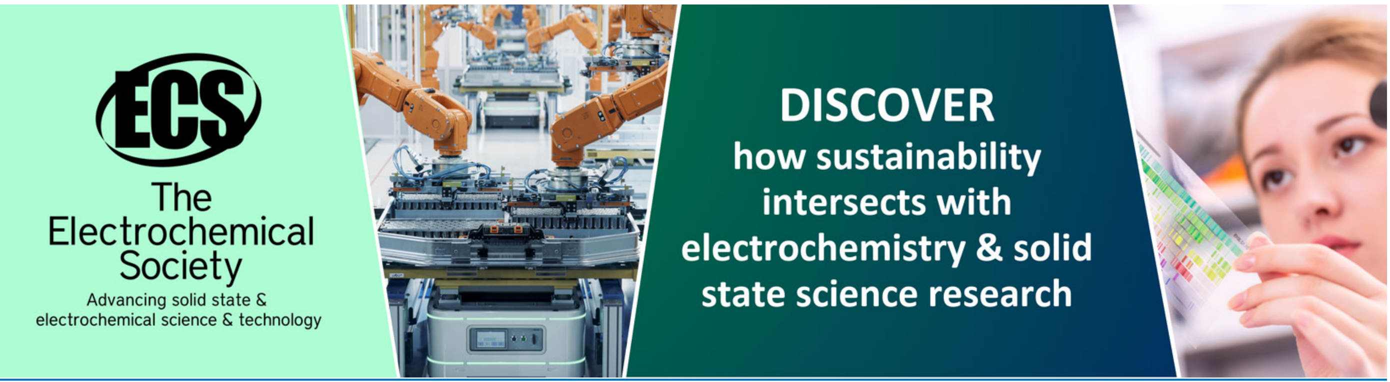
Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Microstructure and mechanical properties of stainless steel 316L obtained by Direct Metal Laser Deposition

To cite this article: D P Bykovskiy *et al* 2019 *J. Phys.: Conf. Ser.* **1238** 012029



IOP Conf. Series: Journal of Physics: Conf. Series **1238** (2019) 012029 doi:10.1088/1742-6596/1238/1/012029

Microstructure and mechanical properties of stainless steel 316L obtained by Direct Metal Laser Deposition

D P Bykovskiy, E D Ishkinyaev, V N Petrovskiy, A V Osintsev, P S Dzhumaev, V I Polskiy, K L Sergeev, A S Shchekin

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia

E-mail: ishkinyaev.emil@gmail.com

Abstract. The microstructure of 316L stainless steel obtained by layer-by-layer direct metal laser deposition is reviewed. Mechanical tests of the samples were performed in accordance with GOST 1497-84. Studies show that changes in power of laser radiation to grow parts lead to changes in their mechanical properties. The research shows dependencies between the strength characteristics of materials and the power of laser radiation. Causes of the forementioned changes are studied through the analysis of the microstructure. Nanosized inclusions of spherical shape were found in the process of studying the microstructure of materials. A study in the nature of the formation of these inclusions and their effect on the properties of the obtained material was performed.

1. Introduction

Addictive technologies not only let one obtain details of complex geometric shapes which can't be obtained by traditional methods, but also give an opportunity to give additional properties to the materials. By choosing various technological parameters of cladding process we can impact the inner structure of materials and obtain details with various required properties.

In this research, direct metal laser deposition (DMLD) technology is used. This method is based on layered jet printing, when the powder is dispensed through the coaxial laser-beam nozzle. This technology is frequently used both for damaged surface recovering and for obtaining details from a scratch.

The research is made towards the analysis of properties and microstructures of the details obtained with DMLD technology. These objects have improved qualities compared to fully identical details obtained by the traditional means of molding without thermal treatment. Possible reasons behind detail hardening compared to molded details and their property changes under various laser radiation capacities in the process of DMLD are observed in this research.

A cyclic impact of laser radiation is made on the obtaining object in the process of layered jet printing. The number of cycles equals the number of layers. A multiple heat treatment in the process of DMLD makes a great impact on the alteration of its mechanical properties.

Besides that, oxides of metals compounded with the powder appear in the obtained details. The reasons of their appearance may be both primary oxidation of powders and interaction with air in the process of cladding, which can't be entirely avoided using this printing technology. These inclusions can alter the properties of materials for the better, since they can be centers of material defect dislocation.

2. Sample growing
Stainless steel mark 316L powder was taken to perform this experiment. The content of chemical elements in this material is shown in the Table 1.

Table 1. Chemical element content. Here, the nominal values are given, without taking into account air oxidation.

Mark powder	Fe	C	Cr	Mo	Si	Mn	Ni
316L	66.17	0.03	17	2.5	0.8	1.5	12

Samples made under various radiation power were obtained using HUFFMAN HC-205 installation equipped with fiber laser capable of delivering 3.5 kilowatts. The radiation power was altered as the most influential parameter for the properties of materials [1]. Technological parameters of laser in the process of detail growing are shown in Table 2. For the purpose of residual tension removement, the layers were cross-cladded [2, 3]. Further on, electroerosional cut was used to obtain blades for rupture testing.

Table 2. Technological parameters of the cladding process. Laser beam diameter on the surface is 300 mcm. The scanning was made in 0.5 mm step and the rollers are cladded tight without any zones unfilled by metal.

Sample number	Power, W	Scanning speed, mm/min	Powder consumption gr/min
1	200	1000	1.2
2	250	1000	1.2
3	300	1000	1.2
4	350	1000	1.2

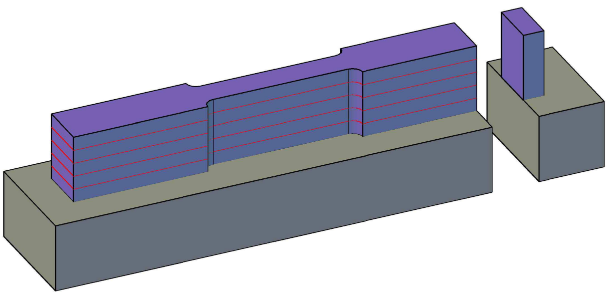


Figure 1. 3D model of the grown sample. The lines show the cutting planes for obtaining the plates for the tensile tests and the sections for analyzing the microstructure.

3. Mechanical properties
Sample stretching using INSTRON 5966 machine showed the following characteristics:

- Tensile strength decreases with the rise of radiation power amount, but the plasticity increases.
- Yield strength increases with power increase.

The Figure 2 shows the results of rupture testing of samples cut from the same areas, so they are matched in the order up from the substrate and are processed through the same number of heating cycles.

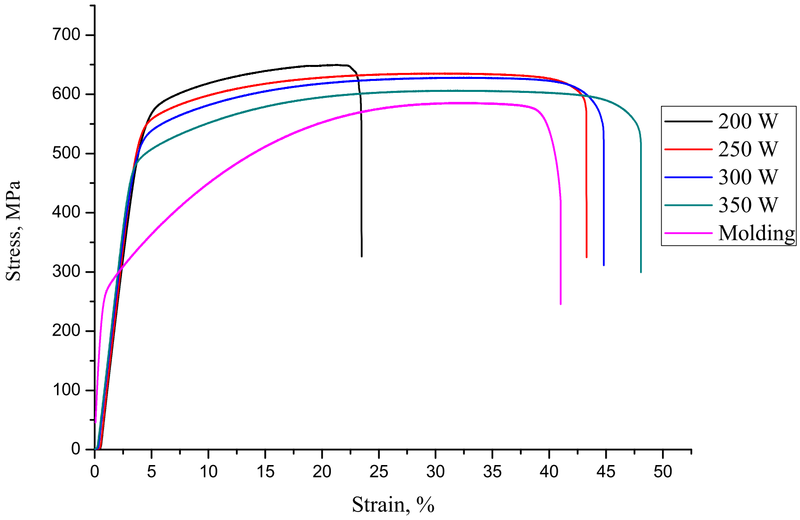


Figure 2. Stress-strain diagram of the samples grown at different laser radiation powers.

While Figure 3 shows the results of rupture testing of all samples on all layers. The diagrams show inevitable heterogeneity in samples properties depended on the height, because every layer is processed through different impact of laser radiation during the cladding.

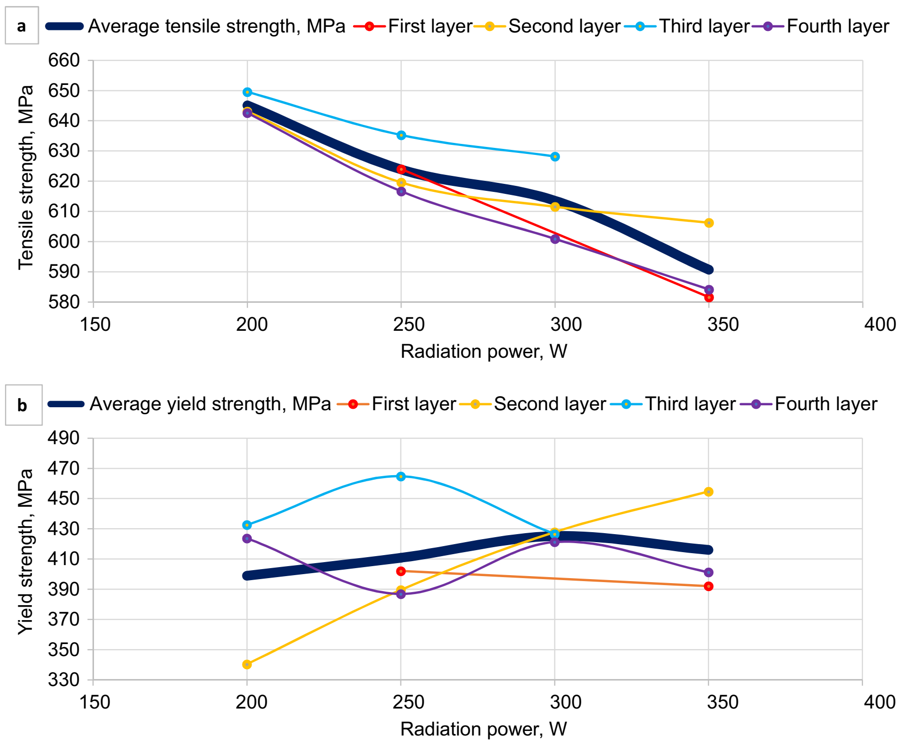


Figure 3. Dependency of tensile (a) and yield (b) strengths on laser radiation intensity. A layer is meant a plate 2 mm thick, located at a certain height from the substrate, the numbering of the layers is from the upper surface of the samples.

Obtained microstructures and mechanical properties of addictive technology materials are not well-studied because of uniqueness and complexity of thermal cycles during the machining. Heat treatment hugely impacts the materials and, due to it, objects obtained through addictive technology methods can have better strength characteristics than the usual ones [4, 5].

4. Microstructure

Structure of the obtained samples is studied using the structural method. Structural method is based on direct observation of material's structure and includes both microscopic and macroscopic analysis. Surfaces of the cladded samples were studied using Carl Zeiss EVO 50 microscope (Made in Germany).

Figure 4 shows that more dark areas appear with radiation power increase. The contrast depends on the crystallographic orientation of the structure's elements. The crystals grow towards the heat sink. It is clearly seen that the orientation of the cells is more chaotic, and that's the reason why these samples have lower tensile strength.

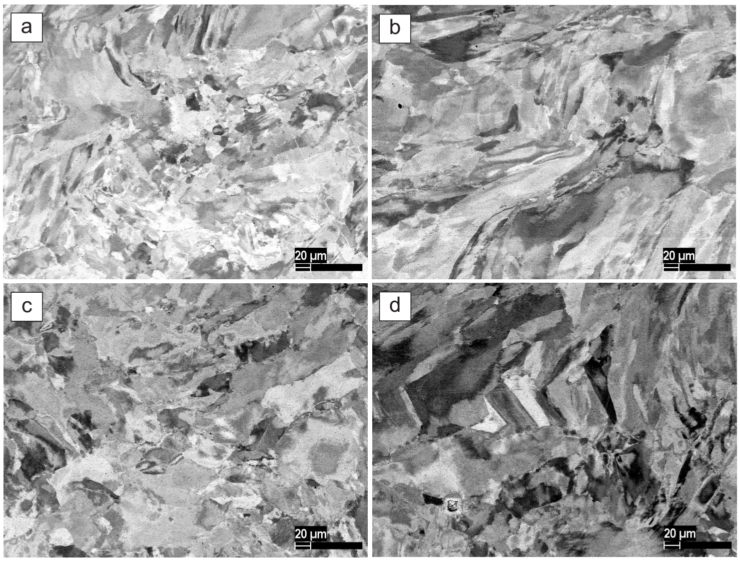


Figure 4. Microstructure (×250) of grown samples in 3 mm from the edge (2nd layer) with different radiation power: a) 200 W, b) 250 W, c) 300 W, d) 350 W.

An even meshed structure resulting in higher tensile strength can be observed in the samples shown in Figure 5. This effect is observed in medium rate of cooling. Elements of such structure are ground with the increase of cooling rate. With higher cooling rate branchings, indicating the start of dendrite crystallization, appear instead of cells. Smaller cells result in higher tensile strength [6].

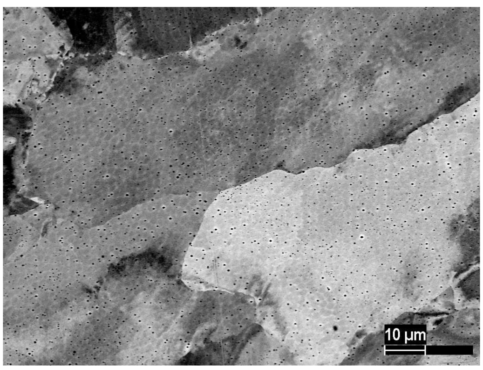


Figure 5. Microstructure (×1000) of grown sample in 3mm from the edge (2nd layer) with radiation power – 300 W (other areas are the same).

Microstructure on the Figure 6 shows minor changes with the height of the sample. Those changes derive from different number of thermal cycles of the layers and are much less significant than the previous ones depending on the power of the laser radiation.

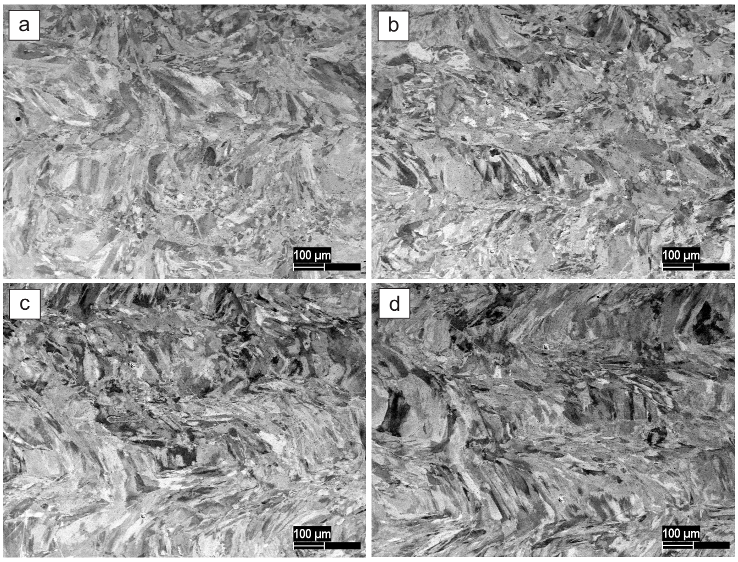


Figure 6. Microstructure (×100) of samples grown at one radiation power (300 W), but at different heights from the upper edge: a) 1 mm, b) 3 mm, c) 5 mm, d) 7 mm.

The analysis of samples structure in the areas of spalling shows presence of spherical particles what look like unmelted powder, though their size is smaller than the size of powder particles - around 100nm, which is 2-3 times smaller than unmelted powder particles (Figure 7).

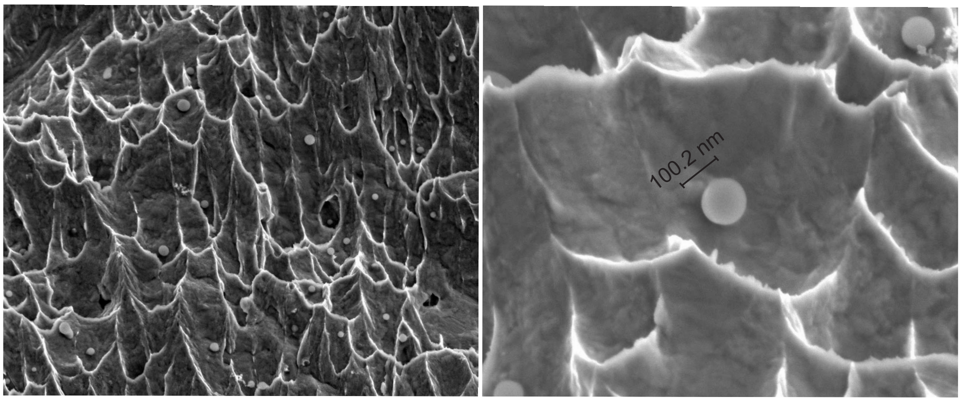


Figure 7. Topography of spalled surface (microscopic view).

Chemical analysis of these particles shows them as being oxides of metals presented in material matrix. They are formed at interaction with air as a result of fast heating-cooling processes. In the process of cladding, defects will necessarily form [7]. This defect areas can form evenly around these particles, resulting in tensile strength improvement.

These oxides appear to be black in the photographs made with electron microscope (Figure 5). They are evenly distributed in on the edges of grains and their concentration and size have no correlation with radiation power during growing of samples and their placement in sample's volume.

IOP Conf. Series: Journal of Physics: Conf. Series **1238** (2019) 012029 doi:10.1088/1742-6596/1238/1/012029

5. Results

The influence of the radiation power on the mechanical properties of the grown samples is presented in this research. With increase of radiation power, the ultimate strength decreases, but the plasticity properties increases. The most common explanation of these results is the fact that at a lower radiation power, a more ordered crystallographic structure is observed. All samples have higher performance of these characteristics than conventional parts of the same material, obtained by traditional methods of molding. Apparently, this is associated with simultaneous thermal treatment of the material during growing. The research shows no heterogeneity of properties over the volume of the material, due to the fact that each layer passes through different processing cycles. The heterogeneity of the obtained values of the strength characteristics are not very noticeable in comparison with the previous one and can subsequently be reduced by changing the laser radiation power during the cladding process.

Based on the results of the microanalysis, spherical particles were found in the volume of the samples, which are the oxides of the matrix metals. Their size and concentration do not depend of the radiation power and the location of the height of the part. They are formed due to the primary oxidation of the powder or the interaction of the melt bath with air. Despite the fact that surfacing occurs with the supply of an inert gas, it is impossible to completely avoid oxidation. There are suggestions that this phenomenon can affect the properties positively, since these particles can collect defects around themselves, evenly distributing them throughout volume.

References

[1] Grigoryants A G, Shiganov I N and Misyurov A I 2008 *Technological processes of laser processing* 2nd ed (Moscow: Bauman Moscow State Technical University)
[2] Kudzal A, McWilliams B, Hofmeister C, Kellogg F, Yu J, Taggart-Scarff J and Liang J 2017 *Materials and Design* **133** 205–215
[3] Wang D, Yu C, Ma J, Liu W and Shen Z 2017 *Materials and Design* **129** 44–52
[4] Popovich V A, Borisov E V, Popovich A A, Sufiiarov V S, Masaylo D V and Alzina L 2017 *Materials and Design* **131** 12–22
[5] Hengsbach F, Koppa P, Holzweissig M J, Burns M, Nellesen J, Tillmann W, Tröster T, Hover K and Schaper M 2017 *Materials and Design* **133** 136–142
[6] Bunin K P and Baranov A A 1970 *Metallography* (Moscow: Metalurgiya)
[7] Darvish K, Chen Z W and Pasang T 2016 *Materials and Design* **112** 357–366