Development of the recovery technology for nickel superalloy blades of the aircraft engine by laser cladding

D P Bykovskiy¹, V N Petrovskiy, V I Polskiy, S N Chirikov and P S Dzhumaev
National Research Nuclear University MEPhI, Kashirskoe sh. 31, Moscow, Russia, 115409

E-mail: d.bykofsky@gmail.com

Abstract. Development of cladding modes was performed with a superalloy nickel based powder on a flat substrate from material identical to compressor and turbine blades. Cross sections were made, and a visual inspection of the shape and the quality of the clad track as well as the metallographic analysis were performed. Microhardness of the deposition zone, chemical composition of the base, cladded metals, and the heat affected zone were determined.

1. Introduction
Turbine abrasion occurs during exploitation due to vibrations of the top edge of turbine blades, which leads to deterioration of its working efficiency [1]. Foreign particles inflow in the turbine is also possible, causing damage to the input edges of the blades, appearance of dents and change of their geometries. A turbine may comprise several hundreds of blades, which are subject to strict requirements on the shape stability. Production of a single blade is a long-term and resource-intensive process, which is the cause of its high cost and, therefore, leads to increase of the turbine cost. Replacement of damaged blades with new ones is not economically profitable, so different methods are used to restore turbine blades that reduce maintenance costs, improve reliability and increase service life. To achieve these objectives, it is necessary to repair the turbine periodically.

Studies have shown that the solution of this problem is possible by using one of the many additive technologies – laser gas-powder cladding [2, 3]. Blades form recovery process consists of sequential deposition of the tracks at each other on the edge of the damaged blades. Metal powder is supplied to the repaired surface coaxially with the continuous laser radiation. After melting and cooling of the metal powder, a track is formed on the blade's surface. In this way, it is possible to deposit one track on top of the other, creating a multi-layer structure with required thickness [4].

The first stage in the development of blade recovery technology is to determine the process window where good formation of single tracks is performed [5], which is the topic of this study.

2. Experimental equipment
Experimental equipment for laser cladding of metal powder is a system consisting of a module with Huffman HC-205 control unit, a powder feeder Sulzer Metco Twin 10-C (figure 1), and the fiber laser IPG-Photonics LS-3.5 and a Riedel chiller. Huffman HC-205 module with the control unit was originally designed for the repair of aircraft turbine blades yet it is also used for volume shaping and restoration of surfaces of various parts after small software revisions.

¹ To whom any correspondence should be addressed.

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3. Experimental results of single track cladding on flat samples

We used the powder of heat-resistant nickel-iron alloy EP718 as a filler material in this study. Cladding was carried out on a plate of the same material. We used three technological windows differing by powder feed rate: the first corresponds to the feed rate of 0.9 g/min, the second – 1.35 g/min, and the third – 1.8 g/min. In each process window the tracks were deposited with different combinations of scanning speed from 6.3 mm/s to 10.5 mm/s and a laser power from 150 to 250 W. Transverse sections of tracks were made after cladding. Studies have shown that an increase in powder feed rate for raising productivity of the process does not lead to good track shaping. Tracks obtained from powder at a small feed rate 0.9 g/min (figure 2) had better adhesion than the tracks obtained at a feed rate of 1.35 and 1.8 g/min (figures 3, 4), which also lacked fusion with the substrate.

Further detailed analysis of the tracks cladded in the first technological window with a powder flow rate of 0.9 g/min was carried out. Microhardness measurements for these tracks were made in the transverse direction (figure 5) by the Vickers method using HVS-1000 device with automatic indenter loading at $F = 1 \text{ N}$. Time of loading was 20 s. Coordinates 0–600 $\mu$m correspond to the cladded track, 600–1200 $\mu$m – to the transition region, and larger than 1200 $\mu$m – to the area of the substrate. Studies showed that there is a decrease in microhardness of cladding. However, taking into account the measurement error, it can be concluded that microhardness was not affected by changing the technological modes.
The element composition showed that the cladded material and the substrate are nearly identical, and changes are insignificant in depth. The substrate and the cladded material are 45Ni-28Fe-15Cr-4Mo-3W-2Ti-Al. Microstructure of cladding is a mesh with polyhedral (equiaxed) grain size of 4... 5 μm. Microstructure of the substrate is a typical austenite with the traces of plastic deformation at the boundary of substrate and surfacing. Clearly defined heat-affected zones are absent in the structure. Penetration of surfacing material into the base material at the grain boundaries to a depth of 0.02–0.09 mm was observed for all samples and for all technological modes. Taking into consideration the requirements of good fusing track with the substrate, as the absence of defects like cracks, pores, and cavities, an optimum mode can be selected from the first technological window for
further work on creating multilayer cladding tracks. Optimal track deposited in this mode (powder flow rate 0.9 g/min, laser radiation power 250 W, surface scanning speed 8.4 mm/s, the gap between the nozzle and the substrate 4 mm) is shown in figure 6.

![Image of cladding microstructure](image)

**Figure 6.** General view of the cladding microstructure no. 6.

4. **Conclusion**

Technological modes were obtained for optimal formation of tracks that meet all the requirements of the welding structure, chemical composition, and microhardness. It was revealed that large powder feed rate increases productivity, but it leads to a lack of fusion at the edges of the tracks. The chemical composition of the deposited coating is similar to that of the substrate material. The microhardness decreases near the top of the cladded tracks. Presumably, this is due to the fine grain structure caused by rapid cooling.

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