# Investigation into the Wear Process of Laser Cladding from TiC Multilayer Coating for GTE Shrouded Blade Platforms

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## Abstract

The object of the study was to create a protective coating Ti-6Al-4V/TiC for applying the possibility technology by the laser metal deposition (LMD) method. One of the most suitable areas for LMD is to repair worn and/or damaged parts. It is well known that during GTE operation the fan blades are subjected to periodically varying forces causing vibrational bending and torsional stresses. One of the methods currently used to reduce the magnitude of the vibration stress is to use a shroud blade platform that significantly changes the vibration characteristics of the individual blades and the overall blade ring. The purpose of this study was to obtain information on the resistance to micro-motion of titanium carbide coatings obtained by LMD and also to consider the possibility of applying this technique to modernize and repair coatings for GTE shrouded blade platforms. For the study of fretting wear (dry alternating friction) a special friction machine «3308» was used. During the test the run-in process of the sample and the functional dependence of the type were examined in detail. The wear-and-friction time of the optical viewing system and the measurement of the friction zone without removing the sample. The evaluation of the properties of the coating material was carried out at various stages of running-in and wear. The experimental device for fretting wear and fretting corrosion was significantly improved the possibility and contact pressures up to 1.0 GPa (with the influence condition of the desired corrosive environment that is easy to implement). As a result of research new information was obtained on the wear rates of coatings under fretting wear conditions fans shrouded blade platforms characteristic and low-pressure compressors of gas turbine engines. The results of the study can be used to increase the design and technical development of the GTE platform anti-friction problem and to improve the application of hardened coatings on GTE components.

## Abbreviations & Acronyms

| | | | |
|---|---|---|---|
| AM | Additive Manufacturing | UMC | Unmelted Carbide |
| LMD | Laser Metal Deposition | | |
| GTE | Gas Turbine Engine | | |

# 1. Introduction

It is well known that during GTE operation the fan blades are subjected to periodically varying forces causing vibrational bending and torsional stresses. One of the methods currently used to reduce the magnitude of the vibration stress is to use a platform that significantly changes the vibration characteristics of the individual blades and the overall crown of the blade. Providing zero clearance between the contact surfaces of the shrouded blade platforms in working condition eliminates the most dangerous first form of flexural vibrations of the blades. Therefore the timely preservation of the geometry of the platform is an important condition for fan reliability and resources [1].
During the operation of the engine in the stationary mode the oscillating motion of the blades and the blade ring causes a slight movement of the contact surface of the platform. In the transient mode of operation the contact surfaces also move relative to each other but under variable contact pressure conditions experimental studies of the electrical activity of the contact surfaces have important practical implications. Since the titanium alloy used to manufacture the fan blades has extremely low resistance under micro-motion conditions it is practically

impossible to operate the blade without the reinforcing coating on the contact surface of the shroud blade platform [2].

The development of modern technology is becoming more and more strict on the requirements of materials and the improvement of wear resistance parts are the top priority of many industries. A promising solution to this problem is to apply a composite coating material on components that are subject to intense wear. The creation and implementation of innovative structural materials with high physical and mechanical properties are currently relevant. Among structural materials carbide titanium is widely used a composite coating material composed of alloy titanium and carbide with a mass fraction of 20-70%. According to their characteristics, they occupy an intermediate position between steel and carbide.

In the Russian practice for the hardening of the contact surfaces, the soldering grains technique of hard alloy and detonation spraying of hard alloys based on tungsten carbide were previously used. Foreign manufacturers of GTE for the shroud blade platforms protection (compressors, turbines) use mainly plasma spraying technology using high-power plasma torches (Gator-Gard®, Teleflex Inc.; Plasmadyne SG-100/80 from Tafa Inc.). Tungsten carbide powder containing 17% cobalt (Metco 73, AMDRY 9830, from Sulzer Metco AG) is used as a material for the coating. This paper investigates the possibility of applying a promising technology to form a protective coating by LMD method. The application of this technology may in the long term allow forming a shroud blade platform on a blade-body during manufacture and recovery after operation in one technological process with the application of a wear-resistant coating. As a wear-resistant material, we consider a composite mixture of titanium with titanium carbide in different ratios [3].

Considering LMD technology and taking into account that some parts are too small that repairing such part using the conventional process could result in damage of the parts especially because of the large heat affected zone. Laser metal deposition process produce very low heat affected zone because of the laser that is used as the energy source and the properties of laser that made it to be applied only to the needed area as a result of its high directionality and coherency. The success of using LMD for effective repair can also be attributed to the rapid cooling of the process that prevent the melt pool from staying too long which is responsible for the low heat affected zone. The high resolution that is also achievable with the laser beam makes it possible to create miniaturize parts and repair of such part with high precision using the laser metal deposition process. Another unique property of LMD process is its capability to produce a new part on an existing part with high metallurgical integrity. These important characteristics of the LMD process have helped to position the technology in product remanufacturing [4–6]. Design modification is also made possible with this technology without having to start from scratch and without having to turn an existing machine or equipment into scrap. This additive manufacturing technology gives designers the flexibility to modify an existing design with ease.

The influence of laser power on microstructure, microhardness and wear resistance properties of laser metal deposited Ti6Al4V/TiC composite was studied by Mahamood et al. [7]. Ti6Al4V/TiC composites were deposited on the Ti6A4V substrate to improve the wear resistance property of the base material. Composition ratio of 50 W% Ti64 and 50 W% TiC were deposited at varying laser power between 0.4 and 3.2 kW while all other process parameters were kept constant. Each of the powders was placed in different hoppers from a powder feeder and the two powders were deposited simultaneously. The microstructures in the deposit zone were found to consist of unmelted carbide (UMC) resolidified carbide and dendritic TiC. The microhardness and the wear resistance properties were found to change with change in the laser power. The study found the optimum laser power to be 2 kW for the set of processing parameters considered in the study. Dongdong et al. [8] investigated the influence of TiC addition on the resulting properties of laser metal deposition pure Inconel 625 alloy and the TiC/Inconel 625 composites. The result of the study showed that the incorporation of TiC particles significantly changed the microstructure of Ni–Cr matrix phase with mostly columnar dendrites and cellular dendrites prevailing in the central zone of the deposited region. With the addition of nano-TiC particles, more and more of columnar dendrites were seen in the microstructure. The addition of nano-TiC particles caused the formation of the more refined columnar dendrites with well developed secondary dendrite arms. Increasing the quantity of the micro-TiC particles causes the columnar dendrites to become coarser and degenerated and the secondary dendrite growth is reduced. The cellular dendrites were found to be refined by the TiC particles. The addition of nano-TiC particles also resulted in significantly improvement in the microhardness, the tensile property, and the wear resistance properties.

## 2. Experimental procedures

*LMD machine*

The set of installations consists (see Figure 1):
- 3000 W ytterbium fiber laser in the optical range of λ ~ 1070 nm;
- complex control cabinets;
- control panel;
- KUKA robot;
- powder feeder;
- a fridge;
- optical components with powder nozzles.

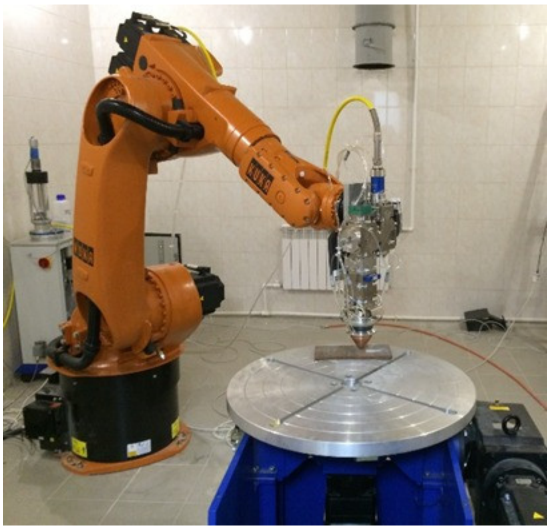


*Fig. 1. LMD Set of Installations*

The laser is designed as a separate stand. To transmit the output radiation, the fiber optic cable exits the rack and terminates at the optical connector at the entrance of

the optics. The laser contains software and hardware tools that can be used to create laser machining programs. In order to achieve coordinated control of the components of the robot system of the composite (feeder, laser source, robotic manipulator) as well as input and monitoring of process parameters the control panel of the control cabinet is used. The controller controls the operation of the robot system according to a previously developed program.
During the operation of the complex system the control module solves the following tasks:
- regulate the flow of transport and shielding gas;
- supplying a carrier gas to the powder feeder;
- providing shielding gas for the optics;
- the operation mode remote control of the powder feeder (setting the metering disc, the speed of the agitator);
- coordinate the matching of the various components of the installation;
- when transferring control to the robot the module transmits information from the robot to the laser source;
- emergency stop installation of components and release information about the failure in an emergency.

The KUKA robot is designed to provide a predetermined motion path of the optical focusing system relative to the substrate surface and a layer-by-layer configuration of the components on the 3D model. A powder feeder is used to deliver the powder material to an optical system with a powder nozzle and to ensure accurate dosing according to specified parameters. The refrigerator is designed for continuous water cooling of the laser system and optical system during LMD process. The optics provide collimation and focusing of the laser radiation to melt the powder material supplied through the powder nozzle to the focus of the laser radiation on the surface of the component structure.

### *LMD Process*

Laser deposition was performed on a robotic laser composite using a fiber laser (KUKA robot + rotator MTS-250; fiber laser LS-4K). A laser nozzle with a multi-jet powder feed (YC-50 head for surface treatment) ensures that a roll of about 4 mm width and 1-1.2 mm height is applied in one pass. The overlapping layer thickness is 50% and for experienced formulations is 2-2.5mm. Thus, the desired layer thickness is achieved in a small number of thermal cycles that heat the surrounding metal to a high temperature above 800 °C. The supply of the powder material was carried out using a dispenser having 2 flasks.
As the filler, a metal powder obtained by a method of atomizing a molten gas is used. All powders used have a fractional size of 40 to 150 microns. The powder mixture of Ti-6Al-4V / TiC in a different proportion by volume is welded onto the sample site in the working size at the mode (see Table 1). Substrate is titanium alloy Ti-6Al-4V. The titanium-based powder is a self-fluxing alloy having high corrosion resistance and wear resistance.

*Table 1 - The Ratio of Powder Mixture and Application Features*

| № | Ti-6Al-4V | WC-8Co | % | Σ | Number of layers | H |
|---|---|---|---|---|---|---|
| 1 | 0.6 | 1.4 | 30/70 | 2 | 2 | 0.6 |
| 2 | 0.5 | 1.5 | 25/75 | 2 | 2 | 0.5-0.6 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3 | 0.4 | 1.6 | 20/80 | 2 | 2 | 0.5 |
| 4 | 0.3 | 1.7 | 15/85 | 2 | 2 | 0.4-0.5 |
| 5 | 0.2 | 1.8 | 10/90 | 2 | 2 | 0.3-0.4 |

Two types of titanium carbide are used as the hardened phase: cut and agglomerated carbides. The agglomerated titanium carbide in the cobalt ribbon is a finely divided carbide which is combined into a spherical particle using a cobalt base. This carbide fuses into the matrix and forms a continuous uniform transition without lattice distortion and microdefect formation.
A powder mixture Ti-6Al-4V / TiC and chipped titanium carbides is deposited at the workplace indicated. The characteristics work of laser was consist the main parameters of coating operating mode (see Table 2).

*Table 2 - Coating Operating Mode*

| **Parameter** | **Value** |
|---|---|
| Power, % | 36-38 |
| Moving Rate, mm/s | 5 |
| Step, mm | 2,5 |
| Substrate | Ti-6Al-4V |

*The Samples Coating Process*

*1.* The surfacing was carried out on experimental cylindrical samples of size 10x6.8 mm. The modes and the percentage of titanium carbides were varied. To eliminate cracks, preheating of the blanks to a temperature of 450 ° C was used.
In the process of applying coatings on experimental cylindrical samples of 10x6.8 mm in size, no cracks or pores were found, the carbides remained undissolved. Figure 2-3 shows the macrostructure of the fusion zone with the substrate for samples with a ratio of 30/70 and 10/90. The fusion is even, the carbides are evenly distributed throughout the thickness and length of the coating. The surfacing was carried out in two passes, the coating thickness was 1.2 mm. The hardness of the coating was at different values of the titanium carbide content from 30 to 40 HRC. With an increase in the carbide phase content at the deposited layer, an increase in hardness and brittleness occurs, therefore the optimal content of Ti-6Al-4V / TiC (10/90 by volume) is found in sample No. 5, since this sample has the most uniform distribution of carbides in thickness and length of the coating.
*2.* As well a sample was made from alloy Ti-6Al-4V, that the working surface was strengthened by induction soldering with powder solder based on titanium (Vpr-16) of WC-8Co hard alloy grains with granulation 180 ... 250 µm.

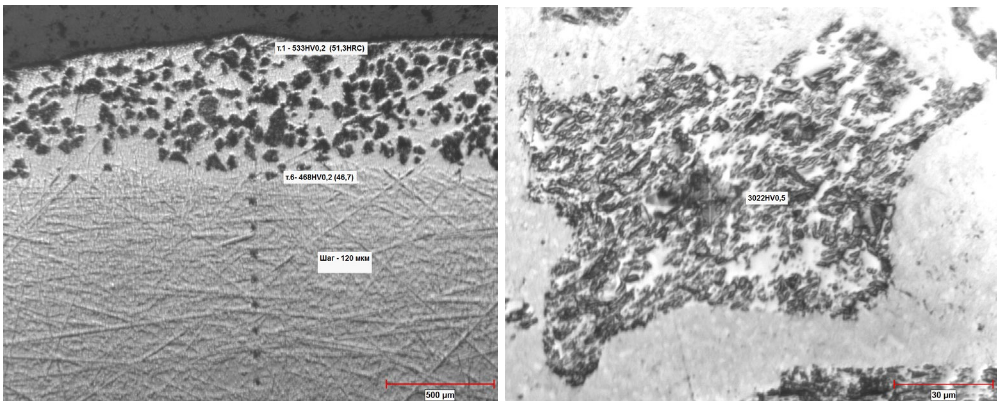



*Fig. 2. Fusion Zone Macrostructure with the Samples Substrate in 30/70 Ratio*

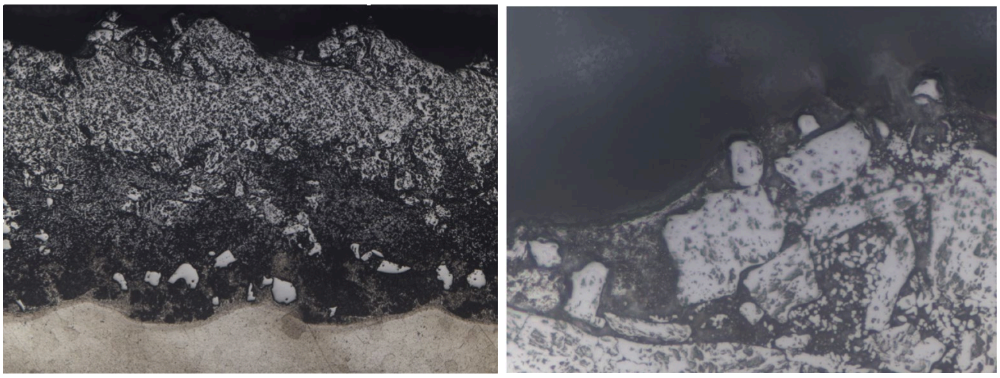


*Fig. 3. Fusion Zone Macrostructure with the Samples Substrate in 10/90 Ratio*

## *Friction and Wear Test*

In order to study fretting wear (dry alternating friction), a specialized friction machine «3308» was used. The friction machine scheme is shown in Figure 4. On the shaft - 1 fixed between the two racks - 2 the body, there are two levers - 3, the specimens at the ends of which are mounted in a tapered sleeve (see Figure 5). Under the action of the leaf spring - 5, a frictional contact with a force "P" is formed by means of a loading unit between the samples – 4. It can be smoothly adjusted by means of a spring displacement unit – 6, by changing springs of different thicknesses load range. The reciprocation of the samples - 4 relative to each other is ensured by the rotation of the shaft - 7 with an eccentricity "e" fixed, while the outer bearing race - 8 is in constant contact with the lower arm.

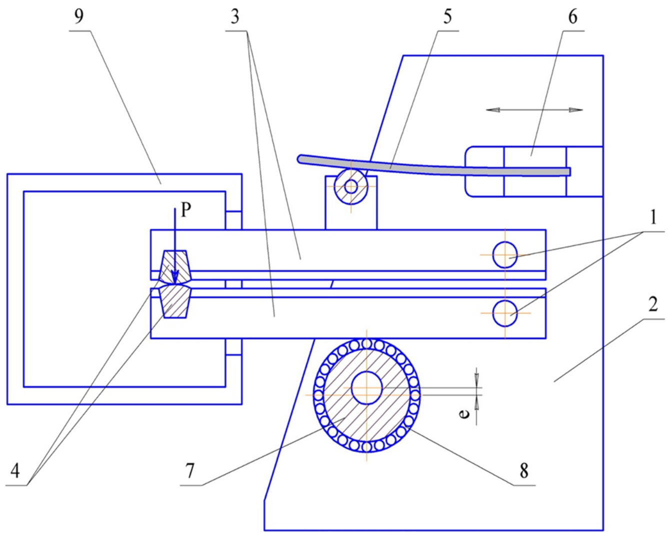



*Fig. 4. Scheme specialized friction machine «3308»*

*1 - axis lever; 2 - friction machine shell plates; 3 – levers; 4 – specimens; 5 - flat springs; 6 - spring displacement units; 7 - eccentric pusher drive shafts; 8 - outer pusher bearing sleeves; 9 – volume modeling friction environment*

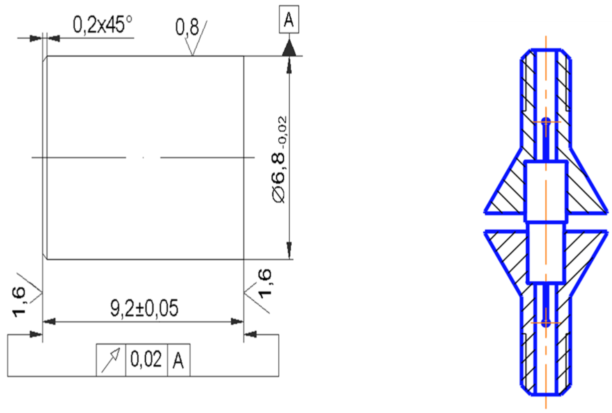



*Fig. 5. Standard Test Coating Sample*

At the first stage of the study, preliminary tests were conducted to select the sample shape and test procedures. For the test, a contact plane scheme was chosen, implemented on a cylindrical sample. After application, the laser coated samples were tested without further processing. At the same time, while soldering the hard alloy WC-8Co, the end working surface of the samples was processed by grinding to form a flat surface. To fix the cylindrical specimen on the friction machine, a high-precision clamping cartridge was developed and manufactured.

Before conducting validation tests for testing the test procedure, selecting test intervals and obtaining information about the behavior of the tested coatings under the given test conditions, evaluation tests were conducted. The tests of the samples were carried out under the following conditions: external environment - air; sample temperature is room temperature; contact pressure in a friction pair - 1.3 kgf / mm2; displacement in a friction pair - 0.7 mm; contact form in the friction zone - degenerate cylinders; frequency - 10 Hz; test time - 360 minutes.

The wear of the samples was evaluated in two ways: during the experiment, the relative convergence of the samples was measured using a Keyence LC2450 laser sensor with the LC2400 controller, and before and after the tests, the samples were weighed on a ViBRA H220CE analytical balance.

## 3. Results and discussion

The results of evaluation of wear on the approximation of samples in the friction process are presented in Figure 6 of which clearly shows that the smallest wear resistance (closest approach) in the process of fretting wear showed a coated sample with a component ratio of 30/70 (Ti-6Al-4V / TiC), and the best three samples with a ratio of components 10/90, 15/85 and 25/75. In this case, the reference point was a sample with a coating obtained by soldering tungsten carbide grains and its wear turned out to be higher compared to the coatings obtained by welding. It should be noted a slight increase in the rate of wear of the sample with a WC-8Co coating on the 240th minute of testing. A similar process was also observed with a 20/80 coverage of 270 minutes. For steel specimens, the wear rate throughout the entire process after the burn-in period was almost the same.

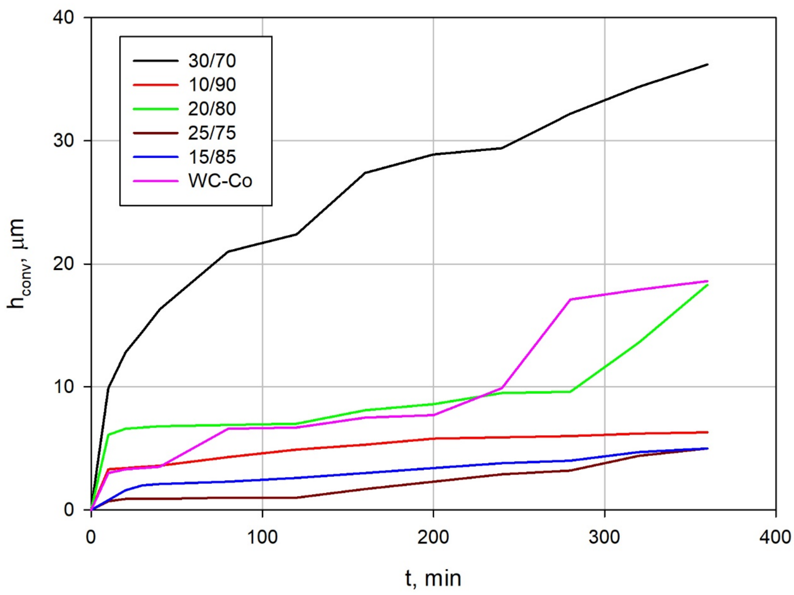



*Fig. 6. Convergence Wear Graph for Tested Samples*

Figure 7 shows the results of weight wear of the coatings. The best indicators are observed for coatings with ratios of 15/85, 20/80 and 25/75, a slightly worse value of mass carryover for a coating of 10/90, while the worst indicators are for a coating of 30/70 and WC-Co. In these results, it is worth making some corrections for different density of coatings due to different ratios and densities of the applied components of the composite coating.

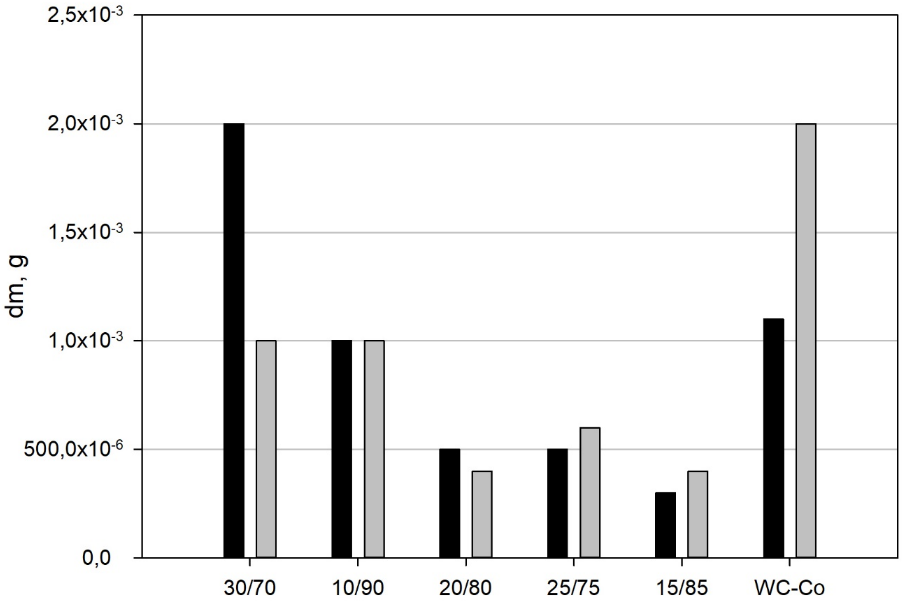
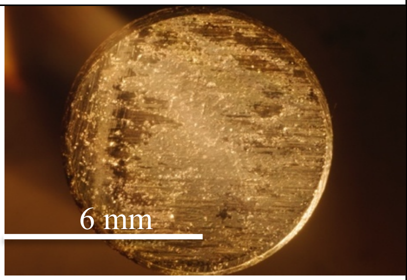
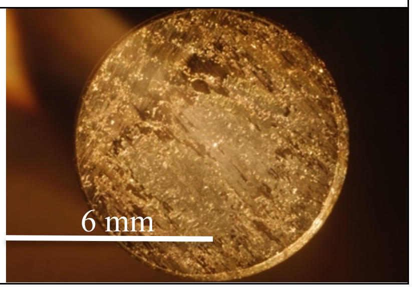
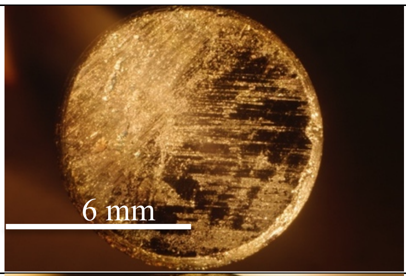
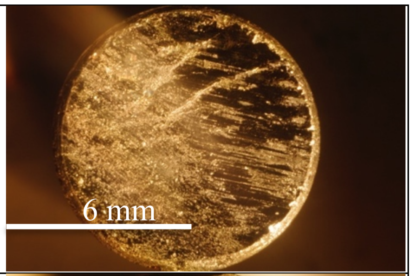
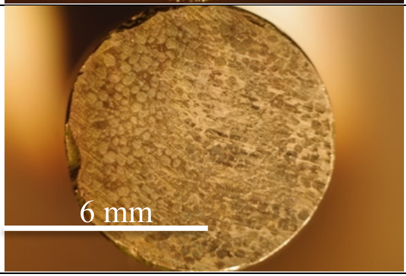
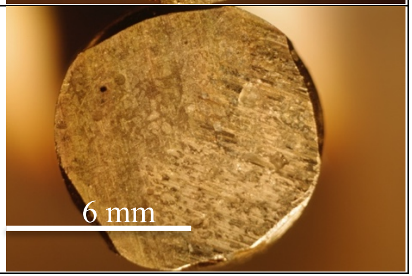



*Fig. 7. Weight Wear Diagram for Tested Samples*

Table 3 shows photographs of wear spots obtained on samples with coatings of 30/70, 10/90, and WC-8Co. As can be seen, the process of wear on the 30/70 coating covered the entire area of the samples, you can also see zones of adhesive wear. Such a process may be due to the fact that the hardening particles TiC are in the coating in the unbound state, and are located in the metal matrix Ti, as can be seen in Figure 2, which leads to low wear resistance. The sample of the coating obtained with a component ratio of 10/90 has a different structure (Figure 3): two interpenetrating matrices of metallic titanium and carbide particles were formed. This led to a lower rate of wear of the latter, as evidenced by the smaller area of the wear spot (Table 3). A similar picture can be observed for the sample with WC-8Co coating. Increased mass wear of the latter is apparently associated with a higher overall density due to the increased content of hardening particles.

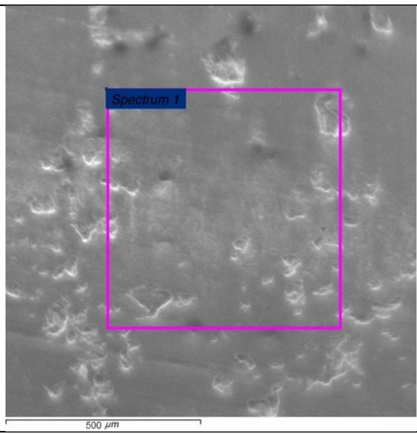
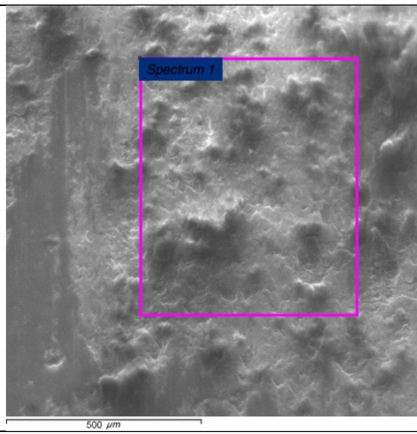
*Table 3. Images of Worn Samples by Special Camera*

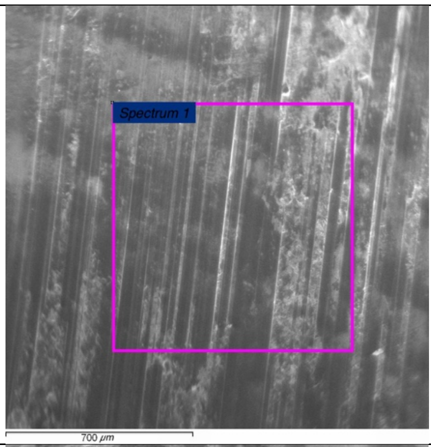
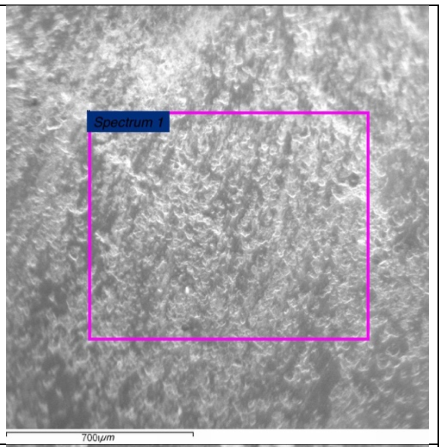
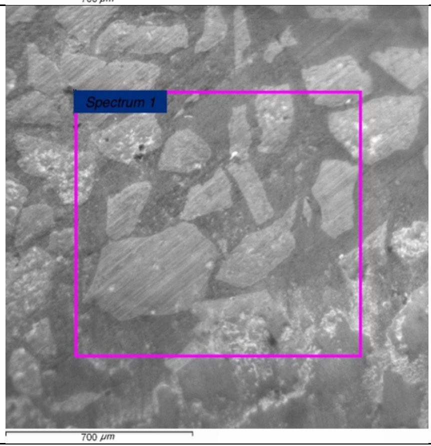
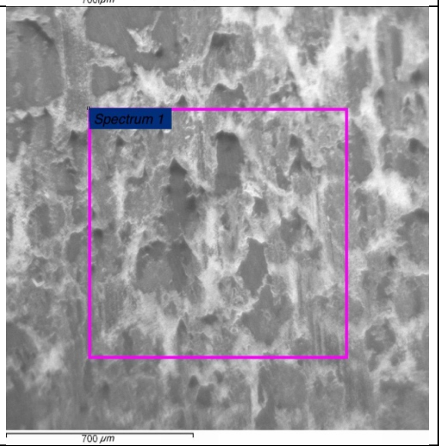
| **Applied material and application method** | **Image of sample number 1 paired** | **Image of sample number 2 paired** |
|---|---|---|
| Ti-6Al-4V */TiC (30%/70%) - LMD method* |   |   |

| | | |
|---|---|---|
| Ti-6Al-4V / *TiC (10%/90%) – LMD method* |  |  |
| WC-8Co - *technology soldering grains of hard alloy* |  |  |

The morphology of wear spots is presented on SEM images (Table 4). So for the 30/70 coating, the areas with painted TiC particles from the metal matrix, as well as the area with uneven relief, formed, apparently, due to the adhesive interaction of the metal matrix of the tested samples, are well manifested.
When worn, the 10/90 coating has a fairly uniform structure of the damaged area, and no dyed particles of the carbide matrix are also observed, which speaks in favor of the formation of a rigid carbide cage with such a ratio of components of the composite coating.
Coating WC-8Co is characterized by large sizes of carbide particles compared to TiC. Due to the peculiarities of the technology for producing such a coating, there is no rigid carbide matrix. The photograph of the worn surface clearly shows that the wear of the coating occurs primarily on a soft matrix, and the size of carbide particles allows the composite coating to withstand increased wear.

Table 4. *Morphology and Phase Composition of the Unworn and Worn Area by SEM*

| **Applied material and application method** | *Morphology and Phase Composition of the* ***Unworn*** *Area* | *Morphology and Phase Composition of the* ***Worn*** *Area* |
|---|---|---|
| Ti-6Al-4V */TiC (30%/70%) - LMD method* |  |  |

| | | |
|---|---|---|
| Ti-6Al-4V */TiC (10%/90%) – LMD method* |  |  |
| WC-8Co - *technology soldering grains of hard alloy* |  |  |

## 4. Conclusions and further work

Studies have shown that the use direct laser synthesis technology allows, when properly selected components of the composite coating, to obtain interpenetrating carbide and metal matrices, the wear resistance whether is higher compared to the coating obtained by the method of induction brazing of tungsten carbide grains.
To solve the problem of the applicability of a TiC coating, in our opinion, additional studies are needed to answer the question about the behavior of the developed compositions of composite coatings during long-term tests, as well as what is the critical contact pressure, including under thermal load.
As a result of the research, new information was obtained on the wear rates of coatings of two different types under the conditions of fretting wear typical for the fans shroud blade platforms and low-pressure compressors of gas turbine engines. The differences in the mechanisms of wear of ceramic coatings based on LMD technology for a powder mixture of Ti-6Al-4V / TiC and induction soldering of hard-grained WC-8Co grains are revealed.
The research results can be used in the design and technological development of the issue of increasing the fretting resistance of GTE retaining shelves and improving the technology of applying hardening coatings to GTE components.

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