STRUCTURAL-PHASE STATE AND MECHANICAL PROPERTIES OF 316L STAINLESS STEEL PRODUCTS OBTAINED BY SELECTIVE LASER MELTING

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Abstract

The results of the structure and phase composition investigation 316L stainless steel of samples formed by selective laser melting in Mlab Cusing R (Concept Laser) equipment are presented. The physical and mechanical properties investigation was carried out by X-ray diffraction analysis, scanning electron microscopy, and micro-hardness measurements. It was found that 316L steel powder after selective laser method has the austenitic structure. The structure of the samples is characterized by cross sections of tracks left by the laser. A thin cell-dendritic substructure has been identified, there are pits inside which droplets with a diameter of about 50 μm are observed, which is typical for objects obtained by laser melting of powder material. Samples are characterized as the structure with high degree of homogeneity.

Keywords: Laser melting, stainless steel, structure, phase, mechanical properties

1. INTRODUCTION

Additive technologies of production allow create a prototype of any object from a computer model. Advantages of additive technologies over traditional methods of creating three-dimensional products from various materials - a significant reduction in production time and a reduction in the cost of finished products, regardless of the configuration of the product.

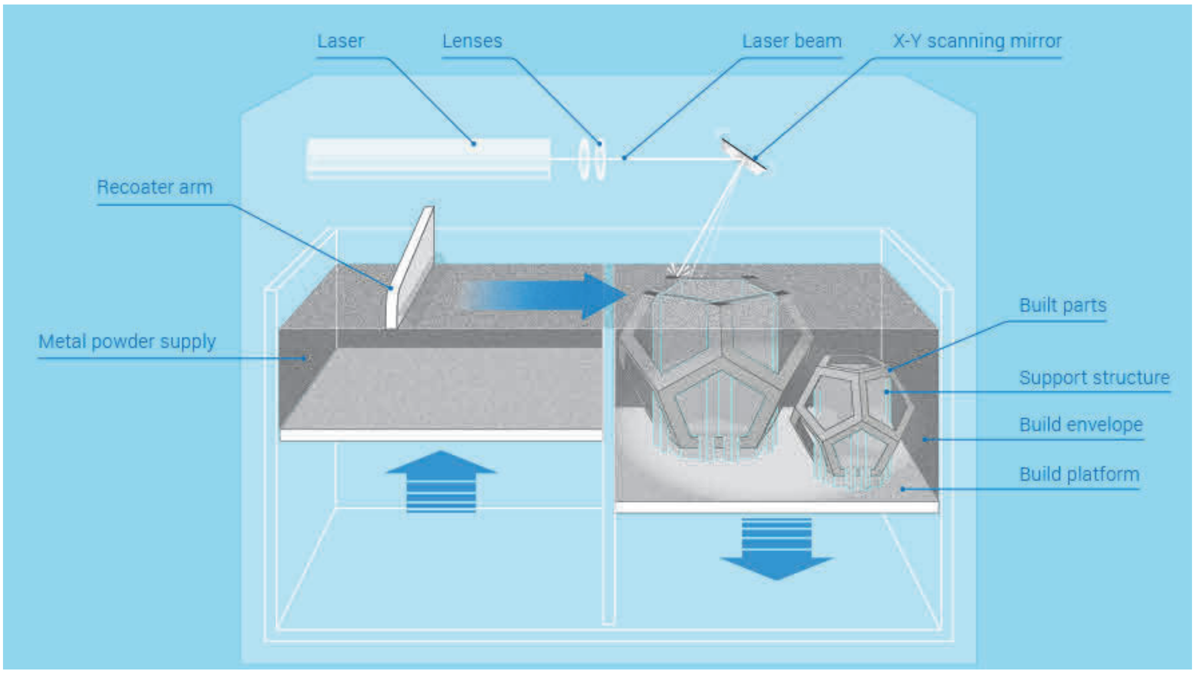

Figure 1 The process of additive production by selective laser melting

One of the promising technologies of additive production is selective laser melting, as well as its varieties. The principle of selective laser melting is to form a three-dimensional object by successively melting the layers of the powder material with a laser beam in accordance with the program (**Figure 1**).

Products obtained by selective laser melting from a powdery material have a high potential and high mechanical properties of the material used. The search for ways to produce solid products is one of the main areas of research. Obtaining such structures is obtained by choosing laser parameters that are in a rather small range [1, 2]. In the process of selective laser melting, complex non-equilibrium processes occur, depending on the material itself, the particle size of the powder used and its properties, the properties of the laser, and the correct selection of the melting regimes.

The work used 316L stainless steel as one of the well-studied objects. Currently, the EKSTU began the production of prototypes by the method of selective laser melting. Therefore, the task was to investigate the mechanical properties and microstructure of the obtained samples, and compare them with similar samples obtained by selective laser melting methods by other organizations, as well as with samples obtained by traditional technology.

2. MATERIALS AND METHODS

The laser melting of the powder was carried out using the Mlab Cusing R machine manufactured by Concept Laser (Germany). The SLM process parameters were: a fiber laser power 90 W, a frequency 50 kHz, a scanning speed 500 mm / s, a spot size 100 μm. The process was carried out in a nitrogen atmosphere. The oxygen content (in accordance with the integrated sensors) at all stages was less than 0.1 %. **Tables 1, 2** show the chemical composition and mechanical properties declared by the manufacturer of the powder material (Concept Laser).

Table 1 Chemical composition of the material, Fe is balanced [3]

Component	Cr	Ni	Mo	Mn	Si	P	C	S
Indicative value (wt. %)	16.5 - 18.5	10.0 - 13.0	2.0 - 2.5	0 - 2.0	0 - 1.0	0 - 0.045	0 - 0.030	0 - 0.030

Table 2 Mechanical properties of the material [3]

	90°	45°	0°
Yield strength $R_{p0,2}$	374±5 MPa	385±6 MPa	330±8 MPa
Tensile Strength R_m	650±5 MPa	640±7 MPa	529±8 MPa
Elongation A	65±4 %	63±5 %	63±5 %
Young's modulus	$200 \cdot 10^3$ MPa	$200 \cdot 10^3$ MPa	$200 \cdot 10^3$ MPa
Thermal conductivity	15 W / mK	15 W / mK	15 W /mK
Hardness	20 HRC	20 HRC	20 HRC

The structural-phase state of steel after laser melting was studied by X-ray diffraction analysis and scanning electron microscopy. The micro-hardness was measured using a DuraScan 20 micro-hardness tester (manufactured by EMCO TEST, Austria).with a vertical adjustment of the loading unit (50 g, 10 sec), by Vickers indenting method

RESULTS AND DISCUSSION

The microstructure of the samples is shown in **Figure** 2. When the particles of the powder material are fused, the laser beam moves relative to the plane of the layer and fuses the previously distributed powder material, resulting in the formation of tracks. Cross sections of tracks fused with a laser are clearly visible in **Figures 2a, b**.

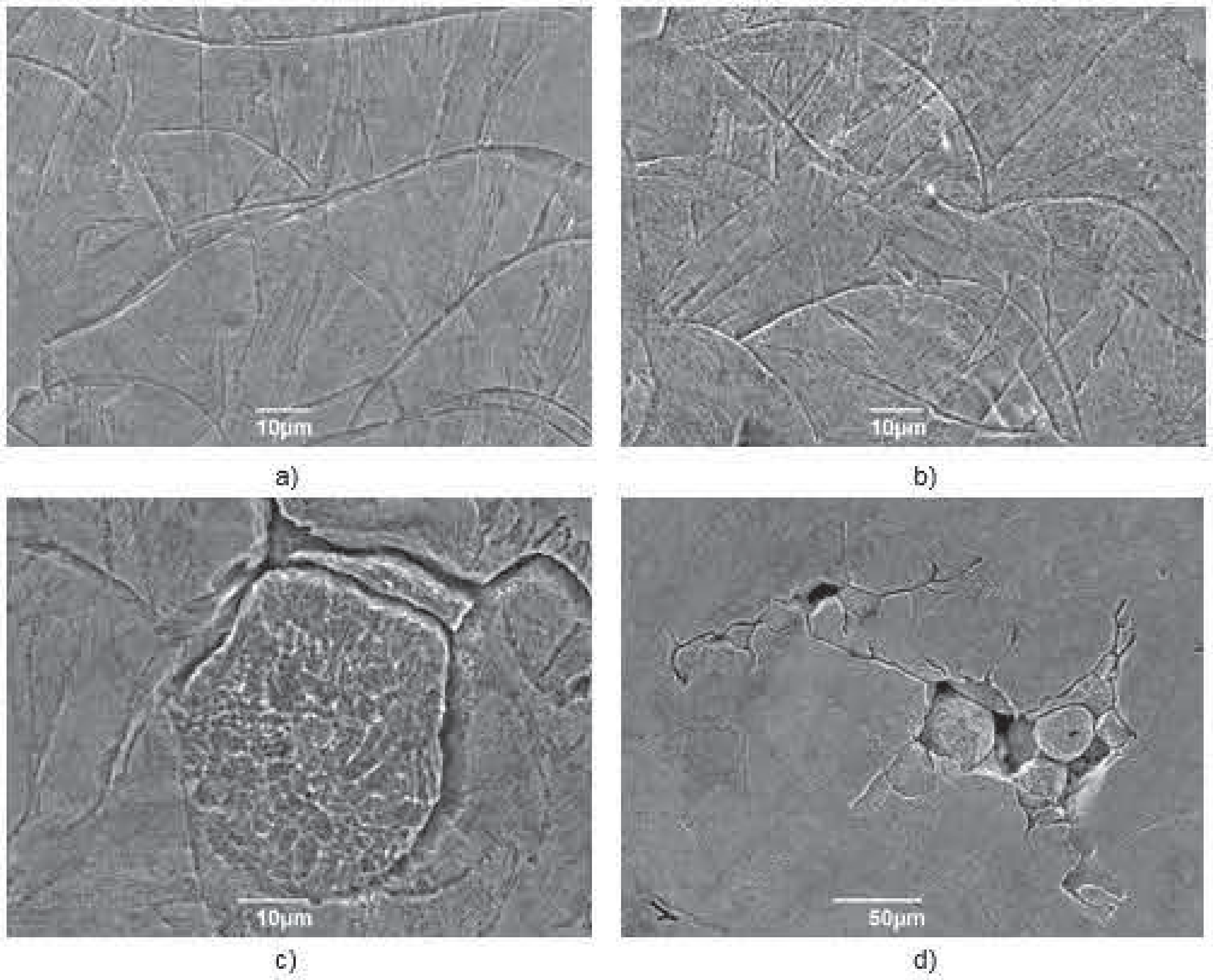

Figure 2 Microstructure of the samples obtained

Figure 2c shows that the grains have a very thin dendritic substructure [4]. This substructure is formed by rapid cooling of the melt and is characteristic of austenitic steels treated with a laser. The growth of grains is directional, but cellular structures are observed instead of dendrites [5]. The direction of grain growth leads to anisotropy of the printed material properties. The change in the characteristic size of the microstructure, due to cooling conditions, was studied in [6].

The results of X-ray phase analysis are shown in **Figure 3**. The peaks in the X.ray diffraction pattern correspond to the face-centered cubic phase, this fact proofs that powder steel after laser melting is in the austenitic state. **Figure 4** shows an untypical structure of objects obtained by laser melting. Namely, in the structure there are few pits with 50 μm droplets are observed.

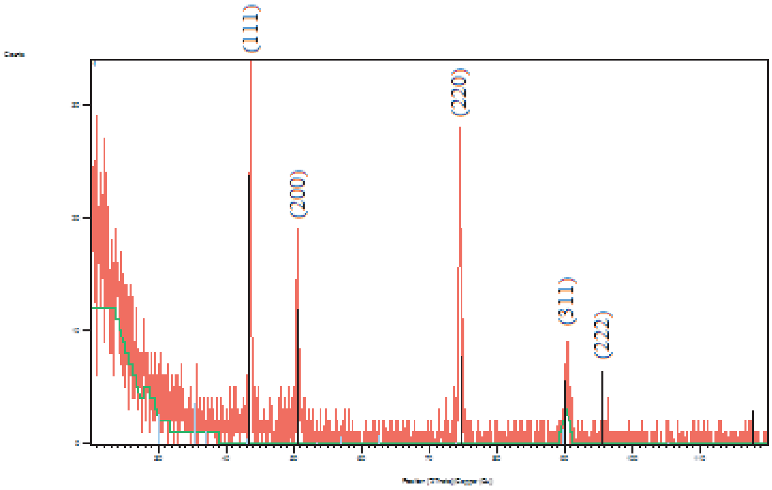

Figure 3 X.ray diffraction pattern of 316L steel obtained by selective laser melting

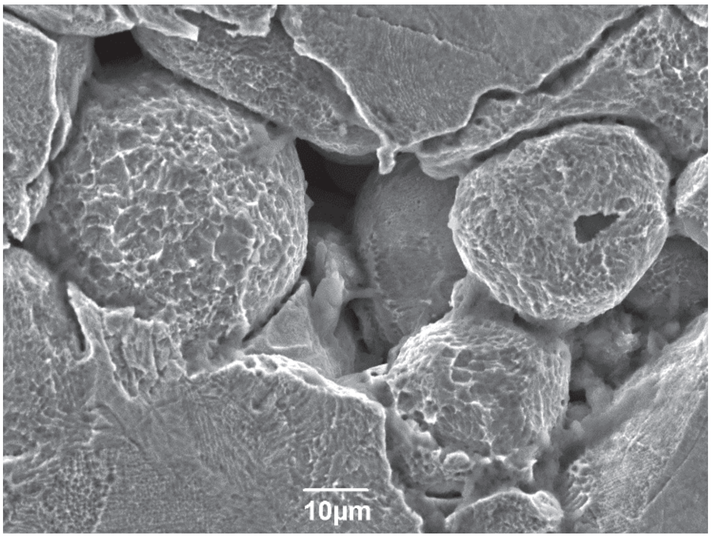

Figure 4 Balling process of 316L steel with laser melting

Balling process occurs due to temperature gradients and the material instability during SLM process. The reason of this process is the surface tension, where the melt tends to reduce the free surface energy, forming a shape with a minimum surface area, i.e. sphere. In this case, the Marangoni effect is observed in the melting zone, leading to convection currents due to the surface tension gradient as a function of temperature, and if convective currents are strong enough, the melted strip is divided into droplets. In addition, the drop under the influence of surface tension attracts adjacent particles of the powder, which leads to the formation of pits around the droplets and, ultimately, to an increase in porosity. Various mechanisms of balling process have been studied in [5, 7].

The hardness was determined by Vickers on the DuraScan 20 micro-hardness in the dimensions of prints created by indenting a diamond pyramid under a load of 50 g for duration of 10 s. As an indenter, a tetrahedral diamond pyramid with a vertex angle of 136 ° was used. The microstructure was investigated by scanning electron microscopy with a magnification of 60 times [8-9]. The results of micro-hardness measurements are given in **Table 3**.

The microphotography of the near-surface region with the marks of the EDX points is shown in **Figure 5**. The chemical composition of the sample according to the results of the EDX analysis is given in **Table 4**.

Table 3 The results of measuring the micro-hardness of 316L steel samples

Sample	Vickers hardness HV (MPa)									
	1	2	3	4	5	6	7	8	9	10
316L	918	983	995	992	1002	1101	892	1048	1033	1186

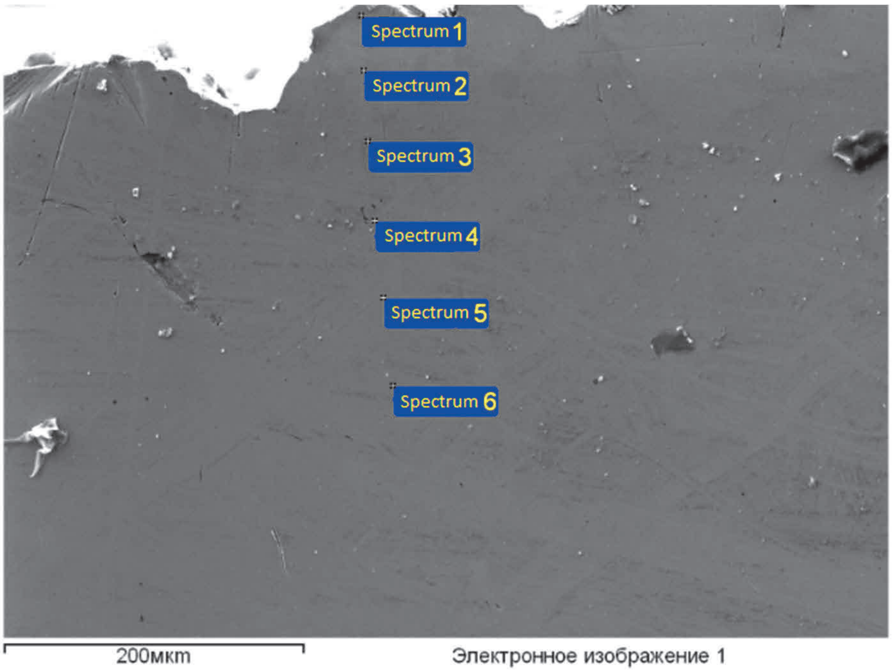

Figure 5 Microphotography of the near-surface region with marks of EDX points

Table 4 Chemical composition according to the results of EDX analysis

Spectrum	In stats	O	Si	Cr	Mn	Fe	Ni	Mo	Total
Spectrum 1	Yes	0.76	0.46	18.69	1.50	64.71	11.74	2.13	100.00
Spectrum 2	Yes	1.98	0.44	18.09	1.42	63.76	11.67	2.63	100.00
Spectrum 3	Yes	1.16	0.39	18.17	1.31	64.87	11.89	2.21	100.00
Spectrum 4	Yes	0.98	0.40	18.63	1.28	64.47	11.72	2.52	100.00
Spectrum 5	Yes	1.12	0.44	18.28	1.31	64.96	11.56	2.32	100.00
Spectrum 6	Yes	0.00	0.44	18.77	1.64	65.32	11.95	1.87	100.00
Average		1.00	0.43	18.44	1.41	64.68	11.76	2.28	100.00
AISI 316L			0.1,0	16.5 - 18.5	0 - 2.0	Balance	10.0 - 13.0	2.0 - 2.5	

CONCLUSION

From the results of the conducted studies it can be concluded that SLM is an effective method of powdered materials forming. The products quality characterized as samples with highly homogenous structure.

However, it should be noted that the formation of a qualitative melt band is associated with the search for the optimal region of process parameters (laser radiation power and scanning speed). When laser radiation is applied to particles, it is difficult to control the rapid processes of heating, melting and combining the powder particles at the location of the laser beam.

Viscosity and surface tension are key factors in the process of balling process. Increasing laser power and scanning speed can reduce the tendency for balling process, but excessive laser power and scanning speed will affect the accuracy of product sizes, as overheating of the powder will result in melting of the area outside the laser spot.

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