

Research on the possibility of restoring blades while repairing gas turbine engines parts by selective laser melting

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Abstract. We study the possibility of restoring the blades of chromium-nickel materials for the repair of parts of gas turbine engines using selective laser melting technology. The stages of preparation of the items to repair and reconditioning are considered in detail, the algorithm of the recovery process to a 3D machine has been developed. Chemical analysis of the raw material and facing material has been performed. Maps of distribution of chemical elements in the fusion zone of the starting material with the surfacing material have been acquired. In order to study the nature of alloying materials fractographic analysis of the places of fusion was performed. A map of distribution of chemical elements in the fusion zone was obtained.

1. Introduction

Restoration of parts to restore their functionality is important in many industries, including aviation [1]. About 70% of the total number of recovered parts of aircraft, made of high-alloy steels and aluminum alloys are parts with surface defects in the form of wear, cracking, corrosion and mechanical damage [2].

The blades of gas turbine engines are the most stressed parts, determining resource labor input and cost of the engine. The number of blades in modern engines reaches 2 ... 3,5 thousand, therefore their manufacture is carried out in a large scale or mass production.

The resource of the blades of military aircraft engines is - 500 ... 1000 hours, for civil aircraft - 10 ... 20 thousand hours. The cost and complexity of manufacturing of a set of blades is 20 ... 35% of the total cost and the complexity of the engine [3, 4].

During operation, blades are subjected to: stretching and bending due to centrifugal forces, bending and twisting under the influence of the gas flow to variable voltages from vibration loads, exposure to elevated and high temperatures (300 ... OS 600 for the compressor blades and 800..1200 OS for turbine blades), etc.

Analysis of damage to parts of aircraft, nonrenewable currently due to lack of methods to restore them, shows that about 70% of the total amount are parts with surface damage depth of 0.4 - 2.0 mm, most of which have not fulfilled their life and are defected due to wear [5].

To restore the geometric dimensions of the surface of the blade by selective laser melting (SLS) an algorithm was developed. It includes a number of stages (figure 1).



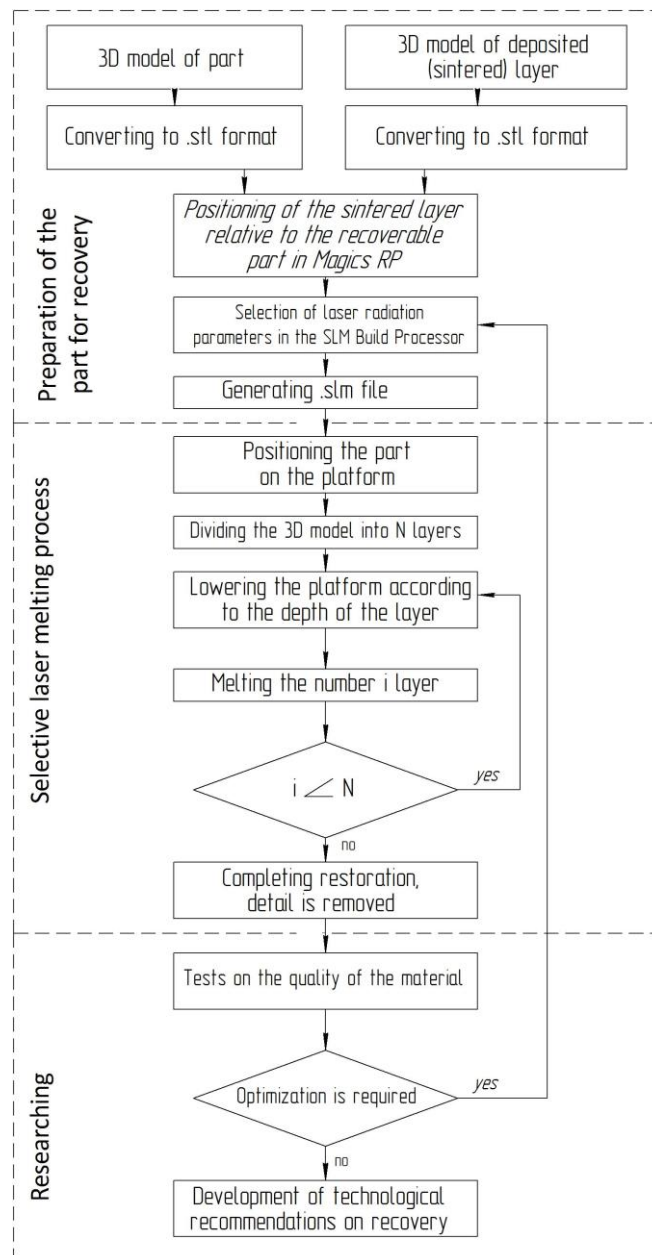


Figure 1. Algorithm for recovery of parts by SLM

Currently at different stages of design and production of new products widely used are methods of layering three-dimensional objects directly from their computer models, known as rapid prototyping technology.

Few areas of manufacturing three-dimensional objects layer by layer have been mostly developed, one of which is SLM technology of metal powder materials [6-8].

2. The methodology of the study

The object of research is a blade of compressor of gas turbine engine recovered by SLM method. Recovery of the end of the blade was carried on a 3D system of selective laser melting SLM 280HL (SLM Solutions GmbH, Germany). The system has a build camera with size of 280x280x350 mm and is equipped with an infrared fiber laser with a wavelength of 1075 nm and a maximum power of 400

W, operating in continuous mode. Growing of the samples was implemented in an inert gas (hydrogen).

Scanning electron microscope Tescan Vega was used for fractographic analysis. For the analysis of the elemental composition of the material X-ray spectral microanalysis was used.

Restoration of the end surface of the compressor blades using SLM technology consists of the following steps: creation of 3D models of the restored parts; creation of a 3D model of the sintered layer; Positioning the 3D model of the reconstructed detail on the construction platform; positioning the 3D model of the sintered layer with respect to the restored detail; preparation of the print file for 3D machine; fixing the recoverable detail onto the construction platform; positioning of the construction platform in the sintering chamber of 3D system SLM 280HL and the recovery itself.

At the first stage of recovery of the blades a 3D model of recoverable detail was created (figure 2a). Sintering layer is a material which is to be synthesized on the surface of the end of the blade [9]. Since the chosen vanes have the wear on the end face of the pen with understating blade height of 2 mm and further processing requires minimum machining allowance of 0.5 mm, the height of the sintered layer was 2.5 mm [10, 11]. Also, allowances of 0.5 mm were added to the 3D model from the trough and back of the blade (figure 2b). Blade profile measurement was performed on CMM [12]. Three-dimensional models have been developed in the software Siemens NX 8.5.

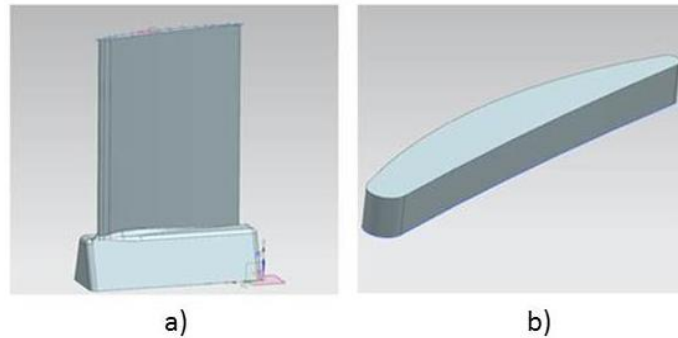


Figure 2. 3D models of recoverable blade and fused layer; a) 3D model of restored blade; b) 3D model of the sintered layer

Positioning 3D model of the blade was performed using the software Magics RP, supplied by 3D machine SLM 280HL manufacturer. Positioning of 3D model of the blade was carried on construction platform of size of 100x100 mm (figure 3a).

Then the blade was mounted to the construction platform using laser welding. Positioning the blade on the platform must exactly repeat the location of the recoverable item on the virtual platform. Before that, the center from which the blade is positioned with grip at four points had been found on the platform (figure 3b).

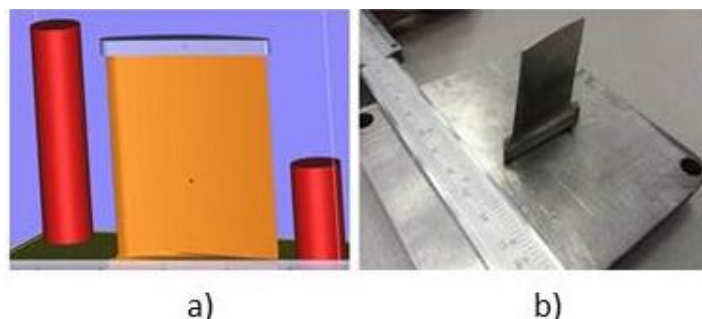


Figure 3. Positioning of the blade on the construction platform; a) orientation of the model of the blade on the virtual platform; b) orientation of the model of the blade on the virtual platform

To position the construction platform in the fusion camera of 3D system SLM 280 HL it is

necessary to establish the beginning of sintering of metal powder with laser, ie the first layer, which is to be grown on the blade end, will be the basis for the subsequent layers. To do this, the construction platform should be lowered down the piston at the height of the blade. The extremity end of the blade must coincide with the upper level of the well (figure 4a). Voids formed between the blade and the well with the use of the recoater are to be filled with powder until the layer is smooth. It took 1.87 kg of metal powder 316L to fill the volume (figure 4b).

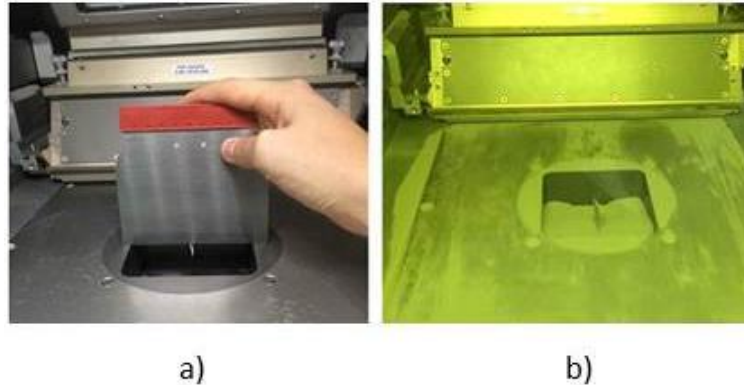


Figure 4. Positioning of the blade on the construction platform; a) the search for zero of construction platform; b) filling the voids with metal powder

After all the preparatory work was carried out the recovery process of the compressor the blade by SLM was implemented. Restored blade is shown in figure 5.



Figure 5. Restored compressor blade.

3. Results and discussion

In order to study the microstructure of reduced layer fractographic studies using scanning electron microscopy method were performed in microsections obtained by electrical discharge machining [13]. Figure 6 shows the macro- and microstructure of the the blade in the recovery zone.

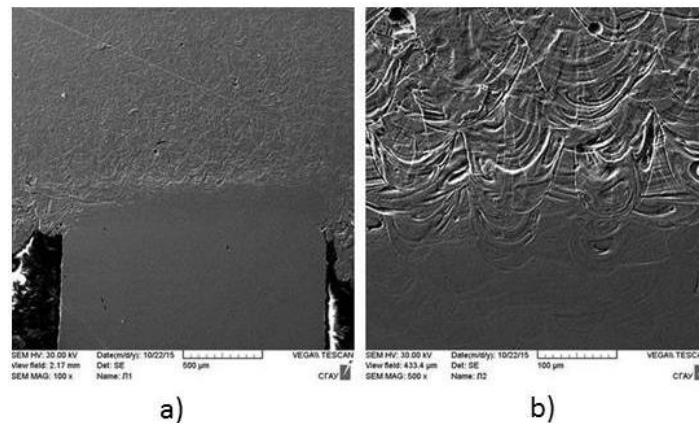


Figure 6. Macro and microstructure of the restored blade; a) macrostructure of the restored blade; b) microstructure of the restored blade

Figure 6 indicates that the border "basic material - surfacing" is clean and there is a metallic bond (figure 6a). At a higher magnification of the reduction zone it is seen that at the border "core material - cladding" and at the surfacing material discontinuities are present, each up to 50 μm in diameter (figure 6b). Defects such as cracks were not found.

To study the border between the basic material and welding material a map of the distribution of chemical elements in the microsection was obtained (figure 7). Figure 7 shows that in the field of fusion "basic material - surfacing" a transition layer of width $\sim 150 \dots 200 \mu\text{m}$ was formed. The transition zone is not clearly defined by boundaries, indicating a good fusion of the base material with the surfacing material.

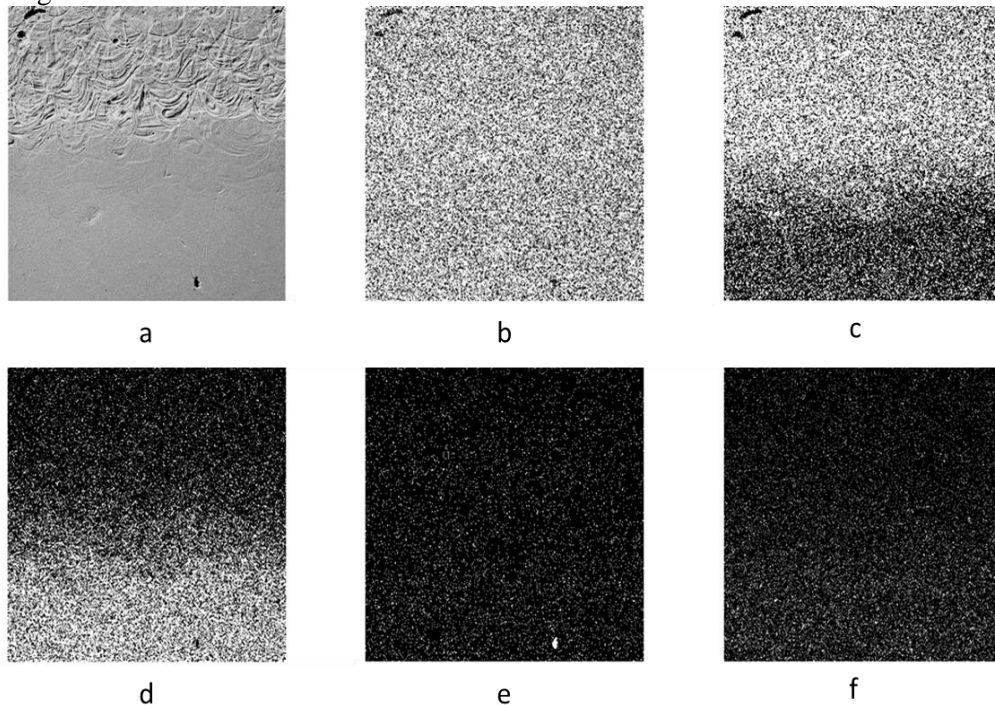


Figure 7. Macro and microstructure of the restored blade; a) electronic image microsection (x500); b) Cr distribution; c) Fe distribution; d) Ni distribution; e) Al distribution ; f) Ti distribution

4. Conclusion

A study of the possibility of restoring a pen of a compressor blade worn during operations has been implemented. On the surface of the sintered layer lack of fusion has been detected, cracks have not been detected.

In all sections of the deposited layer of the blade boundary between the weld and the base material is not clear, there is a transition zone up to 200 μm thick.

Surfacing with SLM method allows to lower the amount of machining of the blades after recovery, since allowances for subsequent machining do not exceed 500 μm . It is possible to reduce the allowance for machining to 100 μm .

The developed method of process optimization by welding with SLM method allows to increase the efficiency of the recovery of parts of aircraft.

Further studies will focus on the impact produced by the main process parameters, such as laser power, scanning speed, thickness of the sintered layer, etc., on the porosity of the sintered layer, with a view to minimizing it.

To reduce the time spent on the preparation to the recovery process of parts by selective laser melting it is planned to design and manufacture devices for quick installation and positioning of parts.

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References

- [1] Barvinok V A, Semenov V G, Sotov A V and Kosirev S A 2014 Recovery of the end of the pen of a blade of turbine engine using pulsed laser deposition *J. Problems of mechanical engineering and automation* **3** 161-5
- [2] Smelov V G, Sotov A V and Agapovichev A V 2016 Recovery Technology Features of Aerospace Parts by Layering Synthesis *J. Key Engineering Materials* **684** 316-22
- [3] Makarov E L 2014 Theory of weldability of steels and alloys ed E L Makarov (Moscow: Publishing house of the MSTU named after Bauman) p 487
- [4] Vdovin R A and Smelov V G 2014 Elaboration of a casting defects prediction technique via use of computer-aided design systems *International J. of Engineering and Technology (IJET)* **6(5)** 2269-75
- [5] Nazarov A P 2013 Features of machine design for selective laser sintering *J. Vestnik MSTU "STANKIN"* **1** 76-79
- [6] Landolfo R, Mammana O, Portoli F, Di Lorenzo G and Guerrieri M R 2008 Laser welded built-up cold-formed steel beams: Experimental investigations *Thin-Walled Structures* **46** 781-91
- [7] Sufiiarov V Sh, Popovich A A, Borisov E V, Polozov I A 2015 Selective laser melting of heat-resistant nickel alloy *J. Tsvetnye Metally* **1** 79-84
- [8] Grjaznov M U, Shoshin S V, Chuvildeev V N 2012 Effect of mesostructural hardening of steel 316L during stratified laser alloying *J. Bulletin of the Nizhny Novgorod University named after N. Lobachevsky* **5 (1)** 45-50
- [9] Vdovin R A 2013 Multiproduct manufacture process improvement *J. Izvestiya of Samara Scientific Center of Russian Academy of Sciences* **6(3)** 612-19
- [10] Khaimovich A I, Balaykin A V and Galkina N G 2016 Phenomenological modeling of rheological properties of polyetheretherketones reinforced with high modulus carbon in the machining process by a reversible analysis method *J. Key Engineering Materials* **685** 119-23

- [11] Skuratov D L, Zhidyaev A N and Sazonov M B 2014 Solid carbide end mills tool life increase in titanium alloys machining by design development and rational choice of geometrical parameters *J. Research journal of applied sciences* **9(11)** 767-70
- [12] Pechenin V A, Bolotov M A and Ruzanov N V 2014 Development of a method of ICP algorithm accuracy improvement during shaped profiles and surfaces control *International J. of Engineering and Technology* **6(5)** 2229-35
- [13] Balaykin A V, Kondratev A I and Galkina N G 2016 Determination of rheological properties of titanium alloys under conditions of high strain rates *J. Key Engineering Materials* **684** 222-26