Investigation of the influence of nickel-based alloy powder EP648, obtained by plasma rotating electrode process, on powder utilization rate, structure and chemical composition, applied to direct laser deposition

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Investigation of the influence of nickel-based alloy powder EP648, obtained by plasma rotating electrode process, on powder utilization rate, structure and chemical composition, applied to direct laser deposition

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Abstract. This work is about study of properties and technological characteristics of powder nickel-based alloy EP648. The influence of initial material characteristics and main technological parameters of cladding process on formation of geometry and structure is considered. The powder flowability influence on the focusing ability of a gas-powder jet is established. The regularities of the process stability and crystallization rate of depositing layer as a function of particle size are obtained. Specimens was deposited using laser cladding technological complex, designed and produced by ILWT, SPbPU.

1. Introduction.
Heat-resistant nickel alloys are widely used in gas turbine industry because of their physicochemical and mechanical properties. At least 70% of mass of modern turbo-fan engines are composed by this type of alloys [1, 2]. Currently, the main industrial technologies for manufacturing parts from heat-resistant alloys are casting, milling and plastic deformation. In recent years, gas turbine industry is introducing additive manufacturing technologies with the use of laser irradiation, which lead to reduce costs, labor and material consumption of products [3, 4]. Cladding with certain physical and mechanical properties has an important place among the high-tech methods of laser processing. The restoration of worn-out assemblies and surfaces and particularly geometry of the turbo-fan blades remains relevant [5, 6].

The most important factor of direct laser deposition, affecting to quality of product, is the process stability, ensured by the constant flow of filler material on its surface [7]. In case of powder-filler, material transfers to forming track partly. Amount of deposited powder depends on number of process technological parameters and focusing ability of gas-powder jet, which influence to powder transportation and melting processes [8,9]. The powder particles distribution in the gas-powder flow is an important parameter. It affects to performance of process and its quality. With constant rates of transporting gas and filling powder, the particle distribution is stationary and depends on many factors: shape and size of particle, density of material. For example, spherical particles take the gas velocity and are transported in a laminar flow. Particles of irregular shape move more fragmentally, their flow is nonstationary [10]. Powder particles can reach the substrate both in the heated and molten state, which affects the stability of deposition formation [11]. Knowing the parameters of direct laser deposition,
thermophysical properties of the material and the particle size, it is possible to calculate the temperature of its particles, thereby the structure and properties of manufacturing part can be predicted [12].

Powders for additive technologies and cladding should have sphericity, high flowability and bulk density [13].

2. Methods, materials and equipment.

The investigation was carried out on heat-resistant nickel alloy EP648 powder of various granulometric compositions obtained via plasma rotating electrode process at Composite JSC. Chemical composition of powder is shown in table 1.

| Element | Ni  | Cr  | W   | Mo  | Al  | Ti  | Nb  | Fe  | Co  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| mass. % | 57.9| 31.9| 4.4 | 2.9 | 0.4 | 1.1 | 1.0 | 0.3 | 0.1 |

The granulometric composition of powder samples was determined by the static light scattering method using a particle analyzer SALD-7500nano, Shimadzu, Japan. The shape factor, bulk density and flowability of powder samples were determined by standard techniques.

The technological properties of various granulometric composition powder samples were evaluated via direct laser deposition. Direct laser deposition of walls was done on laser cladding technological complex based on industrial robot LRM-200iD_7L, Fanuc; laser irradiation source LK-700, IPG Photonics; laser head FLW D30, IPG Photonics with cladding coaxial nozzle COAX-40-S, Fraunhofer ILT; powder feeder Oerlikon Metco Powder Feeder Twin 150 with track transection of metering disk of 5×0.6 mm². The spot diameter of laser beam on the surface, irradiation power, traverse speed of focusing head with cladding nozzle, volumetric rate of filling powder, rate of transporting and shielding gas, length of manufacturing sample and increment of nozzle along the Z-axis after each layer were unchanged.

The cladding was done with the following technological parameters: laser power – 250 W; cladding speed 5 mm/s; powder consumption 2.65 g/min; beam diameter on the substrate 0.9 mm; argon consumption 6+19 l/min.

For calculating powder utilization rate was used formula:

\[ K = \frac{M}{G T} \]  

where M – is deposited mass per time unit T, g; G – nominal powder rate, g/min. Nominal powder rate was determined by weighting of powder, transferred to container in time unit T, min. The focusing ability of cladding nozzle (minimal diameter of gas-powder jet) was evaluated by ratio of molten pool square to powder utilization rate [9]. The width and height of deposited samples were measured. Crystallization rate was determined by metallographic analysis of longitudinal deposited section using formula:

\[ V_s = V_c \times \cos \alpha \]  

where \( V_s \) – is crystallization rate, mm/sec; \( V_c \) –is traverse speed of focusing head, mm/sec; \( \alpha \) – angle between crystallite growth direction and traverse direction of focusing head [17].

Longitudinal and transverse sections were used to study the microstructure of the samples. Metallographic studies were carried out using an optical microscope DMI 5000 (Leica) and a scanning microscope Phenom ProX.

3. Results and discussion.

The Result of determination of chemical composition by X-ray fluorescence analysis of rod and samples from alloy powder EP648 are presented in table 2.
### Table 2. Results of X-ray fluorescence analysis.

| Chemical element | Mass fraction of elements, % |
|------------------|--------------------------------|
|                  | Rod                  | Powder (<125 μm) | Powder (125–160 μm) | Powder (>160 μm) |
| Ni               | 56.79                | 57.66            | 57.95                | 58.12            |
| Cr               | 32.72                | 31.87            | 31.87                | 31.8             |
| W                | 3.84                 | 4.43             | 4.44                 | 4.28             |
| Mo               | 2.44                 | 2.95             | 2.93                 | 2.86             |
| Al               | 1.11                 | 0.44             | 0.34                 | 0.33             |
| Ti               | 0.98                 | 1.07             | 1.08                 | 1.24             |
| Nb               | 0.88                 | 1.00             | 0.99                 | 0.96             |
| Cu               | 0.64                 | 0.03             | 0.03                 | 0.02             |
| Fe               | 0.34                 | 0.29             | 0.28                 | 0.29             |
| Zn               | 0.20                 | 0.02             | 0.02                 | 0.02             |
| Si               | 0.04                 | 0.14             | 0.02                 | 0.03             |
| Co               | 0.01                 | 0.09             | 0.04                 | 0.04             |
| Ca               | 0.01                 | 0.01             | 0.01                 | 0.01             |
| Total:           | 100                  | 100              | 100                  | 100              |

Comparing chemical composition of samples with a metal rod, it can be seen that is stable despite the difference of particle size.

According to obtained data, the granulometric composition of powder samples is wider range than the manufacturer declared it. In each fraction, there are particles of both larger and smaller sizes. Statistical ranges of particle sizes, distribution modes, flowability and bulk density of EP648 alloy powders are given in the table 3.

### Table 3. Granulometric composition, flowability and bulk density of various powder fraction.

| Fraction, μm | Measured particle range, μm | Average particle size, μm | Distribution mode, μm | Average flowability, sec | Average bulk density, g/cm³ |
|--------------|-----------------------------|---------------------------|-----------------------|--------------------------|-----------------------------|
| 40-64        | 35-85                       | 52                        | 55                    | 16.65                    | 4.85                        |
| 64-80        | 55-110                      | 75                        | 69                    | 17.08                    | 4.80                        |
| 80-100       | 70-130                      | 97                        | 88                    | 17.74                    | 4.86                        |
| 100-125      | 90-140                      | 110                       | 110                   | 18.08                    | 4.81                        |
| 125-160      | 110-170                     | 136                       | 140                   | 18.36                    | 4.84                        |

As can be seen from the table, increasing of particle size leads to decreasing flowability of powder. The characteristic dependence of powder bulk density on the particle size was not revealed. Powder utilization rate by molten pool for powders of various fraction is shown in table 4.

During the shape measurement of powder particle, more than 500 particles were analyzed. According to GOST 25849-83 the particle shape factor is 1.15, which corresponds to spherical shape. Figure 1 shows a photograph of powder, indicating the particles involved in the calculation.
Table 4. Powder utilization rate by molten pool for powders of various fraction.

| Measured particle range, μm | Powder mass rate, g/min | Laser irradiation time, min | Deposited powder mass, g | Powder utilization rate |
|-----------------------------|-------------------------|----------------------------|--------------------------|-------------------------|
| 35-85                       | 2.42                    | 2                          | 2.85                     | 0.5889                  |
| 55-110                      | 2.84                    |                             | 0.5876                   |
| 70-130                      | 2.74                    |                             | 0.5663                   |
| 90-140                      | 2.41                    |                             | 0.498                    |
| 110-170                     | 2.21                    |                             | 0.4579                   |

The powder utilization rate depends on area of molten pool and diameter of gas-powder jet focusing point [9]. The width of deposited walls, and hence the approximate diameter of molten pool, is 1.2 mm. Due to the constancy of molten pool area, the powder utilization rate is reduced due to increasing diameter of the gas-powder jet caused by increasing of particle size. The area of gas-powder jet focus point can be estimated by dividing the area of molten pool by the powder utilization rate. Results are shown in table 5.

Table 5. The area of gas-powder jet focusing point.

| Area of molten pool, mm² | Area of gas-powder jet focusing point, mm², where powder utilization rate is |
|---------------------------|--------------------------------------------------------------------------------|
|                           | 0.5889              | 0.5876              | 0.5663              | 0.498              | 0.4579              |
| 1.13                      | 1.92                | 1.92                | 2.0                 | 2.27               | 2.47                |

Reducing the powder utilization rate leads to height decreasing of depositing layer. Figure 2 shows the dependence of layer height on particle size. The nozzle vertical increment after each layer is one of the direct laser deposition parameters. From the self-regulation theory of direct laser deposition [7], it is known that for a time-stable process, the volume of feeding powder flow should be greater than the required volume for forming the layer, which depends on.
Figure 2. The dependence of layer height on particle size.

The productivity of process increases with increasing the height of depositing layer. It influences for temperature condition of process. As a result of metallographic analysis of samples longitudinal sections, the tendency of changing of crystallites angle inclination depending on process productivity is detected. Based on equation (2), the crystallization rates could be estimated for each particle size. Microstructures of deposited walls longitudinal sections are shown in figure 3a, 3b.

Figure 3. a) Microstructure of longitudinal section using of particle size of 35-85 μm; b) Microstructure of longitudinal section using of particle size of 125-160 μm; Direction of molten pool traverse is shown by arrows.

4. Conclusions.

The powder produced by plasma rotating electrode process has a spherical shape and high bulk density. Based on conducted experiments we can say that various of particle size not affect chemical composition.

The flowability of powder increases with decreasing particle size. Increasing the fluidity of powder leads improvement the nozzle focusing ability, which in turn increases the volume of feeding powder flow into the molten pool. Increasing of particle size reduces the stability of the direct laser deposition process. Increasing of particle size increases the crystallization rate of depositing layer.
References

[1] Merkulova G.A. *Metallovedenie i termicheskaya obrabotka tsvetnykh splavov.* (Krasnoyarsk: Siberian federal university; 2007).

[2] Moiseev S.A., Lomberg B.S. *Heat-resistant and deformable alloys for modern and promising gas-turbine engines.* Aviatsyonnye materialy na rubezhe XX-XXI vekov. (Moscow: VIAM; 2002).

[3] Kelbassa I., Albus P., Dietrich J., Wilkes J. *Manufacture and repair of aero engine components using laser technology.* (Proceedings of the 3rd Pacific International Conference on Application of Lasers and Optics 2008; 405:208-12).

[4] Yermolayev A.S., Ivanov A.M., Vasilenko S.A. *Laser technologies and processes in the manufacture and repair of gas turbine engine parts.* (Vestnik PNIPU 2013; 35: 49-63).

[5] Zhatkin S.S., Shchedrin Ye.YU., Kogteva A.V. *Features of restoration of gas turbine engine blade geometry by laser powder cladding.* (Izvestia RAS SamSC 2015; 4: 782-8).

[6] Zemlyakov E.V., Babkin K.D., Korsmik R.S., Sklyar M.O. *Prospects for using laser surfacing technology for the repair of compressor blades for gas turbine engines.* (Photonics 2016; 58: 10-23).

[7] Turichin G., Zemlyakov E., Klimova O., Babkin K. *Hydrodynamic instability in high-speed direct laser deposition for additive manufacturing.* 9th International conference on Photonic technologies – LANE 2016; 83: 674-683.

[8] Turichin G.A., Somonov V.V., Klimova O.G. *Investigation and modeling of the process of formation of the pad weld during laser cladding by radiation of high power fiber laser.* Applied Mechanics and Materials 2014; 682: 160-165.

[9] Korsmik R.S., Turichin G.A., Babkin K.D. *Laser cladding technological machine. Investigation of efficiency of various nozzles design.* IOP Conf. Series: Journal of Physics 2017; 857: 012021.

[10] Asyutin R. D. *Experimental investigation of the gas-powder flow during laser surfacing with the use of various technological nozzles.* All-Russian Scientific and Technical Conference of Students "Student Scientific Spring 2014: Mechanical Engineering Technologies 2014: 454-70.

[11] Drenin A. A. *Investigation of the interaction of the gas-powder flux with laser radiation during coaxial feeding of powder materials with various shapes and particle sizes during the laser surfacing process.* Youth scientific and technical bulletin MSTU after Bauman 2015; 5.

[12] Stankevich S L, Korsmik R S Valdaytseva E A. *Modeling of bead formation process during laser cladding.* IOP Conf. Series: Journal of Physics 2017; 857: 012045.

[13] Alishin M.I., Knyazev A.E. *Production of metal-powder compositions of high purity of titanium alloys by induction gas atomization for additive technologies.* Trudy VIAM 2017; 59.