Optimal parameters for selective laser melting of various steel powders

I V Shakirov, Yu M Markova and D M Anisimov
NRC "Kurchatov Institute" – CRISM "Prometey", Saint-Petersburg, 191015, Russia

E-mail: npk3@crism.ru

Abstract. The data of mechanical testing of samples manufactured by selective laser melting of powders using the EOSINT M270 unit is systematized. Used powder raw materials of a different chemical composition close to common stainless-steel brands. Melting parameters found to obtain a complex of mechanical properties exceeding the characteristics of monolithic samples.

1. Introduction
Improving the technological equipment and the possibility of industrial use of electronic, plasma, laser and other concentrated energy flows initiated the development of new methods for manufacturing parts of complex form, called "additive technologies", and in particular – selective laser melting (SLM). The basis of the technology is a beam of concentrated energy – laser. The trajectory and scanning speed of the beam, as well as the mass of the powder applied in layers, controls the PC computer for a user-defined 3D-model. The relevance and promising of additive technologies are determined by the possibility of manufacturing a bulk product into one cycle from the idea and design before creating a finished sample [1-4]. In the practical implementation of technology, it is difficult to choose the melting parameters, since the parameters of the equipment used will greatly differ. In the list of technological parameters of the process, the dominant influence is rendered the power of the energy source and the rate of its movement along the powder layer.

The aim of the presented work is to determine the melting parameters at the EOSINT M270 unit, which make it possible to obtain a complex of mechanical properties of additive samples, not inferior to the parameters of common grades of cast steel of a close chemical composition.

2. Materials and experimental methods
For the practical implementation of the SLM, on the laboratory areas of Nanocentre NRC "Kurchatov Institute" – CRISM "Prometey" was built a technological line. It includes a plot of input control of powder raw materials of a different chemical composition, SLM EOSINT M270 unit for melting of powders on a given 3D-model, a plot of quality control and evaluation of the mechanical properties of the additive materials obtained. In the EOSINT M270 unit (figure 1), the beam of a solid-state laser with a power of up to 200 W in continuous mode at a speed of up to 1500 mm / s scans the melting area of the powder.

A dispersed steel powders were used for melting (figure 2) after the selection on the sieve with a cell of 80 μm. The granulometric composition of powders (figure 3) was controlled on the Malvern
Mastersizer 2000 installation by laser diffraction using the fraunlonosphere approximation. Powders were made by spraying by Höganäs AB (316L and 410L), JSC Polema (17-4PH and 321), EOS GmbH (MS1). The chemical composition of powders is presented in table 1.

**Figure 1.** SLM implementation scheme.

**Figure 2.** Example of powder from an electron microscope.

**Figure 3.** Granulometric composition of powders for melting.

Manufacturing of the samples was carried out in gradually by applying layers of powder with a thickness of 40 μm on a platform measuring to 250x250 mm. Throughout the cycle of manufacturing, the location of the melting zone of the powder corresponded to a given 3D-model.

In order to objectively assess the complex of mechanical properties, models were designed (figure 4) and samples were manufactured (figure 5), which are traditionally used for mechanical testing for tension, according ASTM E8, KCU, according ASTM D 6110, and also cylinders.

| Alloy | Cr   | Ni   | Mn   | Si   | Mo   | Cu   | Nb   | Co   |
|-------|------|------|------|------|------|------|------|------|
| 410L  | 12.0 | –    | 0.9  | 0.7  | –    | –    | –    | –    |
| 316L  | 16.5 | 10.5 | 1.8  | –    | 2.2  | –    | –    | –    |
| 17-4PH| 15.5 | 3.1  | 0.7  | 0.4  | –    | 3.4  | 0.2  | –    |
| 321   | 18.0 | 10.0 | <2.0 | <0.8 | –    | <0.3 | –    | –    |
| MS1   | <0.5 | 18.0 | <0.1 | –    | 4.9  | <0.5 | –    | 9.0  |
3. Experimental results and discussion

The first experiments with the laser showed that in comparison with the strength characteristics of the monolithic metal samples of a similar chemical composition, in the SLM technology, the increase in the power of the laser leads, on average, to the growth of the strength properties of samples by ~ 1.3 times (table 2) and decrease in resistance to development cracks (KCU). Changes in mechanical parameters are identical [5-8] for all tested samples. It has been established that the strength (yield strength and tensile strength) characteristics (figure 6) of the melted metal, as well as the values of the impact viscosity (KCU) in terms of the average measurement results (figure 7) depend not only from the input power, but also from the scanning speed.

Figure 4. 3D-model of additive sample.

Figure 5. Samples manufactured by SLM.

Figure 6. The reserve of plasticity (yield strength / tensile strength) of the additive samples depending on the scanning speed on the example of steel MS1 (left) and the regression of the scanning speed on laser power according to 316L samples testing (right).

Figure 7. Changes in resistance to crack growth (KCU) depending on the scanning speed on the example of samples from steels MS1 (left) and 321 (right).
Table 2. Mechanical properties of monolithic and additive steels.

| Alloy    | Monolithic | Additive |
|---------|------------|----------|
|         | $\sigma_{UTS}$, MPa | $\sigma_Y$, MPa | $\varepsilon_U$, % | $\sigma_{UTS}$, MPa | $\sigma_Y$, MPa | $\varepsilon_U$, % |
| 410L    | 520        | 310      | 25         | 680        | 589      | 23         |
| 316L    | 560        | 290      | 50         | 696        | 575      | 35         |
| 17-4PH  | 1100-1450  | 1000-1300| 5-10       | 1090       | 535      | 14         |
| 321     | 650        | 480      | 35         | 712        | 624      | 31         |
| MS1     | 1100       | 1050     | 10         | 1130-1160  | 1040-1060| 7-10       |

* In the complex of mechanical properties ($\sigma_{UTS}$, $\sigma_Y$ and $\varepsilon_U$), the assessment of the metal deformation ability is produced relative to yield strength / tensile strength.

From the figures 6 and 7 it is clear that on the EOSINT M270 unit, with an increase in the scanning speed up to 750 mm / s, there is an average reduction of the strength parameters and resistance to the crack growth (KCU) of the additive samples. However, the values of the dispersions of the measured characteristics show that the scanning speed is 700 mm / s leads to the most stable data. This fact is interpreted as the best speed parameters for melting of the powder using the EOSINT M270 unit. It should be noted that similar data were obtained during the melting of all powders (table 2). This fact made it possible to assert that for the EOSINT M270 unit, the optimal melting parameter is: scanning speed 700 ± 10 mm / c. At the same time, the plasticity supply, determined relative to yield strength / tensile strength, suggested the achievement of a homogeneous structural state of samples manufactured by SLM. This assumption was tested on cylindrical samples from 316L and 321 steels by plastic deformation with compression at a temperature of 1200 °C (figure 8). These cylinders were built at the optimal scanning speed of 700 mm / c, but during variations of the laser power from 175 to 195 W.

It can be concluded that the SLM samples have the greatest strength at the laser power of 185 W.

Similar data were obtained after a metallographic study of the samples (figure 9). It was also established that additive samples are actively stronger by localizing the plastic flow.
Figure 9. Homogeneous structure of SLM samples from powders 316L (left) and 321 (right) after melting with a laser power of 185 W and a scanning speed of 700 mm / s.

4. Conclusions
According to the results of the behavior work, it was established that with the EOSINT M270 unit, intended for SLM of metal powders, it is possible to manufacture parts with a complex of mechanical properties that are not inferior to the properties of the monolithic material.

The optimal parameters for selective laser melting are achieved with a laser power of 185 W and a scanning speed of 700 ± 10 mm / s.

References
[1] Froes F, Boyer R 2019 Additive Manufacturing for the Aerospace Industry (Amsterdam: Elsevier) p 482
[2] Brandt M et al. 2016 Laser Additive Manufacturing. Materials, Design, Technologies and Applications (Sawston, Cambridge: Woodhead Publishing) p 498
[3] Kuznetcov P et al. 2018 Structure and Properties of the Bulk Standard Samples and Cellular Energy Absorbers (Rieka: IntechOpen) p 22
[4] Leong K F, Chua C K 2014 3D Printing and Additive Manufacturing: Principles and Applications (Singapore: World Scientific Publishing) p 456
[5] Zhukov A, Barakhtin B, Bobyr V and Kuznetcov P 2019 IOP Conference Series: Earth and Environmental Science 272 № 022233
[6] Hanzl P, Zetek M 2015 Procedia Engineering 100 1405–1413
[7] Wang D, Yang Y 2013 Journal of Materials Processing Technology 213 1734–1742
[8] Zhukov A, Deev A, Kuznetsov P 2017 Physics Procedia 89 172–178

Acknowledgments
Experimental studies were carried out on the equipment of the Core shared research facilities "Composition, structure and properties of structural and functional materials" of the NRC «Kurchatov Institute» - CRISM "Prometey" with the financial support of the state represented by the Ministry of Education and Science of the Russian Federation under agreement No. 13.CKP.21.0014. The unique identifier is RF---2296.61321X0014.