DEVELOPMENT OF PROCESS OPTIMIZATION TECHNOLOGY FOR LASER CLADDING OF GTE COMPRESSOR BLADES

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ABSTRACT

The article describes the optimization technique for the process of titanium gas turbine engine compressor blades cladding. The essence of this technique is a multivariate iterative choice of technological parameters. The use of the given technique may significantly reduce the time of the production technological preparation of production, and also the share of experimental studies. The conduction of repair works concerning the laser cladding of compressor gas turbine engine blades became the experimental confirmation.

Keywords: laser cladding, restoration, input and output blade edges, macro and micro analysis, microhardness, cladding optimization technique.

1. INTRODUCTION

Lasers are widely used in the global aerospace industry for the solution of a wide range of tasks to process a large range of products made of refractory, heat-resistant and hard materials: from the manufacture of an aircraft fuselage and wings, the components and assemblies of launch vehicles, the production of turbine engines (the piercing of cooling channels in turbine blades, the restoration and repair of turbines) to the manufacture of various hermetic elements (fuel tanks, orbital module components, pipelines, etc.) of steering systems.

Laser processing techniques are effective if you want to achieve:

- the design of very small to large one, the size and weight of which should not be changed, no the deformations are absent or minimal ones;
- minimal heat influence zone and minimal residual tense-states with high corrosion resistance.

The laser treatment process is characterized by a good control and flexibility, the moving of a beam along the surface may be performed on any trajectory with the possibility of full automation.

Besides, the high efficiency of laser technology complexes is provided by a quick readjustment of modes and the changeover from one type of the produced details to the other one - which is especially important for the productions, the range of which is very different, but the number of each product is small.

Depending on the particular technological problem the use of different types of lasers (gas, solid-state, lamp pumped, fiber ones), the methods of radiation delivery (fiber output or direct one) and kinematic systems allows to implement successfully the processing of large structures, the work in confined spaces, the high-precision processing of miniature parts with the repeat accuracy of up to 5 microns [1].

The popularity of laser technology in the aerospace industry is conditioned by the following advantages:

- high average (10^4 ... 10^6 W/cm^2) and peak (10^8 ... 10^{10} W/cm^2) values of the radiation power-density give the ability to produce a wide range of technological operations related to the heat influence effects on the processed object;
- minimal thermal deformations of the processed workpiece due to local character and short impact duration (this advantage allows to perform the cladding on thin sections of the GTE blade);
- short period the material heating and the ability to manage pulse time parameters within a wide range (10^{-8} ... 10^0 s);
- no problems of tool wear;
- the ability to process small stiffness products and the articles made of brittle materials due to the lack of mechanical interaction in the contact zone of the laser radiation with the workpiece;
- absence of beam inertia, easy control of the laser beam properties;
- the feasibility of a workpiece hard areas treatment;
- independence of processing technological characteristics on the mechanical properties of the processed material [2].

When repairing the engine the problem of the blade geometric dimensions restoration appears. According to the operation nature and conditions the lateral surface of the turbine blades is subjected to micro damages of mechanical, chemical or thermal nature. The damage analysis shows that about 70% of the total number of parts makes the parts with superficial defects at the depth of 0.4 ... 2 mm.

At the abrasive wear of the blade edges of more than 0.2 mm the blades discarded. Traditionally the used technology of the blade size recovery by an argon-arc welding is not always applicable due to the overheating of the blade material. The use of laser radiation allows to perform a cladding process with minimum heating of products compared with other methods, and the use of fiber-optic delivery systems of the laser beam to the defect site reveals the possibility of the turbine blades repair without its disassembly. The magnitude of the heat impact zone does not exceed 15 microns.

2. METHODOLOGY

The essence of this method consists in the fact that the laser melted surface is mixed with adding material. At that the weld layer due to the adding material composition and high cooling rates are provided with the desired physical and mechanical properties. As a rule, these properties are: high strength and high resistance to corrosive destruction. This technology may be applied to restore the blades of aircraft turbines, the turbines of hydroelectric power plants, gas compressor stations, nuclear, thermal power plants, offshore turbines. Figure-1 schematically presents the restoration technology by pulsed laser cladding [1].

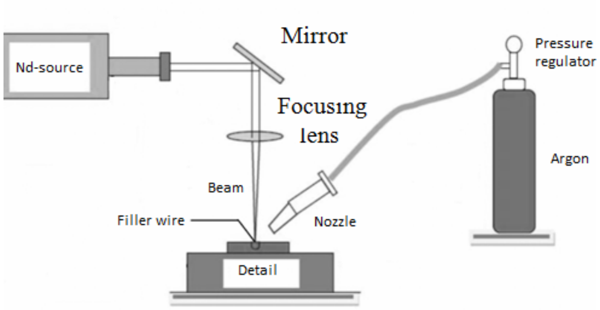

Figure-1. Laser cladding functional scheme.

Traditionally, pulsed lamp-pumped lasers are used for welding and restoring. These lasers are characterized by high efficiency.

The operational GTE compressor blade damage with foreign objects is the major cause of an early removal of a large number of engines. The damages may be caused by the abrasion of the fan surface as the result of dust and sand intrusion with the air into the running part of the sucked by the compressor. The abrasive wear of blades leads to undesirable changes in the basic parameters of the engine: thrust, specific fuel consumption, the gas temperature at the turbine inlet. The greatest damage experience is the inlet and outlet blade edges and the peripheral parts of the rotor and stator blades. With a significant wear the blade chords are decreased, which reduces the supply of the compressor gas dynamic stability.

The possibility of small stones entering the compressor from the runway is not excluded. There is a risk that small and large birds will fly into the engine during the flight, which can also cause the blade damage. There are cases of stator blades touching when you change modes and because of the uneven heating of the compressor rotor and the stator. As a result of the above cases the damages may appear in the form of nicks, dents, with the leading edge curvature, the corner bend on the leading and trailing edges and the blade surface dents (see Figure-2).

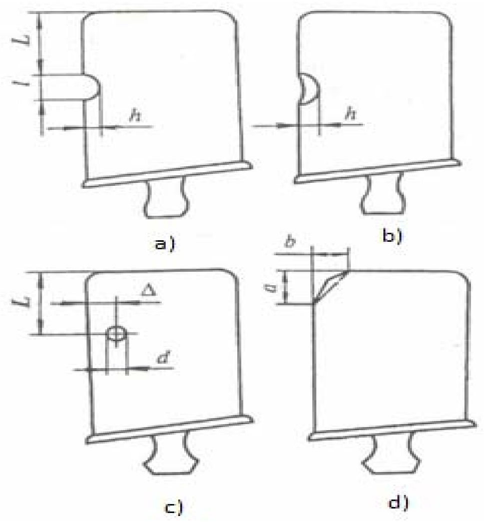

Figure-2. Blade damage types: a) nick; b) dent with an inlet edge ccurvature; c) corner bend; d) blade surface dent.

Given that the blades are made of an expensive metal, and that the engine has a large number of such blades it is economically feasible to eliminate the appeared damages and use the blades during the further operation.

The aircraft parts damage analysis (which are not repairable nowadays due to the lack of their repair methods), showed that about 70% of details from the total amount makethe details with the surface damage depth of 0.4-2.0 mm, most of which were broken early and were rejected due to its wear [3].

In this paper we developed the technology of regenerative repair for GTE rotor blades by pulsed laser cladding using a filler material in the form of wire. The samples of blades were picked after the use with nicks on the input and output edges. The blade sample material is the deformed titanium alloy. According to the work results the recovery technology of the surface geometry for gas turbine engine blades was developed and tested.

During the first phase of work the initial state of restored surface estimation was performed. Also the preliminary surface preparation for cladding was performed. It includes the removing of oxides and contaminants, the removing of heat resistant aluminide coatings with chemical and (or) mechanical method. The preliminary preparation with the use of highly consistent and strong tools is necessary for a number of defects.

After the directed surface state assessment the selection of filler wire under the base material was performed. The selection of filler wire under the basic detail material is an important step to obtain the set chemical composition of the weld metal, which will provide the desired properties of the restored surface. For this purpose, the determination of the wire chemical composition was performed, supplied by the equipment manufacturer.

The chemical composition of the filler wire samples was determined by electron probe microanalysis. As the name implies this is the analysis at the microscopic level, which allows obtaining the information on the structure, phase and chemical composition of the sample. The electron beam (electron probe) interacts with the surface area of the sample at the depth of less than a few microns. As a result of such interaction, numerous signals appear that may be detected using a variety of detectors to obtain the information about the sample.

During the next stage of the operation the setting of the titanium laser cladding was performed. The cladding of surface is recommended to perform at higher speeds.

The titanium alloys in gas turbine engines are widely used. They are highly sensitive to welding, resulting in unfavorable changes of the structure and mechanical properties at heat-affected zone and cladding metal, which require the application of special modes of laser cladding. The major difficulties at titanium cladding are associated with the gas consumption by heated metal, primarily hydrogen, with their diffusion in the processing zone of the base metal, and by the higher content of gases in the base and filler metal. The above cladding conditions of titanium alloys require highly pure protective environment to reduce the porosity in the weld metal and its tendency to delayed fracture. To prevent these phenomena the processing should be performed in a protective atmosphere (argon) at low heat input.

The high rates of cladding provide high cooling rates and lead to the increased dispersion of the weld metal and substantial grain refinement in the weld zone [4].

After the selection of filler material and the process parameters configuration the cladding operation on input and output blade edges was performed with the use of technological device, including a solid-state pulse laser on YAG:Nd with the wavelength of 1.06 microns, the pulse duration of 0.2 to 20 ms, the radiation pulse repetition rate of 1 to 20 Hz and the focused beam diameter of 0.2 to 2 mm. The mastering of cladding technology was carried out on the batch of titanium blades samples with the wear at the input and output edges. The reconstruction of surface was performed using a filler material in the protective gas medium which is argon. The cladding wire diameter made 0.4 mm. The wire material was chosen according the blade material. Prior the cladding performance the face surface was polished to bright metal for the complete removal of various contaminants, as well as to identify the possible defects such as cracks, signs of wear and others. Also acetone was used to degrease the base metal surface. The laser device and the recovery process of the blade edges are shown by Figure-3.

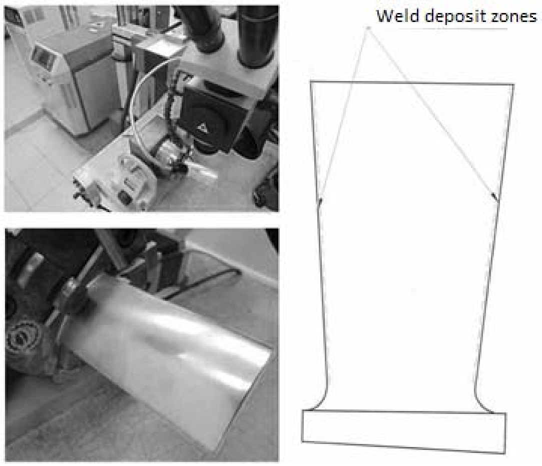

Figure-3. Blade edge restoration process.

The cladding was performed in the modes, the main parameters of which were the energy and pulse duration, the focused radiation diameter, the pulse frequency and velocity, the position of the focal spot relative to the clad element surface.

The laser cladding modes were selected from the conditions ensuring high-quality formation, the required cladding geometry, the preventing of cold cracks, pores formation and the creation of the most favorable structures. This is achieved at high pulse repetition rates and high-quality protection of treatment zone [5-8]. Due to the high chemical reactivity of the titanium with respect to the gases protecting the welding area from the air only inert gases of high purity shall be used.

The degree of the cladding zone protection reliability may be judged by the clad material appearance. The shiny, silvery surface indicates the robust security and the high quality of welding. Yellow-blue color or the appearance of the gray films on the weld material indicates poor protection from the air treatment.

After the laser cladding of the input and output edges for the KND blades the experiments were conducted to determine the clad material quality. In particular the metallographic studies were conducted by measuring the microhardness in the cross section of the main and clad material. For this purpose the transverse microsections from the blade samples were prepared.

3. RESULTS

There were no cracks, poor fusions and other defects at external examination of titanium blade sample weld areas. The sample appearance with is shown by Figure-4.

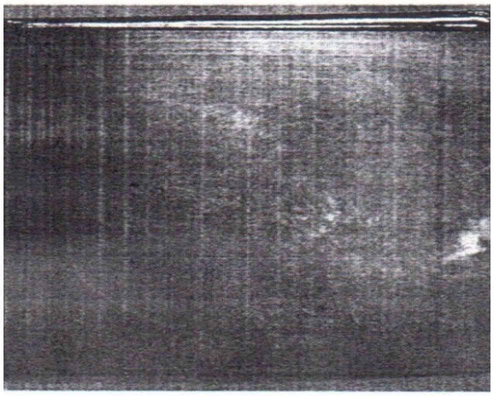

Figure-4. Blade and cladding appearance.

Macro and micro analysis was carried out in the cross-sections of the connection + the cladding in all sent samples. There were no poor fusions, cracks in the studied sections of cladding at input and output blade edges. The boundary between the base material and cladding in all the sections of blade claddings is clean, has metallic junctions. 3 separate fine pores with the diameter of 0.02 mm. were revealed in the separated section of the weld material. This defect is illustrated by Figure-5.

Figure-5. Clad material pores on the inlet and outlet blade edges.

Pore formation (three or more), located densely is unacceptable, since it is the local portion of the cladding strength failure and the stress concentrator. The external features of this defect are absent, because the defect is inside the clad material.

The measurement of microhardness in the cross sections of the blade + cladding is carried out in the clad weld material area, in the heat affection zone and in the blade material. The microhardness measuring device was used to measure the microhardness. The image of indenter trace is shown by Figure-6. The value results are shown by the Table-1.

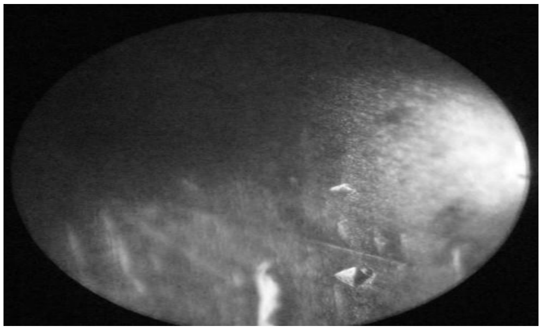

Figure-6. Indenter trace image at the measurement of clad layer microhardness.

Table-1. Microhardness values on the blade section surface.

Measurement surface	Microhardness, HV
Cladding area	566±20
Thermal influence zone	422±3
Basic material	362±10

The analysis of obtained values showed that the clad layer hardness is higher than the blade base metal. The transition zone (ZTV) has the values of microhardness up to 40-50% higher compared with the base alloy that may be associated with the tempering and aging processes in this area and the release of dispersed intermetallic phases [6].

After the conduction of the experiments determining the quality of the clad material the optimization of pulsed laser treatment was performed to remove the cladding defects (pores), the restoration of the input and output edges of new blade models was performed (see Figure-7). The optimization of cladding modes was performed by inert gas (argon) flow increase to protect the treatment zone from the air, and by the repetition rate of the laser radiation increase. The increased rates of laser beam scanning increase the cooling rates, which lead to the dispersion of metal cladding increase and to the significant grain refinement. The decreased rates of radiation following lead to the formation of unfavorable structures and the probability of metal saturation increase with harmful gases.

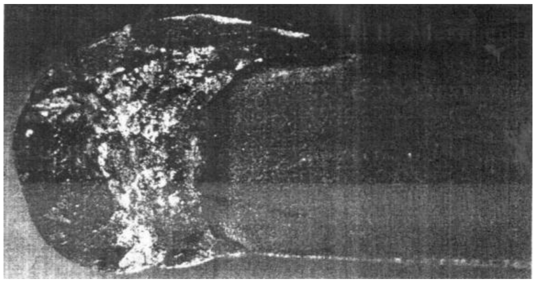

Figure-7. Recovery result after laser cladding mode optimization.

The experiments were also performed to determine the quality of welding for new samples, the results of which showed the absence of poor fusions, cracks, pores. The border between the clad layer and the blade base material is clean. There is a metallic bond.

The algorithm of the technological process methodology development for laser cladding was optimized on the basis of the performed work (see Figure-8). This algorithm was established earlier by the works [6].

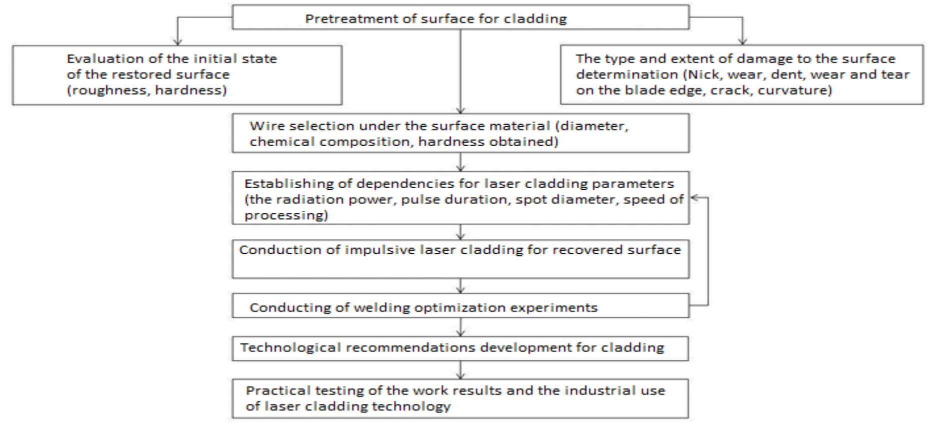

Figure-8. Algorithm of the technological process methodology development for laser cladding.

4. DISCUSSIONS

According to the results of the performed work concerning the restoration of the input and output blade edges by pulsed laser cladding one may draw the following conclusions:

a) The developed technique of laser cladding optimization process allows increasing the efficiency of aircraft elements recovery.
b) The optimized laser cladding process allows obtaining the recovered surfaces of details without defects; in particular, the absence of pore formation is achieved in the clad metal.
c) The pulsed laser cladding technology makes it possible to obtain high-quality connections (welding + blade) at the aircraft repair satisfying the aerospace industry requirements.

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