# THE STUDY OF MECHANICAL PROPERTIES STAINLESS STEEL 316L AFTER PRODUCTION FROM METAL POWDER WITH USING ADDITIVE TECHNOLOGY AND BY METHOD SELECTIVE LASER MELTING

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**Abstract**

The article deals with the study of verification and evaluation of selected mechanical properties of stainless steel 316L (1.4404) after the production of additive technologies (3D printing) by Selective Laser Melting (SLM). For the purpose of the experimental testing were printed two sets of samples from the powder metal by the laser-sintering process at different process parameters. The main difference was in the power of laser for first set was determined half power 200 W and for second set maximum power of 400 W. The machine printed samples were further divided into two sets, one of which has been heat treated by annealing the second set was not thermally affected. Making the test samples were realized on Renishaw AM 400. The investigated parameters were the results of mechanical tests of specimens after the tensile test according to EN 10002-1: 2001 and impact strength test by Charpy according to ISO 148-1.

**Keywords:** Additive manufacturing; SLM; mechanical properties; stainless steel 316L

## 1. INTRODUCTION

The trend of today's time is to produce ever more complex and refined components. To satisfy this demand, a new, progressive technology of so-called Additive Manufacturing is succeeding. Additive manufacturing offers several methods to create mechanical part. The recent progressive methods of manufacture include a selective laser sintering (SLS) and its improved concept called selective laser melting (SLM). The basic principle of this technology lies in the applying coat of metal powder layer-by-layer. This avoids the need for process planning, such as choosing cutting conditions, choosing the right tools and choosing the production technology. The default input for 3D printing is pre-engineered a three-dimensional CAD model, and the process is greatly simplified [1, 2].

In contrast to classic conventional machining, it is important to note that the production process of the additive manufacturing is not just in 3D printing itself but also in accompanying processes such as preprocessing and postprocessing. "Preprocessing" means the design of a component with respect to topological design, preparation in dedicated software (simulation, component layout and support design) and machine calibration. Postprocessing is a more complex discipline and includes heat treatment, surface finishing, finishing (machining, grinding) and final 3D control and measurement. This paper deals with the influence of heat treatment and laser performance in 3D printing by SLM with respect to mechanical properties [1].

## 2. METAL POWDER 316L

The knowledge of the chemical composition of the test material is a prerequisite for proper evaluation of the experimental investigation. Material 316L is a non-magnetic austenitic stainless steel that contains a very low carbon percentage and is alloyed with chromium, nickel, molybdenum and other negligible elements. Its exact percentage composition is shown in **Table 1.** From a nature of the SLM construction, when occurs the local melting of the particles, therefore, the steel must be very weldable and have the potential for high tensile strength with good ductility. It has got also features good resistance to organic and inorganic concentrated acids and increased resistance to various corrosion. The field of application of this steel is in the chemical, food, medical and predominantly aerospace industries, where it has been utilized exclusively for the additive production of 3D printing, for example, as a jet in a jet engine. The size of individual grains in the manufacturer's powder is 45 ± 15 μm. The stainless steel used for the experiment was supplied by Renishaw in the form of powdered metal. Renishaw places great emphasis on warehouse management, so it delivers powdered metal exclusively in a powder transfer container and recommends that it be stored in a dry and stable place [3, 4].

**Table 1** Chemical composition of the stainless steel 316 [4]

| **Element** | Fe | Cr | Ni | Mo | Mn | Si | N | O | P | C | S |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mass [%]** | Balance | 18 | 14 | 3 | < 2 | < 1 | < 0.1 | < 0.1 | < 0.045 | < 0.03 | < 0.03 |

## 3. EXPERIMENTAL SETUP

Experimental testing has been designed and performed to verify the selected mechanical properties of 316L (1.4404) stainless steel after the production of additive technology (3D printing) by Selective Laser Melting (SLM), when was sets different process parameters - see **Figure 1**. The advanced version of the Renishaw AM400 features enhanced optics control, redesigned gas flow, window protection, and a new 400W optical system that provides a beam of 70 μm in diameter. The power of the 400W laser power allows for a larger portfolio for print capabilities, making the first set of samples was printed at a half output of 200 W and a second set of samples at a maximum power of 400 W laser. The supplied Quant AM software allowed you to set different laser power values for both sets of samples on one substrate. Thanks to this, no powder contamination has occurred and consequently the results have not been affected [3, 4].

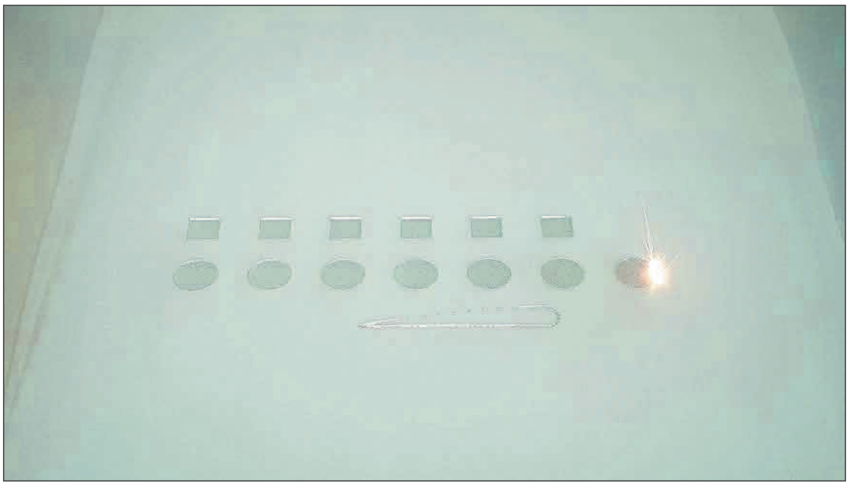

**Figure 1** Sample layout during the 3D printing

The difference in laser performance was not the only criterion for resolving and sorting samples. Another variable, according to which the samples were divided into another set, is post-processing, respectively heat treatment after completion of the construction. For the heat treatment was selected a stress relieving annealing is to apply to minimize residual stress in the structure and thereby reduce dimensional inaccuracies. The process was carried out in a vacuum oven, heating for three hours, stamina and stabilization at 550 °C for an additional three hours, and the final cooling was conducted freely in the furnace for twelve hours without access of air. The final value was around 90 °C. The entire course of heat treatment is shown in the **Figure 2**. Annealing does not change the structure of the material and has no significant effect on its hardness [1, 2].

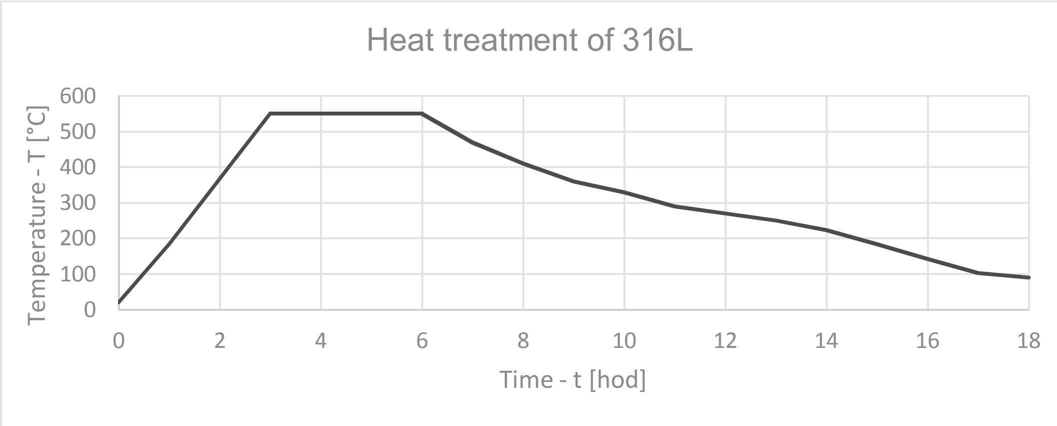


**Figure 2** The course of applied heat treatment

### 3.1. Course and print settings

A consistent constant scanning speed, layer thickness and strategy were set when printing test samples. The only variable was laser performance. The default strategy for 3D printing of all samples has become a strategy called "Meander", whose principle of scanning consists in gradually alternating the layers with mutual orientation by rotating the new layer to the previous layer by an angle of 67 ° (see **Figure 3**). Meander strategy is recommended for components with a small cross-sectional area, as there is inconsistent heat distribution in each layer. The printing process was carried out in a controlled atmosphere (argon). First, air and humidity was sucked out from the building chamber of dimensions 250 mm × 250 mm × 300 mm to a vacuum, and then argon inert gas was pumped into the chamber. The use of inert gas results in extrusion of residual oxygen from the chamber, thereby avoiding the risk of unwanted chemical and physical processes due to reactive gases contained in the air. Furthermore, the risk of explosion of powder alloys, which are volatile due to air, is also reduced. Prior to commencing the build itself, the building board (substrate) is preheated to 170 °C for two reasons. The first reason is the energy saving of the spent laser to melt the particle, and the second reason is related to the thermal influence of the printed parts where deformations occur. Applying a very thin layer of metal powder was done by a wiper spread by a single dose of powder from the back of the chamber towards its front. The worktable moved down with the substrate with a layer thickness of 50 μm after each scanned layer.

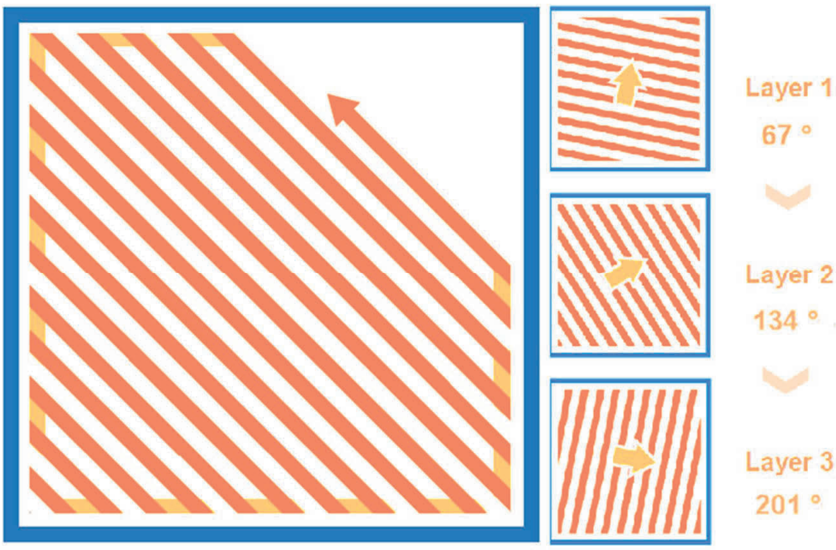


**Figure 3** Strategy of Meander and its rotating layer by 67 °

### 3.2. Tension test evaluation

To determine the mechanical characteristics, the most frequently used test was chosen, the tensile test. The test results are used to assess the quality of the material, design calculations, or a general assessment of suitability for certain technological operations. The essence of the test lies in the deformation of the test rod by tensile loading until breakage. The test is controlled by the standard EN 10002-1: 2001 and determined by the size of the sticks for the determination of the test: the total length of the rod - $L = 100\ mm$, the length of the test part of the rod - $L_o = 57\ mm$ and the initial diameter of the rod - $d_o = 5\ mm$. Testing was carried out on a desk, two-column, computer-controlled testometric M500-50CT at 21 °C room temperature. Cylindrical printed specimens have to be trimmed prior to insertion into the test machine due to surface treatment quality requirements $Ra = 0.8\ \mu m$. The test piece was attached to the mechanical wedge jaws of the test machine and a strain gauge attached to it, which during the test recorded the force applied $F$ on the extension of the test rod [5, 6].

The tensile test results revealed interesting results compared to the different laser power values. For samples printed at 200 W laser power the effect of annealing at the total stress of the tensile stress was significantly affected. Surprisingly better real values of maximum stress strain were achieved by a sample that was not thermally affected, by about 25 %. The stress peak test results from the 200 N sample, this is better than the 400 N sample. More favourable values were reached even at the stress 0.2% proof overall, see **Table 2**. On the other hand, no significant differences in heat treatment were recorded in the samples produced by the 400 W laser power. Young modulus evaluation is distorted because of the small sample rate and is listed for informational purposes only. An overview of all mechanical values is given in **Table 2** and the tensile strength comparison is shown in **Figure 4**. Distorted values at the beginning of the chart can be caused by slipping the sample in the jaws. A brittle fracture was classified at the end of the test.

**Table 2** Overview of the mechanical characteristics

| Designation of sample | Strain Break (%) | Strain Peak (%) | Stress 0.2 % Proof (N / mm$^2$) | Stress Peak (N / mm$^2$) | Young Modulus (N / mm$^2$) |
|---|---|---|---|---|---|
| 200 N | 43.1 | 19.0 | 515.9 | 639.5 | 200050 |
| 200 TZ | 28.9 | 19.3 | 466.4 | 660.5 | 212555 |
| 400 N | 34.2 | 17.3 | 404.8 | 561.0 | 204226 |
| 400 TZ | 28.8 | 17.8 | 355.1 | 573.9 | 185665 |

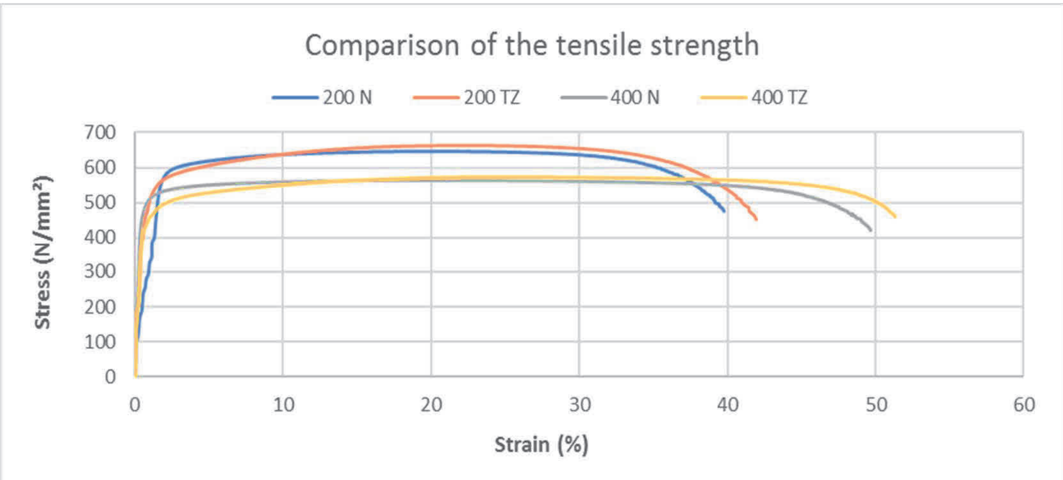


**Figure 4** Comparison of the tensile strength

### 3.3. Impact strength test evaluation

Another observation parameter of the experiment was the result of a bending impact test using Charpy hammer according to ČSN ISO 148-1. The Charpy hammer method consists in breaking the test body with a notch one-stroke of the pendulum hammer from the specified conditions and it is a dynamic test. This test is a very good indicator of the brittleness of the material. The material characteristic determined in the bending impact test is the impact work. The test assesses the sensitivity of the material to the stress concentration at the point of the sample notch. The toughness value is determined by the ratio of the energy used to break the test rod and the area of the smallest cross-section of the rod (at the notch), and its determination is particularly important for heat treated steels or where welding occurs [5, 6].

Four set of samples with squares cross section of dimensions 10 x 10 x 70 mm were designed to evaluate the bending impact test, each set containing 3 test bars. The test sticks were arranged on a substrate in a single row and printed at the same time at 200 and 400 W using the same methodology as the tensile test specimens. The planar surfaces of the blocks are printed parallel to the *XZ* and *YZ* planes of the 3D coordinate machine system. The test bodies were provided with a V-shaped notch at an angle of 45° and a depth of 2 mm in the centre of the length itself, this preparations being carried out after the final heat treatment, thereby avoiding a difference in comparison of the heat treated samples. The Charpy hammer test was performed at 20 °C. The maximum hammer energy used was 300 J.

From the results of the test, it is obvious that the heat treatment has a significant effect on the tenacity of printed material 316L in the positive sense, due to the decrease stress in the structure of the material. The difference in material tenacity is noticeable even with different laser power settings, as illustrated by **Table 3** laser power of 400 W caused better and more intense baking of powdered metal grains. Apart from the notched strength, the appearance of the fracture area was assessed. The test stick bent, but at the same time a quarry formed, thus it is a so called mixed quarry.

**Table 3** Results of the Impact strength

| **Set** | **200 N** | | | **200 TZ** | | | **400 N** | | | **400 TZ** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **No. of sample** | **1** | **2** | **3** | **1** | **2** | **3** | **1** | **2** | **3** | **1** | **2** | **3** |
| **Impact energy [J]** | **109** | **122** | **118** | **133** | **132** | **146** | **162** | **159** | **141** | **180** | **148** | **126** |

## 4. CONCLUSION

Additive manufacturing makes it possible to produce shape-complex components while adhering to the specified quality of material and becomes an integral part of industrial engineering. The potential of additive production is limited only by the imagination of the designer and opens the way for creative thinking. An example of such thinking is a topological design that overcomes all the conventions that have been implemented and brings new possibilities in the development of structures. The growing demand for more complex and refined components in the labour market is evidence that it makes sense to further develop additive technology and come up with new ideas. One of the most significant advances in the additive technology process was the SLM. This method is based on the local melting of the powdered metal particles by the laser and the particular layering of these portions. The progressive development of this method has ensured expansion not only to prototype production but to the entire process of small-series and series production. At present, the SLM method introduces small-scale mould manufacturing for the aerospace and automotive industries and in the health care industry is it the production of various prostheses and implants.

The SLM method was applied to the experimental investigation that was conducted to investigate the core mechanical properties of the corrosion-resistant material AISI 316L. Different print parameters were selected for research, and the main difference was in laser performance: half the machine output was 200 W and the machine's maximum output was 400 W. The printed samples were further divided into two sets, one of which was heat treated by annealing the other set was not thermally Affected. The first observed parameter was the deformation stress, which was measured on the basis of EN 10 002. This test did not show the influence of the heat treatment, but the influence of the machine parameter setting was manifested. Samples printed at 200 watts showed better tensile deformation than samples printed at maximum laser power. The second part of the experimental test examined the toughness of the material. For its determination, a bending test was chosen by the Charpy method according to ČSN ISO 148-1. The test showed a significant influence of heat treatment on the overall toughness of the structure of the material. Ideal setting of parameters to achieve the most optimal toughness is 400 W and application of annealing heat treatment to reduce strain. The results obtained provide a good basis for further research into the mechanical properties of printed materials of additive production by SLM.

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