МІНІСТЕРСТВО ОСВІТИ ТА НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
КАФЕДРА КОНСТРУКЦІЇ ЛІТАЛЬНИХ АПАРАТІВ

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ДИПЛОМНА РОБОТА
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«АВІАЦІЙНА ТА РАКЕТНО-КОСМІЧНА ТЕХНІКА»

Тема: «Дослідження механічних характеристик композиційних покриттів»

Виконавець

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MASTER DEGREE THESIS
ON SPECIALITY
”AVIATION AND ROCKET-SPACE ENGINEERING”

Topic: « Mechanical properties investigation of composite coatings »

Prepared by: ____________ **Pavlo KORZH**

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Kyiv 2021

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

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«_____» ______________ 2021 р.

ЗАВДАННЯ

на виконання дипломної роботи студента

КОРЖА ПАВЛА ОЛЕГОВИЧА

1. Тема роботи: «Дослідження механічних характеристик композиційних покриттів», затверджена наказом ректора від 8 жовтня 2021 року № 2173/ст.

2. Термін виконання роботи: з 11 жовтня 2021 р. по 31 грудня 2021 р.

3. Вихідні дані до роботи: зразки титанового сплаву з нанесеними композиційними покриттями.

4. Зміст пояснювальної записки: приклади використання титану в конструкції літаків ,аналіз сучасних методів підвищення мікроміцності металів, дослідження механічних властивостей захисного композитного покриття на титановому сплаві, аналіз шкідливих та небезпечних виробничих факторів, огляд шкідливого впливу виробництва літаків на навколишнє середовище.

5. Перелік обов'язкового графічного (ілюстративного) матеріалу: авіаційне обладнання, принципові схеми методів виміру мікротвердості, загальний вигляд обладнання, на якому проводилися виміри.

6. Календарний план-графік

№	Завдання	Термін виконання	Відмітка про виконання
1	Огляд літератури за проблематикою роботи. Дослідження проблеми використання титанових сплавів в авіації.	8.10.2021–12.10.2021	
2	Аналіз методів підвищення мікротвердості матерілів.	13.10.2021–16.10.2021	
3	Аналіз методів вимірювання мікротврдості та вибір найраціональнішого.	17.10.2021–22.10.2021	
4	Проведення досліджень та оцінка мікротвердості титанового сплаву Ti 4Al 6V.	23.10.2021–15.11.2021	
5	Виконання частин, присвячених охороні навколишнього середовища та охорони праці.	16.11.2021–21.11.2021	
6	Підготовка ілюстративного матеріалу, написання пояснювальної записки.	22.11.2021–29.11.2021	
7	Перевірка, редагування та виправлення пояснювальної записки	30.11.2021–08.12.2021	

7. Консультанти з окремих розділів:

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Керівник дипломної роботи ____________ Вадим ЗАКІЄВ

Завдання прийняв до виконання ____________ Павло Корж

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APPROVED BY
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«___» ________________ 2021

TASK

for the master degree thesis

PAVLO KORZH

1. Topic: « Mechanical properties investigation of composite coatings », approved by the Rector's order № 2173/ст from 8 October 2021 year.
2. Period of work execution: from 11 October 2021 year to 8 December 2021 year.
3. Initial data: samples of titanium alloy with applied composite coatings.
4. Content: examples of the use of titanium in aircraft design, analysis of modern methods to increase the micro-strength of metals, study of mechanical properties of protective composite coating on titanium alloy, analysis of harmful and hazardous production factors, review of harmful effects of aircraft production on the environment.
5. Required material: aviation equipment, schematic diagrams of microhardness measurement methods, general view of the equipment on which the measurements were performed.

6. Thesis schedule:

№	Task	Time limits	Done
1	Review of the literature on the issues of work. Analysis of methods for increasing the microhardness of materials.	8.10.2021–12.10.2021	
2	Research of the problem of using titanium alloys in aviation.	13.10.2021–16.10.2021	
3	Analysis of methods of measuring microhardness and selection of the most rational.	17.10.2021–22.10.2021	
4	Research and evaluation of microhardness of titanium alloy BT6.	23.10.2021–15.11.2021	
5	Execution of the parts, devoted to environmental and labor protection.	16.11.2021–21.11.2021	
6	Preparation of illustrative material, writing the report.	22.11.2021–29.11.2021	
7	Explanatory note checking, editing and correction.	30.11.2021–08.12.2021	

7. Special chapter advisers:

Chapter	Adviser	Date, signature	
		Task issued	Task received
Labor protection	PhD, associate professor Victoria KOVALENKO		
Environmental protection	D.Sc., professor Tamara DUDAR		

8. Date of issue of the task: «__»___________2021 year.

Supervisor: ____________ Vadym ZAKIIEV

Student: ____________ Pavlo KORZH

ABSTRACT

Master degree thesis “Mechanical properties investigation of composite coatings”
94 p., 41 fig., 3 tables, 20 references

Object of study – physical-mechanical characteristics of the surface layer.
Subject of study – composite coatings on titanium alloy.
Aim of master thesis investigation of mechanical characteristics of composite coatings on titanium alloy.
Research and development methods – nanoindentation, interference profilometry, fracture mechanics.
Novelty of the results – the physical-mechanical characteristics of composite coating on titanium alloy were studied.
Practical value – it is shown that the composite hardening method, in comparison, with the BT6 substrate alloy, the produced protective layer is shown to possess a three times higher hardness, ~50% higher elastic modulus.

MICROHARDNESS, PROTECTION AND IMPROVEMENT OFAIRCRAFT PARTS, ULTRASONIC TREATMENT, COMPOSITE COATINGS, NANOINDENTATION

CONTENT

ABBREVIATIONS

CFRP – Carbon Fiber Reinforced Plastic

SPF-DB – Superplastic forming and diffusion bonding

ECM – Electrochemical machining

TMC – Titanium matrix composites

ATV – Automated Transfer Vehicle

ISS – International Space Station

HRC – Rockwell C Hardness

UIT – Ultrasonic impact treatment

SEM – Scanning electron microscope

FSP – Friction-Assisted Process

PLD – Programmable logic device

ISO – International Organization for Standardization

SHE – Surface hardening efficiency

SPD – severe plastic deformation

PVD – physical vapor deposition

GTE – gas turbine engine

MPC – maximum permissible concentrations

INTRODUCTION

Ensuring scientific and technological progress in mechanical engineering is associated, first of all, with the creation of new structural materials and the improvement of technologies for their hardening. In this regard, in the field of mechanical engineering, the actual task whose is the development of affordable, economical, highly efficient and environmentally friendly technologies for strengthening structural materials, providing the desired performance properties.

In recent years, much attention has been paid to the development of surface hardening technologies. This is due to a new approach to assessing the role of material in ensuring the structural strength of products, according to which it is the state of the surface that largely determines the level of strength and performance properties of machinery.

In this regard, a new scientific direction appeared – surface engineering, which involves the development of technological processes that allow modifying the surface layer, radically changing its structure and properties.

The relationship of surface quality parameters of parts and their performance properties is one of the main areas of research in the field of mechanical engineering and instrument making.

Currently sufficiently studied the relationship of the quality of the treated surface with important performance of parts and components of machines and devices (friction and wear during sliding and rolling, fluid friction, contact hardness, strength of press joints, reflectivity, wear resistance under variable loads, corrosion resistance and quality of paints, accuracy of measurements, a ratio between tolerances of the size and surface roughness, etc.).

The problem of increasing the reliability and durability of machines along with reducing the metal intensity of structures is one of the most important tasks of mechanical engineering.

This problem is especially acute for aviation equipment, where reliability and service life are largely determined by the serviceability of structural elements. Therefore, one of the main conditions for ensuring a high service life of aircraft is the prevention of fatigue failure of parts. Technological methods occupy a significant place in this problem.

Since the necessary set of operational characteristics and service life of products is laid down at the stage of their production, it is extremely important to control the quality of the initial materials and determine the depth of the hardened layer.

It is the control of mechanical properties at the stage of manufacturing that should be of primary importance in the implementation of a comprehensive program of diagnostics of objects during their operation, since only in this case it is possible to fix the trend of changes in those parameters, on which the residual resource.

This is especially important for aviation high-precision parts that are characterized by complex geometric shape, thin walls and low structural rigidity (GTE blades, thin-walled discs, membranes, shafts, etc. parts).

Since the necessary set of operational characteristics and service life of products is laid down at the stage of their production, it is extremely important to control the quality of initial materials and to determine the depth of the hardened layer. It is the control of mechanical properties at the stage of manufacturing that should be of primary importance in the implementation of a comprehensive program of diagnostics of objects during their operation, since only in this case it is possible to fix the tendency of change of those parameters, on which the residual resource depends.

PART 1
TITANIUM APPLICATIONS IN AEROSPACE INDUSTRY

Compared to steels or aluminum alloys, titanium alloys are considered a younger construction material. The first alloys were produced in the United States in the late 1950s. Among them was the classic titanium alloy BT6, which still accounts for most aerospace applications today.

The prominent properties of titanium alloys comprise high specific strength and great corrosion resistance. That's why, titanium alloys are used in the aircraft manufacturing industry where weight, strength, corrosion resistance are combined, and/or the high-temperature stability of high-strength steels, nickel-based superalloys, or aluminum alloys is not enough [1]. The main factors in the use of titanium in the airspace industry are:

- weight reducing (substitution of Ni-based steels and superalloys)
- temperature of application (substitution of Al alloys, nickel-based superalloys, and steels)
- corrosion resistance (substitution of Al alloys and low-alloyed steels)
- galvanic compoundability with polymer matrix composites (substitution of Al alloys)
- space restriction (substitution of Al alloys and steels).

Figure 1.1 shows the proportion of structural weight of different material classes in modern large commercial aircraft, the differences between the airframe and engine materials. For example, the fuselage of the Airbus A330/340 is almost two-thirds aluminum. About 7% titanium alloys have the same proportion of structural weight as steel. However, titanium, which accounts for more than a third of the structural weight, is the second most common material in jet engines after nickel-based superalloys, and titanium alloys are the most common material by volume [2].

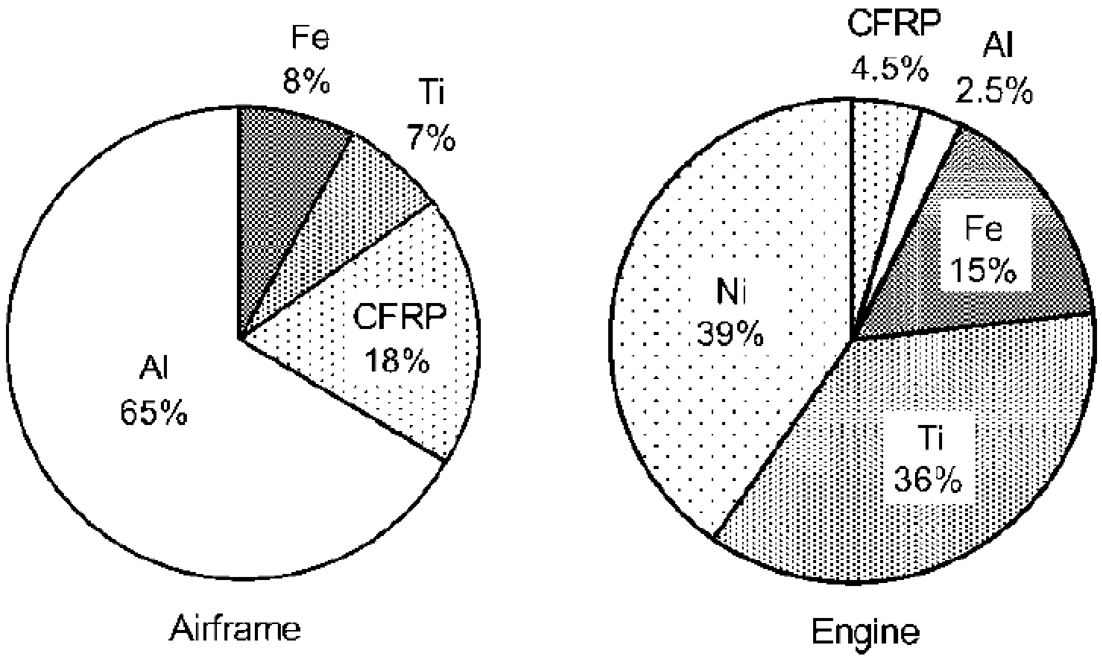

Fig. 1.1 – Percentage of aluminum, titanium, and steel alloys and CFRP structural weight of modern large commercial aircraft and gas turbine engines

In addition to material properties, the determining factor in choosing materials for design is cost. This applies not only to the cost of raw materials, but also to the cost of producing the finished component. Therefore, in addition to the mechanical properties required for part integrity, material performance such as formability, workability, formability (ductility) and weldability are also important cost factors. In the aerospace industry in particular, it is important to take a life-cycle approach to material selection, taking into account the cost of maintenance and repair over the expected life of the component. Aircraft manufacturers and titanium alloy manufacturers and fabricators are under increasing pressure from airlines to maximize the performance of their components while reducing overall costs [3-5].

The use of titanium alloys in the aerospace sector will be discussed in the following sections. First, fixed-wing aircraft will be addressed, then the use of titanium in jet engines will be highlighted, and finally examples for helicopter and space applications will be given.

1.1. Application of Ti-alloys in fuselage structure

In many cases, weight reduction is the main reason for choosing titanium alloys for aviation applications, taking advantage of the high specific strength of the metal. Often it makes sense to replace with high-strength steel, even if the strength of the steel is higher, or with aluminum-based alloys, even if the density of the aluminum is lower. This has led to the increased use of titanium alloys in aircraft frames over the past 40 years. Figure 1.2 shows the steady increase in the use of titanium in Boeing commercial airplanes since the introduction of titanium in the airframe in the 1950s. It is now about 9% of the weight of the Boeing 777 airplane structure. Similar data is available for Airbus aircraft. Typical applications of titanium alloys in the fuselage structures are described below [6].

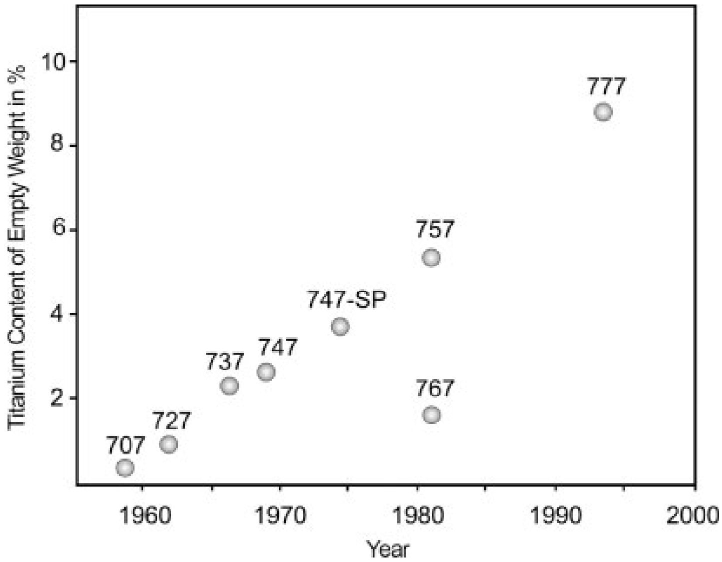

Fig. 1.2 – Application of titanium alloys in commercial Boeing aircraft

Titanium alloys are used to prevent fatigue cracking in aircraft fuselages. Titanium alloy is placed as a thin, narrow ring around an aircraft's aluminum fuselage as a "belt" to prevent catastrophic propagation of potential fatigue cracks in the fuselage.

Currently, titanium alloys are also used in hydraulic pipes for modern aircraft. Compared to steel pipes, they can be up to 40% lighter: for these purposes, the α+β alloy Ti-ZAl-2.5V, which is easily deformable and has sufficient strength, is mainly used.

Commercially pure titanium is used when high corrosion resistance with moderate strength is required. Aircraft floors, enclosing galleys and on-board lavatories are examples of where titanium is needed in highly corrosive environments.

The piping of anti-ice system is made of unalloyed titanium. Here strength is less important than thermal stability. Aluminum alloys can no longer be used because temperatures can exceed 200 °C. In addition, the need to transport hot and aggressive media requires excellent corrosion resistance.

Even though the initial cost is higher, the main landing gear components of airplanes are often made of forged titanium alloys. The high initial cost has long-term advantages because high-strength steel is susceptible to stress corrosion cracking and usually requires replacement at least once during the life of an aircraft. The use of titanium alloys eliminates the need to replace landing gear components, and the use of titanium alloys has become a trend in the Boeing 777 aircraft (Figures 1.3 and 1.4). Here, most of the main landing gear is made from TIMETAL 10-2-3 forgings, nearly double the amount of titanium used in the 777 aircraft. The weight savings were about 270 kg per aircraft [6].

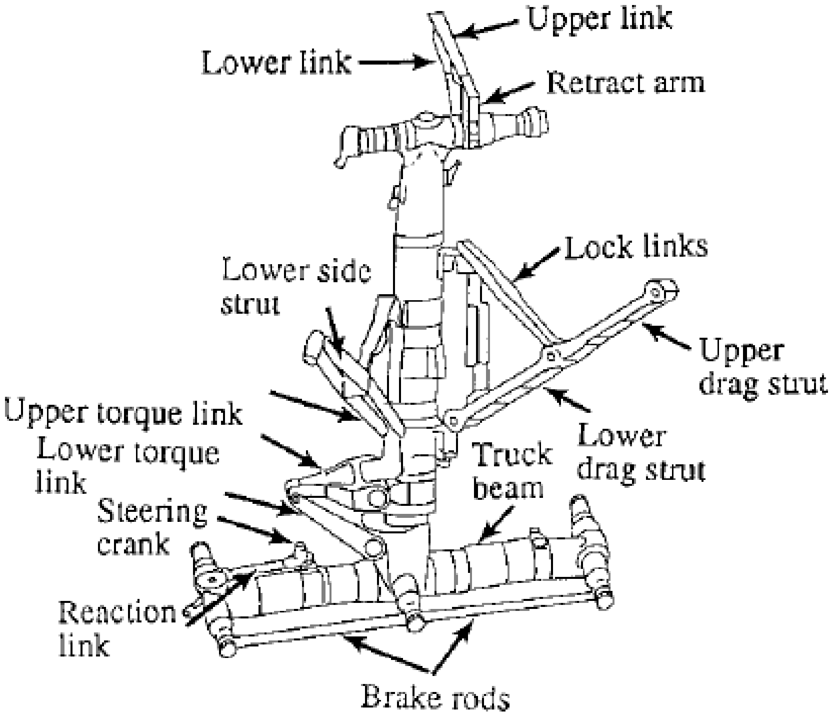

Fig. 1.3 – Main landing gear of Boeing 777 of forged

Fig. 1.4 – The main landing gear of Boeing 777 primarily uses forged parts of Ti-10V-2Fe-3Al

The cockpit window frames are made of forged titanium alloy (Figure 1.5) because of the high stresses that can result from bird strikes, while the other window frames are made of aluminum-based alloys to ensure sufficient strength. Titanium alloys are suitable to support the vertical and horizontal tail stabilization structure, which is made of carbon fiber reinforced polymer (CFRP). This is mainly because the thermal expansion coefficient of titanium is close to that of titanium and aluminum, as well as polymer matrix composites. In addition, titanium alloys are more chemically compatible with carbon fibers than aluminum and are used to avoid electrolytic corrosion problems.

Compared to the commercial aircraft market, the use of titanium alloys in military fighters is much wider. The high degree of use is due to the fact that the structure is designed to improve maneuverability and cope with the increased thermal and mechanical stresses associated with supersonic speeds. The proportion of titanium alloy in the fuselage of military aircraft can exceed 50%, and in the SR-71 "Blackbird" it was 95%. Titanium alloys were used because the thermal characteristics of the more modern high-temperature aluminum alloys were insufficient due to the heating of the skin by air movement.

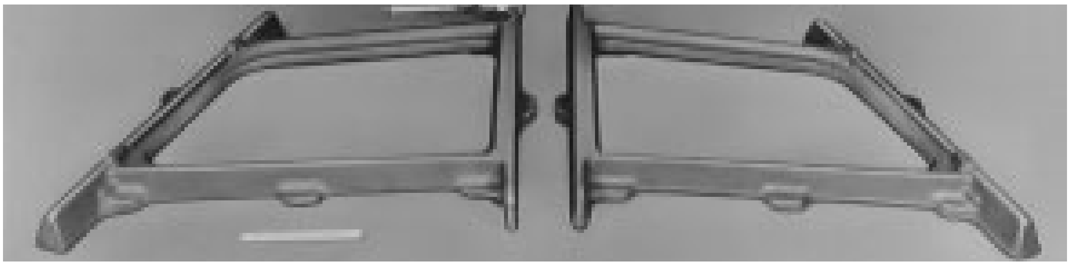

Fig. 1.5 – Window frames of Ti-6Al-4V for the cockpit of a commercial aircraft

Today, titanium accounts for about 35-50% of the weight of modern fighters. Titanium is most commonly used in fighter engine compartments, where temperatures can quickly exceed the capabilities of aluminum. For example, the conventional design of titanium plates and rivets was widely used in the rear section of the American F-15 fighter jet. However, in redesigning the F-15E for the same design, advanced superplastic forming and diffusion bonding (SPF-DB) technology was widely used. This change in technology eliminated the need for 726 parts and 10,000 fasteners, making the aircraft easier to maintain. New alloys such as Ti-6Al-2Zr-2Sn-2Mo-2Cr-0.25Si are used in the airframes of American F-22 and Joint Strike Fighter project aircraft. in the airframes of American F-22 and Joint Strike Fighter project aircraft. This alloy has moderate heat resistance and is mainly used in the engine compartment bulkheads of these aircraft, where fuselage temperatures are highest. In general, meeting high performance requirements is more important for military aircraft than for commercial aircraft, where overall cost-effectiveness is a major factor. The largest and perhaps most spectacular titanium structure in military aircraft is the wing box, which takes the load off the main wing and sometimes has a sweeping wing design. Figure 1.6 shows an example of the center fuselage bulkhead of an American F-22 aircraft that is part of the wing box. At 4.90 m wide, 1.80 m deep and 0.2 m high, it is one of the largest titanium wings ever produced. The final weight is about 150 kg, but it was originally forged from a single cast ingot weighing up to 3,000 kg. This example clearly demonstrates the very high 95% machining losses that occur when forging titanium and shows that there is an opportunity to optimize the forging process in the future.

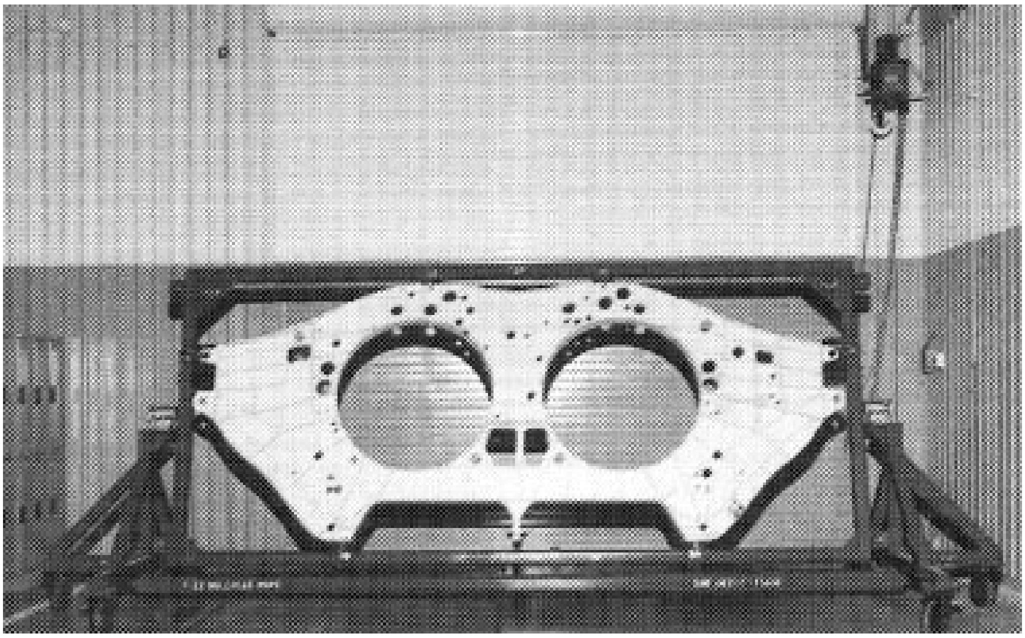

Fig. 1.6 – Center bulkhead of the F-22 (Lockheed-Martin Aeronautics)

Titanium alloys are very suitable as spring materials. Compared to high-strength steels, their density-adjusted modulus of elasticity provides up to 70% weight reduction, up to 50% volume reduction, and improved corrosion resistance. Due to their high strength, β C and β -alloys such as Ti-15V-3Cr-3Sn-3Al are the best candidates for alloys.

1.2. Application of Ti-alloys in gas Turbine Engines

Titanium alloys for the aerospace industry are mainly used in gas turbine engines. Approximately one-third of the structural weight of a modern turbine engine consists of titanium. In addition to nickel-based superalloys, titanium alloys are standard material for engines. Titanium alloys were used in the first jet engines launched by Pratt and Whitney in the United States and Rolls-Royce in Great Britain in the early 1950s. Since then, the titanium content has steadily increased, as shown by the Rolls-Royce engine in Figure 1.7. In addition, over the years there has been a trend away from α+β alloys toward higher-temperature alloys close to α.

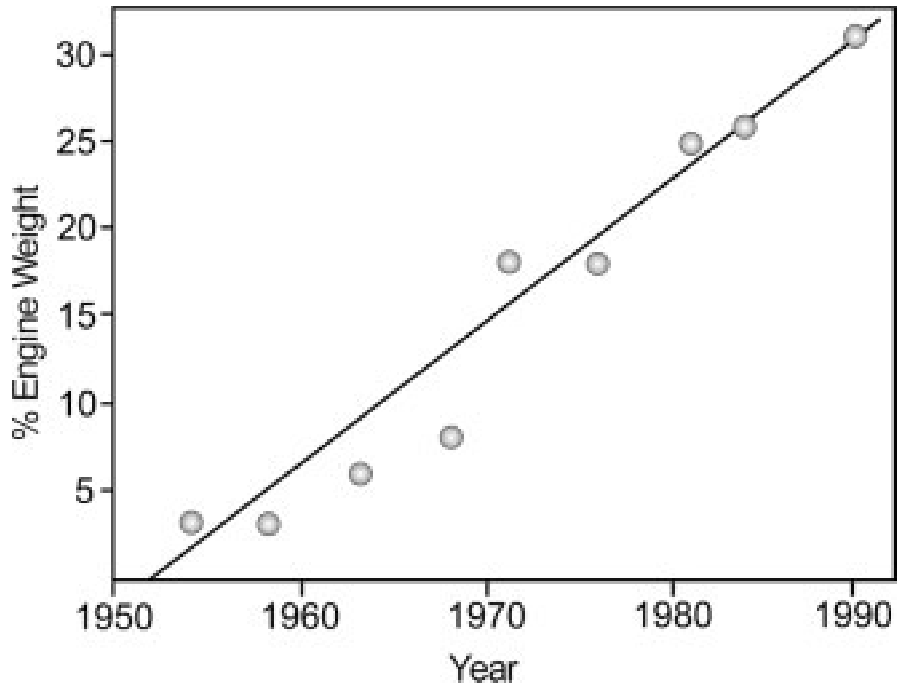

Fig. 1.7 – Applications of titanium alloys in Rolls-Royce engines

Compressor blades were the first engine component made of titanium, followed by titanium compressor disks. Even the large front fan blades of modern jet engines are now often made of titanium alloys. Figure 1.8 shows the scale of such components represented by the Rolls-Royce Trent jet engine series. Because of the ever-increasing deflection rate of the engine, the fan blades of the latest designs are over one meter long. At this length, fan blade agitation becomes a serious problem as the apex of the fan blade reaches the speed of sound, creating a supersonic/subsonic mixed flow field and associated shock waves. To increase the stiffness of the fan blade, a sleeve (snubber) was installed in the middle of the blade. This mid-blade shroud, while reducing vibration, had a negative effect on the aerodynamic efficiency of the fan and reduced fuel consumption. Recent fan designs have dispensed with the shroud, increasing the chord width and blade stiffness and reducing the number of blades by a third. Today, this wide strut fan blade is used in modern jet engines. However, because of the large mass of these blades, it is not possible to use forged titanium alloys, as in the past.

Fig. 1.8 – Fans of commercial Rolls-Royce Trent engines made of Ti-6Al-4V

Major engine manufacturers are exploring different concepts for producing lightweight, high-pitch fan blades for use in the latest large jet engines. General Electric was the first to use fiber-reinforced polymer composites in GE90 fan blades. However, to meet erosion resistance requirements, the leading edge of the blade is made of titanium. Rolls-Royce and Pratt & Whitney continue to use titanium-based designs to reduce engine weight, and both companies have switched to hollow titanium fan and blade technology. The transition has taken place. Early hollow fan blade designs consisted of machined titanium sheet bonded by liquid-phase diffusion to a titanium honeycomb core. In the design shown in Figure 1.9, the outer shell of the bonded structure is expanded with inert gas under pressure and high temperature and mounted on an aerodynamically profiled metal mold. The new Rolls-Royce (Trent 900) and GE/Pratt & Whitney Engine Alliance (GP7200) engine on the Airbus AZ80 has a fan diameter of about 3 meters and hollow titanium blades.

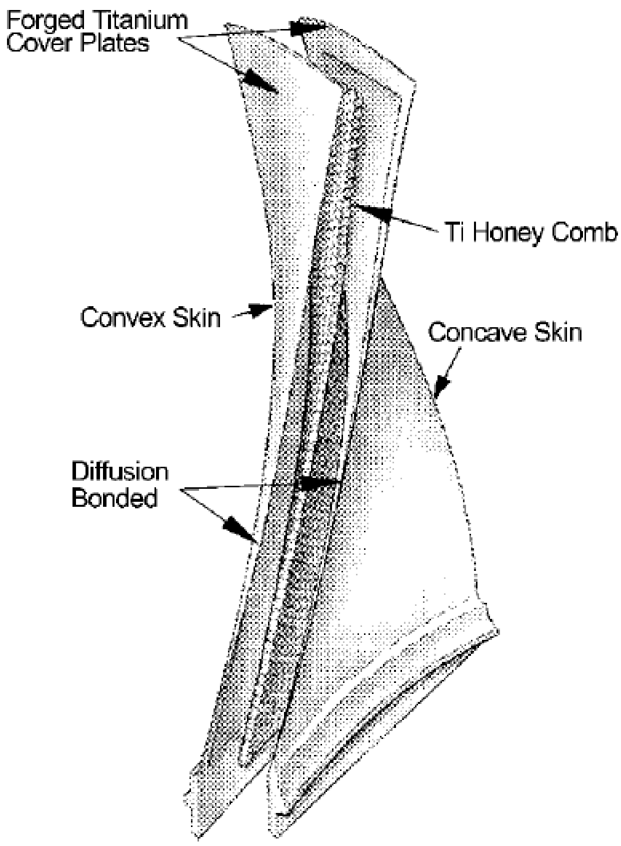

Fig. 1.9 – Hollow fan construction

Evolving engine designs require further reductions in the weight of compressor blades and disks, which increases component life and service intervals. This is achieved through the use of integrated blade discs, or blisk designs. The finished disc is a single piece of disc and blade that are metallurgically bonded together. With a small blade height up to 60-80 mm, it is economically advantageous to make a disk from a forged disk of larger size. Larger blades are usually attached to the disc by direct friction welding.

In addition to the weight reduction due to the blade design, there is no mechanical interface between the blades and the disc, so there are no areas where fatigue cracks can occur. Inspection intervals can therefore be extended: an example of a Blisk compressor stage from MTU Aero Engines is shown in Figure 1.10. For example, in the Eurofighter EJ200 engine, all three fan section stages have a blisk design, with the first two manufactured by friction line welding and the third by electrochemical machining (ECM).

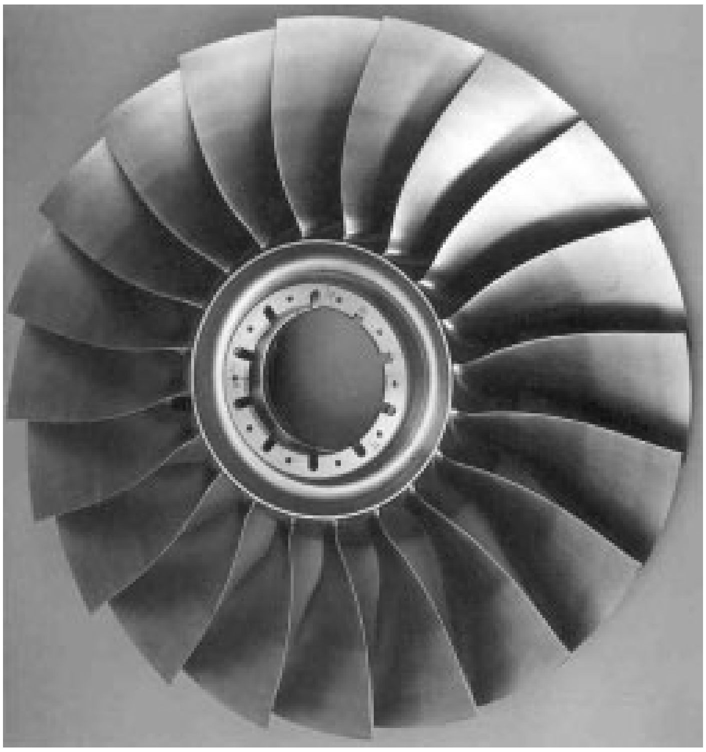

Fig. 1.10 – Titanium blisks for compressor applications

Because fan blades and discs are used at low temperatures, they are usually made of Ti-6Al-4V. The maximum operating temperature for this alloy is about 315 °C. Therefore, the disks and blades in the first four or five stages of a compressor (low-pressure compressor) can also be made from Ti-6Al-4V. However, high-temperature quasi-Alpha alloys are used in high-pressure compressors. The current upper temperature limit for these alloys is about 540°C. This upper limit is not limited by the high-temperature strength or creep resistance of the near-alpha alloys, but by their moderate resistance to oxidation, especially when compared to nickel-based superalloys [10]. During long-term high-temperature applications, titanium alloys form an "alpha box" on the surface. This means that oxygen enrichment creates zones of brittle alpha phase, which leads to a significant reduction in ductility and fatigue strength.

For rotating parts, the temperature limit is even lower because of the flammability of titanium. This occurs when the rotating blade rubs against the inner wall of the motor housing, resulting in localized heating of the blade tip. A high-temperature, high-pressure air environment can cause rapid oxidation of titanium. This situation occurs in high-pressure compressors of engines. The oxidation process, accompanied by the release of heat, can spread and cause titanium combustion. To solve this problem, Pratt & Whitney developed alloy C (Ti-35V-15Cr), a highly stabilized alpha alloy that is resistant to combustion. This alloy is used in the compressor stator, booster, and nozzles of the F-22's F119 engine.

Because of this temperature limitation of titanium alloys, the hottest compressor components, i.e., the disks and blades in the last stage of the compressor, must be made of nickel-based superalloys, which are nearly twice as heavy. In addition, there are problems associated with differences in thermal expansion behavior and the way the two alloy systems are joined. Therefore, an all-titanium compressor is being developed - it requires a titanium alloy that can operate at temperatures above 600°C. This has led to extensive research and development of titanium alloys for high-temperature applications. As shown in Figure 1.11, the maximum operating temperature of titanium alloys has increased over the past 40 years from about 300 °C to about 600 °C.

A class of high-temperature titanium alloys close to alpha has been particularly developed in recent years: IMI 834 (Ti-5.8Al-4Sn-3.5Zr-0.7Nb-0.5Mo-0.35Si), developed jointly by IMI Titanium Ltd. and Rolls-Royce in Great Britain in the 1980s, is the most advanced example of such development. After IMI's acquisition by TIMET (Titanium Metals Corporation), this alloy was used in European military jet engines under the trade name TIMETAL 834. It is now also used as a compressor disc material in the last two stages of the medium-pressure compressor and the first four stages of the high-pressure compressor in the Rolls-Royce Trent series of commercial jet engines. For this particular application, a bimodal microstructure with a primary alpha volume fraction of 15% was found to be optimal. In the United States, mature Ti-6-2-4-2S is still the preferred high-temperature alloy for jet engines [9].

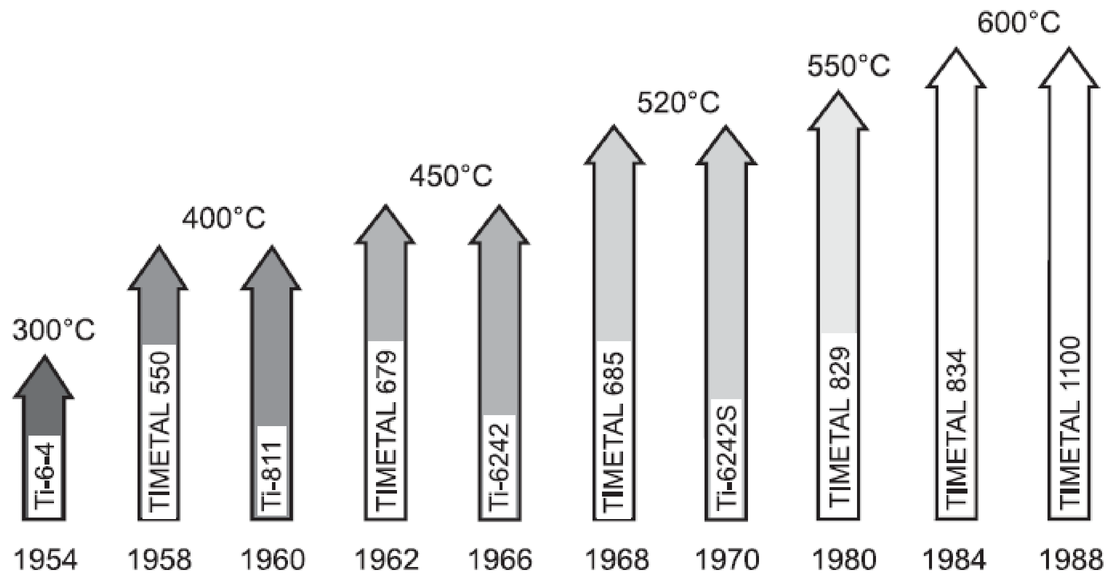

Fig. 1.11 – Increase of maximum application temperatures of titanium alloys

Regardless of the discussion of titanium alloys near α, titanium aluminides have been developed to further improve high-temperature resistance [7-10]. These materials, based on the intermetallic compounds α (Ti3 Al) and γ (TiAl), have been studied for their potential to increase the operating temperature of titanium alloys to 650 °C and 800 °C, respectively [11]. Their excellent creep resistance is due to the ordered nature of their crystal structure. However, this structure makes the intermetallic compound relatively brittle and hence difficult to deform. There are two methods to improve ductility: alloys with Nb, Cr, V, Mn or Mo and microstructure optimization [11,12].

One other important aspect of using titanium aluminides in turbine engines is that these materials are less prone to titanium burnout, as shown in Figure 1.12. In particular, TiAl-based alloys minimize the risk of titanium burning. Therefore, compressor blades in future high-pressure compressors are a potential application area for TiAl alloys. Sufficient damage resistance, satisfactory oxidation behavior, and performance (cost) are the main parameters that ultimately determine the use of titanium aluminides in the aerospace industry.

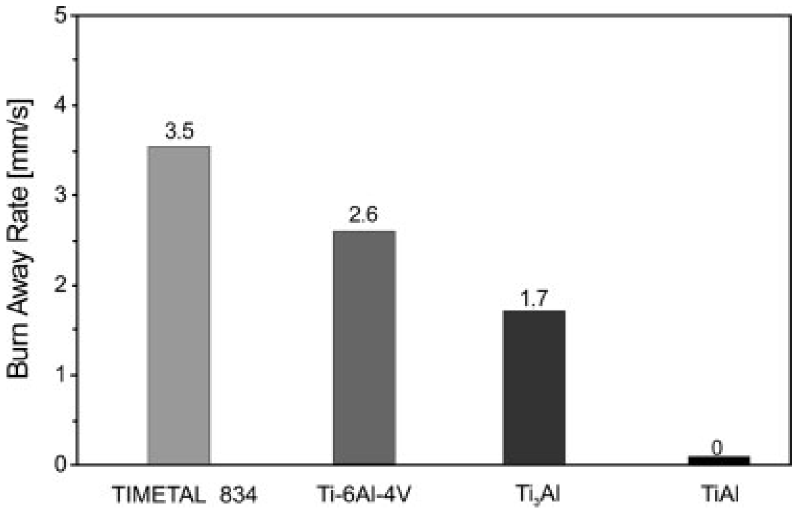

Fig. 1.12 – Burn resistance of titanium aluminides compared to titanium alloys

Figure 1.13 shows the fifth stage of a GE CF6-80C2 jet engine low-pressure turbine with turbine blades made of the light alloy Ti-47Al-2Cr-2Nb. The 98 blades are 50 cm long and weigh 217 g, which is about 55% of the weight of conventional nickel-based superalloy blades. This is only a small fraction of the weight. The lower weight of the titanium aluminide blades reduces the centrifugal forces on the disks and therefore further reduces the overall weight of the turbine. When using these alloys in a large jet engine such as the GE90, a weight reduction of more than 150 kg is possible. For cost reasons, casting is preferred for low-pressure TiAl turbine blades [12]. Currently, the production of TiAl blades is lagging behind, mainly because of cost.

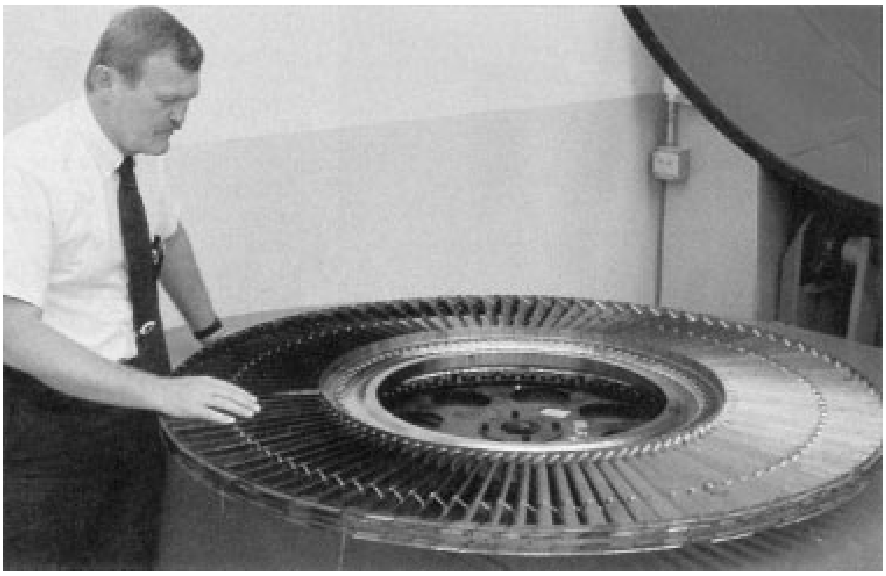

Fig. 1.13 – Ti-Al low-pressure turbine blades for the CF6-80C

Increased stiffness and high temperature resistance are the main goals in the development of long fiber reinforced titanium matrix composites (TMC). Possible applications in jet engines include very stiff and strong blades and thermally stable cylindrical components in high pressure compressors. Most research has been done on long SiC fibers reinforced with Ti-6Al-4V. Alloys close to alpha and titanium aluminide matrices, which are more stable at high temperatures, have also attracted attention. The availability of TMC has enabled designs that were previously impossible, such as compressor rings (blings) with integrated laminate structures. Blinging eliminates the disc hub and reduces component weight by up to 70%. To achieve this, however, it is necessary to significantly increase the strength of the material at the base of the blade to resist centrifugal loading, which requires reinforcement with metal matrix composites. In addition, as with discs, the number of components is much smaller, which means that maintenance costs are much lower than for conventional vane rotors. Such improvements can justify high manufacturing costs and allow for significant reductions in the size of the compressor and the jet engine itself [10].

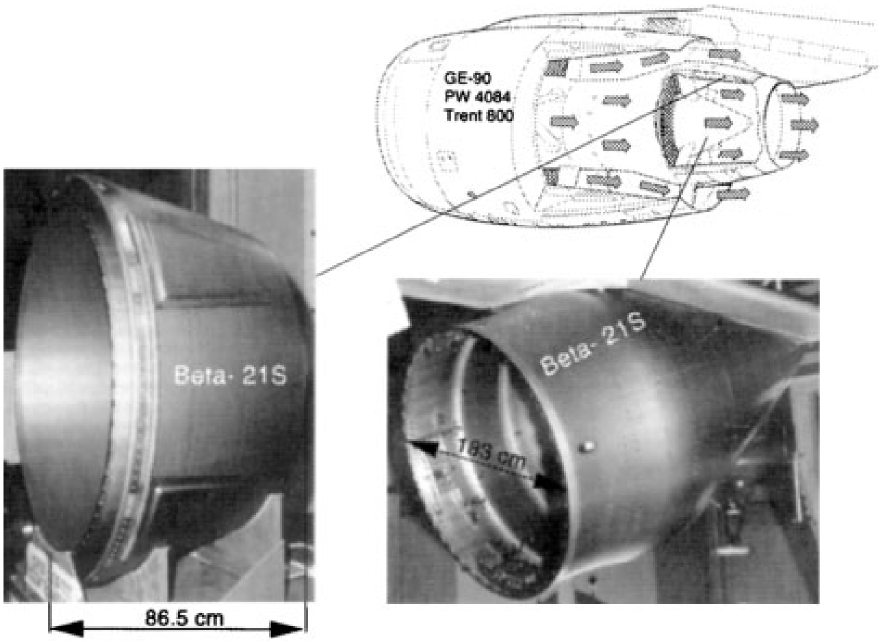

Fig. 1.14 – Applications of TIMETAL 21S in the nozzle area of the Boeing 777

The use of such composites in rotating parts requires continuous research and development, especially with respect to machining methods and part life management. The first use of continuously reinforced titanium composites in the aerospace industry was for a low-risk application as a control piston in the F-22's F119 engine.

Hydraulic fluids in aviation are one of the few aggressive environments for titanium alloys that are normally resistant to corrosion: At temperatures above 130°C, they form acids that etch titanium and cause hydrogen embrittlement of parts. One of the few alloys not subject to this attack is the beta alloy TIMETAL 21S. This is why Boeing uses TIMETAL 21S in the plugs and other nozzle parts of its 777 aircraft (Figure 1.14). The largest jet engines used on the 777 aircraft are the GE90, PW4084 and Trent 875. Pratt & Whitney also plans to use similar components made with TIMETAL 21S in the PW4168 engine that will be installed on the Airbus A340 aircraft.

1.3. Application of Ti-alloys in helicopters

The choice of titanium for this application is based on the strength-to-weight ratio of titanium combined with its operational reliability.

Titanium can be found in both military and commercial helicopters. The design criteria for titanium for this application include operational reliability as well as the strength-to-weight ratio of titanium. Titanium has been used in every major helicopter program, both commercial and military.

Fig. 1.15 – Forged rotor head of the BO 105 and BK117 helicopters

In helicopters, titanium alloys are used for rotor heads, which are the most stressed component. Figure 1.15 shows an example of a forged Ti-6Al-4V rotor head from Eurocopter BO105 and BK117 helicopters. Nevertheless, intensive research is being conducted on alternatives to high-strength β-alloys [10].

For example, β-alloy TIMETAL 10-2-3 is an alternative to Ti-6Al-4V for the main rotor head of Westland Superlinc helicopters. Beta-alloys are currently used in other helicopter programs as well. TIMETAL 10-2-3 is used in the mast and main rotor head of the American RAH-66 Comanche helicopter. The same alloy is used in the propeller part of the V-22 Osprey aircraft.

1.4. Applications of Ti-alloys Space industry

Spacecraft have relatively small payloads, so reducing structural weight is even more important than for aircraft. That is why titanium alloys were widely used in the first Apollo and Mercury missions.

Fuel and satellite tanks are considered standard applications for titanium alloys. Light weight, high strength and long-term chemical compatibility of titanium with fuel give titanium alloys an advantage over high-strength steels. In addition, the integrity of the vessel must be tested reliably and non-destructively before it is placed on the rails, and this is most consistently accomplished for metal tanks. Nonmetallic components require additional effort to ensure their integrity. Figure 1.16 shows a pressure vessel made of titanium alloy for the U.S. space shuttle.

Satellite components need to be very light, so very intensive weight optimization techniques are required to manufacture them. Under favorable conditions, the wall thickness of the last fuel tank in the total satellite propulsion system is machined to less than 1 mm from a 25 mm thick forged half-shell. The tanks can be formed by superplastic molding 6-10 mm thick titanium sheets into a hemispherical shape and simultaneous diffusion welding or conventional welding afterwards. This significantly reduces costs compared to conventional forging or machining.

In addition to forming superplastics, cold-forming beta alloys offers another cost-effective way: MAN Technology used this method to produce fuel tanks for ESA aboard the Automated Transfer Vehicle (ATV) on the International Space Station (ISS) Ti-15-3. The half-shell of the tank is formed using a special patented cold-rolling process called "counter-role spin forming".

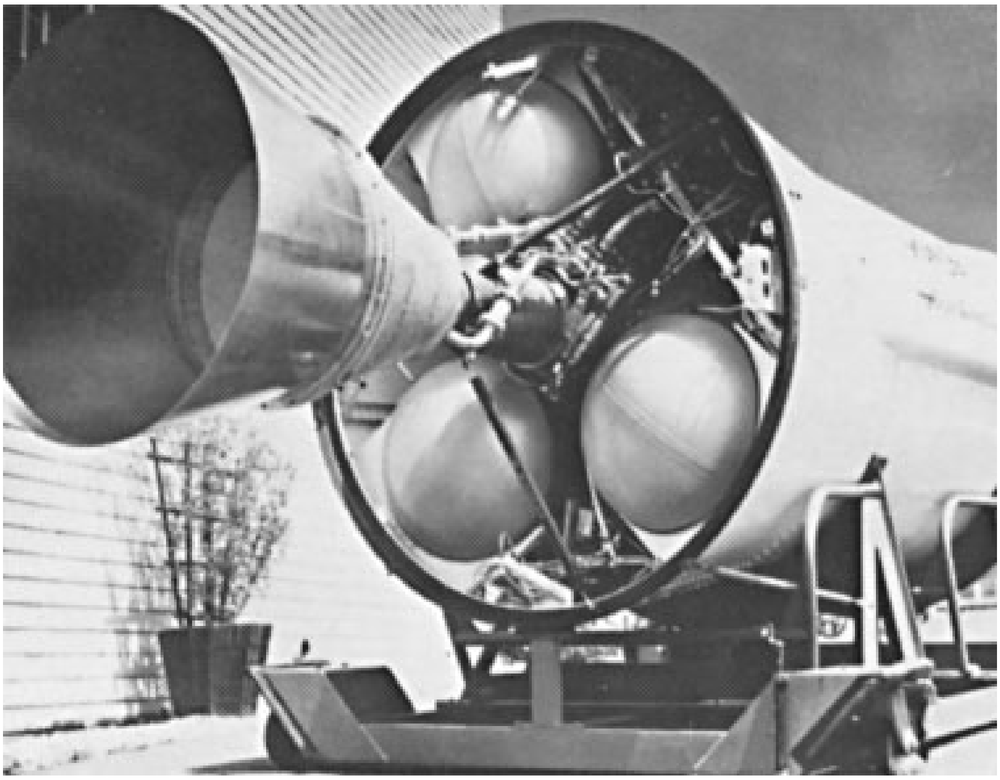

Fig.1.16 – Pressure tanks manufactured for space transportation systems

The sequence of operations in Figure 1.17 shows that the satellite tank half-shell can also be made from Ti-15-3 alloy by simple spinning forging; compared to SPF machining, the infrastructure and tools required are much cheaper. Beta alloy also has very good mechanical properties. Among other things, spinforming has been used to make the half-shells of the storage fuel tanks (EPS) on the upper stage of the Ariane 5 rocket [13].

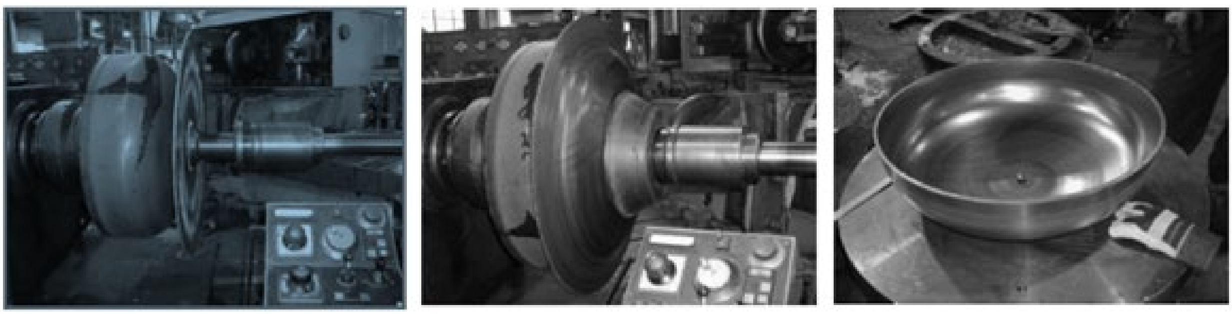

Fig. 1.18 – Sequences during spin forming of Ti-15-3 half shells

Ti-3Al-2.5V was designed specifically for low-temperature applications and demonstrates good viscosity and ductility up to cryogenic temperatures. So it is also used in the high-pressure piping system for the hydrogen pumping system of the U.S. space shuttle.

For the first time in our rocket engineering, titanium was used in the construction of Vostok space ship, more exactly in the space capsule in which Yuri Gagarin made his first flight in space in 1961. Later on, titanium became one of the main constructional materials in manned spaceships "Soyuz", unmanned "Luna", "Mars", "Venus", space system "Energiya" and reusable spaceship "Buran". Today, all the range of titanium alloys is applied for tubular structures in rocket engineering, e.g. titanium tube is used for solid and liquid propellant engines, casings of ballistic missiles Bulava and Topol M. Titanium alloys BT23, BT23M and (α+β)-alloy BT43 with high fracture resistance are used to produce monolithic, welded and brazed tanks for storage of fuel and compressed gases. Along with that, titanium alloy with nickel has found special application in the space industry because its peculiarity is that constructions made of it are able to "memorize" its shape. Radio antennas and solar cell frames are made of such alloys, which can be rolled up at normal temperature and restore their original geometric dimensions on their own when heated.

Conclusion to the part 1

With the development of materials science and the problem of the energy crisis, the aviation industry has placed increased demands on aircraft materials with high temperature, high strength and high durability, as well as new types of high strength, high modulus of elasticity, low density and high temperature, resistance. The need for titanium alloys is becoming increasingly urgent. The application of titanium alloys as aerospace engines and aircraft bodies in the future aviation field will inevitably involve joining the same or different titanium alloys.

Titanium and titanium alloys, compared to aluminum, have higher thermal and corrosion resistance, as well as greater specific strength. The main reasons for increasing the proportion of titanium and titanium alloys in aircraft structures are:

- lower weight while maintaining the required strength characteristics, the strength-to-weight ratio is usually higher than the similar value for higher stronger, but also heavier steels, and lighter but tougher aluminum alloys. Steel and nickel alloys are 1.7 times as dense as aluminum, then the density of titanium;
- titanium and titanium alloys are generally used when the operating temperature is above the rated temperature of the thermal temperature of aluminum is above the allowable operating temperature of 135 °C. Similar conditions are found in the combustion chamber, the auxiliary power unit, and the airfoil protection systems, as well as other parts of the aircraft structure;
- titanium can replace the lighter aluminum alloys where space is limited;
- high corrosion resistance of titanium alloys allows them to be used in most applications without the need for special protective coatings;

To date, literature analysis has shown that the use of titanium in aircraft structures finds a higher application. In addition, to increase the degree of application of these alloys the strengthening of the surface layer is used, which allows improving the mechanical characteristics

PART 2

MODERN METHODS OF SURFACE LAYER HARDENING

The widespread introduction of titanium alloys is still hampered by their relatively high cost. This can be explained by the high affinity of titanium for many elements and the strength of chemical bonds in its natural compounds. Improvement of technological production processes and broad prospects of application of titanium alloys in various industries makes it possible to confidently assert that they will become the most important constructional materials of the nearest future.

Therefore, titanium and its alloys are the most important construction materials of the present and the future. They are increasingly used in the major fields of global machine building, shipbuilding, aerospace and chemical industries. Performance properties of titanium and its alloys, especially wear resistance, heat and corrosion resistance can be significantly increased by alloying and strengthening the surface layer. Currently there is a need to generalize research in the field of alloying and hardening of titanium and its alloys.

2.1 Parameters of the condition of the surface layer of machine parts

The surface layer of a part is a layer that has a different structure, phase and chemical composition than the base material of which the part is made.

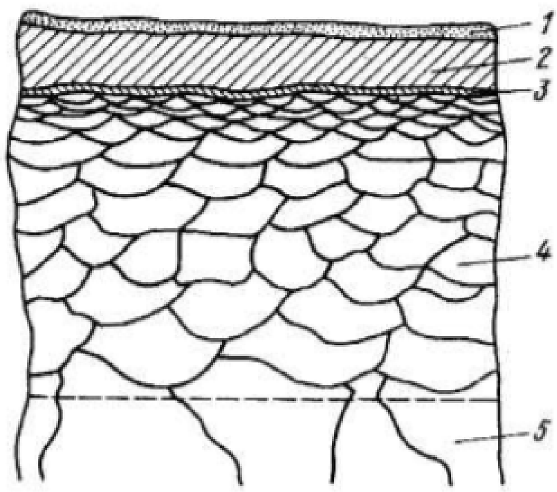

Fig. 2.1 – Scheme of the surface layer of the part

In the surface layer can be distinguished the following main zones (Fig. 2.1):

1. adsorbed from the environment molecules and atoms of organic and inorganic substances. The layer thickness is 1 μm;

2. products of chemical interaction of metal with the environment (usually oxides). Layer thickness is 1 micron;

3. A boundary layer with a thickness of several interatomic distances, which has a different crystalline and electronic structure than in the volume;

4. with changed parameters as compared to basic metal

5. with the structure, phase and chemical composition that occurs during the manufacture of the part and changes during operation.

The thickness and condition of the above layers of the surface layer may vary depending on the material composition, processing method, and operating conditions. Assessment of this condition is carried out by methods of chemical, physical and mechanical analysis. The variety of surface layer condition parameters and methods of their evaluation does not allow us to single out a single parameter that determines the quality of the surface layer. In practice, the condition of the surface layer is evaluated by a set of single or complex properties, which evaluate the quality of the surface layer.

These parameters characterize:

- geometric parameters of surface irregularities;
- physical state;
- chemical composition;
- mechanical state.

The geometrical parameters of surface irregularities are evaluated by the parameters of roughness, regular microreliefs and waviness.

Surface roughness is a set of irregularities with relatively small steps. The approximate ratio of roughness height to pitch is less than 50.

Regular microreliefs are irregularities, which, unlike roughness and waviness, are the same in shape, size and mutual location. Regular microrelief is obtained by machining or surface plastic deformation by rollers, balls, diamonds.

The physical state of the surface layer of parts in hardening technology is most often characterized by the parameters of structure and phase composition.

2.2 Surface plastic deformation

Improving the serviceability, reliability and service life of the executive surfaces of titanium products by means of surface plastic deformation has been widely used.

The choice of the hardening method depends on the grade of the material, the requirements for the properties of the surface layer, the shape and size of the parts, and the operating conditions. For example, compressor blades are hardened by shot blasting, vibratory finishing, hydraulic shot blasting and ultrasonic treatment.

Shot blasting. The process is based on plastic deformation under the action of the kinetic energy of the flow of shot (steel balls). Analysis and comparison of them is more clearly considered, in relation to one part of the most mass production. As an example of such a part, we consider a titanium compressor blade of an aviation gas turbine engine.

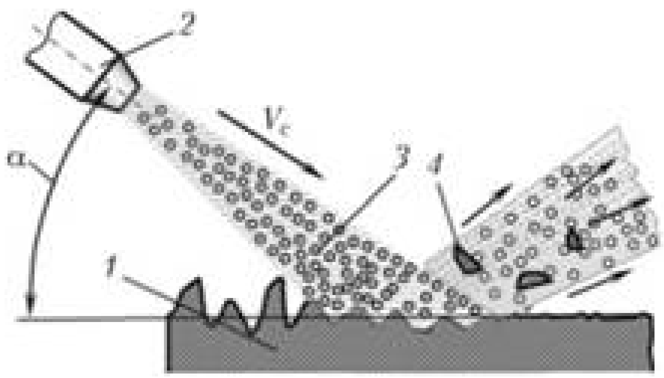

Fig.2.2 – Schematic diagram of shot blasting a part

In the overwhelming majority after shot blasting with ШХ15 balls with diameter of 1,6...2 mm the surface roughness of blades from titanium alloys improves by one class of accuracy. The shot-blasting leads to the formation of residual compressive stresses in the surface layer with a depth of 350-400 μm, the maximum of which falls at a depth of ~ 150 μm (Ti-6Al-4V) and ~ 50 μm (Ti-6Al-6V-2Sn) and makes, respectively, 700 and 1050 MPa. As a result of shot blasting the cyclic strength increases 10...40 times (Ti-6Al-6V-2Sn) and 5 times (Ti-6Al-4V). This is explained by the change in microstructure in PS after shot blasting from fine-plate to fine-grained equilibrium, which leads to a later formation of slip bands and microcracks that nucleate on them, as well as an increase in the resistance to the growth of these microcracks.

Vibratory finishing. (vibration treatment of parts by free particles of the working medium) is carried out to strengthen the surface by formation of a riveted layer on it and residual compressive stresses, as well as to improve the surface roughness by smoothing the irregularities to increase the endurance of parts.

The effectiveness of hardening depends not so much on the value of the absolute amplitudes of vibration of the vibration system, as on the relative movements of the hardener and workpiece. Steel balls with diameter of 2...4 mm are used for vibro peening the surfaces of titanium products. For example, compressor blades hardened by vibratory finishing practically keep the endurance limit unchanged after operation, at the same time non hardened blades have lower endurance limit by 25...30 % in comparison with the initial level. After vibro-hardening not only the blade endurance limit increases, but also the resistance to contact and chemical corrosion, mechanical damage by solid particles increases.

For hardening of titanium blades, a combined technological process is used that includes hydro shot peening and vibratory finishing with steel balls, but due to low energy capabilities of this method, the endurance limit is increased insignificantly by 10...12% [14].

Ultrasonic treatment. The main element of the unit is a magnetostrictive transducer of electric vibrations into mechanical ones, which are transmitted to the concentrator (oscillation transducer), where the source of vibrations is an ultrasonic generator. Concentrator has working chambers, in which the parts and the working body (balls) move. The energy of mechanical vibrations of the concentrator of ultrasonic frequency is transmitted by the balls, which hit the wall of the part and strengthen the surface. As a rule, finished parts are processed with balls with diameter of 1...3 mm moistened with emulsion. It is established that the duration of hardening of blades from BT8 alloy in the ultrasonic field with balls with a diameter of 1...3 mm should not exceed 5 minutes. . The required degree of strain hardening is ensured by selecting the processing duration, the diameter of balls, the distance of the part from the walls of the concentrator. In the treatment of BT3-1 titanium alloy with ultrasound, an increase in microhardness was observed in the surface layer with a thickness of 20 μm. Residual stresses of 1150 MPa occur in this layer during processing, which significantly affects the increase in the endurance limit. It was found that ultrasonic hardening increases the fatigue resistance by 30% [15].

However, considering the value of residual stresses, it was found that for compressor blades, which are made of titanium alloy BT3-1, have optimal thermomechanical treatment, and have high cyclic strength, the use of ultrasonic hardening plays a negative role: the material of these blades during the treatment is strongly degraded.

2.3. Galvanic method of coating Ti-alloys

In the initial period of titanium use, the technology of galvanic surface coatings, widely used on steel materials, was developed. It was found that surface preparation was the most difficult during electrochemical deposition of metals on titanium, because the natural oxide film always present on titanium and titanium alloys prevents obtaining good adhesion between the applied layer and the base metal. It turned out that it is necessary to activate the surface of titanium alloys, for example, by etching or vacuum annealing at 200...550 °C. But in all cases the electrolytic deposition of metals on the surface of titanium and its alloys failed to obtain a good bond , the bond strength to the base is 5...6 MPa. However, a stronger bond of applied layers of considerable thickness up to 70 μm can be achieved using special diffusion annealing. Traditional coating methods such as chromium plating, nickel plating and bronzing were tested first.

To obtain high quality Cr coatings of 3...50 μm thickness on titanium alloys, a 1...15% Ni-P sublayer of 2...30 μm thickness, also obtained by electrochemical deposition, with subsequent heat treatment at 300...500 °C for 0.5...2 hours, is first applied. The coating sublayer contains intermediate phases of the systems Ni-Ti, Ni-P, Ti-P and is a product of titanium alloy β-phase transformation. After the diffusion annealing the hardness (up to 900 NR), wear resistance of the coating and the strength of its adhesion with the base increases. In addition, electroplated Fe coatings are also used on titanium alloys as an underlayer. This helps to prevent carbide shearing, significantly increase the thickness of the diffusion layers and increase their hardness.

a) b) c)

Fig. 2.3 – Equipment for electroplating: a - compressor blade holder; b - galvanic bath; c - compressor blades with nickel cadmium coatings

In the aircraft industry, electrolytic nickel-cadmium coatings are used to protect the surfaces of compressor blades that work at 500 °C for a long time and at 600 °C for a short time. The coating thickness is 9...15 μm (Fig. 2.3) [15].

2.4. Chemical heat treatment

This technology of surface hardening of titanium alloys is one of the most common and is used for the hardening of critical parts, for example, in aircraft construction for application of hardening coatings on the surface of gas turbine engine compressor blades. Diffusion saturation of the surface with the elements of introduction: boron, chromium, silicon, carbon, nitrogen, etc. is most often used. At the same time, the heat resistance of titanium alloy increases by 1,5...2 times and the resistance to thermal cyclic shocks by 1...2 times, the Young modulus and residual stresses in the surface layer increase, hardness increase and fatigue limit increase from 15% to 40%. As a result, the service life of parts increases by up to 10 times [16].

Boriding is carried out at temperatures of 900...1450 °C for 3 min to 20 h using boron powder, powder mixtures, for example, [55% Al_2O_3 + 45% (50% B_2O_3 + 50% Ti) + 2% NaF], pastes B_4C, $Na_2B_4O_3$ and $45B_4C + 45Cr + 8Na_3AlF_6 + 2CuCl_2$. The use of high-frequency currents for heating can reduce the processing time by up to 20 times. To reduce the influence of air on the structure of the surface layer of titanium alloys the solid-phase treatment is carried out in an Ar atmosphere or in a vacuum. As a result of the treatment the boride layers of Ti_3B_4, TiB_2 with thickness of 10...55 μm were obtained, at that the film growth rate was 4...4,5 μm/h. It was found that the layer thickness increases with increasing processing time. Depending on the brand of hardened titanium alloy, microhardness of borated layers reaches 9...13 GPa; moreover, the introduction of ~20 % Cu in powder mixture changes the phase composition of borated layer towards the decrease in the volume fraction of high-boride phase which reduces its hardness and brittleness [17].

Chroming. As a result of studying the chromium saturation process for the Ti-alloy VT3-1 it was established that the addition of 10...15% FeCr to the chromium powder mixture (40...50% FeCr, 3...5% KCl, the rest carburetor) allows the saturation mixture activity to increase. As a result of chrome plating in powder mixtures containing Cr, potassium chloride and aluminum oxide at 900...1000 °C for 2...6 hours a dense diffuse layer is formed mainly from the $TiCr_2$ phase, having high hardness of 8500 MPa and depth of 70...80 μm.

Siliconizing. This method of chemical treatment of titanium products surfaces allows in the process of saturation to form Ti silicides, which are characterized by high indicators of heat resistance, corrosion resistance and hardness. Thus, silicification in pure Si powder, Si+Cu and Si+Cu+Zn powders, saturating mixtures [(30% Al +70%SiO_2) +2%NaF] increases the heat resistance of VT1 and VT3-1 titanium alloys by 10 times, the oxidation resistance of titanium alloys increases by ~60 times in comparison with untreated samples, corrosion resistance increases up to 100 times in 80% sulfuric and concentrated hydrochloric acids at room temperature during 300 hours, resistance in thermal fatigue (low-cycle fatigue) increases 45 times. To increase the saturation capacity of the mixture by 1.2...1.3 times during the technological process the authors suggest using the following ratio of components (in %): SiO_2 26...32, Al powder 12...16, Cu powder 30...40, Zn powder 7...11, Al fluoride 1...3, Al oxide - the rest. Additional alloying of coatings with some fusible and transition metals increases their resistance to high-temperature oxidation at 1000 °C. The siliconizing process of titanium alloy surfaces is carried out at 850...1150 °C for 10...72 h in a closed container in Ar medium. As a result of surface treatment, a silicide layer with a depth of 0.07-0.09 μm, microhardness HV50 12250...13720 MPa is formed. In addition, siliconizing the surfaces increases the elastic modulus by 30...50% due to the formation of intermetallic phases.

Cementation. The technological process is carried out for a very long time, provides diffusion of carbon, forms in the surface layer solid solutions with Ti. After curing, the tempering is carried out at 600 °C for more than 2 hours. This method of hardening, taking into account the possible warpage, allows achieving HRC>58. Carbidization and carbonitriding increase the modulus of elasticity by 2...3 times. These processes have a significant impact on the grain size refinement in the surface layer and lead to an increase in strength properties and ductility. After treatment of surfaces of products from titanium and its alloys, the increased stable rigidity and improved operational characteristics in a wide range are received.

Researchers have revealed the influence of titanium products surface cyanidation on the cyclic strength characteristics of compressor blades made of VT-8 alloy. It was found that cyanidation increases the endurance limit of blades by 15...20%.

Nitriding. Saturation of titanium surface with nitrogen resulting in surface layers with high strength. The difficulty of nitriding titanium is the use of higher temperatures due to the lower diffusion mobility of the nitrogen atoms in titanium, the need to use nitrogen that is very pure of oxygen, and vacuum chambers for the use of low (up to 1.3 Pa) working gas pressure. Nitriding is carried out at temperatures from 850 °C to 1100 °C and lasts from 1.5 to 100 h. The most frequently used nitriding process is at 950°C, with dwell times from 15 to 20 h in pure nitrogen or argon diluted nitrogen at atmospheric pressure, sometimes the process is carried out in pure nitrogen at a pressure of ~100 Pa, or in an atmosphere of dissociated ammonia. To activate and stabilize the process, the surface is carefully degreased and heated in a vacuum or neutral atmosphere at 10-20°C above the nitriding temperature for 1 h. Parts and samples after nitriding are sometimes subject to diffusion annealing in vacuum or inert gas at 600 ... 825 °C for 4 h. The listed operations are generally similar for various titanium alloys. Nitriding the surfaces of titanium alloys in an atmosphere of dissociated ammonia gives similar results to nitriding in pure nitrogen at lower temperatures, but with a longer heating time. The thickness of the nitrided surface layer reaches 10 μm to 150 μm.

Nitriding requires careful control of the process. To obtain optimal results, the amount of nitrogen or ammonia entering the furnace must be precisely regulated. It is known that the thickness and properties of the surface layer depend on the dwell time and heating temperature. It is interesting that an increase in the holding time during nitriding in ammonia for more than 20...25 h leads to a decrease in the thickness of the nitrided layer. Therefore, a long dwell time (more than 25 h) is inexpedient.

The nitrided titanium surface has a gold color, and the nitrided layer consists of two parts: an outer layer of titanium nitride TiN with a hardness of about 1500 HV and a sublayer of the solid solution of nitrogen in titanium (diffusion layer) with a maximum hardness of 700 HV. The thickness of the outer nitride layer is 5...8 μm, the diffusion layer is 40...80 μm. Nitriding at reduced nitrogen pressure gives deeper diffusion layers. The microhardness of the nitride layer has a parabolic growth and is fixed at >20 GPa.

Studies of the nitrided layer of various industrial titanium alloys, as well as studies of the effect of some alloying elements on the diffusion of nitrogen into titanium have shown that the alloy composition is essential in forming the properties of the nitrided layer. The change in the properties of the nitrided layer depending on alloying is due to the different effect of the polymorphic transformation of titanium, and, most importantly, to the sharp difference in the solubility and diffusion mobility of nitrogen in the α- and β-phases: the diffusion coefficient of nitrogen in α- titanium is three orders of magnitude lower than in β-titanium, but the solubility of nitrogen in the α-phase is significantly greater than that in the β-phase. Laboratory studies have shown that a nitrided layer with high mechanical properties is formed on titanium alloys containing vanadium, zirconium, and niobium.

Ion nitriding. The process is carried out in a vacuum chamber at a pressure of $\leq 1\text{-}10^{-3}$ Pa in a nitrogen atmosphere. The process temperature varies from 350 °C to 1000 °C, with a holding time of 2.5...13 h. It was shown that the phase structure of diffusion PS is determined by the composition of the gas medium. The greater the saturating component in the working gas mixture, the stronger the processes of nitride formation on the surface. At temperatures of 350 ° C and above in the PS the transformation of β-α is observed, depends on the temperature and time. The thickness of the surface layer in which this transformation is observed increases with increasing temperature and duration of heating and reaches between 20 μm and 60 μm. The transformation is caused by static stresses arising from the bombardment of the surface by ions. An increase in temperature contributes to a decrease in the activation energy of the conversion process and cannot be observed at lower temperatures. The maximum thickness of the nitrided surface layer was formed at a pressure of 8...16 mm Hg. The hardness value of the nitrided layer depends on the morphology and number of structural components and the length of the diffusion layer and is HV0.01 ~3000. The structure of the layer of compounds is determined by the initial chemical composition and the modes of ion nitriding. In this case, the presence of δ-nitride is fixed after all treatment modes; the formation of ε-nitride depends on the conditions of ion nitriding. With increasing process temperature, the maximum hardness value increases. The temperature has a more significant effect on the growth rate of the nitrided surface layer than the dwell time, as the layer of nitrides formed on the surface during the first dwell time, prevents the diffusion of N_2 in the deeper layers.

2.5. Methods of gas-thermal spraying

Spraying of small particles (powder or droplets) on the executive surface of parts is widely used to improve the serviceability of aircraft parts, as well as for their restoration. The main gas-thermal methods of coating the surfaces of titanium alloys are gas-flame, plasma and detonation sputtering. These coating deposition methods are rapidly developing since they allow for rather thick coatings of 1 mm and more at component heating temperatures of 200...300 ºC, the methods give good adhesion and possibility to use almost any materials as coating material. In principle by these methods, it is possible to obtain multilayer coatings, achieving good adhesion with the base metal and high cohesion of the coating even in case of heterogeneous coating.

In plasma spraying the applied material is melted and atomized by an ionized gas plasma flow, which is characterized by a high temperature of 5000...10000 ºC and a relatively moderate flow rate of 250...600 m/s, while the spraying distance is within 80...110 mm, the plasma-forming gas consumption is 40 l/min and the powder consumption is 2.5...3.5 kg/h. Alloys based on nickel Ni-Cr-B-Si-C and Cu-Ni-In are used as powders with dispersion of 10...44 microns to increase wear- and corrosion-resistant surfaces; W2C (or Cr3C2) and Al2O3 to increase scale-resistance and heat-resistance, Mo-based alloys with Mo, Co and P disulfide additions to increase wear-resistance.

As a result of the technological process, it was found that the thickness and depth of hardening are determined by the time and temperature of processing, and the formed phases according to the state diagrams. The microhardness of the obtained coating is the same in depth and is in the range of 1500...3950 +300 MPa.

A development of the plasma method is the technology of pulse-plasma modification of the surface of products using high-speed plasma jets formed by a detonation wave, which was developed at the Institute of Electric Welding named after E.O. Paton. The high velocity of the plasma jet (up to 5 km/s) when it is deposited on the product surface leads to the formation of a shock-compressed layer containing alloying elements and protecting the heated product surface from oxidation by air. This technology provides high productivity of the process (up to 1 m^2 per hour at 10 kW installed power), is carried out in an air atmosphere and does not require special surface preparation. After the treatment of products made of titanium-based alloys a layer of increased hardness of $7...9 \cdot 10^3$ MPa is formed on the surface with thickness up to 30...50 μm.

Detonation spraying. These methods refer to gas-thermal methods, which are based on complete or partial heating of the coating material to a melting state and atomizing it with a gas jet. The material to be sprayed can be in wire or powder form. The sprayed material can be heated by a gas flame, electric arc plasma, or by the detonation of an explosive gas mixture. The detonation method uses the energy of an oxygen-acetylene explosion, which provides the necessary heating and acceleration of the sprayed material, while the plasma method uses the energy of a plasma jet. The sprayed material particles hit the substrate and flatten, forming thin flakes that are fixed on the surface rough layer by mechanical and physical-mechanical interaction with the substrate material. As a result of the interaction of individual flakes a peculiar structure of the sprayed coating is formed. The higher the speed of particle impact, the higher the strength of the applied coating. In detonation spraying, the velocity of the sprayed powder is 600-1000 m/s, which is 4-7 times higher than in plasma and flame spraying methods. The peculiarity of these hardening methods is the possibility to apply refractory materials to a metal substrate without significant heating (not more than 1500 C), i.e. to coat finally heat-treated and hardened steel, aluminum, titanium and other alloys after the finish machining without fear of changing the properties of the surface layer structure.

The formation of the coating occurs due to the collision of the particles with the surface of the workpiece, their strong deformation, flattening and splashing. As a result, the resulting coating, as well as in the case of detonation spraying, consists as if of flakes of the sprayed material, interconnected along the contact surface by welding areas, so the strength and density of the coating is lower than the strength and density of the original material. In detonation spraying, the kinetics and mechanism of coating formation are determined by plastic deformation of the powder and substrate particles in the impact zone, where there is a local increase in the activity of the solid substrate under the action of pressure from solid particle impact, causing elastic distortion of the lattice and plastic deformation. This leads to an increase in the bonding strength of the coating with the base metal. To improve the physical and mechanical properties of the sprayed layer and to improve adhesion to the substrate an additional melting operation is used. Its essence: the sprayed layer is heated to a temperature close to its melting. As a result of heating a diffusion process takes place between the sputtered layer and the base metal and a dense coating is formed when it cools down. The pores that remain after spraying are filled with the molten part of the sprayed material. After cooling, a uniform, thin, pore-free, homogeneous layer is obtained. In this case, cooling is carried out together with the furnace.

The detonation method is used to spray plastic metals and alloys (Cu, Ni, Fe, etc.), solid non-plastic metals and refractory compounds (W, Al_2O_3, etc.).

Application: motor construction; aircraft, machine tool and instrument engineering; chemical and metallurgical engineering; tool production; rocket, space and nuclear engineering.

In plasma spraying, argon, neon, nitrogen, hydrogen, helium, ammonia, natural gas and their mixtures are used as plasma-forming gases. The powder is injected into the plasma jet.

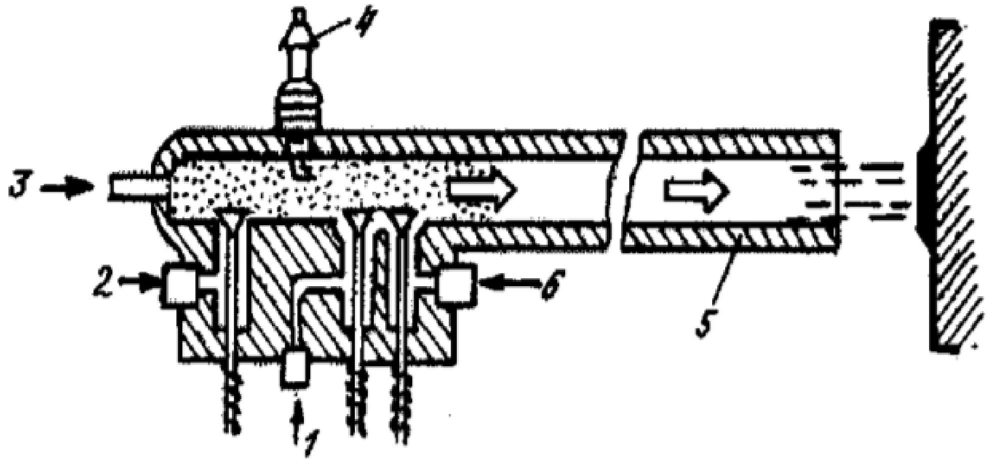

Fig. 2.4 – Schematic diagram of a detonation unit with internal mixing: 1-acetylene; 2 - nitrogen; 3 - powder feed; 4 - spark plug; 5 - outlet tube; 6 - oxygen

Developed designs of detonation units with internal and external mixture formation. In the first case, the role of a chamber for the formation of combustible mixture is performed by the barrel; in the second case, combustible mixture prepared in the mixer is fed into the barrel. The detonation unit with internal mixers is a water-cooled barrel with a length of 1-1.8 m and an internal diameter of 10-40 mm. A mixture of oxygen and acetylene along with a batch of powder is fed into the barrel. The explosive gas mixture is ignited by an electrical pulse and a detonation wave travels down the barrel, accelerating and heating the powder. The powder particles are accelerated to a velocity of 500-1000 m/s and hit the part, forming a spot with a diameter depending on the diameter of the barrel. The barrel is then cleaned with nitrogen, and the process is repeated. The repetition frequency is 4-8 cycles/sec.

2.6. Ion implantation of the surface

This method consists in bombarding the substrate with an implanted substance. In this case ionized atoms or molecules of the alloying substance are introduced into the near-surface layer, "get stuck" in the crystal lattice of the target, form solid solutions or new chemical compounds. The technology of implantation modification makes it possible to introduce into the surface the necessary amount of almost any chemical element to a given depth, i.e. it is possible to alloy metals, which in the molten state do not mix, or to alloy one metal with another in those proportions, which cannot be achieved even when using high temperatures. A review of works devoted to the influence of ion implantation on the physicochemical, mechanical and performance properties of Ti alloys has shown that N, C, Ba, Pt, Pd, Si, Hf, etc. are used as the main alloying elements. Typical parameters of the ion implantation process: ion energy 30...150 keV, ion current density 40...60 mA/m^2, the dose $5 \cdot 10^{16}$ ... $6 \cdot 10^{17}$ ion/cm^2.

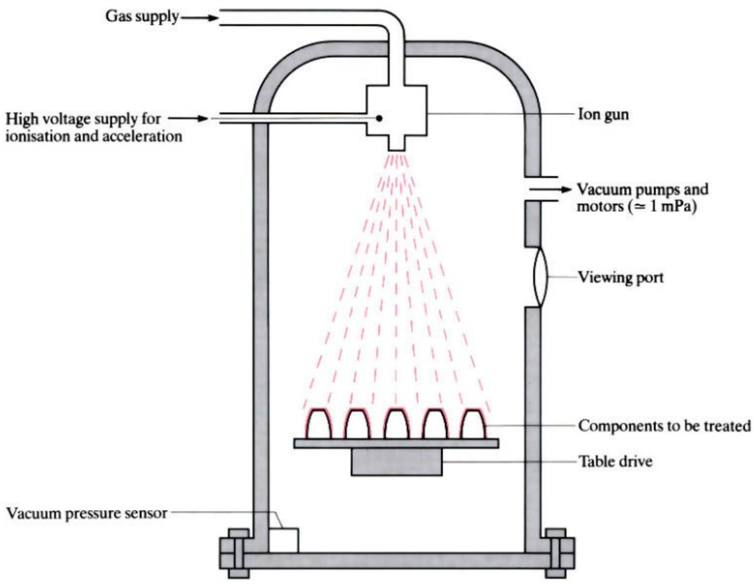

Fig. 2.5 – Schematic diagram of an Ion implantation

Ion implantation of Ti alloy surface N and C leads to an increase in the microhardness of PS, which is caused by the formation of dispersed nitrides or carbides. The ion implantation of N and C surface allows to decrease the friction coefficient to 80 %, to increase the resistance to high-cycle fatigue more than in 20 times and the heat resistance in 2,45 times, to increase the yield strength that is proved by interaction with dislocations. Besides, at optimum regimes decrease of a surface roughness on parameter Ra = 0,13 ± 0,02 microns (for an initial condition Ra=0,22 ± 0,02 microns) is marked. Ion implantation of N and Pt leads to the increase in resistance to electrochemical corrosion, and ion implantation of Ba allows to increase the heat resistance of samples at 600 ºC.

2.7. Electron-beam and laser surface treatment of Ti-alloys

Electron Beam. This surface treatment technology for titanium alloys belongs to the most knowledge-intensive technologies, has a great perspective and efficiency for increasing the operability of surfaces and durability of parts.

Review, showed that as a result of melting by electron-beam treatment with microsecond beams of Ti alloy surfaces it is possible to change the phase composition and surface structure of ~ 0.5...5 mm thickness (from globular to columnar, depending on the value of energy density and number of pulses) with different grain size from 100...250 µm to the initial. The hardness of the hardened samples surface changes depending on the heating temperature. The greatest efficiency of electron-beam processing has in combination with other technological processes. Researchers established that microhardness of PS alloy BT-6, with deposition on its surface at substrate temperature below 400 ºC of coating based on Sn-Cr-MgO, reaches values of 16...18 GPa. Such combination of mechanical properties, at high adhesive strength of a coating and a substrate, is provided by nanostructural condition of a metal-ceramic coating creating smooth transition from a substrate to soft binding layers and further to the top layers of a coating with high level of hardness on a ceramic basis. It was noted that electron beam treatment of TiO_2 and Ni-Ti gas-thermal coatings of titanium alloys increases the bonding strength of the coating with the substrate by 8...10 times, with an increase in microhardness and wear resistance. It is shown that an additional treatment with ion-implanted nitrogen of the surfaces of compressor blades made of VT18-U and VT9 titanium alloys increases the endurance limit by 15.5 % with a change in the mechanism of fatigue failure of Ti alloy parts from surface to subsurface.

However, as the review showed, electron-beam processing has a number of significant disadvantages:

1) There is a large discrepancy in the results of experimental studies and low reproducibility of properties.

2) Significant thickness of the coating (minimum value of 50 microns) limits the use of the technological process for hardening compressor blades.

3) Increased processing costs due to the complexity of technological processes.

Laser processing. Surface treatment of Ti alloy parts, as a kind of electron-beam treatment, is carried out by scanning the surface with a continuous or pulsating laser beam. High-energy coherent radiation in interaction with the surface is capable of carrying out a variety of processes in the surface layer: melting, alloying, hardening, chemical-thermal reactions, phase transformations, etc. These processes lead to a change in the characteristics of the strength of the surface layer. It has been established that laser oxidation increases the durability of Ti alloys under low-cycle bending load in an asymmetrical cycle by 2...5 times; treatment by CO_2 laser increases corrosion resistance; laser treatment in an atmosphere of nitrogen, hydrogen, carbon and argon leads to an increase in erosion resistance and mechanical properties of the surface by 70...80 %.

Large rates of heating and cooling (10^5 ... 10^6 K/s), high temperatures (up to 1500 ºC and more), minimum relaxation time of the metal (~ 10-11 s), large values of specific energy (energy in the laser beam, 10 ... 100 times higher than the energy of the transition from solid to gaseous state at 40 ... 900 J / mole) contribute to the appearance of large temperature gradients (1500 ºC/cm) and heat flux and affects the properties of Ti-metal. With increasing power (up to 5 kW) of laser influence the hardness increases up to 16 GPa with growth of hardening zone depth up to 250 μm. The duration of thermochemical reactions is regulated by the speed of beam movement when scanning the surface. As the scanning speed decreases, the thickness of the hardened layer grows with a significant increase in hardness, but there is a significant cracking of the surface. Short-term irradiation provides a penetration depth of 1 to 2000 μm, while the cooling rate reaches 10 5 ... 106 K/s. Such rapid solidification produces amorphous structures, metastable and oversaturated phases with an ultramicrocrystalline structure. For example, after laser nitriding a continuous layer of TiN with a thickness of 1 mm to 5 mm is formed on the surface. Under it there is an intermediate layer consisting of a two-phase mixture of TiN and α-Ti, in which the TiN phase with a strong texture (200) prevails over the second phase and represents a dendritic structure. Below is the unmelted dark zone of thermal influence with a martensitic structure with α'-Ti and a small concentration of nitrogen. The thickness of the nitrided PS is determined by the power density, nitrogen content and exposure time. It was found that the hardness of the dendritic TiN layer increases HV from 500 to 650, while the hardness of the intermediate surface layer does not change at 100% overlap of the hardened PS and N content of 80% in the atmosphere. As the beam speed increases, the hardness of the PS decreases as the nitrogen concentration in it decreases. Cracks in the PS do not occur only if the exposure time is short and the nitrogen content is low, and the number of cracks increases with increasing content.

Vacuum ion-plasma method. This method is one of the most advanced modern technological processes to improve the durability of the surfaces of titanium alloys, such as compressor blades, which consists in the generation of plasma flow of solid and gaseous substances with high energy and regulated in a wide range of particle sizes followed by obtaining materials by condensation from the plasma environment. In the world practice of protective coating deposition, which is called PVD (Physical vapor deposition), or the method of physical vapor deposition - the possibility of varying physical and mechanical characteristics of coatings in the process of deposition itself provides the best ratio of wear resistance, durability and flexibility of coating for various specific conditions of parts.

Vacuum plasma coatings of refractory metal compounds are designed to create special surface properties of parts, including titanium alloys. During the treatment the substrate is slightly heated to 100...150ºC (depending on the type of coating), and this temperature has no considerable effect on the phase composition and the sign of the residual stresses. As a rule, the coatings applied are nitrides, carbonitrides, metals, alloys. In this case, their deposition rate is high and is ~ 1 μm/min. Coatings with heterogeneous multiphase structure are formed on the surface of Ti-alloy, at which residual compression stresses are formed after deposition. These coatings have dense layers, have good adhesion to the substrate, high hardness, wear and corrosion resistance. Additionally it is possible to apply two or more coatings by composition and properties, multi-layer coatings of different materials, alloys with complex composition, thick and uniform layers (up to 25 microns) of composite coatings with continuous and regular discrete structure.

Vacuum plasma coatings reduce surface roughness of Ti alloys from R_a=2.5 microns to R_a=1.25 microns, increase resistance to high-temperature creep and heat resistance at temperatures of 500...700 ºC, increase the endurance limit by 20... ... 40 MPa, increase the resistance to low-cycle fatigue and 7... 10 times, reduce the rate of gas abrasion of the surfaces of articles made of titanium alloys, for example, compressor blades. Thanks to their physical and mechanical properties, vacuum-plasma coatings can increase the serviceability of parts by 1.5...5 times. Because of this, given all the advantages and compliance with the requirements for the IP of products made of titanium alloys, the vacuum-plasma method has found wide application in aircraft engine construction when applying them to the compressor blades of power plants.

2.8. Enameling of titanium alloys

Enameling of titanium alloys is used to protect the structural elements of power installations from the external exposure environment using synthetic resins, which are applied to the surface in the molten state by brush, immersion, spraying, gas and vortex spraying. Soluble polymers are used for this purpose: polyethylene, polyamides, fluoroplastics, polypropylene, polystyrene, glass plastics, epoxy resins, etc. Glass enamel coatings are known to increase the properties of Ti alloys tenfold at elevated temperatures and are more effective at temperatures above the temperature of polymorphic transformation. Also, enamel coatings when heated up to 800°C provide uniform protection for Ti alloys. The authors found that silicon-phosphate glass prevents the embrittlement of titanium alloys at 700 ... 800 °C for 12 hours.

At present, to protect against erosion-corrosion damage of aircraft parts, for example, a blade of the inlet guide vanes of the compressor of the power plant Al-21F-3, epoxy-polyamide enamel EP-586 is used (Fig. 2.6).

The enamel is applied on the previously prepared blade surface to provide its adhesion from both sides in 4 to 6 layers by paint spraying with a thickness of 8-11-10 -5 m under air pressure of 0,29-0,44 MPa. This method of coating also has a number of significant features, namely:

- the process is time-consuming and requires careful monitoring;
- increased consumption of enamel;

Fig. 2.6 – Inlet guide vanes with protective epoxy-polyamide enamel

- formation of coating defects in the form of bubbles and streams in case of poor surface preparation;

- the removal of the coating uses environmentally hazardous substances (orthophosphoric acid and hippy-4 solvents);

- formation of coating defects in the form of bubbles and streams in case of poor surface preparation;

- the removal of the coating uses environmentally hazardous substances (orthophosphoric acid and hippy-4 solvents);

- coatings have a large thickness of about 100 microns;

- low coating application temperature (up to 300 ° C).

2.9. Electrospark alloying of titanium alloys

Electrospark alloying of titanium alloys the electrospark alloying method has recently been widely developed. In the electrospark alloying process, as a result of the discharge between the electrode (anode) and the product (cathode), the electrode material is transferred to the product surface. The most qualitative coatings (surface roughness no less than 20...40 R_z, coating integrity 60...80 %, thickness from 30 microns to 200 microns, microhardness 8...10 GPa) are obtained at electroplating of titanium with metals of 4-6 groups. It is shown that electrolytic electroplating of Al on Ti makes it possible to increase its heat resistance by 10...15 times at a temperature of 800...1000 ºC. At that a number of zones with different phase composition and microhardness appear on the sample surface. The upper zone represented by pure Al, then there is a zone with the advantages of γ-phase and the chemical compound TiAl3, in the third zone the lines TiAl3 and α-Ti are detected radiographically. The microhardness of the zones can exceed the microhardness of the starting materials by 5...10 times. The number of layers obtained by electrodeposition depends on the processing modes and the interelectrode medium.

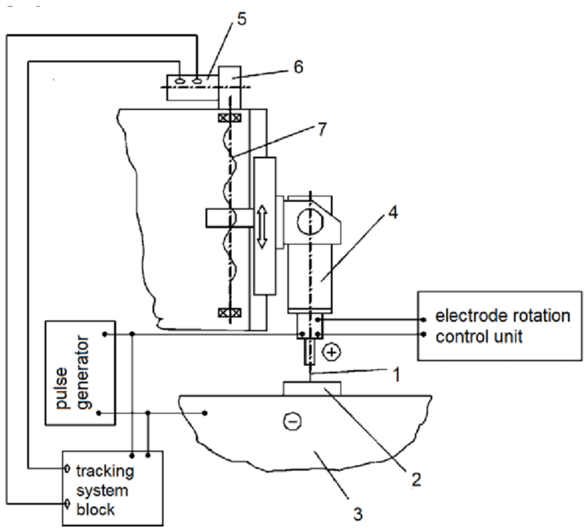

Fig. 2.7 – Electrospark alloying process scheme

As a result of electro spark electroplating a difference in the composition of LS electro spark coatings from the composition of the anode material was found, which is a consequence of the chemical-thermal effect of the discharge on the electrode material, different erosion rate of the anode material components and the unequal ability of their fixation on the substrate material. Metallographic studies have shown that in the base of the alloy in the areas adjacent to the EIL-coating zone, structural changes are observed, in particular, the orientation of the base zone. The character of the structure is mixed: along with dispersed structure coarse-grained structure is formed. Mutual diffusion of the base elements and EIL-coatings is indicated by X-ray spectral analysis. However, the impossibility of obtaining 100% coating continuity, the large roughness of the surface layer, the presence of significant residual stresses and a 40...50% decrease in the fatigue strength of parts, as well as the low productivity of the process still limit the use of EPL to improve the mechanical properties of titanium alloys.

Conclusion to the Part 2

In a market economy, one of the important tasks is to ensure the quality of machine parts, increasing their performance indicators. These indicators are determined by surface layer quality parameters. About 70% of the causes of failure of machines and mechanisms are related to surface layer destruction. Consequently, one of the directions to ensure the quality of machines is to increase the operational characteristics of these parts, which can be achieved by including a running-in period at the stage of manufacturing through the use of appropriate technological processes of manufacturing. Operational characteristics depends on many surface layer quality parameters, so it is important to know the possibilities of controlling the complex of these parameters during machining, including geometrical, mechanical, physical and chemical structural properties.

Despite the numerous advantages of titanium alloys, their use in various mechanisms and structures is limited due to the low level of properties - low hardness and the tendency of titanium to grip when working in friction pairs. The reliability of products depends on the fatigue strength of heavily loaded parts during operation. Fatigue failures of parts almost always start in the surface layer, where there are usually a large number of defects. The most effective solution to eliminate this problem is the formation of a high-strength surface layer of the material. Many surface hardening methods are used today, but in the case of titanium alloys it is reasonable to use only some of them: cladding with powder materials, laser cladding, electron beam and ultrasonic treatment. In this paper we studied the effect of ultrasonic surface treatment of titanium alloy on its properties. Ultrasonic hardening is suitable for increasing the strength of parts with complex profile geometry - blades of GTE, fuselage parts. The method also improves surface performance characteristics: contact stiffness and sliding friction coefficient.

PART 3

MECHANICAL PROPERTIES INVESTIGATION OF PROTECTIVE COMPOSITE COATING ON TITANIUM ALLOY

3.1. Depth-sensing indentation

The main mechanical properties of metals are hardness, yield strength, ultimate tensile strength, relative elongation, impact toughness, fatigue endurance. Hardness is most important for products working under friction and high contact stresses, the limit of strength and yield strength are characteristics that directly reflect the strength of the metal, the relative elongation is a characteristic of the plasticity of the material, the impact toughness indicators are especially important for products operating at negative temperatures or high dynamic loads, the endurance limit describes the metal resistance to fatigue failure process under cyclic repeated loads.

Each metal product or part is characterized by certain mechanical properties that determine reliability in operation. Based on the functional purpose of the part, the nature of the loads to which it is subjected during use, and the type of failure, the expert concludes that some kind of investigation is necessary and, based on the results of the study, determines the causes that led to increased wear, failure, deformation, etc. unpleasant consequences for the metal or alloy product.

Hardness describes the resistance of a material to large plastic deformations. The most common methods of determining hardness involve inserting a special body, called an indenter, into the test material with such force, that plastic deformation occurs. This procedure leaves a print of the indenter in the material and is used to determine the hardness value. Hardness testing is the most common method of testing material properties. There are several reasons for this: hardness determination is a non-destructive method because the part can be used for its intended purpose after such a measurement. There are a large number of methods for assessing material, the most common are the Brinell, Vickers and Rockwell method.

The available equipment for measurement of the reduced microhardness allows to measure reliably the size of a diagonal of a print from 4 μm and above (GOST 10717-75 "Devices for microhardness measuring"). However, the given method is laborconsuming enough and at measurements under a microscope of the small sizes of a diagonal of a trace has the essential error as a result of objective and subjective factors.

To expand the amount of information obtained, minimize labor-intensiveness and the role of the subjective factor in measuring the impression, to surpass the "optical" limit of resolution, the method of continuous indentation with recording of the indentation diagram (instrumental indentation) was proposed.

Its implementation made it possible to determine the depth of restored and non-restored indentation, total work of indentation, as well as work of plastic and elastic deformation during indentation, modulus of elasticity, coefficient of plasticity and other material characteristics.

Elasticity is the ability of a material to restore its shape and volume after the cessation of external forces or other causes of deformation. Plasticity is the ability of a material to undergo plastic deformation, that is, the ability to produce a residual change in shape and size without compromising its integrity.

The method of continuous indentation is based on automatic recording of the load P on the indenter and its indentation depth h. Measurement results are presented in the form of an indentation diagram, which provides more complete information on the physical-mechanical properties of the material than the size of the recovered impression. Processing of the diagram allows to determine micro/nanohardness, modulus of elasticity, to study features of microdeformation, plasticity of materials.

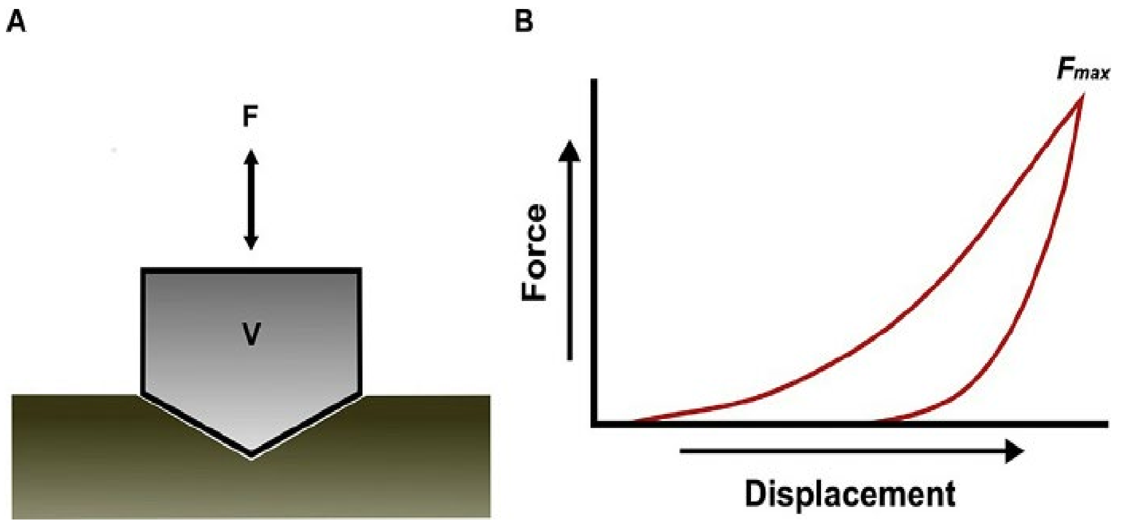

Fig. 3.1 – Diagram of indenter indentation and schematic representation of unrecovered and recovered prints

The analysis and processing of registered indentation diagrams to determine the hardness and contact modulus of elasticity are based on the method of Oliver and Farah and selected as an international standard (ISO/FDIS 14577-1: 2002).

From the diagram of the indentation diagram (Fig. 3.1) it can be seen that the contact depth is:

$$h_c = h - h_s \tag{3.1}$$

where h_s is the displacement of the contact surface during the indentation due to the deflection of the surface around the impression, depends on the indenter geometry and is calculated by the formula:

$$h_s = \varepsilon\ (P/S) \tag{3.2}$$

where S = dP/dh - contact stiffness determined by linear approximation of about 30 % of the unloading curve, starting from P, or as a derivative to the unloading curve at point h; ε - coefficient of indentor shape (for Berkovich pyramid ε = 0,75).

The value of the projection of the contact plane of the impression is defined:

$$A = 24{,}5h_c^2 \tag{3.3}$$

The hardness by instrument indentation is calculated by the formula:

$$H_{IT} = P/A = P/24{,}5h_c^2 \tag{3.4}$$

The contact modulus of elasticity, a value that takes into account the elastic interaction of the material with the indentor, is calculated by the formula:

$$E = \frac{\sqrt{\pi}}{2\beta}\frac{S}{\sqrt{A}} \tag{3.5}$$

β = 1.034 is the correction factor for the Berkovich indentor.

The ductility characteristic δ_A for tool indentation is calculated from the ratio of areas in the indentation diagram:

$$\delta = \frac{A_p}{A_t} = 1 - \frac{A_e}{A_t} \tag{3.6}$$

where A_P, A_e, A_t are, respectively, the work spent on plastic, elastic, and total deformation during indentation.

The plasticity characteristic δ_A for tool indentation is determined in a single experiment during the contact interaction of the indenter with the sample under study and does not require additional determination of Young's modulus, hardness and Poisson's coefficient [21].

3.2 Protective coating

A commercial, pure BT6 alloy (Grade 5: (in wt.%) 6.29 AI, 3.98 V, 0.35 Fe, 0.21 Zr, < 0.05 Si, 0.08 C, 0.05 N, 0.12 O, and < O.O 15 H) was investigated. Disc-shaped specimens with a thickness of 5 mm and a diameter of 12 mm were polished with 600 grit SiC paper. The prepared disks were vacuum annealed for 2 h at 960°C (just below the β-transformation temperature). The resulting duplex microstructure included a mixture of primary α phase and lamellar α+ β grains with β transformed inter-layers possessing enough plasticity.

Alumina powder was used to create the surface layer of the composite, the surface morphology of which is shown in Aluminum powder in its initial state contains particles of 20-120 μm.

A low value of the fracture toughness (K_{1c}) of alumina particles instigates their fracture during the UIT process and easier incarnation into the matrix alloy. Additionally, the high melting point of the alumina/titania and similar thermal expansion coefficients α_t of Al_2O_3 and the BT6 matrix alloy [13-15] allow expecting the enhanced thermal properties (heat-proof resistance) of the formed surface composite layers. A minimum mismatch of α_t helps to minimize thermal stresses and further exfoliation/peeling of the protective oxide film. This will ensure a longer service life at high temperatures.

Protective coatings were created two-step process was used to prepare the protective alumina layer on the BT6 samples. This process has some similarities with the process of preparing composite surface layers using FSP [16, 17], especially with respect to the strong plastic deformation and mechanical mixing of the near-surface layers of the treated samples. Second, air oxidation treatment of samples coated with an Al_2O_3-reinforced composite layer was performed in a tube furnace. Figure 3.2 shows a schematic of the loading apparatus for the UIT process and the processed sample. The main components of an ultrasonic treatment system are an electric oscillator and an ultrasonic oscillating system. Ultrasonic oscillation systems generally consist of a transducer, a waveguide concentrator and an emitter connected to an assembly unit. The generator converts the energy of direct current into electric vibrations with a certain frequency, which pass through the transducer and converted to a mechanical vibration of the waveguide-concentrator and after increasing the amplitude of oscillations transferred to the acoustic head, which includes a deforming element - a hard-alloy indenter of different shapes and sizes. Generator is a key element of the set - it defines frequency and amplitude of oscillations, i.e. determines speed of longitudinal vibrations of the tool, which allows to control dynamic parameters of the processing mode. The static clamping force of the deforming tool on the workpiece and the machining speed are set by the numerical control of the machine tool. In this technique, it is powered by an ultrasonic generator with a frequency of 21.5 kHz and a power of 0.6 kW. The amplitude of the ultrasonic horn was 25 μm. The treated surfaces were subjected to several shocks with a frequency of about 1-2 kHz and an estimated energy E of about 18 mJ. BT6 samples were placed in the holes of an iron anvil (12.5 mm diameter, 10 mm depth), alumina powder was placed between the surfaces of the machined samples, and a flat pin 12 mm in diameter was placed in the holes. The UIT treatment was performed in stages, with the specimen being inverted every 30 seconds and new alumina powder being added to the surface of the specimen. The total duration of the UIT procedure for each side of the sample was 150 seconds. It should be noted that because of the high strength of the titanium matrix, the UIT mode was chosen to be more severe (higher amplitude and longer processing time) than the method previously used to obtain the surface layers of the Al-based composite [18-20].

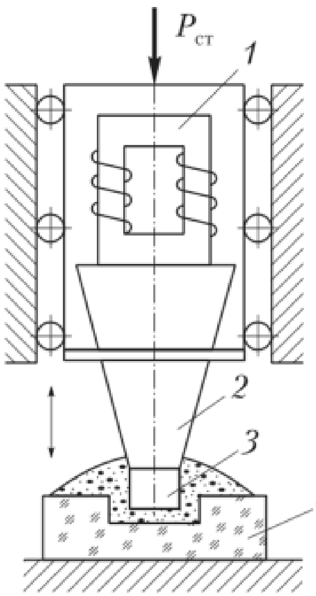

Fig. 3.2 – FI Scheme of the UIT unit used for the mechanical embodiment of the Al_2O_3 powder into the surface layer of the BT6 specimen

It is important to note that during the mechanical mixing of the SPD and the surface layer by the UIT method, the alumina particles are gradually broken up, captured and coated by the matrix alloy. Naturally, the smaller the size d and surface area S of the alumina particles, the higher the specific energy (ratio of unit impact energy to particle size (surface area) E/S) applied to the alumina particles and the greater the penetration of the particle into the sample surface. A rough estimation of the E/S values for the original and decomposed particles shows that the specific energy of small particles (e.g., 10 μm) is two orders of magnitude greater than that of the original particles (~100 μm). Given the specific heat capacity and low thermal conductivity of titanium, the temperature increase due to UIT in the upper layers near the surface can locally reach ~500°C. Such deformation heating can increase the ductility of the titanium matrix and improve the interfacial bonding between the matrix and reinforcing particles. Finally, the formed surface composite layer mainly contains fragments of alumina 5-10 μm thick, and the sample turns into a sandwich flap, both sides of which are covered by the surface composite layer about 30-50 μm thick.

Samples coated with a composite layer reinforced with Al_2O_3 particles were then oxidized in air. The oxidation temperatures were chosen based on the literature review to be sufficient for oxide formation and at the same time safe in terms of preventing/minimizing oxide exfoliation/oxidation. shows literature data on the weight increase of BT6 samples oxidized in air at various temperatures. Even after repeated heating and cooling, it was possible to form an oxide layer without chipping or peeling. The electric tube furnace used for air oxidation was equipped with a programmable logic device (PLD) controller to maintain a constant temperature with an accuracy of ±5 °C. The furnace was also equipped with a sample holder and furnace tube. Recrystallized alumina was used for the sample holder and furnace tube. Each cycle consisted of slow heating (heating rate ~11°/min), immersion in water for 5 hours, and slow cooling in the furnace tube (cooling rate maximum ~1°/min to minimize the risk of shell detachment) [22].

3.3 Surface topography investigations

To analyze the surface morphology of the sample, a 320 x 240 μm^2 area was scanned using a "Micron-alpha" optical profiler [23]. The results obtained show that the surface roughness (Ra = 0.14 μm, Rz = 0.59 μm) is higher after all the modified treatments. The air oxidation treatment of the first samples leads to rapid and irregular growth of the oxide film, increasing the surface roughness parameters by a factor of about 10 (R_a = 1.52 μm, R_z = 3.63 μm) (Fig. 3.4 b). Because of the size of the alumina particles and the pulsation caused by deformation, an outer surface with a roughness five times higher than that of the original sample was obtained (R_a = 0.7 μm, R_z = 2.19 μm) (Fig. 3.3 c).

However, subsequent air oxidation treatment only increases the surface roughness of the composite layer obtained by the MSE (R_a = 0.8 μm, R_z = 3.64 μm) by 15%, especially considering the Ra value (Fig. 3.4 d). It is important to note that this change in Ra is negligible compared to the original oxidized sample.

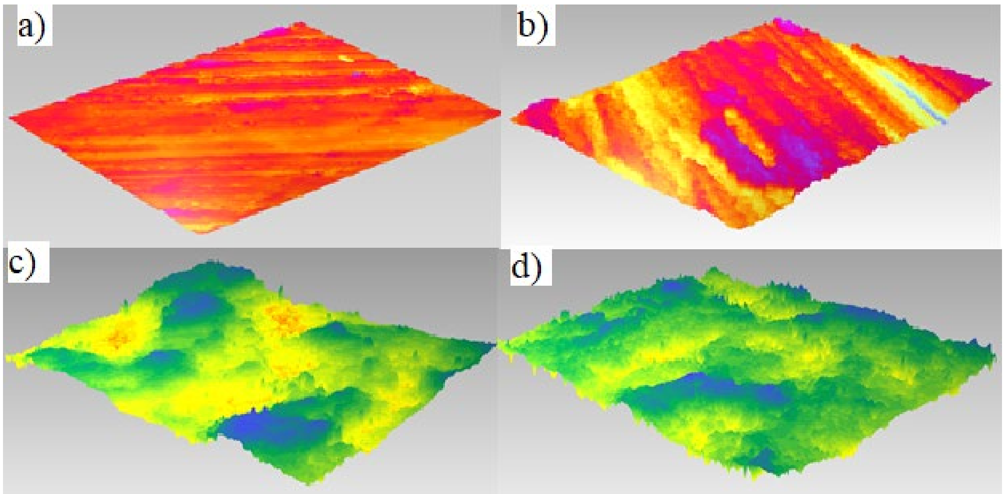

Fig 3.3 – Surface topography of BT6 alloy in the initial state (a), after air-oxidation at 650°C (b), after the UIT-induced formation of the surface (c) and after air-oxidation of the UIT-formed alumina reinforced surface composite at 650° C (d)

This is due to the much lower oxidation rate of this sample compared to the original oxidized sample and the protective effect of the surface of the alumina composite obtained in the UIT process. In this case, the matrix alloy itself forms an oxide film on the surface, through which oxygen diffuses, while the alumina reinforcement particles remain unchanged or become slightly larger. The formation of a TiO_2 layer as a result of selective oxidation of the matrix alloy between the embedded

Al_2O_3 particles appears to slightly increase the overall surface roughness of the oxidized composite layer. Reducing surface roughness is known to minimize surface tension [20] and is therefore favorable in terms of prolonging fatigue life and/or wear resistance of the material.

3.4 Protective layer mechanical properties investigation

A universal device "Micron-Gamma" (Fig. 3.4) was used to study the physical and mechanical properties of the coatings by instrument indentation [24]. Information on the instrumental indentation hardness (H), elasticity modulus (E) and physical plasticity coefficient (δ_A) of the studied modified BT6 samples surfaces (Table 3.1) was obtained by analyzing the load displacement curves recorded during the penetration of the Berkovich indenter (Fig. 3.5 - Fig. 3.7).

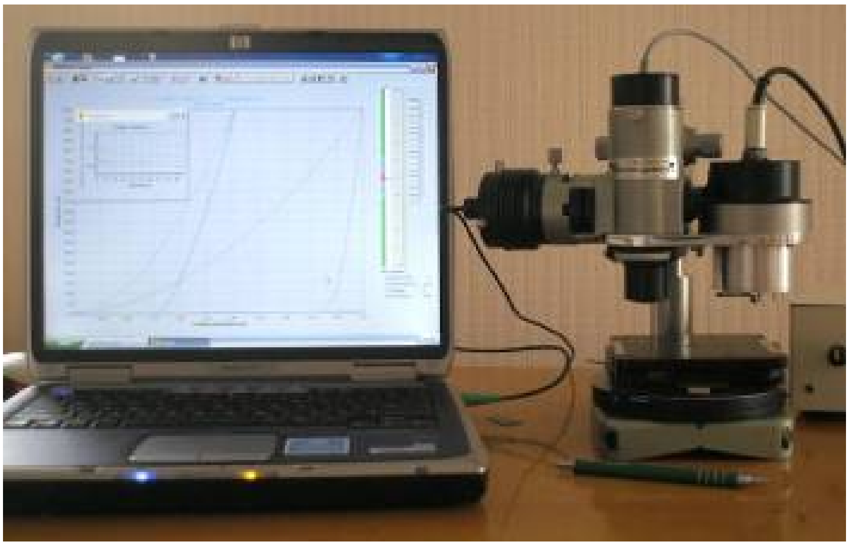

Fig. 3.4 – View of the Micron-Gamma device

A distinctive feature of the device is application of differential sensor of small displacements, which principle of work consists in measurement of depth of indentor penetration concerning not a device bed, and surface of investigated sample.

Measurements of mechanical characteristics were carried out with a Berkowitz indenter at a load of 50 gf, with a loading rate of 5 gf/s. Six punctures were made on each specimen at 50 μm intervals.

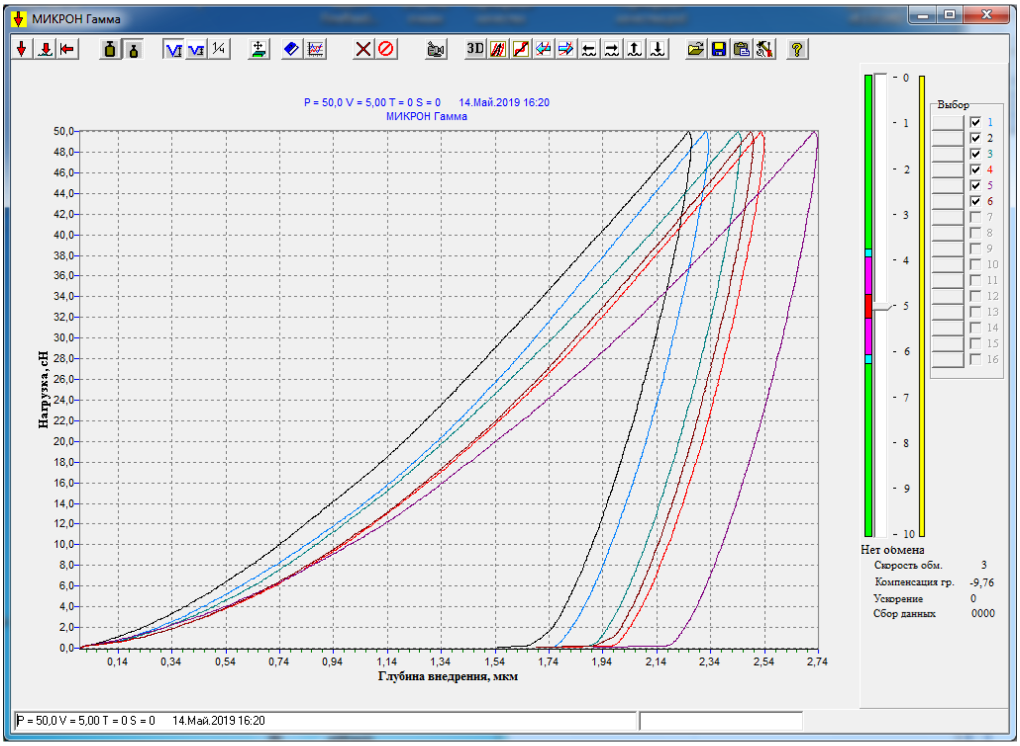

Fig. 3.5 – The load-displacement curves obtained at the penetration of a Berkovich indenter into the specimens in the initial state

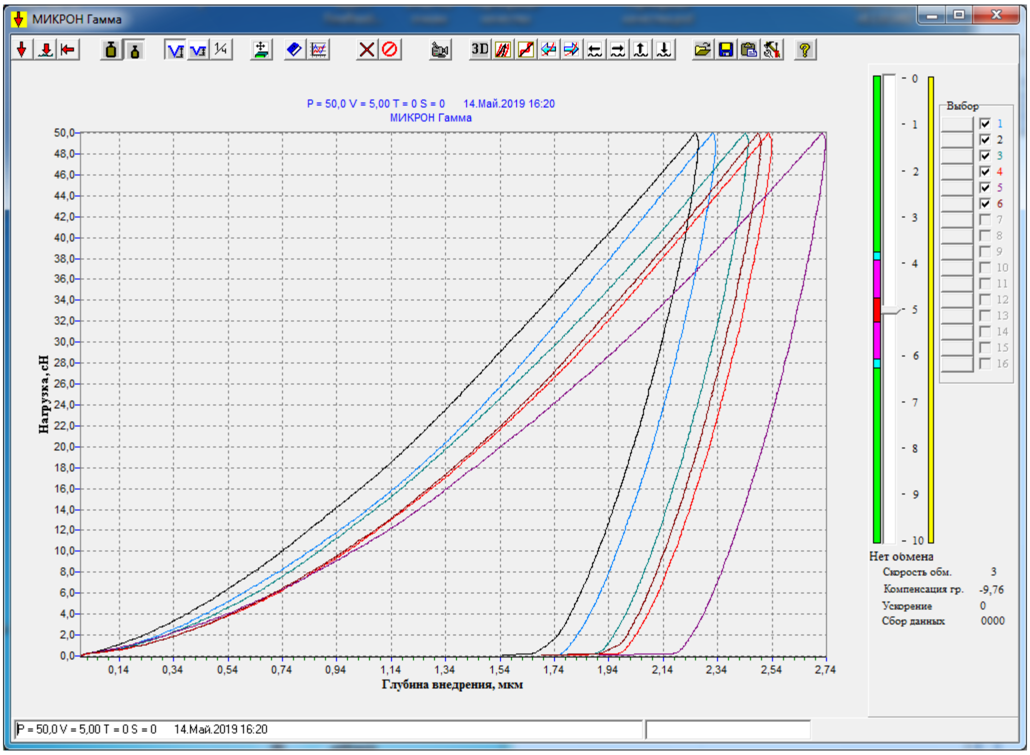

Fig. 3.6 – The load-displacement curves obtained at the penetration of a Berkovich indenter into the specimens in the oxidized state

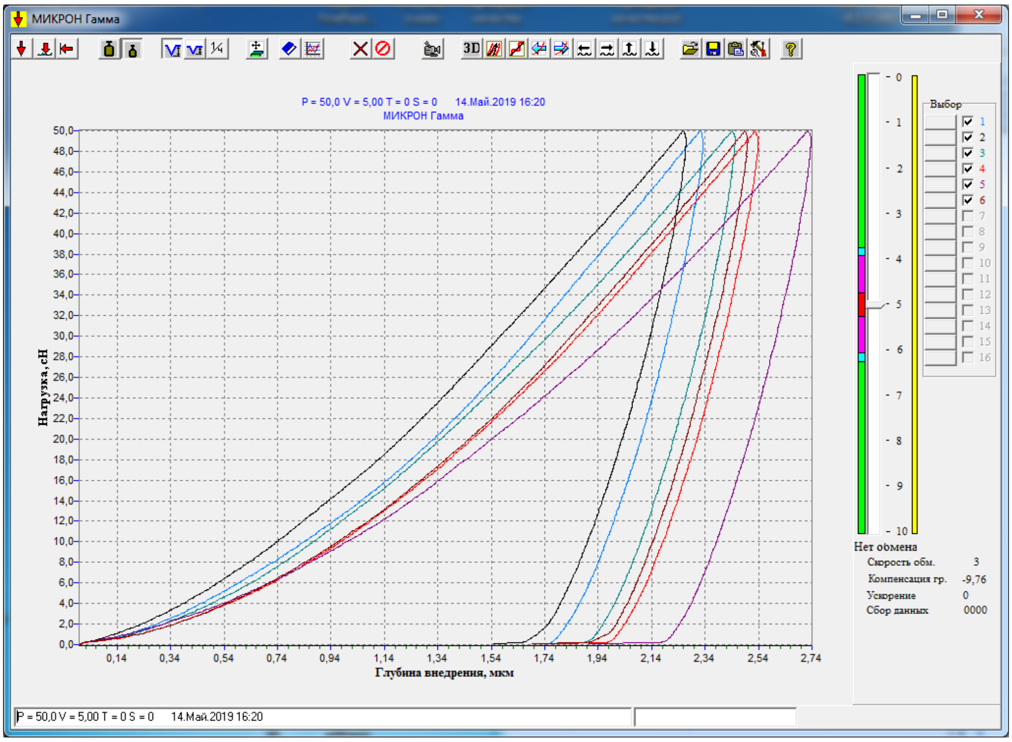

Fig. 3.7 – The load-displacement curves obtained at the penetration of a Berkovich indenter into the specimens in covered by UIT-synthesized surface layer of $A1_2O_3$ reinforced composite

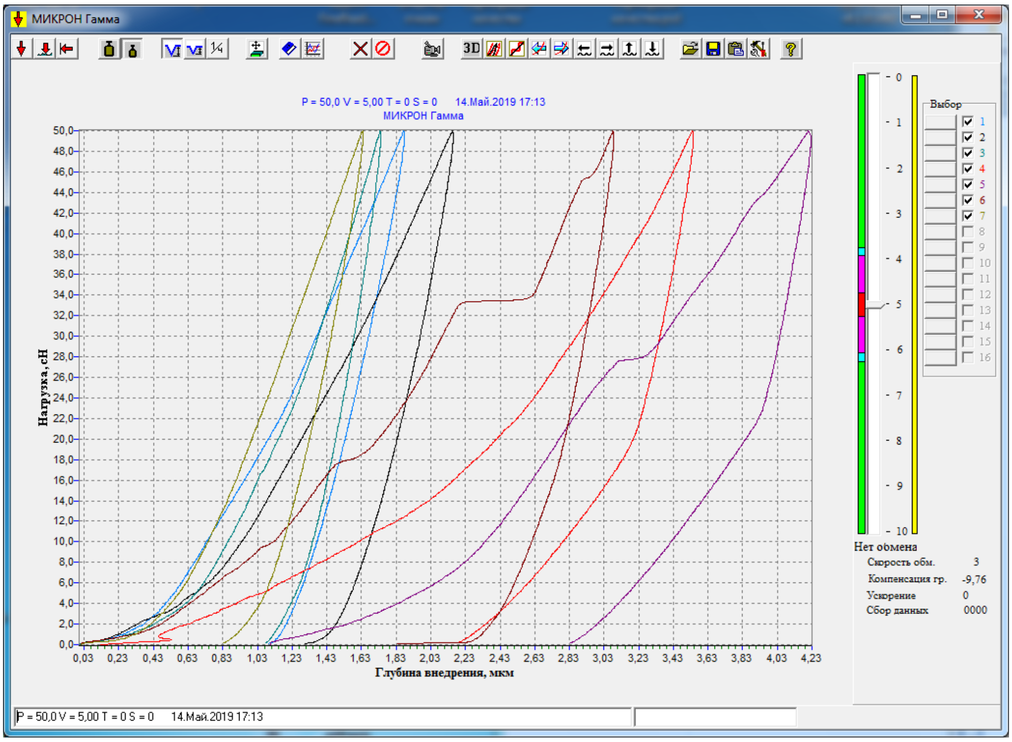

Fig. 3.8 – The load-displacement curves obtained at the penetration of a Berkovich indenter into the specimens by the oxidized composite coating

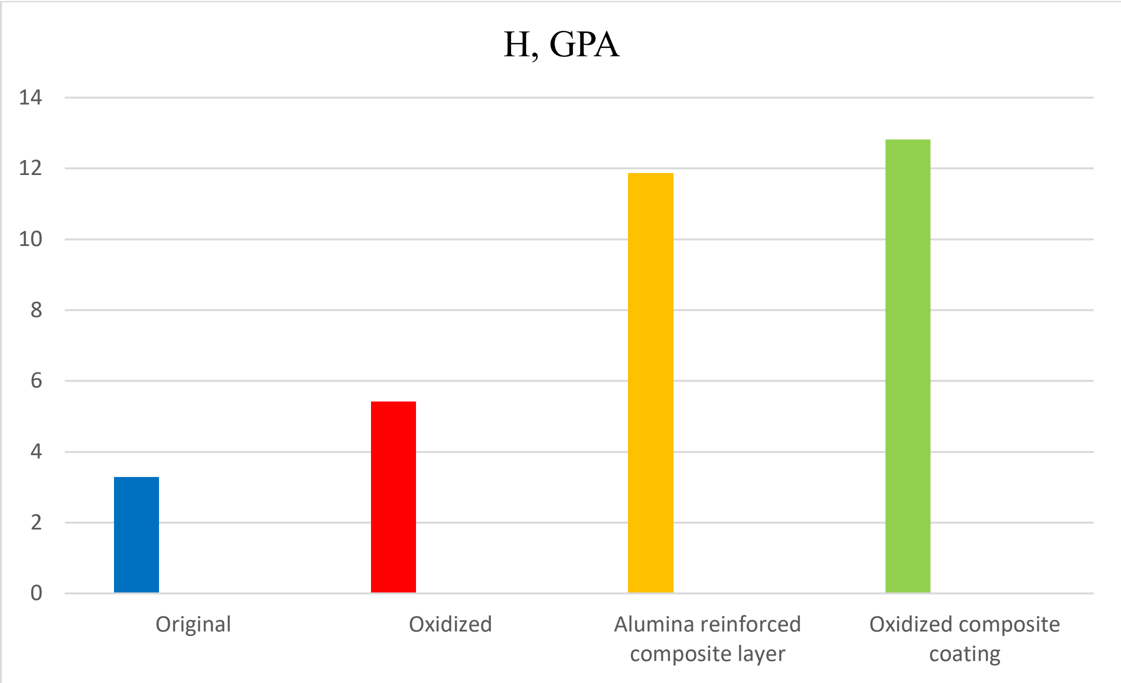

Fig. 3.9 – The results of measurements of H

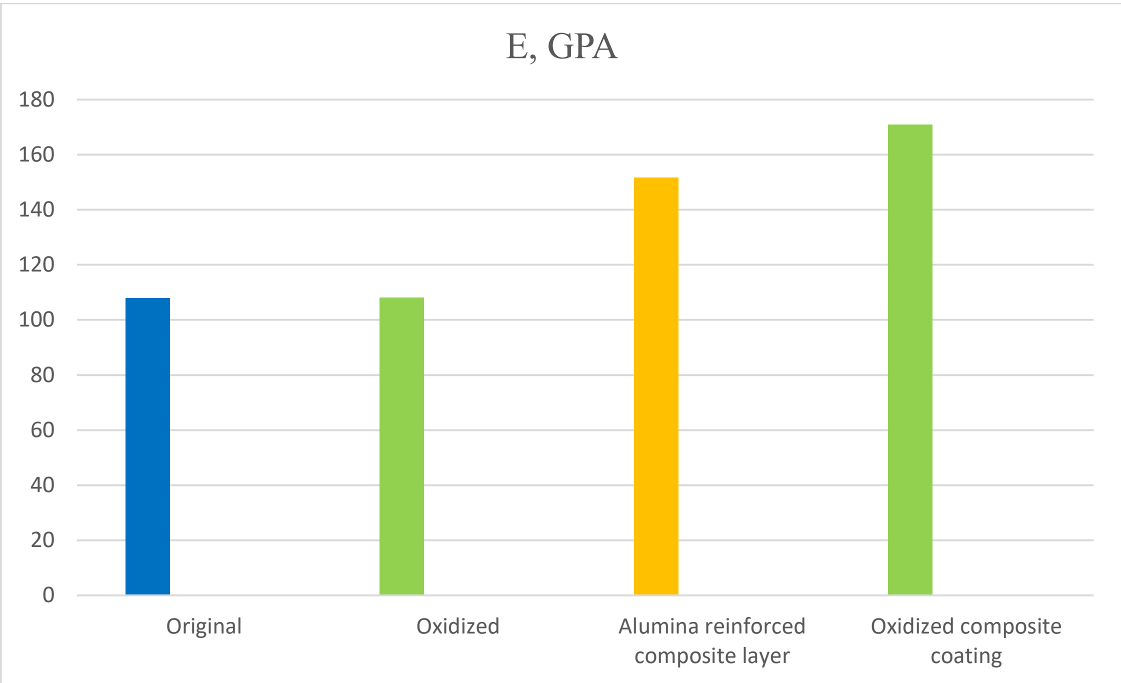

Fig. 3.10 – The results of measurements of E

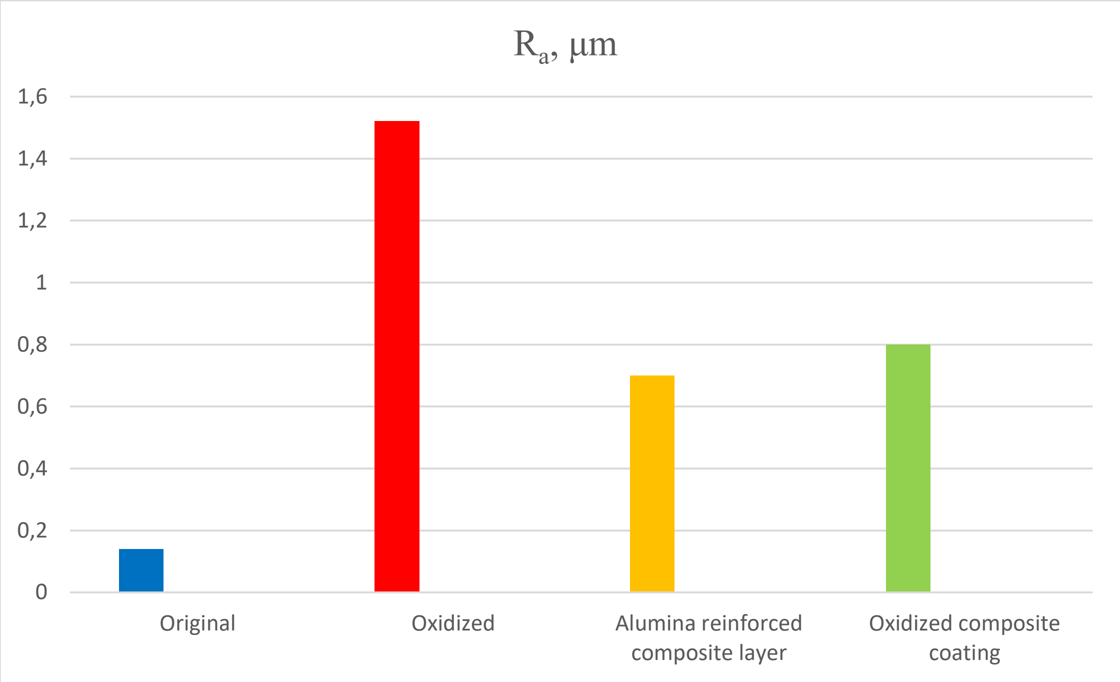

Fig. 3.11 – The results of measurements of R_a

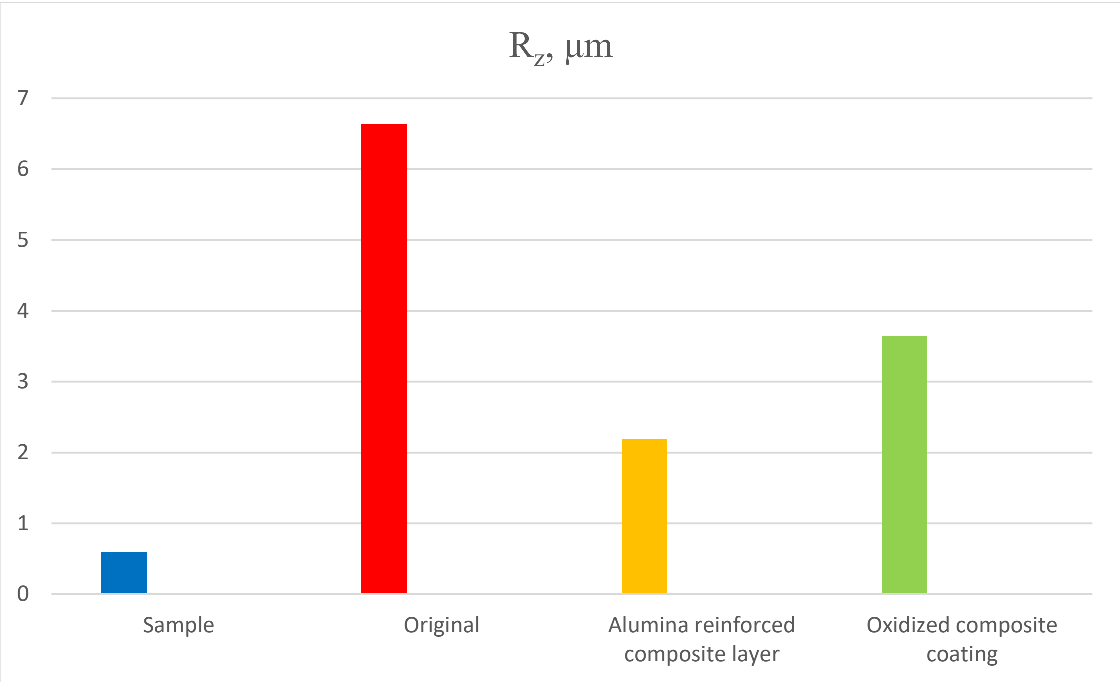

Fig. 3.12 – The results of measurements of R_z

The information regarding the instrumental indentation hardness (H), elastic modulus (E) of the studied modified surfaces of the BT6 specimens (Table 3) was obtained by analyzing the load displacement curves registered during the penetration of a Berkovich indenter. The mean values of H, E, R_a and R_a are presented in Table 3.1

Table 3.1– Experimental values of mechanical properties of the BT6 specimens

Sample	H(Gpa)	E(Gpa)	R_a	R_z
Original	3.285	108	0.14	0.59
Oxidized	5.417	108.5	1.52	6.63
Alumina reinforced composite layer	11.869	151.8	0.7	2.19
Oxidized composite coating	12.814	170.9	0.8	3.64

Obtained results shows the increased in H values for all modified surfaces. The surface hardening efficiency evaluated for the air-oxidized sample gives a 65% increase in H values (5.417 GPa) compared to the original sample (3.285 GPa), which can be explained by oxide film formation and the α-case effect. A much greater increase in H values was observed for the sample coated with a UIT synthesized surface composite layer reinforced with Al_2O_3 particles (~ 11.9 GPa) and for the sample coated with an oxide composite layer (~ 12.8 GPa).

The surface hardening efficiencies are, respectively, 4 and 4.5 times higher compared to the oxidized original sample. The experimental values of elastic modulus estimated for the latter samples are increased by 40-60%. However, compared to the literature data for dense Al_2O_3 (~20 GPa and 215-413 GPa, the experimental H and E values are underestimated (~12-13 GPa and ~150-170 GPa, respectively). At the same time, the experimental H is higher than the hardness of TiO_2 (~7 GPa), and the experimental modulus of elasticity is very close to that of TiO_2 (151 GPa) [21]. The observed H_v and E values become clear when the idea of air oxidation-induced formation of a surface layer of composite coating reinforced with Al_2O_3 particles, continuous TiO_2/ Al_2O_3 interlayers and covered with a top layer of TiO_2 is taken into account.

Conclusion to the part 3

In this work, the surfaces of BT6 alloy samples were modified by cyclic air oxidation, fabrication of Al_2O_3-reinforced composite surface layer, and cyclic air oxidation of composite surface produced by UIT. The investigations of microstructures and properties of nontreated and modified samples allow us to conclude.

Method of intense plastic deformation by ultrasonic shock treatment with addition of Al_2O_3 powder particles to the deformation zone followed by oxidation in the air at 650°C allows to obtain a protective composite coating covered with an external Al_2O_3/ TiO_2 film of high density and thickness ~ 1 μm, tightly adhering to the surface of Ti6Al4V alloy.

The indentation experiments and calculations show that the hardness and modulus of elasticity of the protective composite coating are 12.8 GPa and ~ 170 GPa, respectively, which is three times and ~50% higher than that of the original BT6 alloy.

The results showed that the low surface roughness of the initially polished samples increased after all modification treatments. During the air oxidation treatment, the surface roughness parameter increased by a factor of about 10 due to the rapid and uneven growth of the oxide film. The UIT treatment resulted in the formation of alumina particles on the surface of the specimens under strong plastic deformation, and due to the relatively large size range of the alumina particles and the wave formation caused by the deformation, the outer surface became about five times rougher than the original specimens. The outer surface is now about five times as rough as the original sample. However, the subsequent oxidation treatment in air increased the surface roughness of the ITU-generated composite surface layer by only 15%, especially when Ra values are taken into account. This small change in Ra compared to the original oxidized sample is of particular importance, as the oxidation rate of this sample is much lower and seems to be due to the protective effect of the alumina composite layer produced by UIT. In this case, the oxide film is formed in the parent alloy on the upper surface and undergoes oxygen diffusion, while the alumina reinforcement particles remain unchanged or slightly increase.

The UIT method significantly increases the hardness and changes the modulus of the titanium alloy, which was experimentally confirmed by the nanoindentation method.

PART 4
LABOR PROTECTION

The purpose of this section is to analyze harmful and dangerous factors, in which there is a risk of injury to the body or conditions that can lead to injury in the process of surface treatment of BT-6 alloy by ultrasonic shock treatment, as well as to develop measures aimed at eliminating these factors. In this section, the means of labor protection in the performance of research conducted on the device УСО-300 are considered. To solve the tasks, we should use the following production reasons:

1) analysis of harmful and dangerous production factors:

2) engineering solutions to ensure occupational safety in the laboratory;

3) calculation of the engineering solution;

4) safety requirements in emergency situations.

4.1 Analysis of the presence of harmful and hazardous production factors

4.1.1 Microclimate

The master's thesis was performed at the Aircraft Department of the Aerospace Faculty of the National Aviation University in Building No. 11 on the 1st floor in Room No. 121. Schematic representation of the laboratory with the arrangement of elements in it is shown in Fig. 4.1.

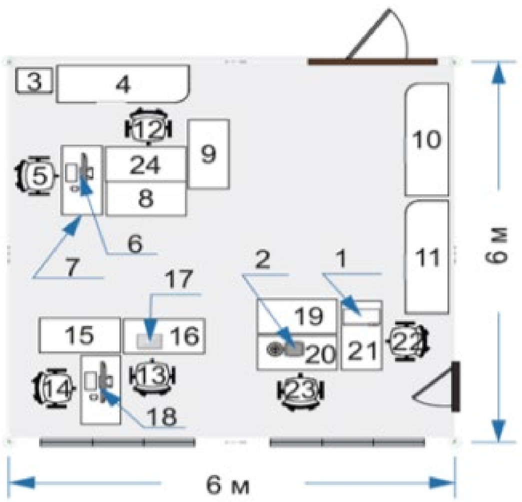

Fig. 4.1 – Scheme of the laboratory in which the research work was carried out.

1 - microhardness tester "Micron-gamma"; 2 – Profilometer "Micron-alpha"; 3 - drawer; 4, 10, 11 - bookcase; 7, 8, 9, 15, 16, 18, 19, 20, 21, 24 - desk; 5, 12, 13, 14, 22, 23 - chair; 6, 17, 18 - computer.

The dimensions of the laboratory room are analyzed:

1) room dimensions: width - 6 m, length - 6 m, height - 2.7 m;

2) window dimensions: width - 2.5 m, height - 2 m.

Laboratory room 108, which has three employees, has an area of 36 m^2 and a volume of 97.2 m^3. The area per person is 12 m^2 and the volume is 24.4 m^3. In other words, the volume and area of the laboratory are fully consistent with the norms, according to ДСанПіН 3.3.2-007-98, which establishes standards for the size of working space, where a workplace for one person should be not less than 6 m2 and 20 m3 in volume.

An important factor also for the normal performance of workers is the cleanliness of the air in the work area, lighting and temperature in the workroom and many other factors. Therefore, the performance of the master's thesis was accompanied by a study of the microclimate in the laboratory room 108.

According to the "Sanitary norms of the microclimate of industrial premises" ДСН 3.3.6.042-99, the optimal and admissible parameters are established: relative humidity, temperature, air velocity in the workroom, depending on the period of the year and the category of work severity.

According to ДСН 3.3.6.042-99, microclimate conditions are referred to the category of work severity - light I b. This category includes light physical work up to 150 Kcal/h, accompanied by some level of physical exertion performed while sitting or standing, and work associated with walking. There are also categories of work according to their severity: light I a, light I b, medium heavy II a, medium heavy II b, heavy III.

The results of measurements and standardized values of microclimate parameters in the working area of laboratory No. 108 are presented in Tables 4.1 and 4.2.

Table 4.1 – Measured values of the parameters of the microclimate of the room

Period of the year	Measured actual values

	Temperature, °C	Relative humidity, %	Speed of air, m/sec.
Cold	20	70	0,1
Warm	23	55	0,2

Table 4.2 – Standard values of parameters in microclimate before ДСН

Period of the year	Measured actual values		
	Optimal temperature air, °C	Optimal relative humidity, %	Optimal speed of air, m/sec.
Cold	20	70	0,1
Warm	23	55	0,2

Analysis of the measured values allows us to assert that the actual parameters of the microclimate meet the optimal conditions and the requirements of sanitary norms.

4.1.2 Air of the working area

The air of the working area in the laboratory may contain harmful substances and dust. The content of harmful substances and dust in the air of a working area shall not exceed the maximum permissible concentrations used for the design of production buildings. According to ГОСТ 12.1.005-88, maximum permissible concentrations of harmful substances in the air of a working area of production facilities are established. Entry of harmful substances or dust into the air of a working area depends, in turn, on the technological process and raw materials used.

There was no polishing, grinding, or UIT treatment processes with materials in a solid state in the laboratory where the master's research work was performed. Wet cleaning of the laboratory was performed daily. All ultrasonic impact treatment processes were conducted in an enclosed volume of the unit chamber, so there was no emission of harmful substances into the atmosphere of the laboratory.

4.1.3 Noise

Noise is some unwanted sound that can cause ill health or ill health. Noise also reduces performance, can contribute to injuries, due to increased levels of distraction and attentiveness.

The master's thesis was performed on an ultrasound deviceshock treatment УЗГ-300, which created some noise during operation.

Prolonged and excessive noise causes damage to human health, namely:

1) memory impairment;

2) dizziness;

3) increased fatigue;

4) irritability.

Prolonged, systematic and excessive exposure to ultrasonic waves, of course, adversely affects the human body. Causes disorders of the nervous, cardiovascular, endocrine and auditory systems.

There are the following personal protective equipment against noise and ultrasound:

1) anti-noise (soundproof) headphones;

2) helmets;

3) costumes;

4) soundproof cabins;

5) acoustic screens.

The setting of noise limits at workplaces and in laboratory premises is provided by ДСН 3.3.6.037-99. This document establishes the principles of certain parameters of noise, based on the classification of premises for their use for work in different areas.

During the operation of ultrasonic installations, the sound pressure levels at the workplaces must comply with ДСН 3.3.6.037-99. It is allowed to use installations with electric power less than 250 W and operating frequency not lower than 44 kHz without means of protection against ultrasound. Work on devices that emit ultrasonic vibrations and waves must exclude the possibility of direct human contact with ultrasonic tools or parts that are processed. The ultrasonic shock treatment took place in a closed chamber, and the installation itself is equipped with a soundproof casing covered with rubber to prevent the propagation of sound and ultrasonic waves into the laboratory space. Noise-canceling headphones and acoustic screens were additionally used in the work.

4.1.4 Vibrations

Work on the device for ultrasonic shock treatment УЗГ-300 is accompanied by a certain level of vibration. Vibrations - mechanical oscillations of elastic bodies or oscillating motions of mechanical systems. In general, the effects of vibration have a negative effect on the human body. The most important method of vibration protection used in this work is their damping, which was carried out by isolating the sources of oscillations from the bearing surfaces using rubber, spring or combined insulators .

Vibration parameters are normalized in accordance with the requirements of LTO 3.3.6.039-99. State sanitary norms of industrial and general vibrations and GOST 12.1.012-90 "Vibrational safety. General requirements ”. The UZG-300 unit operates in the ultrasonic range. Samples were processed from 5 s to 200 s. The scheme of UZUO in Figure 2.1. The effect of vibrations is not known, as there is no contact of the person with the installation during processing. In order to prevent the harmful effects of ultrasound, low-power ultrasonic equipment was used.

4.1.5 Electrical safety

Electrical hazards - systems of organizational and technical measures and means, which in turn protect people from the harmful and dangerous effects of electric current, electric arc, electric field and static electricity. According to the current rules of construction and placement of electrical installations ДНАОП 0.00-1.32-01 laboratory № 508, where research work was carried out, the risk of electric shock is classified as a room without increased danger (dry rooms with a temperature of 18 ° C - 25 ° C and non-conductive floor), according to the source.

The main factors influencing the severity of human injury electric current, are divided into three groups: electrical, non-electric, factors of the production environment.

The main characteristics of the electrical nature:

1) the amount of current flowing through a person;

2) voltage;

3) body resistance;

4) type and frequency of current.

The main factors of non-electrical nature:

1) the path of current through a person;

2) individual features;

3) the state of the human body;

4) the action of current.

Causes of electric shock:

1) damage to the insulation, as a consequence, human access to live parts of the equipment, respectively;

2) the appearance of voltage on the open live parts, due to incorrect switching on of the installation;

3) non-compliance or incorrect compliance with the requirements of electrical safety, inattention at work.

The passage of electric current by the human body is a complex process that is accompanied by a significant range of physico-biological and chemical reactions, the main of which are thermal, electrolytic, electrolytic. The thermal reaction of the tissues of the human body occurs due to the conversion of electrical energy into heat. The electrolytic effect of electric current on living tissues consists in the decomposition of intracellular organic fluid into ions. The mechanical reaction of the human body to the flow of electric current is manifested in the form of an electrodynamic effect, which consists, for example, in a sharp contraction of muscle tissue. The biological reaction of the human body to electric current is formed as a result of its action on internal bioelectrical processes, in the irritation of living tissues.

In the laboratory where the research was conducted, protective earthing of electrical equipment housings and devices was performed. Arrangement of workplaces is performed in such a way that excludes the possibility of simultaneous touching to the housings, electrical equipment and devices, according to the source.

4.2 Engineering solutions to ensure occupational safety

4.2.1 Workplace organization

Production facilities, organizations and equipment of workplaces given in НПАОП 0.00-7.15-18. Organization of the user's workplace personal computer should provide optimal maintenance working posture with the following ergonomic characteristics.

1) wrists bent at an angle of not more than 15 ° - 20 ° relative to the vertical plane;

2) elbows bent at an angle of 70 ° - 90 ° to the vertical plane;

3) forearms are set in a vertical position;

4) the thighs are in the horizontal plane;

5) the soles of the feet are placed on the floor or on a footrest.

The height of the working surface of the table for work in a sitting position in the range of 680 mm - 800 mm, and the width provides the ability of the employee to perform the necessary operations in the range of the motor field. Recommended table parameters for work: height - 725 mm, width of the working area in the range from 600 mm to 1400 mm, length from 800 mm to 1000 mm.

4.2.2 Ventilation

According to ДСТУ 2388-94, local ventilation must ensure the removal of polluted air from areas where the release of harmful substances is concentrated. In other cases, general exchange ventilation is used. It must be performed in combination with local ventilation, which is designed to remove from the production premises of harmful substances not localized by local exhaust devices.

4.3 Calculation of engineering solution

4.3.1 Calculation of ventilation

Calculate the amount of air you want to remove locally ventilation Lm is determined based on the set suction speed at the source of harmful substances, the characteristics of the spectrum of suction rates for a particular design of the suction hole and the presence of surfaces enclosing the suction area. In this case:

$$L_{М} = 3600 \cdot F_0 \cdot V_0 \tag{4.1}$$

where F_0 is the open cross-sectional area of the exhaust opening of the suction, m2; V_0 is the suction rate of air in this slot, m / s.

The area F_0 is found by the design features of the technological equipment and the selected exhaust device. The value of V_0 is calculated based on the specified air velocity V_x = (0.5 m / s) in the processing zone at a distance x from the center of the suction hole:

$$V_0 = 16 \cdot V_x \cdot (x/d)^2 \quad (4.2)$$

where d is the diameter of the hole, m; x - distance to the work surface, m.

In fig. 4.2 shows the schematic diagram of local ventilation required for conducting UIT.

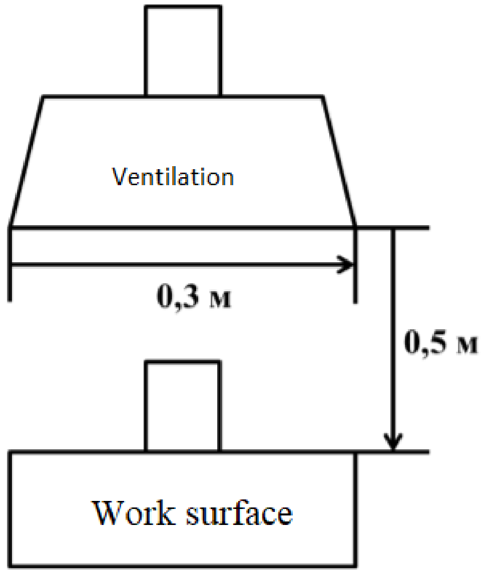

Figure 4.2 – Scheme of local ventilation

As a result of calculations, it was found that the suction speed of air in the slot V_0 should be 22 m/s, and the volume of air to be removed by local ventilation Lm – 2376 m^3/h.

4.4 Emergency safety requirements

Emergency - violation of normal living conditions and activities of people in facilities or territories caused by accidents, catastrophes, epidemics, natural disasters, epizootics, epiphytosis, large fires, the use of means of destruction that have caused or may cause human and material losses, and also a great contagion of humans and animals.

During the research work, the following emergencies may occur: fire, earthquake, explosion, accidents on power systems, destruction of building.

4.4.1 Fire safety

The category of fire hazard of the premises (buildings, structures) is a classification characteristic of fire hazard of the object, which is determined by the number and flammable properties of substances and materials that are (rotate) in them, taking into account the peculiarities of technological processes. According to NAPB B.03.002-2007, premises for explosion and fire hazard are divided into five categories (A, B, C, D, E).

It can be concluded that the laboratory premises № 108-11 for fire hazard belongs to category "G" (the laboratory contains non-combustible substances and materials in hot, hot or molten state, the processing of which is accompanied by the release of radiant heat, sparks, flames; combustible; gases, flammable liquids, solids that are burned or disposed of as fuel). The most fire-hazardous place in the laboratory is the place where the wiring is laid. Indoor fires can occur due to a short circuit in the wiring. The plan of evacuation from the laboratory in case of fire is shown in Fig. 4.3.

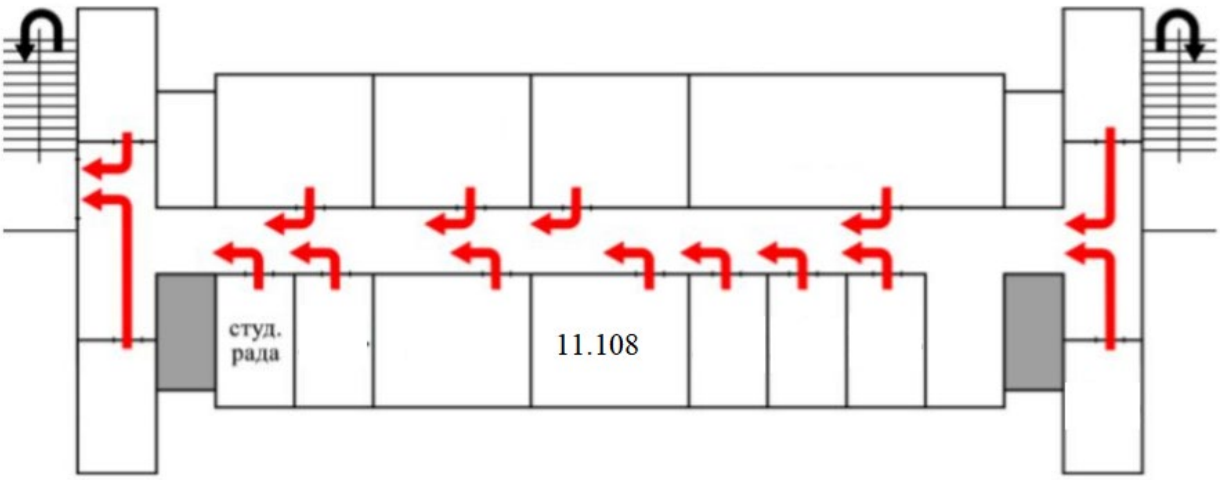

Figure 4.3 – Laboratory evacuation plan № 108

ОУБ-2 fire extinguishers are available in the laboratory as fire extinguishers. Means of detection and notification of fire - automatic sensors, alarms such as accidents. Means of communication and notification of employees about the fire situation - internal communication. In case of fire there is a plan to evacuate employees from the laboratory № 108.

4.4.2 Safety in emergency situations

If there is a breakdown of electrical voltage on the housing of the device

UZG-300 must, first of all, turn off the switch and bring to the notice of the master or the head of the department. If someone is exposed to voltage, the appliance must be switched off UZG-300 from the network, put the victim on a wooden deck, put a pad under his head, call a doctor at number 103 and, if necessary, make the victim an artificial respiration.

If the appliance catches fire, switch off the switch and start extinguishing the fire with the help of a fire extinguisher.

Conclusion to the part 4

Analysis of harmful and dangerous production factors was made. It was found that the most significant negative harmful production factor is increased noise in the workplace. It can lead to serious health consequences. And it is difficult to maintain it at the required level at places like engineering office which is full of different electrical technique, air-conditioning systems and in some cases working premises located near shops, the sound from which can cause a lot of problems with noise regulation. Measures to reduce the impact of harmful and dangerous production factors especially noise pollution were performed. Finally, instruction on labor protection when working at the computer in office building were proposed. There are general labor protection requirements, labor protection requirements before work, during work, after work and labor protection requirements at emergency situations

5. ENVIRONMENTAL PROTECTION

5.1 Impact to environment due to aircraft manufacturing

One of the most important branches of mechanical engineering is aviation industry, which produces aircraft to meet the needs of the population, the national economy and defense of the state in air transportation and aviation operations.

Ukraine is one of seven leading aviation countries in the world that have closed (full) production cycle of aircraft - from their design to launch into serial production. The modern state of aviation industry is difficult enough. Quite a bit of enterprises industry stopped a production and sale of airplanes, have an account payable. Substantially wear productive funds of enterprises, majority from that ended up in a that critical condition, when without the financial making healthy their activity is impossible. Therefore, hereupon substantially the problem of influence of aviation industry became sharp on a natural environment. But also except it on the enterprises of aviation industry there is plenty of dangerous areas that render negative influence of environment and population. Galvanic, thermal workshops, workshops of tooling of metals, area of painting and instrument-making enterprises that provide aviation industry navigation, radiolocation and informative complexes, belong to the most dangerous areas.

Therefore, on this time actual is a question of study of estimation of influence on the environment of aviation industry.

The aim of this division is research of ecological safety of aviation industry. And suggestions for an increase to the level of ecologization of enterprises of aviation industry.

All technological processes in the industry pollute the environment to a greater or lesser extent. But the most "dirty" are:

- Foundry
- Metal processing shops
- Galvanic production

- Paint and varnish works
- Welding production

Almost all machine-building enterprises without exception use substances with a high level of contamination in their production processes. For example, foundry production, this is one of the most dangerous industries. During iron production, nitrogen and carbon oxides, sulfur oxide and sulfur dioxide, as well as dust, ammonia, phenol, formaldehyde, cyanide are emitted and released into the atmosphere through pipes, and the solids in the molding mixtures enter water bodies.

Metal processing shops are the main pollutants - oils and metal dust that enter the atmosphere, water, and soil. There is about 260 kg of waste per one ton of processed metal, and at some companies in the industry it reaches 50%. The air is also polluted by vapors from cutting fluids when machines are in operation.

Galvanic shops use the most water compared to other mechanical engineering industries. And, as a consequence, the greatest amount of wastewater is generated. Nickel plating, chrome plating, copper plating, zinc plating, etc. are carried out here. As a result of these processes, many harmful substances, mainly metals and their salts, get into water bodies.

Paint and varnish production. An environmental hazard is posed by the constituents of varnishes and paints used in production (about 40 harmful substances, including lead, epichlorohydrin, hexamethylenediamine, etc.). Their volatile compounds are released into the atmosphere.

Welding production. The air is polluted with welding dust and aerosol vapor, which includes oxides of silicon and chromium, fluorides, manganese compounds, etc. Most of the emissions are generated during electric arc welding, and less - under the flux.

Pollution of the biosphere by waste from machine-building enterprises harms both flora and fauna, and the human beings themselves. Emissions of harmful substances into the atmosphere

In industrial areas air pollution is felt most strongly. Here the air constantly contains:

- sulfur dioxide, carbon monoxide and carbon dioxide;
- nitrogen oxides;
- fluorine and chlorine compounds;
- heavy metals.

The air saturated with these substances, in turn, causes many diseases, especially lung diseases.

Wastewater discharge

Wastewater from the mechanical engineering industry pollutes surface and groundwater. Four main hazards can be distinguished:

A lot of biodegradable organic compounds enter water bodies with the effluent. This process leads at best to a decrease in the activity of aquatic organisms, and at worst to their death.

Macronutrients (nitrogen, phosphorus) provoke the growth of biological productivity - algae growth, followed by die-off and mineralization. This process leads to a decrease in oxygen content and, consequently, to the death of animal life of water bodies due to hypoxia.

Wastewater brings to water bodies, for example, non-ionized ammonia, tannins, chromium-containing compounds. These substances directly cause death and poisoning of plants and animals.

Thermal pollution caused by discharges of heated water inhibits or makes it impossible for fish to reproduce. Most valuable species spawn at temperatures below 16 ^{0}C. Even a small increase of a couple of degrees sharply reduces the ability of fish to reproduce. The reduction of fish stocks and animal life of water bodies in general reduces the number of animals and birds foraging near the river.

Soil Pollution

Waste dumps and secondary pollution through precipitation pollute the soil. Mechanical engineering companies contribute to this process as well. For example, hot and incinerated waste can ruin the soil irreversibly, since all microorganisms die in it.

Toxic substances, heavy metals, lead, nitrogen oxide, mercury, etc. first get into the soil, then - into plants and further - into the human body (or first - into animals, and then - humans), which increases the number of diseases and develops allergic reactions.

Pollutants entering the biosphere, and the most dangerous pollutants are:

- hexavalent chromium;
- sulfur dioxide;
- nitrogen and carbon oxides;
- sulfates;
- chlorides;
- phosphorus;
- cyanides;
- salts of heavy metals;
- lead;
- ester-aldehyde fractions;
- Alkalis and acids;
- colloidal particles;
- nitrates and nitrites;
- phosphates;
- SURFACTANTS;

5.2 The ways how to improve manufacturing processes.

In general, environmental safety problems can be solved by:

- recycling of solid waste;
- installation of recycling water supply;
- increasing the efficiency of emissions treatment (both in the atmosphere and in water sources);
- introduction of ecological and waste-free technologies.

Recycling of solid waste - an activity consisting in the management of waste in order to ensure its reuse in the national economy and obtain raw materials, energy, products and materials.

It is an environmentally friendly alternative to conventional waste disposal. Reduces the amount of resources used and also reduces greenhouse gas emissions.

Recycling can prevent the disposal of potentially useful materials and reduce the consumption of primary raw materials, thereby reducing energy consumption, air pollution (from incineration), water pollution, and soil pollution (from landfilling).

According to the generally accepted hierarchy of responsible consumption and waste management, the principle of reducing waste generation comes first, followed by reuse and recycling, and then incineration. The landfill method is considered the least preferable option.

The metal processing and machine-building industrial enterprises are relatively large consumers of fresh water, and the enterprises of these industries generate especially toxic wastewater containing heavy metals, soluble and insoluble organic substances and other contaminants in their technological processes. In this regard, there is an urgent need to create water recycling systems for enterprises and reduce wastewater discharges into water bodies.

In the process of solving these problems, namely, transition to rational water supply and minimization of industrial wastewater discharge, it is necessary to apply the Best Available Technologies in order to organize low-waste (partial water recycling) and waste-free (complete recycling) technological processes based on technologies of electroflotation, ultrafiltration and reverse osmosis, vacuum distillation, thermal utilization of liquid and solid waste of industrial enterprises.

Recycled water supply is a closed system, which allows the reuse of treated wastewater, passed the treatment process at the treatment facilities of the enterprise. The concept of recycled water supply of the enterprise completely excludes discharge of industrial wastewater into water bodies or municipal sewerage system. Recycling water supply allows to solve ecological and economic problems: to reduce water consumption by an industrial enterprise significantly (by 85-95%), to reduce losses of valuable components with industrial waste water, avoid payments for water disposal and fines for exceeding maximum permissible concentrations of MPC - maximum permissible concentrations of waste water.

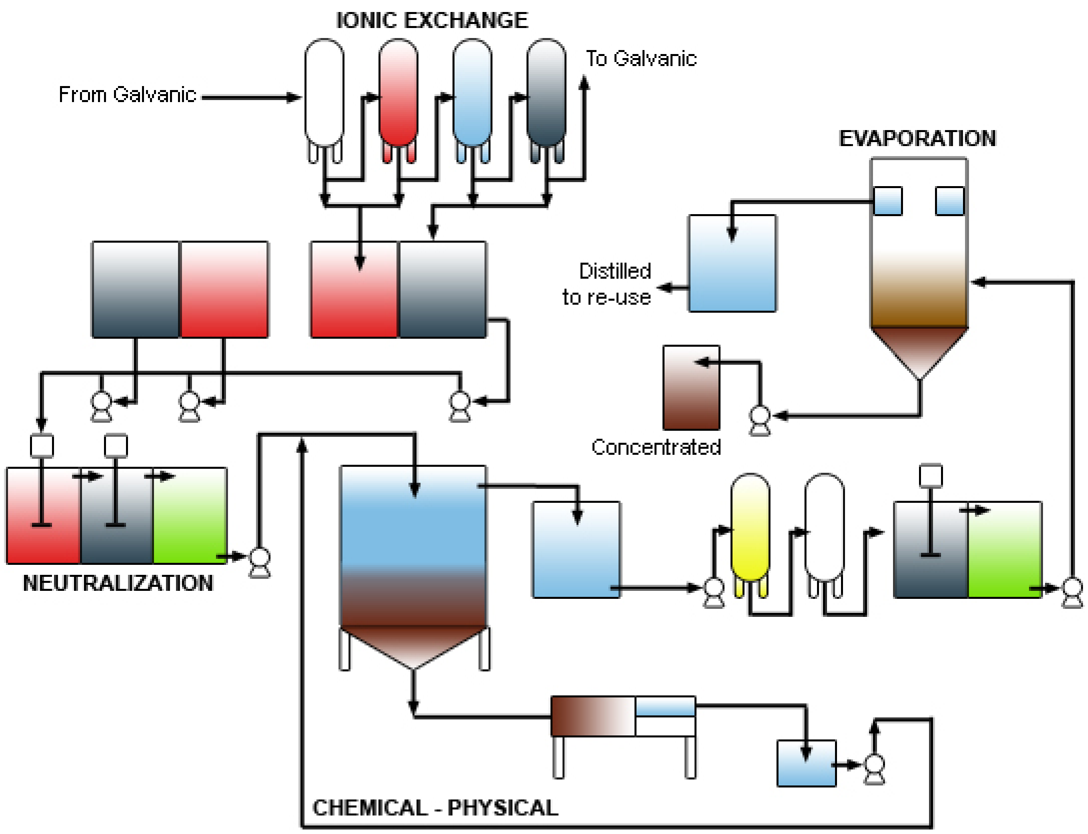

Figure 5.1 – Scheme of recycling water supply system

Ecological safety of environment, minimization of extras of contaminants, can be provided with application of methods of rendering (moving away) of pollutants harmless or use of no waste technologies.

The following methods contribute to the purification of gases and wastewater:

- Sedimentation. In this process, solid particles in liquids or gases are deposited by gravity;

- filtration. Used to clean wastewater and gases. With the help of different filters, solid particles are separated from the gas or liquid form;
- coagulation. In this process, small particles stick together and thus become enlarged, after which they can be separated and removed;
- magnetic. Gas or water is passed through an apparatus in which a magnetic field is created. Under its influence, the metal particles change their trajectory, thus creating the conditions for their separation;
- Ultrasonic. Sound vibrations of a certain frequency affect the dispersed systems, resulting in the formation of sediments to be removed;
- adsorption. Contaminating impurities are adsorbed by an adsorbent, usually represented by activated carbons;
- adsorption. Method for gas cleaning only. Based on absorption of gases. Liquid absorbents clean them of by-products and acidic products;
- neutralization. Acidic gases are washed with aqueous neutralizing solvents;

reduction. To purify wastewater from nitro compounds as well as air from nitrogen oxides, resulting in nitrogen, water, and carbon dioxide;

flotation. For treatment of wastewater from oil, petroleum products and fats. As a result of the reaction, a foam layer is formed on the surface of the liquid, which is easily removed.

Conclusion to Part 5

In this work, the following was done.

• 1. The general characteristic of the aviation industry of Ukraine is given. The main stages of aircraft creation are described.

Technological areas of aviation industry enterprises, as well as main productions are considered.

• 2. The ecological impact of the aviation industry on the environment is studied. In the manufacture of aircraft on enterprises of the aviation industry pollute such components of the environment as: atmospheric air,
soils, ground and groundwater. Harmful substances get into atmospheric air, namely: aromatic hydrocarbons, aerosols, industrial dust, carbon monoxide and nitrogen oxide; solid particles. Soils are contaminated with liquid waste
(fuels and lubricants, battery fluids) and solid waste in the form of scrap metal, shavings, scrap and remnants of composite and plastic materials. The aquatic environment is polluted due to technological processes of the aviation industry. The most dangerous areas of enterprises are galvanic, thermal shops and storage areas for fuel and lozenges, as well as areas for direct painting of aircraft devices.

Having identified the main pollutants generated during the various production processes of the aviation industry, it is possible to conclude that the amount of their income should be regulated by applying environmental measures and adhere to regulatory documents. It is possible to reduce the formation of these substances by replacing them production technologies to more modern ones, introduction of low- and zero-waste technologies, application of treatment facilities, and development of methods for utilization and processing of waste from the aviation industry.

It is investigated that with the use of directions and ways of greening it is possible to significantly reduce the negative effects of production on the environment. The introduction of low- and zero-waste technologies will allow not to spend extra funds for waste disposal and recycling. Cleaning equipment will help reduce the amount of impurities and harmful substances in industrial effluents and dust-gas mixtures, capturing them with filters and absorbers. Transfer waste of the enterprise in related industries, will reduce the production of new natural raw materials and reduce costs of their extraction. The use of alternative energy sources will ensure the conservation of fossil fuels (gas, oil, coal), and reduce the release of oxides of sulfur, nitrogen, carbon, heavy metals, incomplete products combustion of fuel into the atmosphere. Thus, the processes of greening the aviation industry are important for improving the environment and resource conservation. 4. Measures were proposed from ensuring the environmental safety of the aviation industry, which covers the water and air environment. Considered methods of utilization and processing of solid waste of the aviation industry.

GENERAL CONCLUSION

The urgent task of modern mechanical engineering is to ensure the durability of machine parts, which is largely determined by the quality of the surface layer. Important are the issues of increasing the reliability of devices, installations, improving their quality and efficiency, and, consequently, the issues of metal saving, combating corrosion and wear of machine parts. It is especially important nowadays, as development of the majority of industries (aviation, rocket, heat power, nuclear power, radioelectronics, etc.) is connected with increase in loads, temperatures, aggressiveness of environments in which a part works. The solution of these problems, first of all, is connected with strengthening the surface layers of metal products. It is possible to change surface layer properties in different ways: by applying on a surface a new material with needed properties; by changing the structure of metal surface layer; by heat, chemical and mechanical surface treatment and by other means. As the necessary set of operational characteristics and resource of products is laid down at the stage of their production, it is extremely important to control the quality of the initial materials and determine the depth of the hardened layer. It is the control of mechanical properties at the stage of manufacturing that should be of primary importance in the realization of a complex program of diagnostics of objects during their operation, since only in this case it is possible to fix the tendency of change of those parameters, on which the residual resource depends.

Thus, to determine the characteristics of surfaces, microstructure and mechanical properties of the hardened layers of metal products, it is advisable to use nondestructive testing, which is currently turning into an independent industry that solves the problems of inspection and creation of equipment, testing methods, scientific research, certification, standardization and training. Researches has shown that this method of hardening can increase the hardness by about three times, the modulus of elasticity approximately on 50% (170 GPa). Master thesis is prepeared according to the requirements of aircraft design department [25].

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