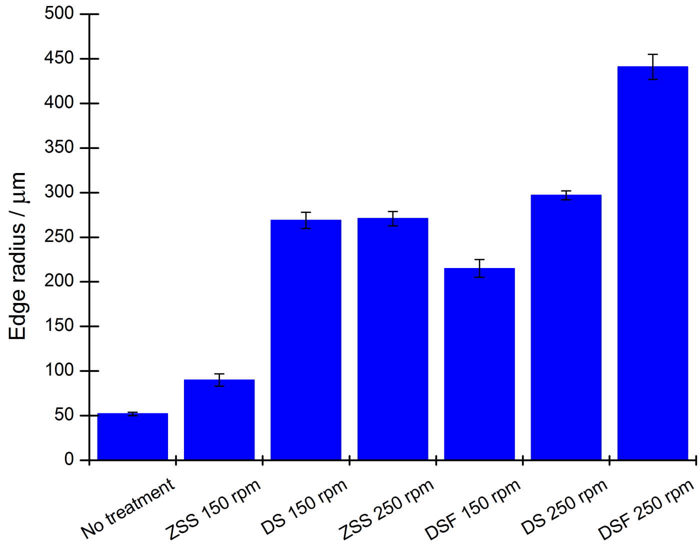

Figure 14: Edge radius of the upward directed 90° edge from the samples with tilted-orientation after 300 min grinding process depending on the grinding media.

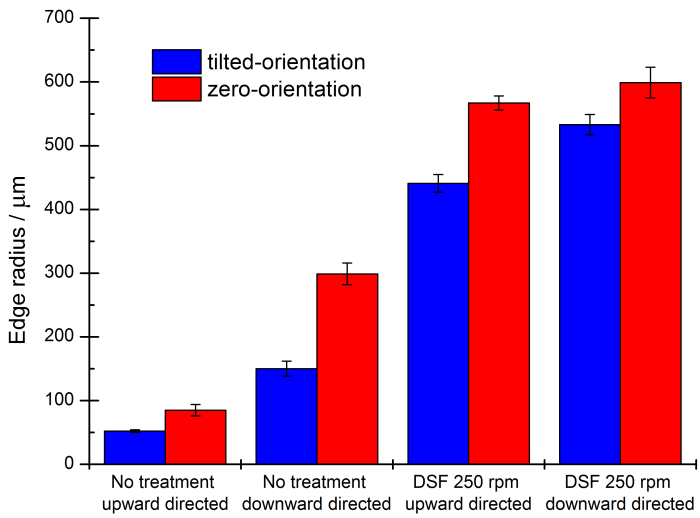

Figure 15: Edge radius of the 90° edges depending on the direction and treatment with DSF grinding media for 300 min at 250 rpm.

Summary and Outlook

This work investigated the smoothing of SLS polymer parts using mass finishing method as a post-process. We examined three different grinding media regarding material, geometry and size using rotation speeds of 150 rpm and 250 rpm up to total process duration of 300 min. A sample was designed to cover build orientations of surfaces from 0° to 180° in 15° steps. Analysis was made with a 3D optical measurement system to evaluate roughness values as well as edge radius determination. Roughness analysis featured a reduction down to 15 % of initial values with the chosen materials and parameters. Simultaneously the rounding of edges was monitored with increasing the radius by a factor of up to ten. However, by reference to all used analysis no or low difference can be obtained in how fast a surface is smoothed though a softer but longer grinding process may lead to a decreased rounding of edges.

Further work contains a detailed analysis of the time dependent evolution of the rounding. Furthermore sharper grinding media geometries may help to improve the efficiency of the process and reduce the minimal process duration for an acceptable surface roughness. Finally more complex sample geometries will be used to evaluate the transferability of the found results.

Acknowledgement

The authors want to thank all industry partners of the DMRC as well as the federal state of North Rhine-Westphalia and the University of Paderborn for the financial and operational support within the project "STEP: Surface Topography Analysis and Enhancement of Laser Sintered Parts".

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