# Surface Quality of Maraging Steel Parts Produced by DMLS

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*The main applications of the additive manufacturing are in rapid prototyping, for production of different types of prototypes and models. During the last decade, due to advances in fields of materials and technologies, the additive manufacturing has also become a competitive technology for production of tools. The competitive advantage of the additive manufacturing is the possibility to build, in a very short time, complex models with adequate precision. However, besides the precision and the speed of production, the parts produced by additive manufacturing need to satisfy a wide spectrum of requirements concerning their mechanical characteristics. One of the most demanding requests in the tooling production is high surface quality. During manufacturing process arise flaws within the material volume, such as porosities, inclusion, voids and micro-cracks. Later, during the post-processing of the manufactured tools by machining, grinding or polishing, these flaws are brought to the surface of the tool. In most cases, the appearance of the flaws on surface is an undesirable phenomenon in tooling industry, especially for the tools with high-gloss surface. The paper presents a comparison of the surface quality of parts produced by additive manufacturing and parts produced by a conventional technology. The surface quality has been estimated and by visual inspection of surfaces using the microscopy with the aim to study the surface porosity.*

**Keywords: Additive manufacturing, surface quality, surface porosity**

## 1. INTRODUCTION

Unlike subtractive manufacturing methods that start with a solid block of material and then cut away the excess to create a part, additive manufacturing builds up a part (or features onto parts) layer by layer from geometry described in a 3D design model. The 3D models are, usually, created by Computer-Aided Design (CAD) software package. After the process of the modelling, parts have been divided into a thin layers and prepared for additive manufacturing. The layer thickness depends on several different factors, such are a type of the technology, the type of the material, speed, etc.

Additive manufacturing it covers a several different technologies which can be divided on the basis of the method of layer manufacturing [1-3]. Major processes include material extrusion, material jetting, binder jetting, sheet lamination, vat photo-polymerization, powder bed fusion and directed energy deposition.

The technology of the additive manufacturing has been invented 1980’s. In the beginning, the additive manufacturing has been focused on the Rapid Prototyping and on the visualisation of the final products. More recently, additive manufacturing is used for production of the end-user products, parts for the automotive, aerospace, dental industry, for production of the medical implants as well and for “printing” a human tissue. Each of this different technologies have its own advantages and drawbacks, therefore, depends on the industry requests, on the market we may found almost all types of the additive manufacturing technologies.

In the last years, beside the rapid prototyping, the additive manufacturing has significant role in the rapid production and digital fabrication.

The additive manufacturing has a lot advantages compared to subtractive manufacturing methods, such are the speed, precision, building the parts without moulds, build the parts with complex geometry. Disadvantages of the additive manufacturing are slow building rate, high production costs, parts steel needs to be post-processed, relatively small building volume, poor mechanical properties.

In this paper, the surface quality of the parts produced by Direct Metal Laser Sintering (DMLS) are presented. The surfaces of the parts produced by DMLS are compared with surfaces of the parts produced by subtractive manufacturing methods.

## 2. DIRECT METAL LASER SINTERING

Direct metal laser sintering is an additive manufacturing technology which belongs to powder bed fusion and it is occasionally referred to as selective laser sintering (SLS) or selective laser melting (SLM). DMLS allows us to build a metal parts and tools directly from digital – CAD models using a variety of the metal alloys powders.

### 2.1. Building process

The DMLS process begins with a 3D CAD model, which is, in the next step, is sliced in z direction on thin layers. Using a laser, the metal powder has been melted in created layers, so we can say that whole process of the manufacturing is performed in one plane. When the melting in one plane is finished, the building platform is moved down, the recoater applying a new layer of the metal powder on the building plate, see Figure 1 and the melting in the new plane is again performed. The laser has enough power to transform powder to liquid state, and it is allowed to liquid metal solidify before a new layer is recoated and melted.

The process of metal sintering is performed in the highly controlled environment. The scanning speed of

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laser beam, layer thickness, temperature, level of the oxygen and gas flow in the working chamber of the DLMS machine are highly controlled.

In the process of the laser sintering, besides that the level of the oxygen is very low (from 0,5% to 1%), a metal oxide called residuals, has been created, as it is shown in the Figure 2. A certain amount of the residuals has been removed by gas flow in the working chamber, see Figure 1, while one part of the residuals remains over and around the sintered parts, in the powder bed.

2.2. Porosities

The density of the parts produced by DMLS should be around 99% and mechanical properties of these parts are very close to the pars produced by machining out of ingots or cast stock.

The latest research in the field of DMLS has shown that produced part have a certain voids or inclusions through the whole volume. These irregularities in the material composition of the parts are also called and porosities. According to some researchers [4,5,6] these porosities are connected to the process of the sintering and to the part orientation during building of the parts. On the other side, these inclusions can be result of the not melted powder, gasses or residuals which are trapped inside melted metal [7, 10-14], shown in Figure 3.

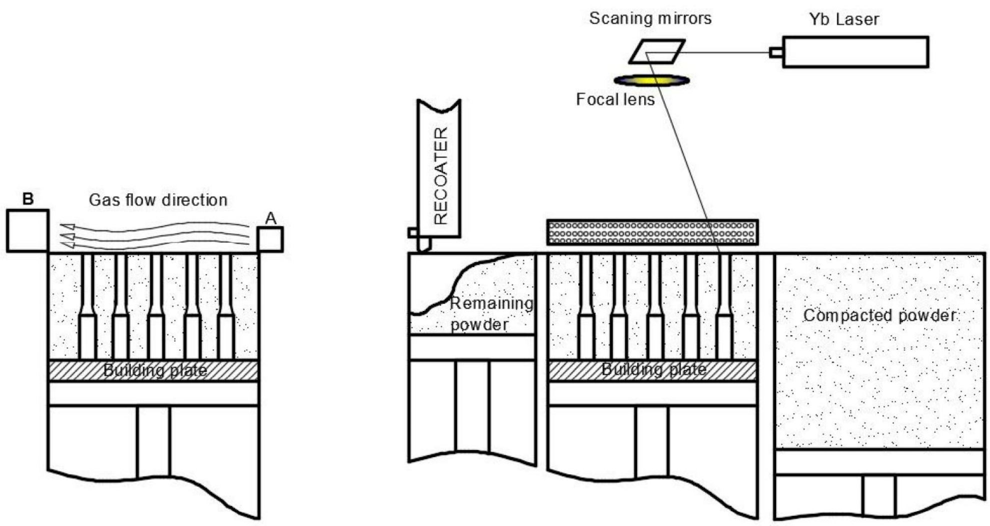


*Figure 1. Schematic representation of the building volume and gas flow*

Regarding that oxygen is not completely removed from working chamber, there is possibility and to some oxide be trapped into melted metal [15]. The trapped inclusions in the melted metal can be connected and to process parameters, such are layer thickness, scanning strategy, laser power, working atmosphere, etc.

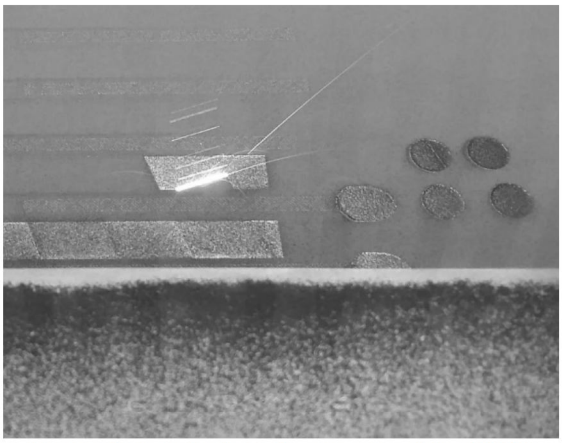

*Figure 2. Residuals in the process of the DMLS*

Those inclusions are present in all parts produced by DLMS, regardless of the type of metal which is used for parts production. Those imperfections are spread into whole volume of the part as well and on the part surface.

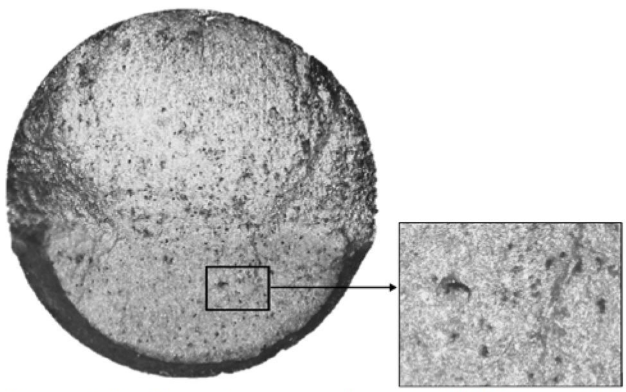

*Figure 3. Voids inside part pruduced by DMLS from MS1 – marginig steel*

The parts produced by DLMS has major applicability in the moulding industry for production of the moulds and inserts. Regarding to possibility to create very complex shapes in relatively short time, this type of the production starting to be competitive in the moulding industry.

In the tool production industry, especially for the cosmetics products, the surface quality is one of the main parameters which have a big influence on the final part quality.

In order to compare the quality, the surface of the parts produced by DMLS are compared to the surface of the part produced by subtractive methodology.

## 3. THE SAMPLES PREPARATION

In order to compare the surfaces of the parts produced by DMLS, the set of the samples has been produced on EOS M 280 machine, from maraging steel – MS1. The maraging steel - MS1 is a steel which has been optimized especially for processing on EOSINT M systems. The MS1 have a chemical composition corresponding to US classification 18% Ni Maraging 300, European 1.2709 and German X3NiCoMoTi 18-9-5 [17].

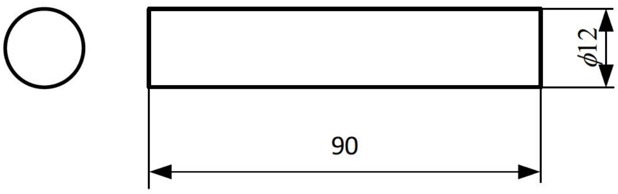


*Figure 4. Test sample geometry*

The bars 90 mm length and 12 mm of diameter has been chosen as test samples, shown in Figure 4.

Test samples by DMLS has been orientated in the vertical direction. The samples have been directly connected to the base plate, the support structure was not being used between samples and base plate. All samples were produced in one building volume in EOS M 280 machine, with same set of the parameters call "direct tool", with layer thickness of 0.4mm. This set of parameter has double exposition in the first 3 layers in order to provide better bonding of the samples to the base plate.

*Figure 5. Samples position and orintation in working volume on EOS M 280*

In order to create references for surface comparison, the set of the reference samples has been created from steel who has similar mechanical properties to the margining steel MS1 and it is a commonly used in tool production. The reference samples have created from tool steel and hard alloy with chemical composition according to European classification 1.2343 and German X37CrMoV5-1 [20].

The samples polished with diamond paste with particle size of 9µm has noted as K2.1 and K2, while the samples polished with diamond paste with particle size of the 0.25 µm has been noted as K1.1 and K1. Samples K1 and K2 are made by subtractive methods – turning and polished from steel 1.2343. Samples noted K1.1 and K2.1 are manufactured by DMLS on EOS M280, heat treated according to the EOS recommendation, and finally polished.

All samples are polished with corresponding diamond paste, after production, in same manner – 3 hour on polishing machine.

Visual inspection of the surface was conducted with Olympus Bx51-P Polarizing Microscope, shown in Figure 6, with magnification of 50x and 100x.

*Figure 6. Olympus Bx51-P Polarizing Microscope*

Surface roughness was tested with Taylor-Hobson Surtronic 3P measuring device, shown in Figure 7. The surface roughness was tested on the surface length of 25mm. Each specimen is tested three times, where between tests specimen is rotated for 90º.


*Figure 7. Taylor-Hobson Surtronic 3P for measurement of the surface roughness*

## 4. RESULTS AND DISCUSSION

Results of the visual comparison of the parts produced by subtractive methods (K1 and K2) and parts produced by DMLS are shown on Figures 8 – 15. From the provided figures it is clear that parts produced by DMLS have more voids (inclusions) on the surface than the parts produced substractive methods from 1.2343 steel. This surface condition and amount of the inclusion on it is best shown on the parts wich are polished with diamond paste with aprticle size of the 0.25 µm , which is presented on the Figures 12-15. The arithmetical mean roughness value - Ra and maximum roughness depth – Rzmax are measured on the surface of the specimen.

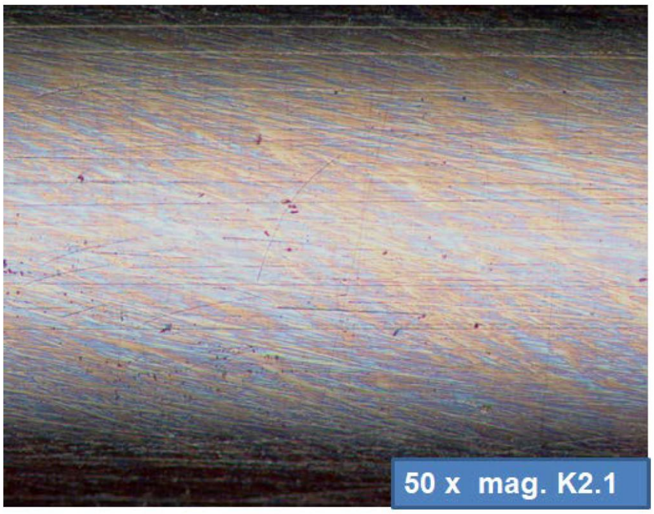


*Figure 8. Test sample K2.1, material: steel 1.2709, polished with diamond paste 9 µm, magnification 50x*

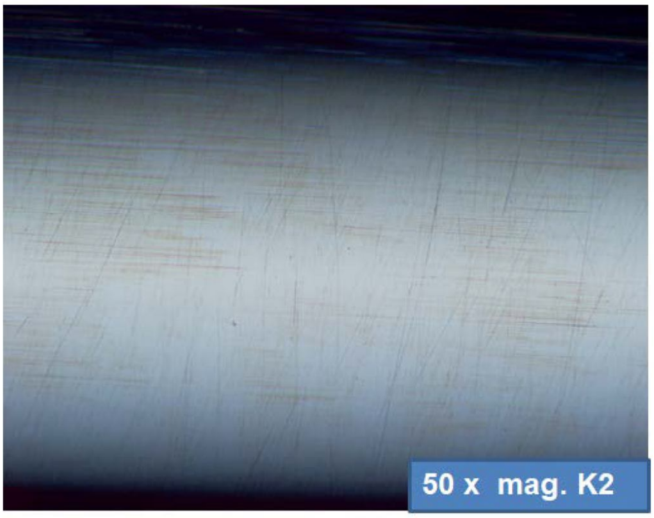


*Figure 9. Test sample K2, material: steel 1.234, plished with diamond paste 9 µm, magnification 50x*

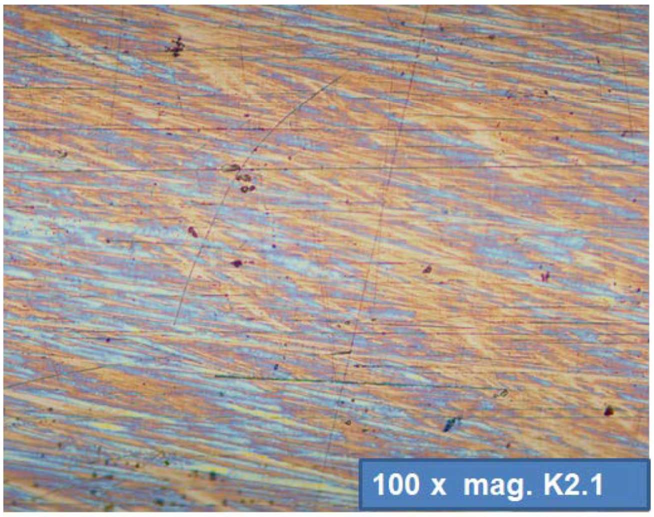


*Figure 10. Test sample K2.1, material: steel 1.2709, polished with diamond paste 9 µm, magnification 100x*

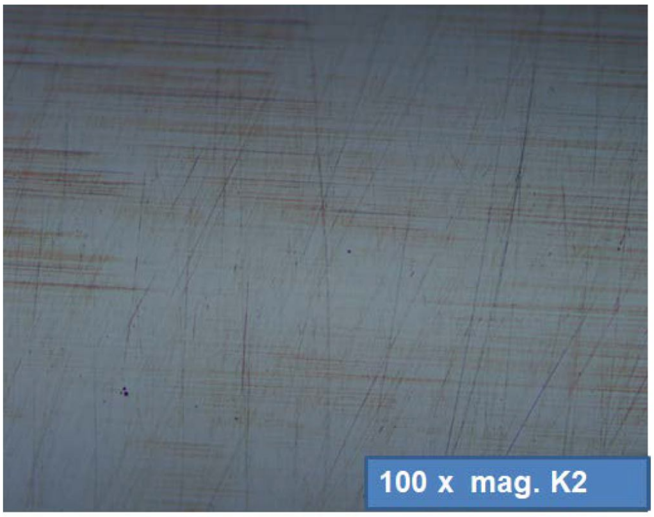


*Figure 11. Test sample K2, material: steel 1.2343, plished with diamond paste 9 µm, magnification 100x*

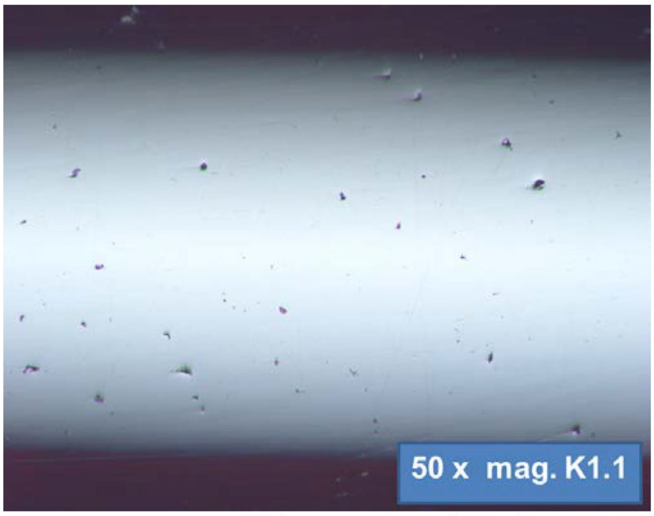


*Figure 12. Test sample K1.1, material: steel 1.2709, polished with diamond paste 0.25 µm, magnification 50x*

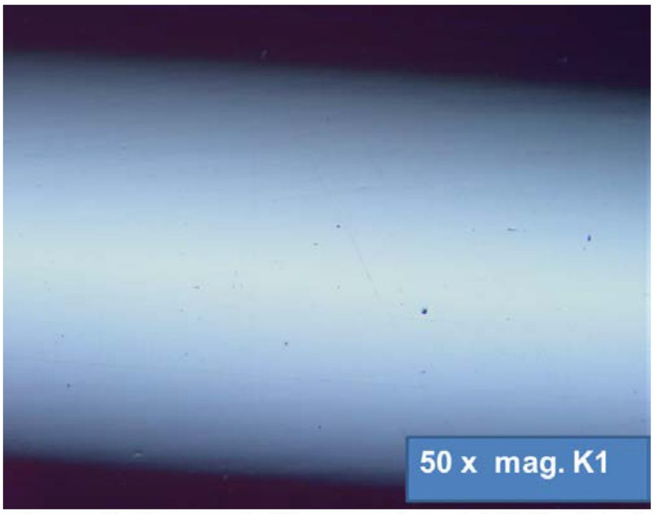


*Figure 13. Test sample K1, material: steel 1.2343, plished with diamond paste 0.25 µm, magnification 50x*

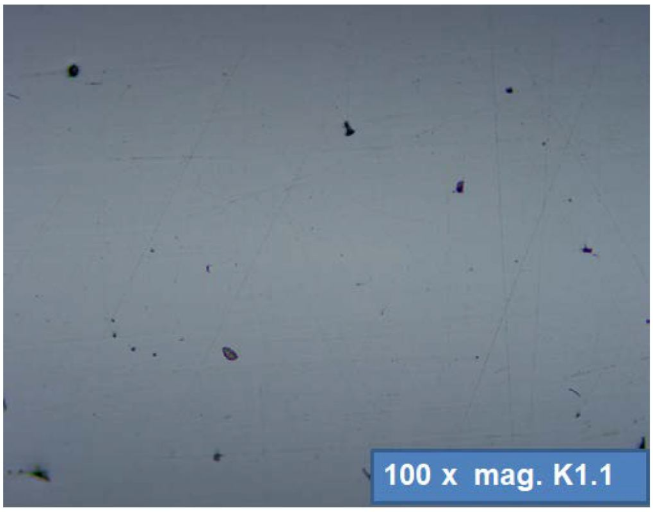


*Figure 14. Test sample K1.1, material: steel 1.2709, polished with diamond paste 0.25 μm, magnification 100x*

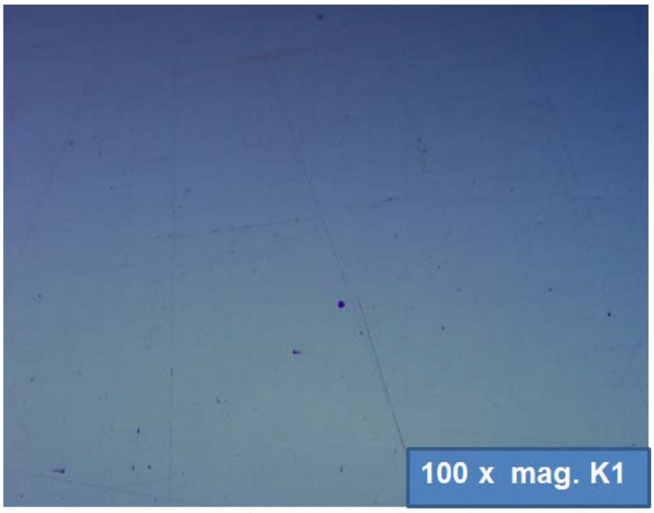


*Figure 15. Test sample K1, material: steel 1.2343, plished with diamond paste 0.25 μm, magnification 100x*

The results of measurement of the surface roughness are shown in the Table 1. From obtained results it can be seen that there are not significant differences in the surface roughness between specimens. This can be explained that inclusion – voids on the surface of the specimen are not an empty space. Each "black spot" on the surface is filled with metal oxide and during of the process of the polishing is levelled with the rest of the material. Because of this, the measurement of the surface roughness is not capable to distinct voids from metal surface.

*Table 1. Masurement of the surface roughness*

| Samples | **Ra** (μm) | **Rzmax** (μm) |
|---|---|---|
| Surface polished with 0.25 μm polish paste | | |
| **K 1** | 0.05 | 0.32 |
| | 0.06 | 0.44 |
| | 0.04 | 0.35 |
| **K 1.2** | 0.05 | 0.38 |
| | 0.04 | 0.63 |
| | 0.07 | 0.78 |
| Surface polished with 9 μm polish paste | | |
| **K1** | 0.08 | 1.12 |
| | 0.12 | 0.90 |
| | 0.1 | 1.10 |
| **K2.1** | 0.1 | 0.98 |
| | 0.12 | 1.1 |
| | 0.1 | 0.95 |

## 5. CONCLUSION

The surface comparison of the parts produced by DMLS from margining steel and parts produced by subtractive methods are presented in this paper.

From obtained results can be concluded that parts produced by DMLS has significant amount of the residues (inclusion, voids), on the surface. Those inclusions may have a big influence, in the tooling industry, on the quality of the injection molded parts, especially on the surface conditions.

Measurement of the surface roughness has not gave the clear distinction between parts produced by DMLS and parts produced conventional methods. From one side this is good, because, we may achieve on all parts same surface quality. On the other side, measurement of the roughness has not able to detect the existence of the inclusion on the part surface. The surface imperfections, in this case, may be detected only under the microscope.

In order to improve surface on the parts produced by DMLS, the micrography and metallography should be conducted. The influence of the parameters of the sintering process on the inclusion during part production should be considered.

Based on the presented results of the surface quality, the production of the tools and molds for the cosmetic parts by injection molding should be considered in the future.

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