MICROSTRUCTURE AND MECHANICAL PROPERTIES OF WELDED JOINT ON AUSTENITIC 316L STEEL PRODUCED BY SLM METHOD

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Abstract

This work deals with the influence of heat treatment and TIG welding technology on the mechanical properties and microstructure of welded joint. The weld was performed on a product from austenitic 316L stainless steel which was made by using SLM additive technology. In the experiment, test welds were welded and subsequently non-destructive and destructive tests were performed, including evaluation of the microstructure. All samples were evaluated as satisfactory by non-destructive tests. The tensile test was performed both for the welded joint and for the base material in the transverse and longitudinal direction. The values of the yield strength of the samples with the welded joint correspond to the values required for the base material - forged steel 1.4404. Microstructural analysis revealed significant differences between samples with and without heat treatment.

Keywords: Selective Laser Melting, 316L, TIG, Welded Joint, Properties

1. INTRODUCTION

Selective Laser Melting (SLM) is one of the most promising 3D printing technologies available today and is used for both rapid prototyping and mass production. Unfortunately, the range of available metal alloys for the SLM method is currently quite limited. This technique can be used for the additive production of stainless steel, tool steel, titanium, cobalt and aluminium parts. The SLM is a very energy-intensive process because each layer of metal powder must be heated above the melting point of the metal. The high-temperature gradients that occur during the SLM production can also lead to stresses and strains within the final product [1,2].

The main problem with SLM technology is often poor surface quality. In addition, a partially melted powder may adhere to the surface, melt or powder can form splashes on the surface during production. Also, a deformed product can be made. Alternatively, a crack may occur, or the product may separate from the base platform [3,4]. Residual stress negatively affects the mechanical properties of manufactured parts [4].

The SLM process enables the production of strong, light, and complex metal structures. Another disadvantage of this method is the limited size of the products, due to the limited size of the production space of the machine for SLM. If we need a larger component, we must proceed to combine the individual smaller parts into one whole [5]. For 316L, welding appears to be promising. For this reason, this work is focused on the influence of TIG welding and the influence of heat treatment on the mechanical properties and microstructure of the welded joint. Specifically, the proven TIG method without additional material was used to connect two 316L stainless steel parts made with SLM additive technology.

2. EXPERIMENTAL

The basic material for welding were test specimens made using SLM 3D printing technology from 316L powder. **Figure 1** is a view of manufactured plates ready for welding a test weld.

A total of four test welds were made, labelled 3D1, 3D2, 3D3 and 3D4. **Table 1** shows the chemical composition of the base material. Optical emission spectrometry analysis (GDOES) was performed using a Spectruma Analytic glow discharge optical emission spectrometer in accordance with [6,7].

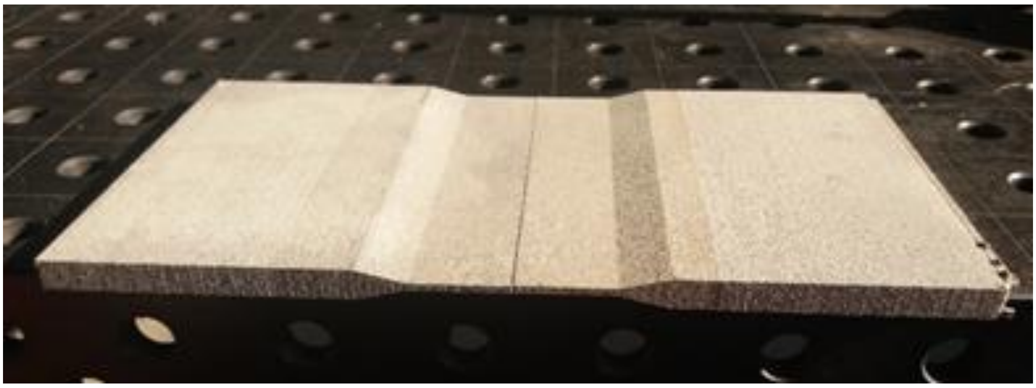

Figure 1 – Test plates made by the SLM method ready for welding

Table 1 – Chemical composition of the base material

Element content [%]										
C	Mn	Si	P	S	Cr	Ni	Mo	W	Nb	Al
0.016	1.17	0.22	0.023	0.0067	17.72	14.24	2.73	0.19	0.013	0.01

Test specimens 3D3 and 3D4 were heat-treated (HT) by annealing in a furnace with a protective argon atmosphere before welding. In the first phase of the heat treatment, heating was performed at a rate of 250 °C per hour to an annealing temperature of 1040 °C, endurance at a temperature of 30 minutes. This was followed by accelerated cooling by a fan for 30 minutes. Samples 3D1 and 3D2 were left without heat treatment.

The TIG method (141) was used to weld all test specimens. The welding took place without additional material. The individual parts of test specimens were assembled without a gap. The welding current was in the range of 80-90 A and the welding voltage was in the range of 8-13 V. Argon shielding gas was used to protect the weld and the root. The set flow rate for the weld was 11 l / min and for the root 6 l / min.

The capillary test was performed according to the EN ISO 3452-1 [8] standard and evaluated according to the EN ISO 23 277 [9] standard. No indications were found for all samples and the test was evaluated as acceptable.

The radiographic tetsing was performed according to the EN ISO 17 363-1 [10] standard and evaluated according to the EN ISO 10 675-1 [11] standard as acceptable for all samples, while some minor defects were found.

3. RESULTS

The Vickers hardness test was performed according to the EN ISO 6507-1 [12] standard on samples 3D1 (without HT) and 3D3 (with HT). The results of the hardness measurements are shown in **Figure 2**.

It is clear from **Figure 2** that the sample which has undergone the HT process (3D3) has a lower hardness in the base material. This is because the solution annealing (1040 °C) caused the dissolution of carbides and a new homogeneous structure was formed, which externally manifested itself in the lower hardness of the material. In contrast, in the weld metal, the 3D3 sample has a higher hardness, and in the HAZ (heat affected zone), the hardness of both samples is approximately the same.

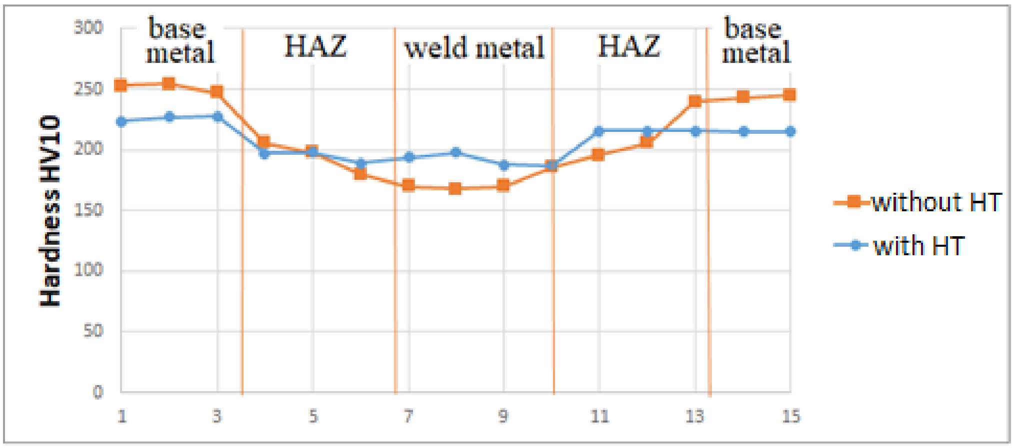

Figure 2 Hardness comparison of samples without HT (3D1) and with HT (3D3); HAZ – heat affected zone

The tensile test was performed on the welded joint (transverse tensile test) and the base material (in the transverse and longitudinal direction). Samples 3D2 (without heat treatment) and 3D4 (with heat treatment) were tested.

The transverse tensile test of the welded joint shows the ultimate tensile strength value of 570 MPa for the sample without HT. The sample with HT reached the ultimate tensile strength value of 550 MPa.

Standard values for rolled steel 316L (1.4404) according to EN 10216-5 [13] standard are: ultimate tensile strength: 490-690 MPa, yield strength min. 190 MPa, ductility min. 30 %. Welded joints are therefore satisfactory in terms of strength.

Table 2 shows the tensile test values of the base material in the longitudinal and transverse directions. In the longitudinal direction, the value of the yield strength and the ultimate tensile strength of the sample with HT is lower in comparison with the sample without HT. However, the ductility of the sample with HT is approximately 30 % higher in comparison with the sample without HT and is safely above the lower limit of the required values by the EN 10216-5 standard. The ductility of the sample without HT is directly at the lower limit (30 %).

Table 2 Tensile test results of the base material in the longitudinal direction and in the transverse direction

Base material in the longitudinal direction				
Sample	Yield strength Rp0.2 (MPa)	Ultimated Tensile Strength Rm (MPa)	Ductility A (%)	Percentage Reduction of Area Z (%)
Without HT	553	670	30	42
With HT	411	648	39	51
Base material in the transverse direction				
Without HT	469	569	11	21
With HT	384	503	8	16

In the transverse direction concerning the layers in 3D printing, the resulting values are significantly worse. As in the previous case, the yield strength and the ultimate tensile strength values are slightly lower for the HT sample. The yield strength value is near the lower limit of the standard values (503 MPa). The ductility of both samples is well below the standardized lower limit.

If we compare the results in the transverse direction with the results in the longitudinal direction the following facts arise: The values of ductility and contraction in the transverse direction have significantly reduced the plasticity of the material, and the achieved values are non-accetable concerning the EN 10216-5 standard (8

% and 11%, respectively). As for the ultimate tensile strength and the yield strength, there was also a significant decrease in the transverse direction for both the sample with HT and without HT.

The structure in the HAZ changes from the characteristic structure of 3D printing to an almost homogeneous austenitic structure with a visible occurrence of pores towards the fusion boundary. This change is due to the high temperature during the welding process when carbides dissolve and recrystallize. **Figure 3** shows how the initial 3D texture in the HAZ gradually disappears towards the fusion boundary. The same microstructural changes were observed in [14].

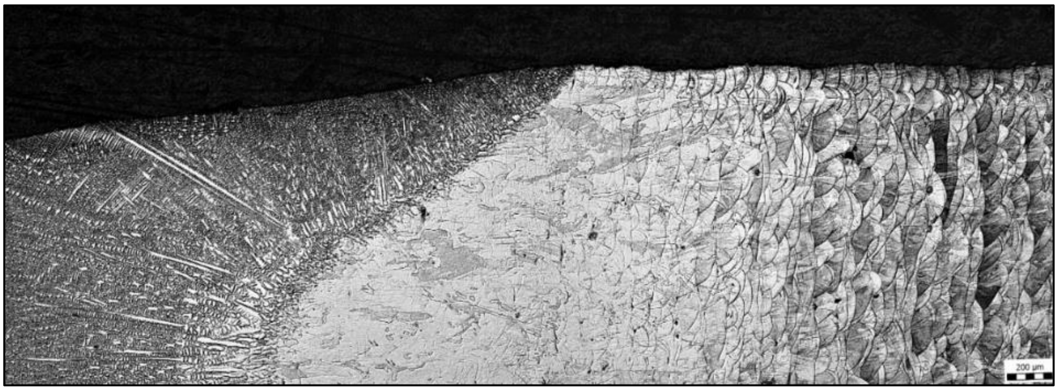

Figure 3 Panoramic image of the sample 3D1 without HT

The HAZ microstructure of the sample 3D3 with HT is practically identical to the microstructure of the base material. The weld metal has a cast austenitic structure, just like the previous sample 3D1 without HT. **Figure 4** shows the transition from the weld metal to the base material of the HT sample. The characteristic structure of 3D printing in the base material has completely disappeared due to HT.

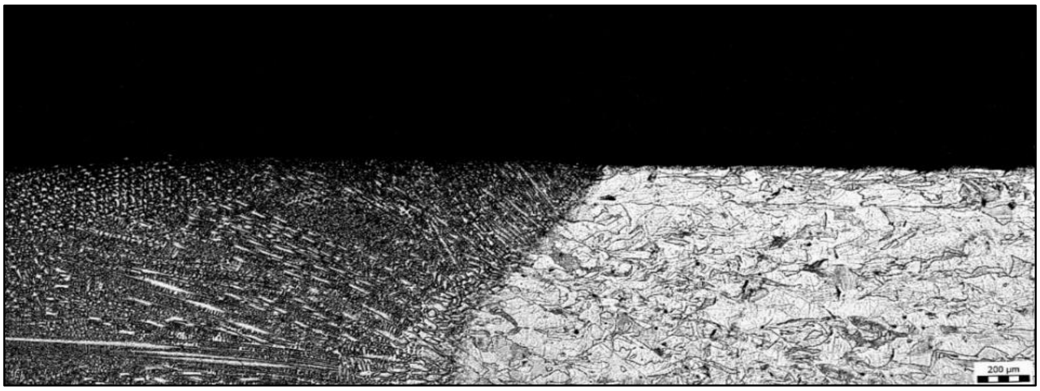

Figure 4 Panoramic image of the sample 3D3 with HT

4. CONCLUSION

Within this work, TIG welding was performed on samples produced by the SLM method without additional material, i.e., by simply melting the base material. Non-destructive tests were subsequently performed on all manufactured welded joints, namely: visual inspection, capillary test, and radiation test. All samples were evaluated as satisfactory by these tests.

Microstructural analysis revealed a significant difference between the basic material of samples with and without heat treatment. The sample 3D1 without heat treatment shows the characteristic structure of 3D printing in the form of "melting baths", while the sample 3D3 underwent partial recrystallization due to heat treatment and the structure changed to purely austenitic. However, the carbides were not dissolved completely in the sample 3D3. This is probably due to the short time selected for the heat treatment the sample has been subjected to heat treatment.

The tensile test was performed both for the welded joint and for the base material in the transverse and longitudinal direction. The values of the ultimate tensile strength for the welded joint correspond to the values required by the EN 10216-5 standard.

For samples with heat treatment, the measured values of the ultimate tensile strength are slightly lower. This is due to the heat treatment at 1040 °C/30 min, which leads to an increase in the toughness of the material and at the same time to its hardening, which corresponds to lower values of both the ultimate tensile strength and the yield strength.

Larger differences are seen when comparing samples printed in the longitudinal and transverse directions concerning printing. Significantly lower values of the ultimate tensile strength were measured in the transverse direction compared to the values measured in the longitudinal direction. In addition, there has been a significant reduction in ductility in the transverse direction and the results are non-acceptable due to the EN 10216-5 standard. However, such low ductility is common in 3D prints made of 316L material and is in accordance with [3,4].

The weldability of 316L stainless steel prepared by the SLM additive method is comparable to the weldability of conventionally produced material of the same quality. If the necessary technological parametrs are reached, satisfactory values of the mechanical properties of the welded joint can be achieved. The main problem is the unsatisfactory values of the mechanical properties of the base material measured in the transverse direction concerning the printing layers. It is therefore very important that the direction of the main stress is, if possible, oriented longitudinally to the printed layers.

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