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Laser sintering of antifriction tribological surface for large-dimensioned marine propeller shafts

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Abstract

Implementation of laser sintering (cladding) and growing technologies in the production cycle can significantly reduce the costs of critical marine engineering parts manufacturing. Reducing the cost by reducing the time of manufacture simultaneously with material saving is one of the main advantages of additive technologies over traditional metal-working technologies.
The article presents results on researching and development of technology for laser sintering of maritime machinery items surfaces, in particular - marine propeller shafts. Different types of Fe-, Ni-, Co-, Cr- and Cu-based cladding materials were investigated in this work. The evaluation of metallurgical process features and influence of melt dynamic on surface quality were carried out. Microstructure analysis of cladding surfaces including structural-phase determination and quantitative composition of components was made.
Developed technology provides formation of antifriction surface for large-dimensioned marine propeller shafts with high tribological properties and allows decreasing labor consumption of installation works on vessels heavy-loaded propulsion devices.

Keywords: laser sintering; laser cladding; additive manufacturing; marine propeller shafts

The reliability and the operation efficiency of transport vessels are characterized mainly by the trouble-free operation of the propulsion system. It can only be ensured by a set of progressive engineering and technological solutions implemented during the construction of the vessel. This is especially related to arctic vessels, which made increased demands on reliability, operational efficiency and environmental friendliness.

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The propulsion systems of modern transport vessels, in particular, icebreakers, are classified as heavy-loaded and consist, as a rule, of a powerful multi-shaft powerplant (unit capacity of about 20 MW) and a short rigid shafting with a minimum number of bearings. Shafts have a diameter of 700 mm and above. On the icebreaker of the project 22220 "Arktika" (Fig. 1 a), the shaft diameter is more than 800 mm, and in the designed icebreaker of the project 10510 "Leader" (Fig. 1 b) it will be more than 1000 mm.

a b

Fig. 1. Modern arctic vessels (a) icebreaker (project 22220 "Arctic"); (b) icebreaker (project 10510 "Leader")

Design features and significant weight and size characteristics of propulsion systems require special manufacturing, centering and installation techniques, since the existing technologies mastered by the shipyards in the 70s of the last century will not meet the requirements that are currently imposed on the modern vessels propulsion systems.

The existing technology of antifriction friction surface formation of the stern bearing is based on the installation of bronze linings on the marine propeller shaft with a "hot" fit. Considering the dimensions of the propeller shaft and linings, the risk of jamming of the liner during the setting is very high. In addition, with this technology, lining is a stress concentrator, which reduces the fatigue strength of the propeller shaft and can lead to its breakage.

To replace the traditional technology of setting expensive bronze linings on the marine propeller shaft it was proposed by JSC SSTC to use the laser sintering (cladding) technology with the aim to create an antifriction layer of bronze on a steel bush. For a long time JSC SSTC develops equipment and technologies for cladding (hardfacing) with high automation level for manufacturing and reworking the critical engineering parts (mainly for plasma cladding).

The technology of laser powder cladding is promising and is actively being introduced into production processes, primarily to restore worn parts and assemblies. However, implementation of laser cladding technologies in the production cycle can significantly reduce the costs of high-tech products manufacturing. Reducing the cost by reducing the time of manufacture simultaneously with material saving is one of the main advantages of additive technologies and laser cladding in particular, over traditional reworking and metal-working technologies including machining on CNC machines or technology of casting with further machining.

One of the main advantages of laser cladding versus conventional methods like TIG or PTA welding is the low heat input into the base material. This results in less distortion of the component. The high cooling rate produces a very desirable fine-grained microstructure. The overlay is fully metallurgical bonded to the base material with much lower dilution compared to conventional welding methods, so a single coating layer is in most cases sufficient to achieve full transformation between the two materials. Thickness tolerances and surface quality is very good and depending on the application requires minimal or no rework.

The main task in the development of laser sintering process is obtaining a high quality coating (without pores), with good adhesion to the base material. It is required to ensure a minimum mixing and dissolving the deposited material to the substrate. The optimum spot size and power density at which the maximum deposition rate is provided can be determined for a given velocity of movement and feed rate of filler material (powder or wire).

During laser powder cladding process powders feed usually with the help of pressure or gas injector feeders-dosing directly into the laser radiation zone. At the same time powder is mixed with the gas stream, heated and accelerated with jet during the passage from the mixing zone to the sprayed surface and then falls on the surface of the substrate. Initially, studies were conducted vehicle gas jet stream nozzles for different configurations: coaxial and non-coaxial. The scheme with a coaxial nozzle with a four-feeding powder was chosen (Fig. 2).

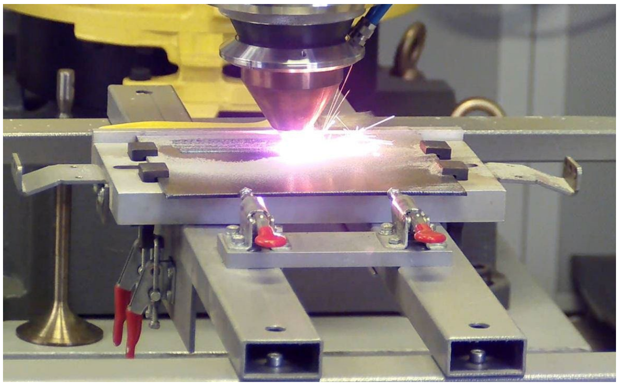


Fig. 2. Coaxial laser powder cladding

During the experimental work three characteristic profiles were identified that describe the interaction of the deposited material. At high values of powder feed rate or insufficient radiation power density profile occurs forming regular spherical shape on the surface of the article ("Type 1"), which is not providing the possibility of correct layers overlapping. Excessive dissolution of the surface and deformation of the shape of the deposited layer ("Type 2") is characterized, on the contrary, at high power density radiation and insufficient supply of filler powder. Most preferred is a profile of an elliptical shape with sharp edges and minimal optimal fusion based dissolving ("Type 3"). This profile is preferred to perform the deposition (cladding) on the surface with overlapping of layers.

In the course of layers overlapping cladding the pore formation may occurs in nature of the powder transfer onto the substrate, which is close to the "Type 1", for the cases of high-flow powder and thicker deposited layers. Thus, the nature of forming single layers can predict the emergence of internal porosity in multipass overlaying overlapping beads.

The first stage was carried out at the plate sample using laser cladding of Co-based metal powder (EuTroLoy 16006, Castolin Eutectic). The chemical composition of the powder is shown in Table 1.

Table 1. Chemical composition of EuTroLoy 16006 powder

Main alloying additions in powder (wt.%)	C	Si	Cr	W	Fe	Ni
Co - base	1,2	1,23	28,7	1,9	1,9	1,9

The shape of the powder particles is also an important parameter. If the shape of the particles deviates from the spherical, an increase in the drag coefficient and an increase in the particle velocity occur. So the speed of a particle with a diameter of 80 microns increases from 6.2 to 8.0 m/s when changing its shape from spherical (φ = 1.0) to non-spherical (φ = 0.4). However, the difference between the velocities of particles with a spherical (φ = 1.0) and ellipsoid (φ = 0.8) shape is small.

The limiting acceleration of gas and particles occurs during their movement in the narrowing part of the nozzle. The velocity of the particles reaches a maximum value not in the nozzle, but in the external flow. At the exit of the nozzle, the gas expands and its velocity decreases. However, the particles continue to accelerate due to the persistent difference between the velocity of the particles and the velocity of the gas. Particles with a smaller diameter dp = 20 μm have the highest speed, and the smallest speed have particles with a larger diameter dp = 100 μm. It is noticeable that the difference between the velocities of particles with a diameter from 50 to 100 microns is negligible throughout the journey. And the difference between the velocities of particles with a diameter of 20 and 50 μm is more significant because of the strong influence of the gas flow on the movement of small particles as compared with inertial large particles.

Thus, the use of powders with particles having a shape close to spherical allows improving the feed consistency of powder due to a more similar behavior of particles in a gas flow.

To increase the efficiency of the laser sintering (cladding) process, it is recommended to place detail at a distance of 18 to 20 mm from the nozzle. At this distance, the constriction of the powder flow is formed, which has the highest concentration of particles.

A feature of laser sintering (cladding) processes is the interaction of many different physical phenomena: the absorption of laser beam energy by the base metal and filler material, heat propagation and metal melting, the formation of the melt surface under the pressure of the powder flow and the surface of the weld bead. Part of the metal powder does not fall into the molten bath and is blown off from the surface of the base; this powder amounts to losses. The powder trapped in the melt is mixed with the base metal and, solidifying, forms a weld bead.

Experimental work was carried out on the robotized complex for laser powder cladding developed by JSC SSTC (Fig. 3). This complex is built on a modular principle which allows to change the number of modules that make up the complex by increasing, reducing or replacing them, which makes it possible to adapt the system for various tasks, both research and practice, with the use of laser technology. Complex is equipped with 4 kW fiber laser source, a module of movement and positioning (six-axial manipulator and two-axis positioner), an optical module, powder feeding unit and control system, providing complex adjusting and work in manual and automatic mode. Complex is also equipped with CCTV system to monitor the process in real time, as well as a protective cabin to meet the requirements of laser and industrial safety.

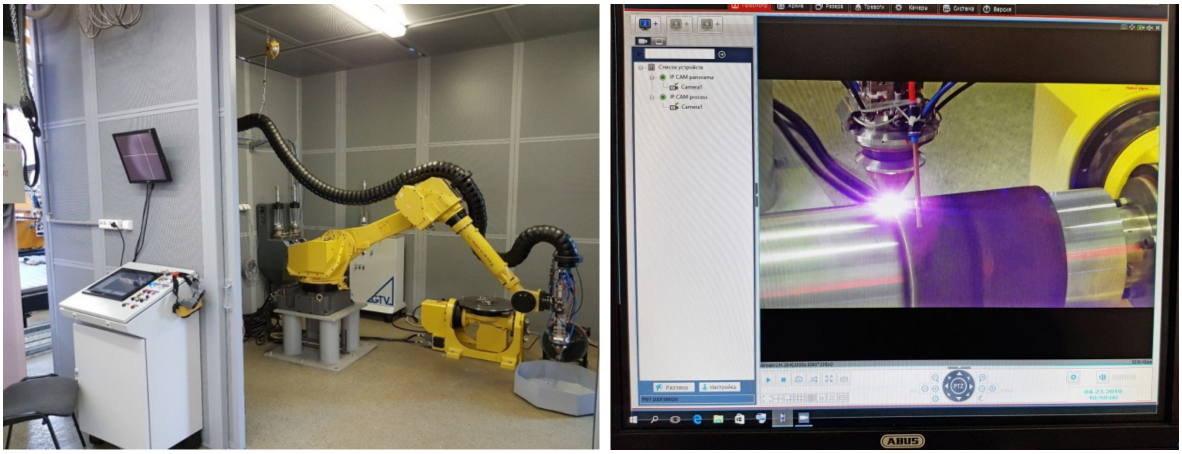


Fig. 3. Robotized complex for laser powder cladding

With the aim to develop laser sintering technology of antifriction tribological surface for large-dimensioned marine propeller shafts two types of base material – analogue 41CrMO and analogue 34CrNiMo6 were used. To create an antifriction layer, bronze powders RotoTec 19850, RotoTec 19868 and metal powder EuTroLoy 16625G.04 were used (Table 2 -4) with size of particles from 53 to 150 microns.

Table 2. Chemical composition of RotoTec 19850 powder

Surface hardness	Mass alloying additions (%)	Cu	Al
130 HV10	Cu - base	90	10

Table 3. Chemical composition of RotoTec 19868 powder

Surface hardness	Mass alloying additions (%)	Cu	Al	Ni	Fe
130 - 160 HV10	Cu - base	83	10	5	2

Table 4. Chemical composition of EuTroLoy 16625G.04 powder

Surface hardness	Mass alloying additions (%)	Cr	Mo	Fe	Nb+Ta	Si	Mn	Al	Ti
210 HV30	Ni - base	21,5	9,0	5,0	3,7	0,4	0,35	0,02	0,02

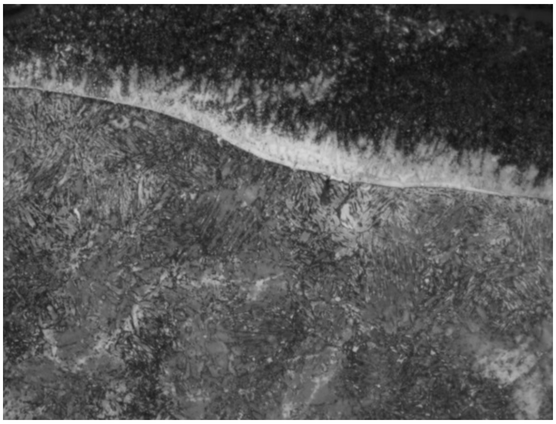
During the study, samples were obtained with clad beads in one or several passes (Fig. 4 a). Sample microsections (Fig. 4 b) were made on a Buehler MetaServ 250 grinding and polishing machine.

a b

Fig. 4. Experimental samples (a) laser powder clad beads; (b) sample microsections

The study of the microstructure and grain size of the surface layer of thin sections was carried out on a Nikon MA200 metallographic microscope, with an increase from 100 to 1000 times, depending on the research methods.

The width of the transition zone between the base metal and the deposited layer was 0.1-0.2 mm. The structure of the alloy obtained by the fusion of EuTroLoy 16625G.04 (Fig.5) powder consists of a nickel solid solution and precipitates of chromium carbides, borides and silicides uniformly distributed in the alloy matrix. The transitional area is characterized by a mixed austenitic-marten structure. The precipitates of carbide, boride, and silicide phases disappear as they approach the base metal.



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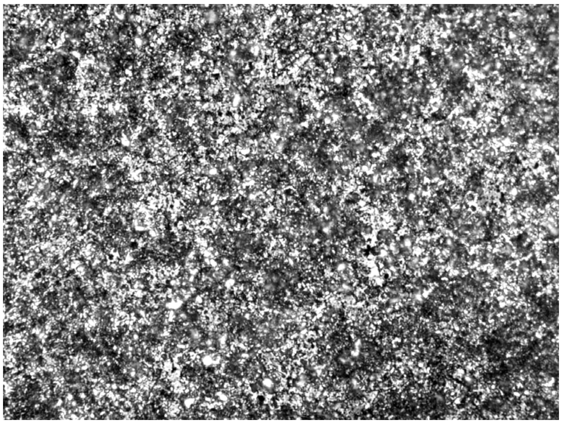

b

Fig. 5. Microstructures of cladding samples (a) microstructure of the transverse section of the deposited layer using EuTroLoy 16625G.04 powder; (b) microstructure of the longitudinal section of the surface layer of nickel alloy (x1000)

Samples made using bronze powders characterize the layer structure consist mainly of copper with a grain size of 5 to 15 microns. The transitional zone of the fusion of bronze and steel base is characterized by the presence of precipitations of a solid solution of copper in the ferritic-bainite structure of the steel matrix.

A test multi-pass sintering on a workpiece shaft with a diameter of 218 mm was performed to obtain a product with a diameter of 220 mm according to the drawing. The powder feed rate is 14 g/min. The width of the transition zone between the base metal and the deposited layer was 0.1-0.2 mm. The average value of the height of the surfacing roller H (thickness of the layer obtained by laser welding in one pass) is 0,5 mm.

It has been established that with multipass laser sintering it is necessary to clean the weld surface from burr before applying each subsequent layer.

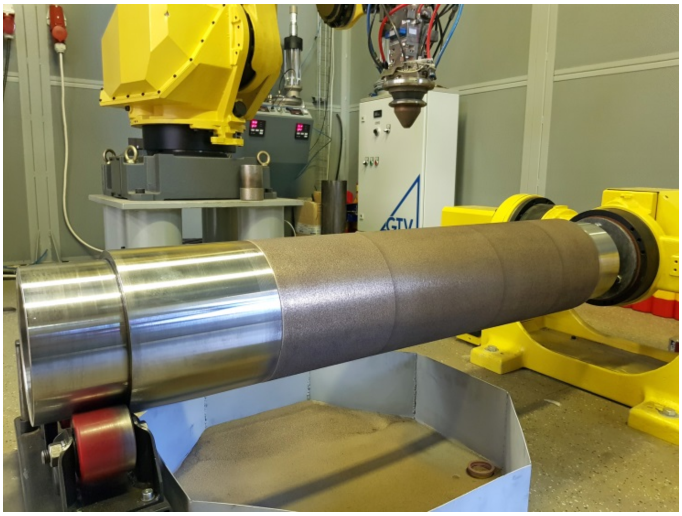

Fig. 6. Creating of anti-friction bronze layer on a steel bush

Derived samples with anti-friction bronze were tested for abrasive wear according to the Brenelle-Haworth scheme. The studies were carried out as follows: a sample with a deposited layer was pressed to a rotating rubber disk for 10 minutes, feeding quartz sand with a particle size of 200-600 µm into the friction zone. According to the test results of three samples, the average value of the weight loss of the deposited coating was determined.

The test results confirmed the high antifriction properties of the bronze layer. The weight loss of the deposited coating during the abrasive wear tests was no more than 0.0055 g.

Laser cladding comparing to conventional technologies allows to achieve some advantages:

- Low heat inputs and heat distortions (laser cladding inputs less than 20% of the heat compared to arc cladding the same part);
- Small heat affected zone;
- Very low dilution with the base metal;
- Thin clad layers and control of part configuration.

On basis of executed works can conclude that laser sintering (cladding) provides formation of antifriction surface. Developed technology can be implemented for production of large-dimensioned marine propeller shafts with high tribological properties and allows decreasing labor consumption of installation works on vessels heavy-loaded propulsion devices.

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