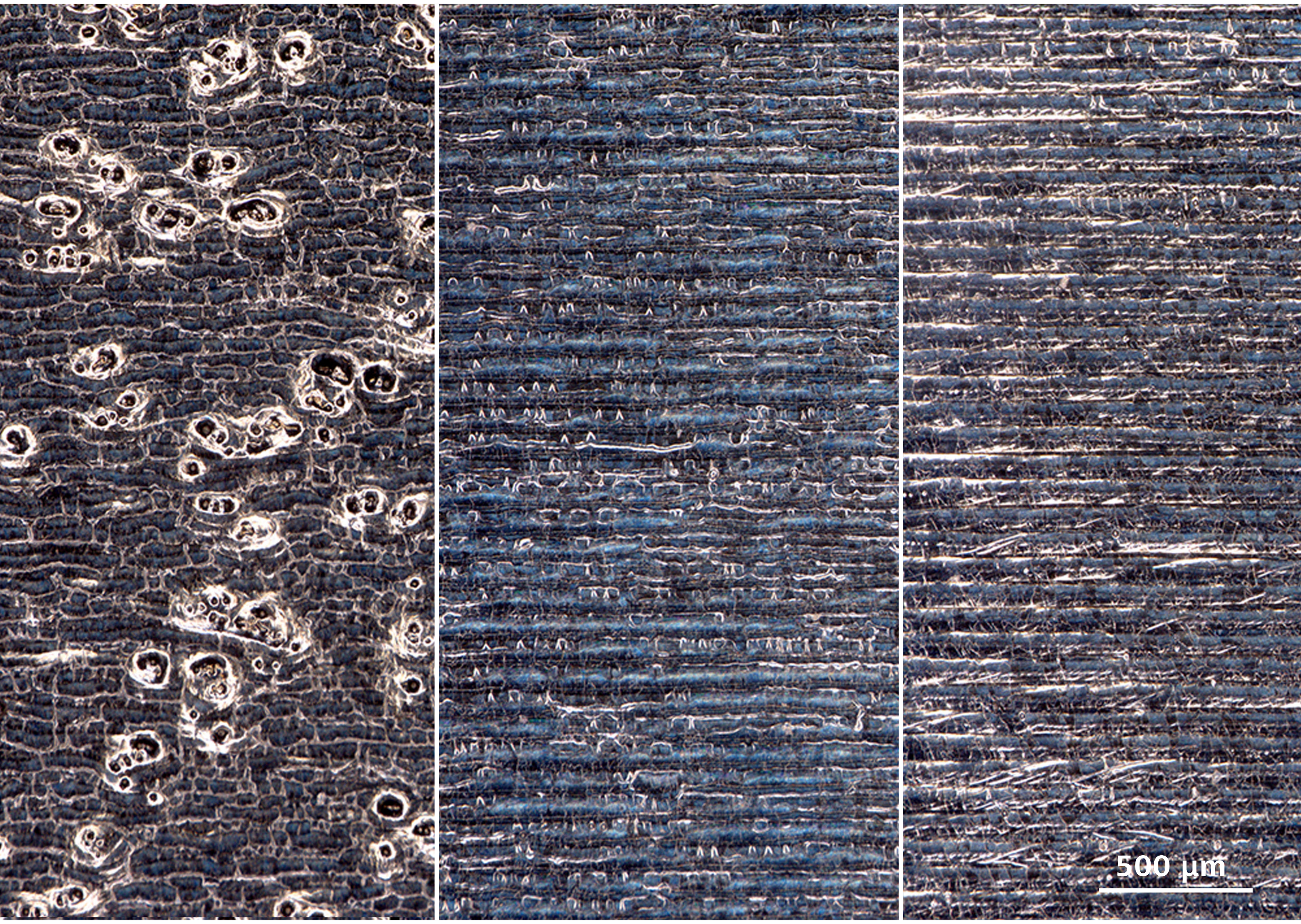
Application Note



Surface Analysis of Laser Polished Additively Manufactured 316L Stainless Steel Using ZEISS Smartproof 5

ZEISS

Seeing beyond

Surface Analysis of Laser Polished Additively Manufactured 316L Stainless Steel Using ZEISS Smartproof 5

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In laser-based additive manufacturing a great concern is the surface finish of parts in the as-build state. Due to process characteristics a surface roughness of approximately half the mean input-powder diameter can be expected which is often not desired. To reduce the surface roughness to a desired value a post-processing step is required which up to date is mostly done by mechanical surface grinding and polishing. Due to the large geometric variety of the additive manufacturing process, mechanical surface treatment is sometimes limited and always combined with material volume loss. To overcome limitations and to reduce required oversize in manufacturing recently polishing by laser surface re-melting is adapted. In parameter development for laser polishing of additively manufactured 316L stainless steel Smartproof 5 is used to characterize surface quality in a quick and reliable way.

Introduction

In comparison to subtractive grinding and polishing to smoothen metallic surfaces, laser re-melting of near-surface areas is a very innovative method. With this method it is possible to work contactless and without loss of material volume and also complex geometries can be processed. Typical fields of application are functional surfaces like friction- or sealing-surfaces or the processing of complex geometries in tool- and mold-making. Normally this requires extensive manual polishing work. Automated processes like laser polishing are a promising way for time- and cost-reduction in these fields of application. To prevent surface reactions with the atmosphere during laser re-melting or to reduce surface oxidation, the whole process is done in special process chambers under inert or active atmosphere using e.g. Argon, Nitrogen or forming-gas, (see Fig. 1).

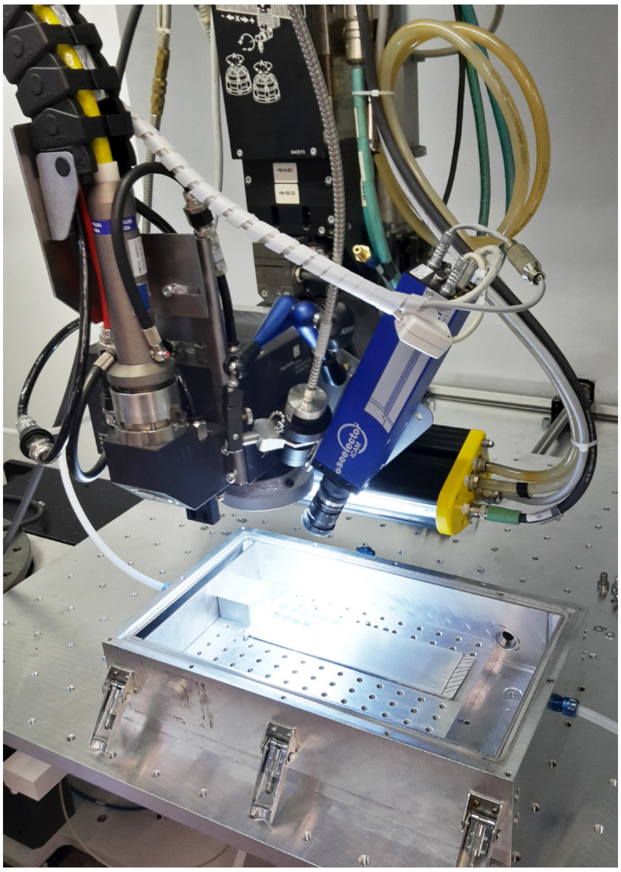


Fig. 1: *Laser process chamber with polishing optics and process control equipment at Laser Application Center, Aalen University.*

Depended on the material to be polished and the initial surface quality comprehensive parameter studies have to be conducted. In these studies a large variation of laser and process parameters such as laser power, pulse duration, traverse speed or track overlap have to be taken into account. To achieve a high sample throughput small polishing fields with dimensions of 10 × 10 mm^2 are prepared on additively manufactured 316L stainless steel plates in a matrix (see Fig. 2).

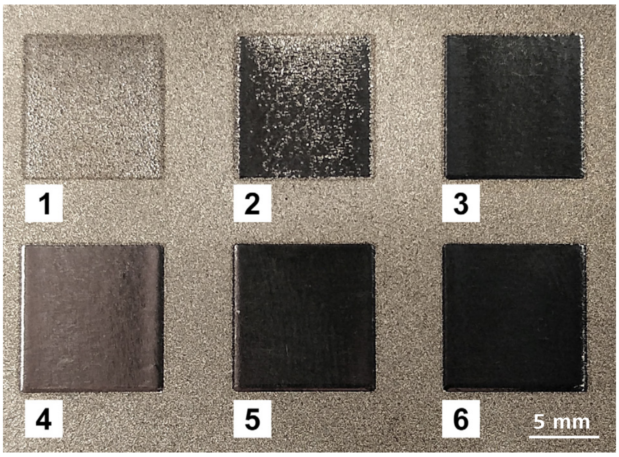


Fig. 2: *Laser polishing parameter study on 316L test piece, field 1-6 equal increase in laser power.*

Figure 2 shows a parameter matrix consisting of 6 fields with increasing laser power imaged with digital microscope Smartzoom 5. The digital microscope is here also used to characterize surface defects such as pores, waviness, spatters and smoke residues as well as surface oxidation and other residues. Figure 3 shows the polished surfaces of fields 2, 4 and 6. Besides the said surface defects it is difficult to estimate differences in roughness just from digital microscope images and even impossible to quantify roughness values according to international standards. Especially field 4 and 6 show a very similar surface with parallel lines visible and no directly visible surface defects.

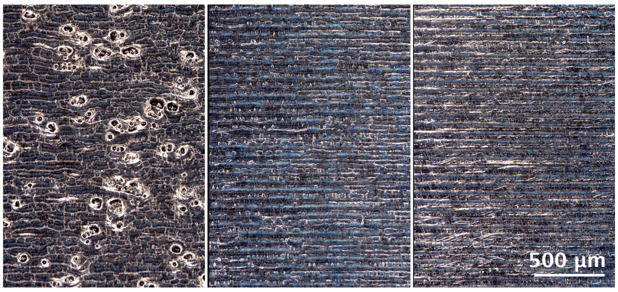
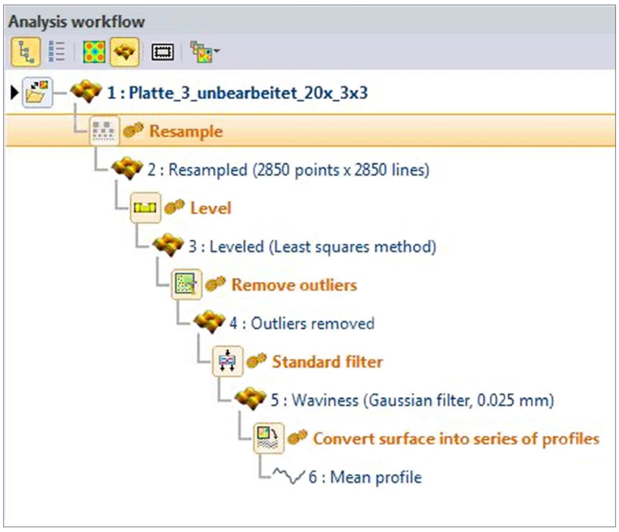


Fig. 3: *Surface of field 2, 4 and 6 imaged with ZEISS Smartzoom 5, surface inhomogeneities in field 2, no clear differentiation between surface of field 4 and 6.*

To quantify the achieved surface smoothing, evaluate the process quality of laser polishing and to narrow down a suitable process window for surface treatment of additively manufactured 316L stainless steel the integrated widefield confocal microscope Smartproof 5 is used. For high throughput surface analyses like in the shown case, Smartproof 5 provides an ideal balance between required resolution and acquisition speed and with ConfoMap, the ZEISS version of Mountains-Map which is the standard in metrology software, repeatable results can be obtained.

The different polished fields are imaged using the 20× objective lens and a 3×3 tile imaging to analyze a larger surface area (ca. 1.5 × 1.5 mm) for suitable statistics in measurement. The guided workflow of the imaging software ZEN core allows a quick and easy setup for data acquisition and the once created setup can be reused as a job-file for repeatable acquisition and results. The acquired Z-stack is then transferred to ConfoMap and can be filtered and analyzed according to international standards. Figure 4 shows an example protocol in ConfoMap with the specific tree-view above that allows the user to refit every filter and/or analysis-step. Below a filtered topography representation according to ISO 25178 is shown. The field of view is 1.5 × 1.5 mm and each color represents a different height-level of the measured surface.



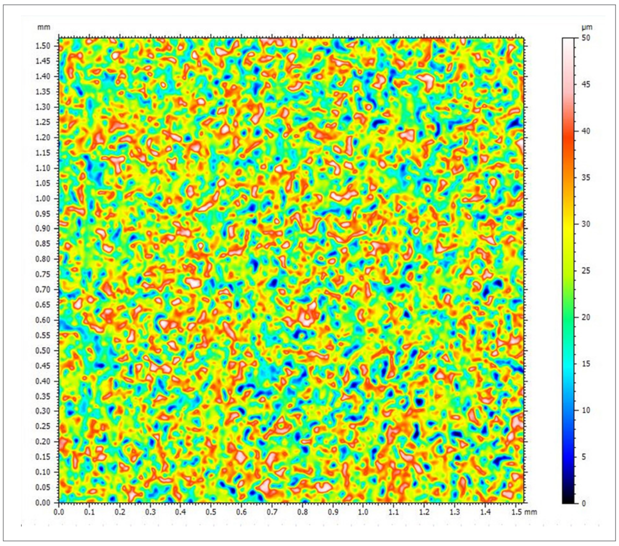
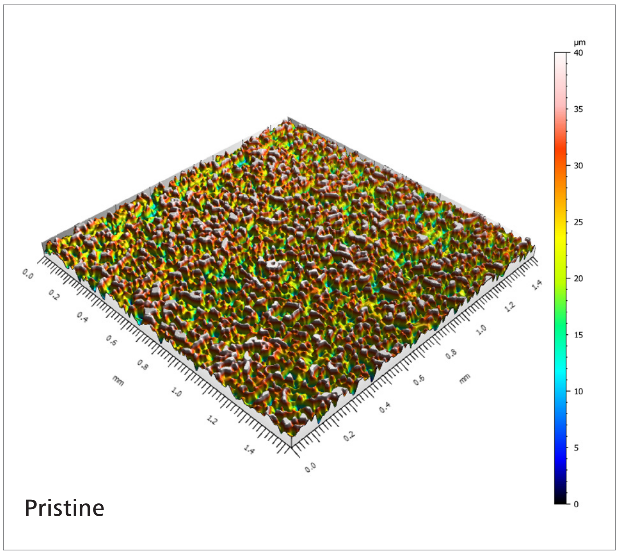
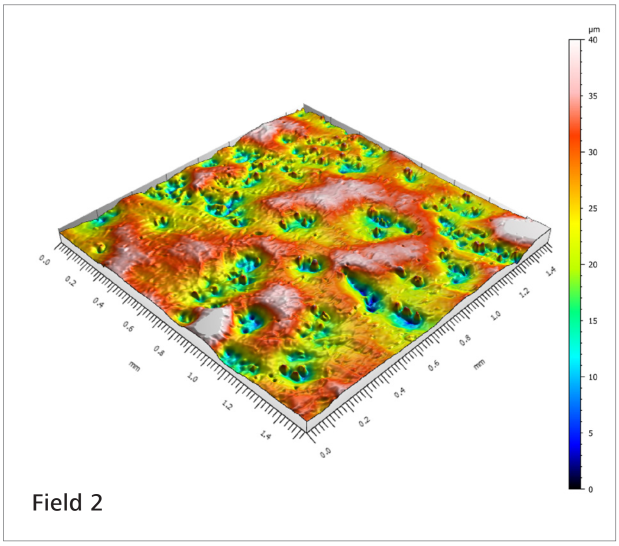


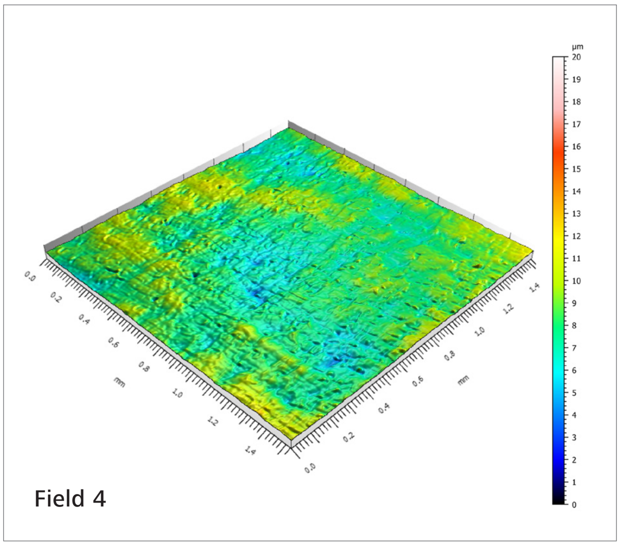
Fig. 4: Exemplary analysis protocol ConfoMap; above: Tree-view of used filters/analyses; below: processed surface topography map.

The architecture of ConfoMap software allows the user to prepare and save standard protocol for filtering and analysis which also serves as a report for fast and repeatable measurement results. Once the measurement protocol is set up new corresponding data sets acquired with Smartproof 5 can just be loaded into ConfoMap and the software automatically applies all filters and measurements set in the protocol. The user just has to proofread results and make adjustments when needed.

After qualitatively analyzing the 6 polished fields in Smartzoom 5 three fields were chosen for further surface analyses with Smartproof 5. To have a good comparison and visualize the effect of laser polishing the pristine surface (as-build state) was also analyzed.







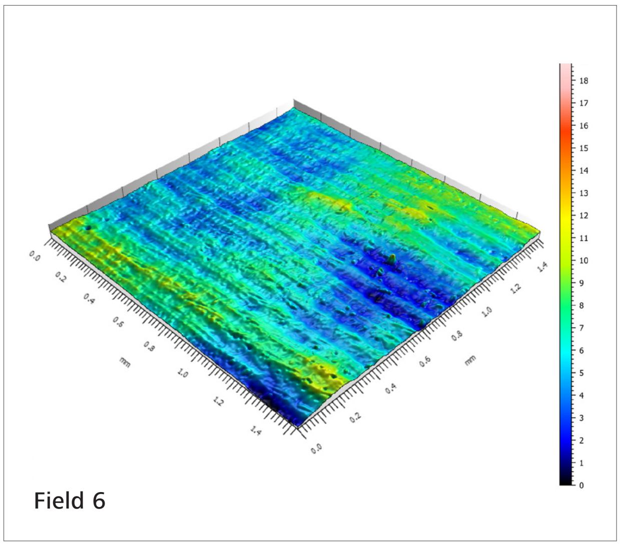


Fig. 5: 3D surface representation of examined pristine surface and polishing-fields created in Confomap, pristine and field 2 with max. 40 µm scale, field 4 and 6 with max. 20 µm; 3×3 tile image, 20x objective lens.

Figure 5 shows a direct comparison of 3D representations of pristine surface and fields 2, 4 and 6. Here field 2 represents a low, field 4 a medium and field 6 a high applied laser power during polishing. Traverse speed and track overlap where kept constant in the analyzed fields. Just by a qualitative comparison it can be seen that the surface is significantly smoothened from pristine to field 2 and 4. Field 6 however shows a repetitive line like structure that will probably lead to an increased surface roughness. Due to higher roughness, the z-scale is set to max. 40 µm for pristine and field 2. Field 4 and 6 are set to max. 20 µm. To quantify the observations of decreasing roughness with increasing laser power up to a specific value and then again possibly increasing roughness, different surface roughness values according to ISO 25178 were measured over the whole field of view of ca. 1.5 × 1.5 mm. The values are compared in a bar graph for all four fields and shown in figure 6.

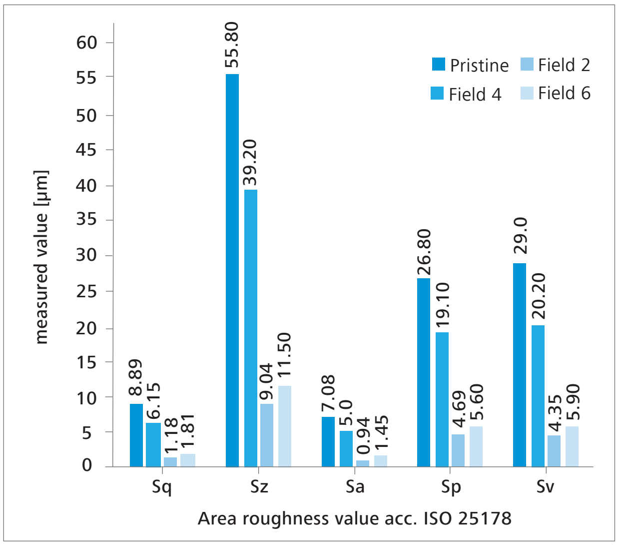


Fig. 6: *Comparison of area roughness values acc. ISO 25178, decrease of values from pristine to field 4, increase to field 6.*

In summary all measured surface roughness values show a similar behavior with increasing laser power. Up to field 4 all values drop with different intensity and increase again with the highest laser power represented by field 6. Sq represents the root mean square value of ordinate values within the measured area and corresponds to the standard deviation of heights over the surface. The strong drop of the Sq value from field 2 to field 4 corresponds to the overall smoother appearance of the surface in the 3-dimensional view in fig. 5. The whole surface becomes more even with less peaks and pits at the given laser power. This can also be seen in the strong drop of Sz value from field 2 to 4 which is defined as the sum of the largest peak height and the largest pit depth within the measured surface area. A common parameter to define surface roughness is Sa that represents the arithmetic mean value of all height values within the measured area. The measured values Sp and Sv represent the largest peak height (Sp) and the largest pit depth (Sv) in the measured surface area. For all measured characteristics the value drops from pristine to field 4 and slightly increases to field 6. This drop is also visualized in figure 7.

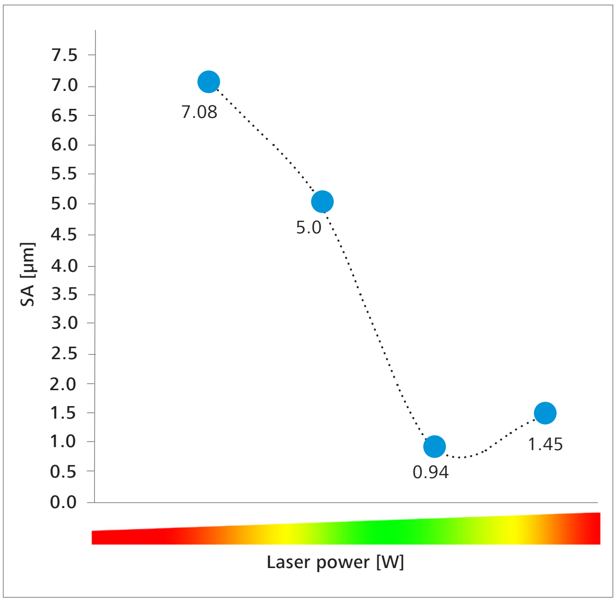


Fig. 7: *Development of surface roughness (Sa) with increasing laser power, lowest roughness measured in field 4.*

The graphic visualization of the surface roughness (Sa) over the laser power (Fig. 7) shows that there is an optimum of polishing quality with the parameter set of field 4. It can be estimated that the parameters of field 4 form a homogeneous melt-pool that, due to surface tension of the melt, has a tendency to smoothen peaks and pits from the additive manufacturing process. The higher energy input in field 6 however creates larger melt quantities that tend to solidify in the shape of the laser-path and create a repetitive superstructure resulting in increasing surface roughness.

The presented work shows that digital microscopy with Smartzoom 5 in combination with fast, reliable and repeatable surface measurement using the widefield confocal microscopy Smartproof 5 is a suitable toolbox for high throughput parameter development in laser polishing of metallic materials as well as quality control in the application of laser polishing.

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