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АЕРОКОСМІЧНИЙ ФАКУЛЬТЕТ
КАФЕДРА ПІДТРИМАННЯ ЛЬОТНОЇ ПРИДАТНОСТІ ПОВІТРЯНИХ СУДЕН

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
канд. техн. наук, доц.
________________О.В. Попов
«_____»_____________2022 р.

КВАЛІФІКАЦІЙНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ МАГІСТРА

ЗА ОСВІТНЬО-ПРОФЕСІЙНОЮ ПРОГРАМОЮ «ТЕХНІЧНЕ ОБСЛУГОВУВАННЯ ТА РЕМОНТ ПОВІТРЯНИХ СУДЕН І АВІАДВИГУНІВ»

Тема: «Дослідження зносостійкості високотемпературних покриттів при фретинг-корозії»

Виконав: ______________ **О.В. Семенюк**

Керівник: канд. техн. наук, доц ______________ **А.М. Хімко**

Консультанти з окремих розділів пояснювальної записки:

Охорона праці: канд. техн. наук, доц. ______________ **К.І. Кажан**

Охорона навколишнього середовища:
канд. техн. наук, доц ______________ **Л.І. Павлюх**

Нормоконтролер: ______________

КИЇВ 2022

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
AEROSPACE FACULTY
AIRCRAFT CONTINUING AIRWORTHINESS DEPARTMENT

PPERMISSION TO DEFEND
Head of the department
Ph. D., Assoc. Professor
_____________ O. V. Popov
«____”_____________ 2022

MASTER`S DEGREE THESIS

(EXPLANATORY NOTE)

GETTER ACADEMIC MASTER DEGREE

FOR EDUCATIONAL-PROFESSIONAL PROGRAM
«MAINTENANCE AND REPAIR OF AIRCRAFT AND AVIATION ENGENS»

Topic: «Research of wear resistance of high-temperature coverings at fretting corrosion»

Createdby: ______________ **O.V. Semeniuk**

Supervisor:
Candidate of science (Engineering),
assoc. prof. ______________ **A.M. Khimko**

Advisers on separate parts of the explanatory note:
Labour precaution:
Candidate of science (Engineering), assoc. prof.______________ **K.I. Kazhan**

Environmental protection:
Candidate of Science (Engineering),
assoc. prof. ______________ **L.I. Pavlyukh**

Standard inspector: ______________

KYIV 2022

NATIONAL AVIATION UNIVERSITY

Faculty: Aerospace faculty
Aircraft Continuing Airworthiness Department
Educational and Qualifications level: «Master Degree»
The specialty: 272 «Aviation transport»
Educational-professional program «Maintenance and Repair of Aircraft and Engines»

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Ph. D., Assoc. Professor
_____________ O. V. Popov
«____”_______________ 2022

TASK

for diploma work performance of master

SEMENIUK OREST

1. Work theme: «Research of wear resistance of high-temperature coverings at fretting corrosion» approved by rector order № 1786/ст of September 26, 2022.
2. Work execution period: from September 26, 2022 till November 30, 2022.
3. Initial data for work execution: basic data about wear resistance of composite materials in civil and military aviation.
4. Content of explanatory note: basic definitions and classifications, defects of composites, reseach methods for composite materials for friction, friction test.
5. List of required illustrated material: Slide show presentation for to highlight the idea of a thesis. Illustrated material is prepared using OSP-KOMPAS and Microsoft PowerPoint Presentation programs.

6. Timetable

Tasks	Completion dates	Remarks
Analysis of using of the composite elements in the aircraft engine	26.09.2022 – 28.09.2022	
Analysis and generalization the material collected	29.09.2022 – 10.10.2022	
Friction formation. Types of friction. Influence of friction on the engine elements of the aircraft	11.10.2022 – 16.10.2022	
Description of problem areas of the gas turbine engine	17.10. 2022 – 25.10. 2022	
Solving the problems associated with the formation of friction wear with the help of powder composites	26.10.2022 – 30.10. 2022	
Preparation of special sections: Labour Precaution, Environmental Protection	01.11. 2022 – 03.11. 2022	
Preparation of illustrate material, writing the report	04.11. 2022 – 07.11. 2022	
Explanatory note checking, editing and correction	08.11. 2022 – 12.11. 2022	

7. Advisers on individual sections of the Thesis:

Section	Adviser	Date, Signature	
		Assignment Delivered	Assignment Accepted
Labour precaution	Candidate of science (Engineering), assoc. prof. K.I. Kazhan		
Environmental protection	Candidate of Science (Engineering), assoc. prof. L.I. Pavlyukh		

8. Assignment issue date «___» _____________ 2022

Thesis supervisor: _____________ A.M. Khimko

Assignment is accepted for performing _____________ O.V. Semeniuk

ABSTRUCT

Explanatory note for diploma work named as “Research of wear resistance of high-temperature coverings at fretting corrosion”:

112 pages, 47 figures, 15 references, 4 tables

Object of research is the process of wearing composite materials when friction.

Subject of research airpowder composite materials that are used to protect parts from wear.

Purpose of the work is improving the characteristics of turbine blades, increasing their durability, strength.

Research method is method on the base of improving of wear resistance of the turbine blades with the help of powder composites and spray coating.

Practical meaning of diploma work results is showed increasing of effectiveness, cheaper, reducing the amount of time.

Materials of diploma work are recommended to use during study process and practical activity of design bureau specialists and at repair factories.

COMPOSITE MATERIALS, AIRCRAFT COMPOSITES, WEAR RESISTANCE, REPAIRMETHODS, POWDER COMPOSITE, FRICTION OF COMPOSITE

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LIST OF CONDITIONS, SYMBOLS AND INDEXES

CM – composite materials

OMC – organic Matrix Composites

MMC – metal Matrix Composites

CMC – ceramic Matrix Composites

PMC – polymer Matrix Composites

FRP – fibre Reinforced composites

COF – coefficient of friction

THE – turbojet engine

SEM – scanning electron microscope

XRD – with X-ray diffraction

SiC – silicon carbide

BC – boron carbide

GTE – gas turbine engine

LPPS – low pressure plasma spraing

VPHET – vacuum plasma high energy technology

UV – ultraviolet

MF – maintenance factor

LLF – light loss factor

UF – utilization factor

BOD – biochemical oxygen demand

DO – dissolved oxygen

UFP – ultrafine particles

EASA – EuropeanAviationSafetyAgency

FAA – FederalAviationAdministration

LCA – lifecycle assessment

ISO – InternationalOrganizationforStandardization

GLARE – glass laminate aluminum reinforced epoxy

Θ – angle from horizontal coefficient of friction

μs – static coefficient of friction

N – normal force

A – amplitude of relative displacement

P – specific contact load

υ – frequency of vibrational displacement

T – external temperature

E – illuminance level

F_{max} – maximum force

INTRODUCTION

Working conditions of turbine blades modern aviation gas turbine engines (GTE) characterized by high levels of current static loads, wide range of operating temperatures, high speed of rotation, and as a result – high vibroloading. Given the general trend towards the growth of inter-repair and general technical resources are increasing the increase of traction characteristics becomes more significant GTE, which causes an increase in the limits of permissible loads and operating temperatures of blades.

To reduce the vibroload, the blades are tightened in the upper part on the zigzag surfaces. As a result of vibro displacement is intense wear contact the surfaces of the shelves as a result of the development of fretting-corrosion that leads to increased wear and premature release parts of the system [1]. In addition, the destruction due to the occurrence cyclic displacements in a nominally fixed connection. The shanks of the blades are also subjected. The purpose of the study was to find such a material, which at higher operating temperatures should have higher values wear resistance.

PART 1

BASICDEFINITIONS AND CLASSIFICATIONS. DEFECTS OF COMPOSITES

1.1 Classification of composites

Composite materials are commonly classified at following two distinct levels:

- The first level of classification is usually made with respect to the matrix constituent. The major composite classes include Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs). The term organic matrix composite is generally assumed to include two classes of composites, namely Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon-carbon composites.

- The second level of classification refers to the reinforcement form - fibrereinforced composites, laminar composites and particulate composites. Fibre Reinforced composites (FRP) can be further divided into those containing discontinuous or continuous fibres.

- Fibre Reinforced Composites are composed of fibres embedded in matrix material. Such a composite is considered to be a discontinuous fibre or short fibre composite if its properties vary with fibre length. On the other hand, when the length of the fibre is such that any further increase in length does not further increase, the elastic modulus of the composite, the composite is considered to be continuous fibre reinforced. Fibres are small in diameter and when pushed axially, they bend easily although they have very good tensile properties. These fibres must be supported to keep individual fibres from bending and buckling [2].

- Laminar Composites are composed of layers of materials held together by matrix. Sandwich structures fall under this category.

- Particulate Composites are composed of particles distributed or embedded in a matrix body. The particles may be flakes or in powder form. Concrete and wood particle boards are examples of this category.

Polymer Matrix Composites /Carbon Matrix Composites or Carbon-Carbon Composites

Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. It follows, therefore, that high temperature resins are extensively used in aeronautical applications.

Two main kinds of polymers are thermosets and thermoplastics. Thermosets have qualities such as a well-bonded three-dimensional molecular structure after curing. They decompose instead of melting on hardening. Merely changing the basic composition of the resin is enough to alter the conditions suitably for curing and determine its other characteristics.

They can be retained in a partially cured condition too over prolonged periods of time, rendering Thermosets very flexible. Thus, they are most suited as matrix bases for advanced conditions fiber reinforced composites. Thermosets find wide ranging applications in the chopped fiber composites form particularly when a premixed or moulding compound with fibers of specific quality and aspect ratio happens to be starting material as in epoxy, polymer and phenolic polyamide resins.

Thermoplastics have one- or two-dimensional molecular structure and they tend to at an elevated temperature and show exaggerated melting point. Another advantage is that the process of softening at elevated temperatures can reversed to regain its properties during cooling, facilitating applications of conventional compress techniques to mould the compounds.

Resins reinforced with thermoplastics now comprised an emerging group of composites. The theme of most experiments in this area to improve the base properties of the resins and extract the greatest functional advantages from them in new avenues, including attempts to replace metals in die-casting processes. In crystalline thermoplastics, the reinforcement affects the morphology to a considerable extent, prompting the reinforcement to empower nucleation. Whenever crystalline or amorphous, these resins possess the facility to alter their creep over an extensive range of temperature. But this range includes the point at which the usage of resins is constrained, and the reinforcement in such systems can increase the failure load as well as creep resistance. Figure.1.1 shows kinds of thermoplastics.

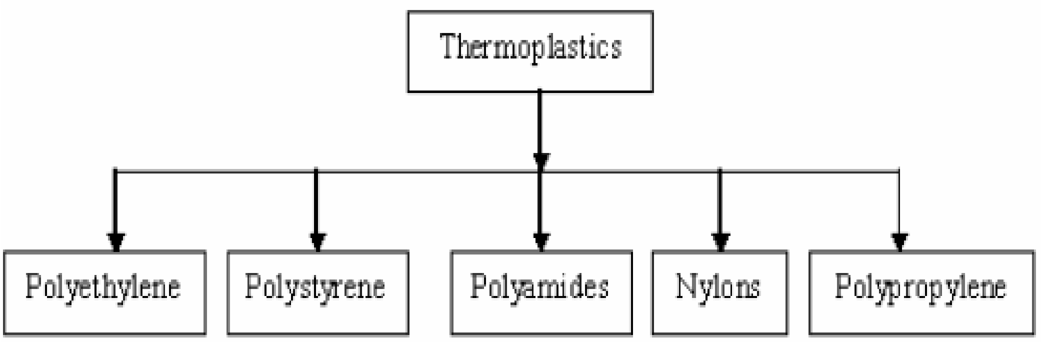


Figure 1.1 – Thermoplastics

A small quantum of shrinkage and the tendency of the shape to retain its original form are also to be accounted for. But reinforcements can change this condition too. The advantage of thermoplastics systems over thermosets are that there are no chemical reactions involved, which often result in the release of gases or heat. Manufacturing is limited by the time required for heating, shaping and cooling the structures.

Thermoplastics resins are sold as moulding compounds. Fiber reinforcement is apt for these resins. Since the fibers are randomly dispersed, the reinforcement will be almost isotropic. However, when subjected to moulding processes, they can be aligned directionally.

There are a few options to increase heat resistance in thermoplastics. Addition of fillers raises the heat resistance. But all thermoplastic composites tend lose their strength at elevated temperatures. However, their redeeming qualities like rigidity, toughness and ability to repudiate creep, place thermoplastics in the important composite materials bracket. They are used in automotive control panels, electronic products encasement etc.

Newer developments augur the broadening of the scope of applications of thermoplastics. Huge sheets of reinforced thermoplastics are now available and they only require sampling and heating to be moulded into the required shapes. This has facilitated easy fabrication of bulky components, doing away with the more cumbersome moulding compounds.

Thermosets are the most popular of the fiber composite matrices without which, research and development in structural engineering field could get truncated. Aerospace components, automobile parts, defense systems etc., use a great deal of this type of fiber composites. Epoxy matrix materials are used in printed circuit boards and similar areas. Figure1.2 shows some kinds of thermosets.

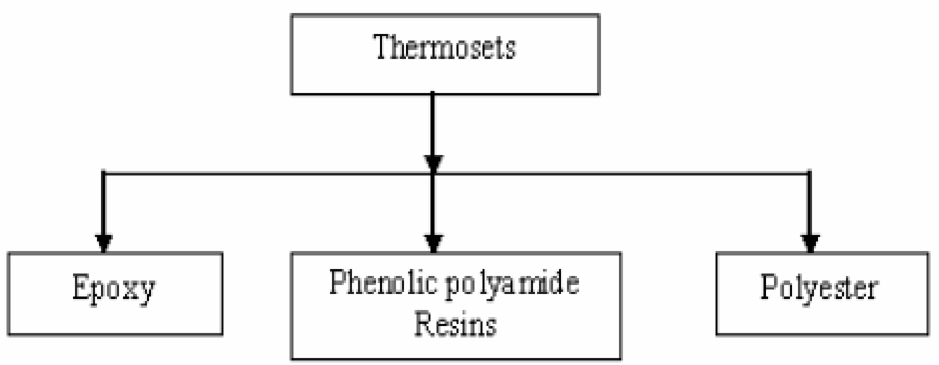


Figure 1.2 – Thermoset Materials

Direct condensation polymerization followed by rearrangement reactions to form heterocyclic entities is the method generally used to produce thermoset resins. Water, a product of the reaction, in both methods, hinders production of void-free composites. These voids have a negative effect on properties of the composites in terms of strength and dielectric properties. Polyesters phenolic and Epoxies are the two important classes of thermoset resins.

Epoxy resins are widely used in filament-wound composites and are suitable for moulding prepress. They are reasonably stable to chemical attacks and are excellent adherents having slow shrinkage during curing and no emission of volatile gases. These advantages, however, make the use of epoxies rather expensive. Also, they cannot be expected beyond a temperature of 140 ºC. Their use in high technology areas where service temperatures are higher, as a result, is ruled out [4, 5].

Polyester resins on the other hand are quite easily accessible, cheap and find use in a wide range of fields. Liquid polyesters are stored at room temperature for months, sometimes for years and the mere addition of a catalyst can cure the matrix material within a short time. They are used in automobile and structural applications.

The cured polyester is usually rigid or flexible as the case may be and transparent. Polyesters withstand the variations of environment and stable against chemicals. Depending on the formulation of the resin or service requirement of application, they can be used up to about 75 ºC or higher. Other advantages of polyesters include easy compatibility with few glass fibers and can be used with verify of reinforced plastic accouter.

Aromatic Polyamides are the most sought after candidates as the matrices of advanced fiber composites for structural applications demanding long duration exposure for continuous service at around 200-250 ºC .

Metal Matrix Composites

Metal matrix composites (MMC), at present though generating a wide interest in research fraternity, are not as widely in use as their plastic counterparts. High strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites. Most metals and alloys could be used as matrices and they require reinforcement materials which need to be stable over a range of temperature and nonreactive too. However the guiding aspect for the choice depends essentially on the matrix material. Light metals form the matrix for temperature application and the reinforcements in addition to the aforementioned reasons are characterized by high modules.

Most metals and alloys make good matrices. However, practically, the choices for low temperature applications are not many. Only light metals are responsive, with their low density proving an advantage. Titanium, Aluminium and magnesium are the popular matrix metals currently in vogue, which are particularly useful for aircraft applications. If metallic matrix materials have to offer high strength, they require high modulus reinforcements. The strength-to-weight ratios of resulting composites can be higher than most alloys.

The melting point, physical and mechanical properties of the composite at various temperatures determine the service temperature of composites. Most metals, ceramics and compounds can be used with matrices of low melting point alloys. The choice of reinforcements becomes more stunted with increase in the melting temperature of matrix materials.

Ceramic Matrix Materials

Ceramics can be described as solid materials which exhibit very strong ionic bonding in general and in few cases covalent bonding. High melting points, good corrosion resistance, stability at elevated temperatures and high compressive strength, render ceramic-based matrix materials a favourite for applications requiring a structural material that doesn’t give way at temperatures above 1500 ºC. Naturally, ceramic matrices are the obvious choice for high temperature applications.

High modulus of elasticity and low tensile strain, which most ceramics possess, have combined to cause the failure of attempts to add reinforcements to obtain strength improvement. This is because at the stress levels at which ceramics rupture, there is insufficient elongation of the matrix which keeps composite from transferring an effective quantum of load to the reinforcement and the composite may fail unless the percentage of fiber volume is high enough. A material is reinforcement to utilize the higher tensile strength of the fiber, to produce an increase in load bearing capacity of the matrix. Addition of high-strength fiber to a weaker ceramic has not always been successful and often the resultant composite has proved to be weaker.

The use of reinforcement with high modulus of elasticity may take care of the problem to some extent and presents pre-stressing of the fiber in the ceramic matrix is being increasingly resorted to as an option.

When ceramics have a higher thermal expansion coefficient than reinforcement materials, the resultant composite is unlikely to have a superior level of strength. In that case, the composite will develop strength within ceramic at the time of cooling resulting in micro cracks extending from fiber to fiber within the matrix. Micro cracking can result in a composite with tensile strength lower than that of the matrix.

Laminar Composites/Laminate Reinforced Composites

Laminar composites are found in as many combinations as the number of materials. They can be described as materials comprising of layers of materials bonded together. These may be of several layers of two or more metal materials occurring alternately or in a determined order more than once, and in as many numbers as required for a specific purpose.

Clad and sandwich laminates have many areas as it ought to be, although they are known to follow the rule of mixtures from the modulus and strength point of view. Other intrinsic values pertaining to metal-matrix, metal-reinforced composites are also fairly well known.

Powder metallurgical processes like roll bonding, hot pressing, diffusion bonding, brazing and so on can be employed for the fabrication of different alloys of sheet, foil, powder or sprayed materials. It is not possible to achieve high strength materials unlike the fiber version. But sheets and foils can be made isotropic in two dimensions more easily than fibers. Foils and sheets are also made to exhibit high percentages of which they are put. For instance, a strong sheet may use over 92 % in laminar structure, while it is difficult to make fibers of such compositions. Fiber laminates cannot over 75 % strong fibers. The main functional types of metal-metal laminates that do not possess high strength or stiffness are single layered ones that endow the composites with special properties, apart from being cost-effective. They are usually made by pre-coating or cladding methods [6].

Pre-coated metals are formed by forming a layer on a substrate, in the form of a thin continuous film. This is achieved by hot dipping and occasionally by chemical plating and electroplating. Clad metals are found to be suitable for more intensive environments where denser faces are required.

There are many combinations of sheet and foil which function as adhesives at low temperatures. Such materials, plastics or metals, may be clubbed together with a third constituent. Pre-painted or pre-finished metal whose primary advantage is elimination of final finishing by the user is the best known metal-organic laminate. Several combinations of metal-plastic, vinyl-metal laminates, organic films and metals, account for upto 95 % of metal-plastic laminates known. They are made by adhesive bonding processes.

Common Categories of Composite Materials based on fibre length

Based on the form of reinforcement, common composite materials can be classified as follows:

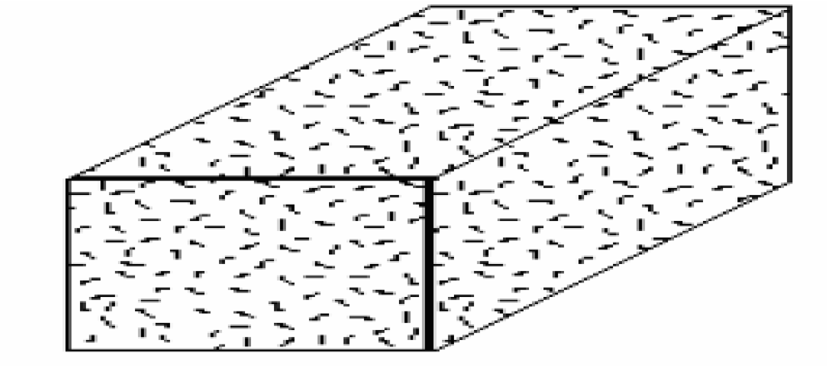


Figure 1.3 – Short-fibre reinforced composites

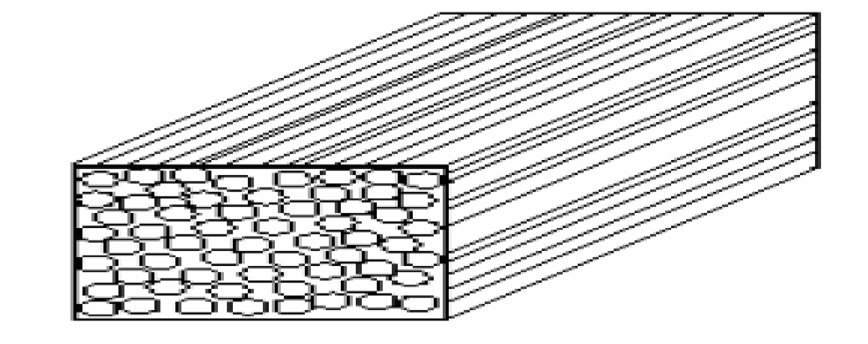


Figure 1.4 – Long-fibre reinforced composites

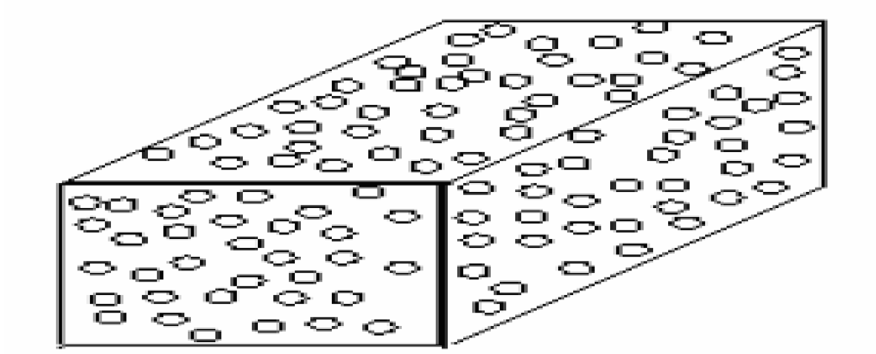


Figure 1.5 – Particulate Composites

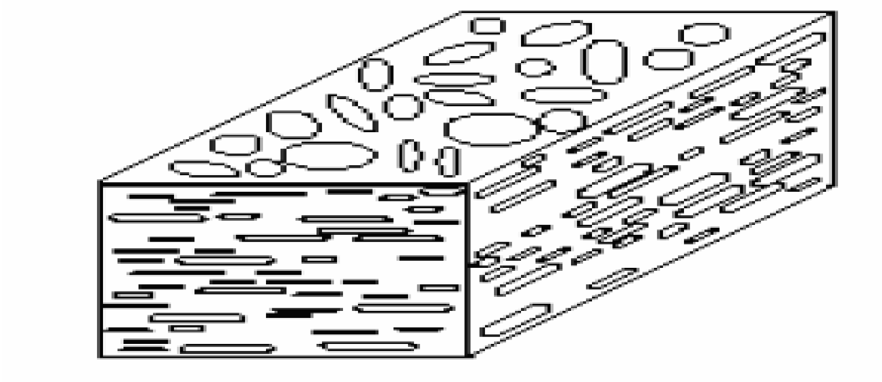


Figure 1.6 – Flake Composites

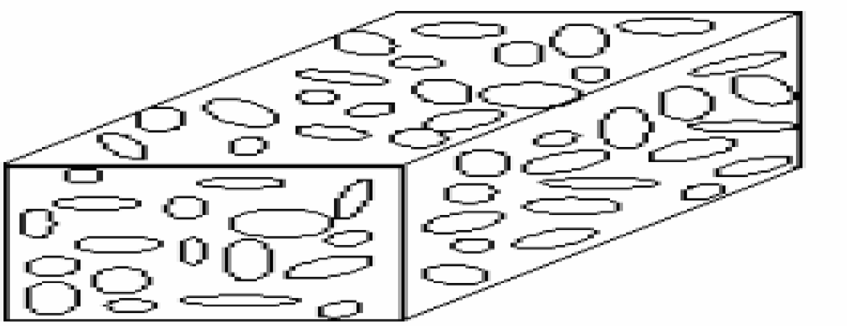


Figure 1.7 – Filler Composites

Role and selection of fibers

The points to be noted in selecting the reinforcements include compatibility with matrix material, thermal stability, density, melting temperature etc. The efficiency of discontinuously reinforced composites is dependent on tensile strength and density of reinforcing phases. The compatibility, density, chemical and thermal stability of the reinforcement with matrix material is important for material fabrication as well as end application. The thermal discord strain between the matrix and reinforcement is an important parameter for composites used in thermal cycling application. It is a function of difference between the coefficients of thermal expansion of the matrix and reinforcement. The manufacturing process selected and the reinforcement affects the crystal structure.

Also the role of the reinforcement depends upon its type in structural Composites. In particulate and whisker reinforced Composites, the matrix are the major load bearing constituent. The role of the reinforcement is to strengthen and stiffen the composite through prevention of matrix deformation by mechanical restraint. This restraint is generally a function of the ratio of inter-particle spacing to particle diameter. In continuous fiber reinforced Composites, the reinforcement is the principal load-bearing constituent. The metallic matrix serves to hold the reinforcing fibers together and transfer as well as distribute the load. Discontinuous fiber reinforced Composites display characteristics between those of continuous fiber and particulate reinforced composites. Typically, the addition of reinforcement increases the strength, stiffness and temperature capability while reducing the thermal expansion coefficient of the resulting MMC. When combined with a metallic matrix of higher density, the reinforcement also serves to reduce the density of the composite, thus enhancing properties such as specific strength [7].

1.2 Damage types in details

Damage mechanisms in composites are not as well understood as metals. Defects can be happen in composite materials and structures during the manufacturing process or in the service life of the structure/part/component. The manufacturing process has a wide range of potential for causing defects in composites. The most common one is porosity which is the presence of a void in the matrix. The porosity can be caused by incorrect or non-optimal curing parameters. Inclusion of foreign bodies in matrix is another defect which happens during the manufacturing process which ranges from backing film to a greasy finger marks.

Dent: A Dent is depressed or hollow deformations without removal of material or change in cross sectional area (see scratch & crack definition below). Stress wrinkles caused by failure of a fastener are not considered a dent. Generally dents are caused by impact from a smoothly contoured object. One characteristic that all dents should have is a "pushed in surface" and a relatively smooth bottom where metal is not displaced, folded or creased. Many Aircraft Structural Repair Manuals specify that a "crease" be treated as a crack. Generally when evaluating dents, the width of the dent is the second longest distance across the dent, measured at 90 degrees to the direction of the length.

Nicks: Broken edges without cracks, but with portions of material removed. Negligible damage limits will vary with structure, material, and loading.

Scratches: Marks penetrating the surface that reduce the structural cross section of the material but do not penetrate the complete thickness. The depth of a scratch may be determined by use of an optical micrometer. Generally, scratches in Alclad aluminum alloy sheet that do not penetrate the protective Alclad layer are classified as negligible.

Cracks: Fractures that would not separate the material into two parts if the surrounding supports were removed; usually originating at edges, holes, or points where concentrated loads are applied or where abrupt changes in cross-sectional area occur. Cracks cause a significant cross-sectional area change. This damage usually has an irregular line and is often the result of fatigue in the material. The length of cracks that may be tolerated varies widely with material, structure, and application. No crack should be regarded as negligible until the damage limits for the affected structure have been determined.

Holes: Punctures, penetrations or cutouts that breach the complete thickness of the material and is fully surrounded by undamaged material. The size, shape, and distance from edges and supporting structures must be considered when evaluating hole damage.

Abrasion: A damaged area that is the result of scuffing, rubbing, scraping, or other surface erosion. This type of damage is usually rough and has an irregular shape.

Gouge: A damaged area where the result is a cross-sectional change caused by a sharp object and gives a continuous, sharp or smooth groove in the material

Corrosion: Deterioration of a metal because of an electrochemical reaction with its environment. Depending on the type of corrosion, this deterioration may take the form cracking, exfoliation, or erosion of the corroding material. Corrosion damage is typically classified as light, moderate, or severe, depending on the extent of the corrosion and the loading requirements of the corroded part. Aircraft-specific structural manuals should be consulted for the correct classification of corrosion damage on a given part.

Delamination: Separation of the layers of material in a laminate, either local or covering a wide area, that occurs during manufacturing or in service. Fiber-reinforced and composites may delaminate when impacted and not exhibit visible damage.

Disbonds: An area within a bonded interface between two adherents in which an adhesion failure or separation has occurred. If the separation is performed deliberately to referred to as a debond [8].

Damage classifications

All damage must be classified to determine what repair action should be taken. Ultimately, all discrepancies will be placed into one of three categories—negligible damage, nonrepairable damage, or repairable damage. The decision concerning disposition must be made considering the requirements of the aircraft, the particular parts involved, the limitations that can be placed on the repaired aircraft, the degree of urgency, and any other circumstances impacting the situation.

Negligible damage is damage that can be permitted to exist “as is,” or corrected by a single cosmetic refinishing procedure with no restrictions on flight operations. This damage may also include some delaminations, disbonds, and voids.

Nonrepairable damage exceeds published criteria or limits. Nonrepairable damage may be reclassified as repairable, if cognizant engineering authority prescribes a repair on an individual basis. Normally, nonrepairable damage requires the changing of components.

Repairable damage is any damage to the skin, bond, or core that cannot be allowed to exist “as is” without placing performance restrictions on the aircraft. All permanent repairs must be structural, restore load-carrying capabilities, meet aerodynamic smoothness requirements, and meet the environmental durability requirements of the aircraft. Repairable damage is divided into several classifications. The aircraft's SRM provides the approved repair procedures for all levels of maintenance. Information contained in the SRM includes damage classifications; procedures; typical repair procedures; and tool and material lists. Damage exceeding any of these classifications requires engineering disposition. The examples listed below may vary somewhat, depending upon the type of aircraft and the specific location of the damage on the aircraft.

Class I – Cuts, scratches, pits, erosion or abrasions not exceeding 0.005 inch in depth and 5 inches in length [9].

Class II – Damage with dents in the skin up to 3 inches in diameter and 0.01 inch in depth with no delamination between skin plies; no cracks or graphite fiber breakage; or skin to honeycomb core separation.

Class III – Delaminations between plies, including the skin land area, opened up to external edge and up to 1 1/2 inches in diameter.

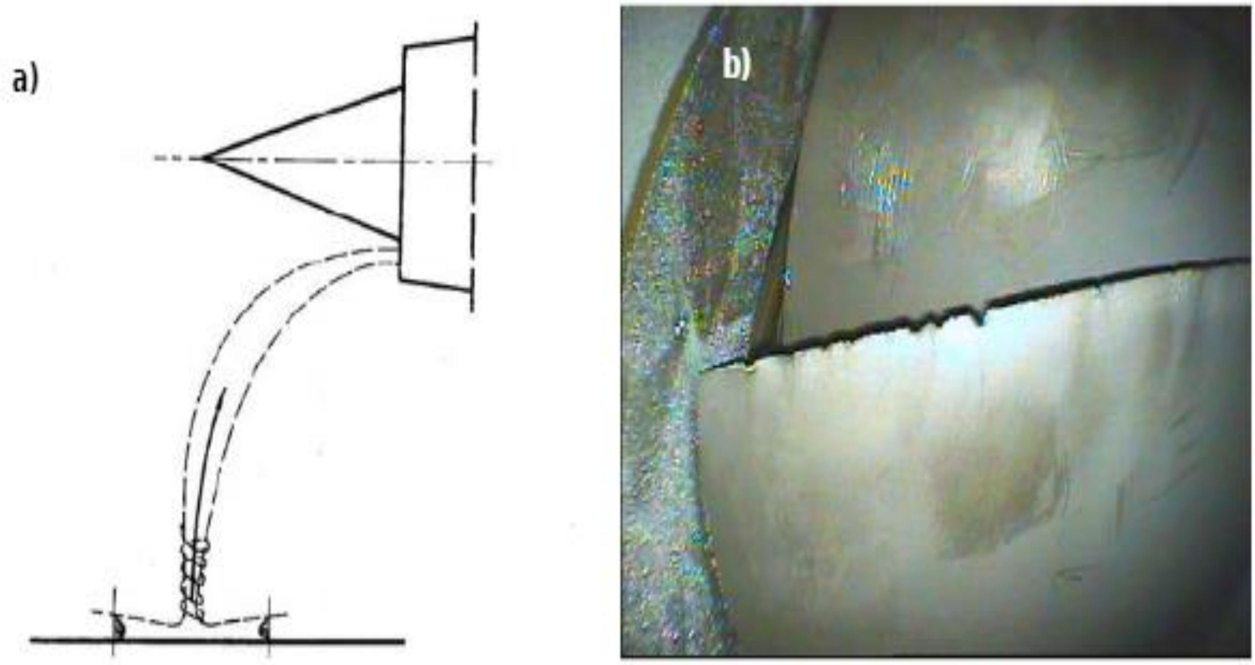
Class IV – Skin damage including delaminations, cracks, cuts, scratches or skin erosion exceeding 0.015 inch in depth, but less than full penetration, with no damage to honeycomb core.

Class V – Damage to single skin, including full penetration, accompanied by honeycomb core damage.

Class VI – Damage to both skins, including full penetration, accompanied by honeycomb core damage.

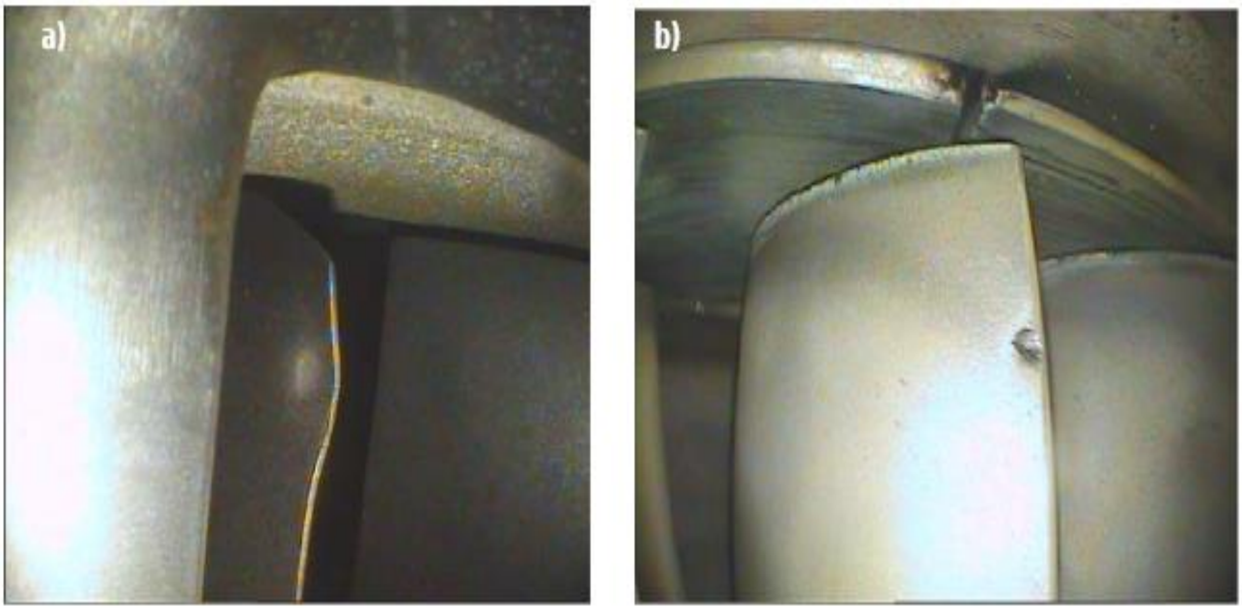
Class VII – Damage with water trapped in honeycomb area.

Impurities ingested by air vortex cause mechanical damages to individual components of gas path – in particular, to compressor rotor blades (Figure 1.8). The result of such damages is disturbance of engine performance parameters, what has also adverse influence on working temperature of the gas turbine. On account of the complicated nature of thermal and mechanical loads on turbine blades inadmissible are any mechanical and thermal damages to blades, because it may lead to the break-off of a blade, and consequently to the engine damage, and hence, hazard to flight safety. Some types of mechanical damages resulting from the foreign-matter ingestion are detected after finding damages to the compressor’s first-stage components during pre- or after-flight maintenance, or in the course of the first borescope examination after the event, carried out during periodical maintenance of the engine. (Figure 1.9)



a – vortex at engine intake ; b – damage to compressor blades caused by impurities

Figure 1.8 – Schematic diagram of air vortex



a – compressor blades b – turbine blades

Figure 1.9 – Examples of damages effected by the ingestion of steel balls from the runway

Small spot damages or small abrasions of blade surface are often invisible during first hours of engine operation after the damage has occurred, and they are not detected by a diagnostician in the course of diagnostic examination. A damage to blade protective coating together with high temperature and exhaust-gas induced aggressive environment may result in the overheating and burnout of the native material of the blade (Figure 1.10).

Figure1.10 – Exemplary types of thermal damages to leading edges of turbine rotor blades

Manufacturing and repair-effected defects are another group of damages detected within the hot section of the engine during preventive diagnostic tests. These are damages beyond the user’s reach and can reveal throughout the entire period of engine operation. The break-off of a turbine rotor blade caused by spreading a new type of a protective coating applied with diffusion method onto the blade material is one of the most interesting and at the same time the most dangerous events. In the course of turbine operation a fragile coating suffered cracking; the crack propagated into the native material of the blade and finally resulted in the break-off of the blade (Figure 1.11).

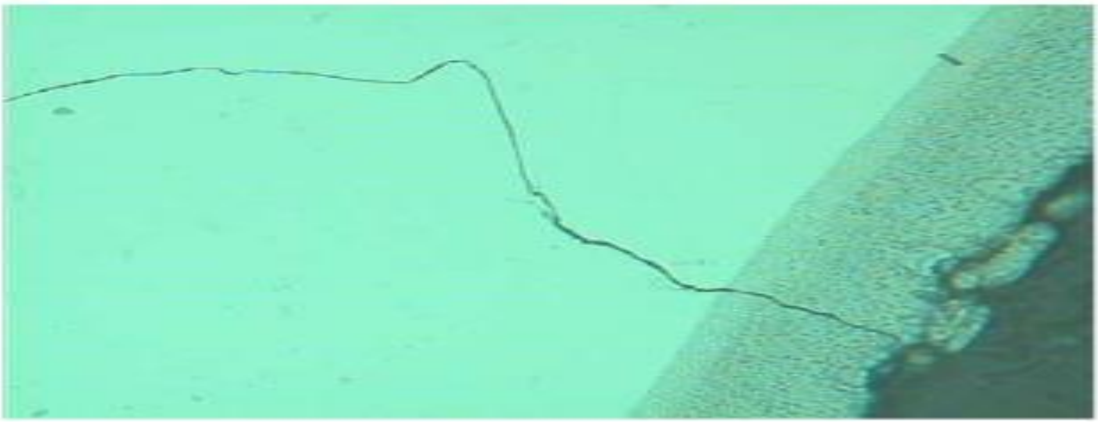


Figure 1.11 – Protective-coating cracking; the crack keeps propagating into the blade’s native material

The hitherto experience gained in the course of research work at the Air Force Institute of Technology shows also that the majority of turbine defects are directly related with incorrect adjustments of the engine and poor quality of aviation fuel. Incorrect fuel pressure, its physical and chemical properties deteriorated by various kinds of impurities, and misalignment of the flame tube injector prove conducive to the formation of carbon deposit on the injectors (Figure 1.12 a) and other sub-assemblies, what results in faulty fuel spraying. This, in turn, results in disturbance of the combustion process organisation, and consequently of temperature distribution and cooling of individual components of the hot section of the engine. What results is overheating of material of combustion chamber and turbine blades (Figure 1.12 b)

a – fuel injector b –turbine blades

Figure 1.12 – Carbon deposit on fuel injector of a turbojet and thermal damage to turbine blades

1.3 Friction

Friction is the force resisting the relative motion of solid surfaces, fluid layers, and material against each other.

Static friction

Static friction is friction between two or more solid objects that are not moving relative to each other. For example, static friction can prevent an object from sliding down a sloped surface. The coefficient of static friction, typically denoted as μ_s, is usually higher than the coefficient of kinetic friction. Static friction is considered to arise as the result of surface roughness features across multiple length-scales at solid surfaces. These features, known as a sperities are present down to nano-scale dimensions and result in true solid to solid contact existing only at a limited number of points accounting for only a fraction of the apparent or nominal contact area. The linearity between applied load and true contact area, arising from asperity deformation, gives rise to the linearity between static frictional force and normal force, found for typical Amonton-Coulomb type friction. The static friction force must be overcome by an applied force before an object can move. The maximum possible friction force between two surfaces before sliding begins is the product of the coefficient of static friction and the normal forceWhen there is no sliding occurring, the friction force can have any value from zero up to Any force smaller than attempting to slide one surface over the other is opposed by a frictional force of equal magnitude and opposite direction. Any force larger than overcomes the force of static friction and causes sliding to occur. The instant sliding occurs, static friction is no longer applicable — the friction between the two surfaces is then called kinetic friction.

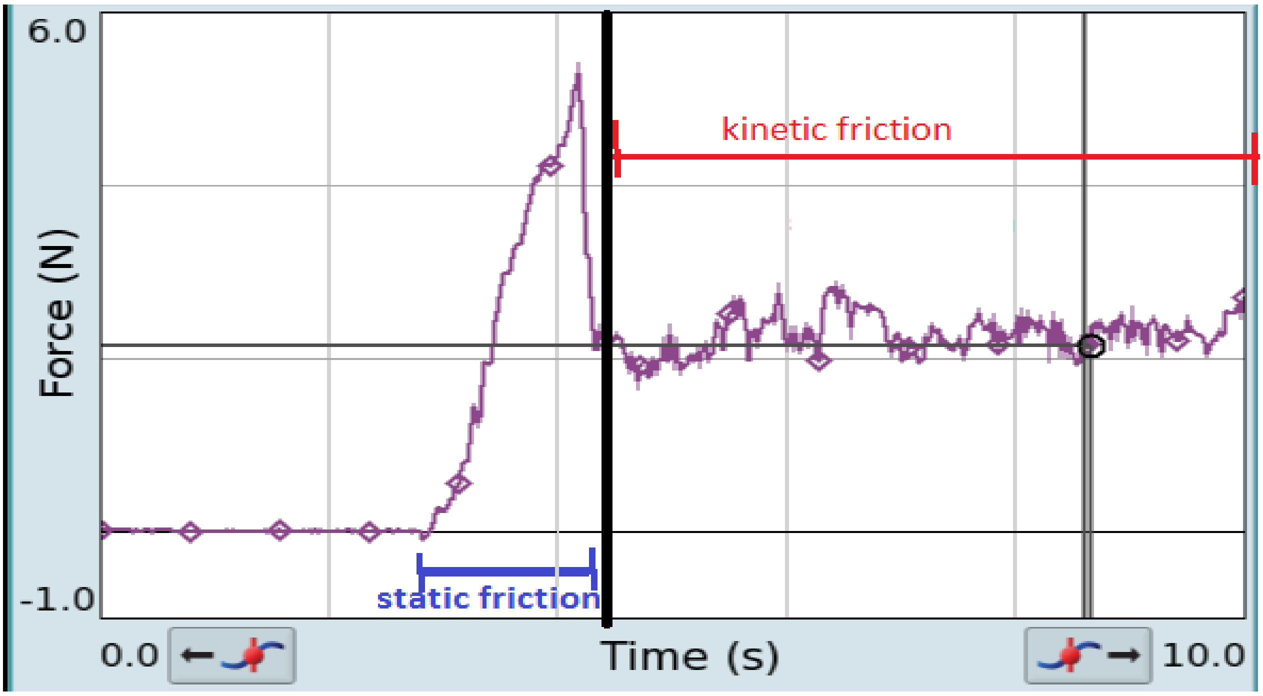


Figure 1.13 – Friction graph

When the mass is not moving, the object experiences static friction. The friction increases as the applied force increases until the block moves. After the block moves, it experiences kinetic friction, which is less than the maximum static friction.

Kinetic friction

Kinetic friction, also known as dynamic friction or sliding friction, occurs when two objects are moving relative to each other and rub together (like a sled on the ground). The coefficient of kinetic friction is typically denoted as μ_k, and is usually less than the coefficient of static friction for the same materials. However, Richard Feynman comments that with dry metals it is very hard to show any difference. The friction force between two surfaces after sliding begins is the product of the coefficient of kinetic friction and the normal force.

New models are beginning to show how kinetic friction can be greater than static friction. Kinetic friction is now understood, in many cases, to be primarily caused by chemical bonding between the surfaces, rather than interlocking asperities; however, in many other cases roughness effects are dominant, for example in rubber to road friction. Surface roughness and contact area affect kinetic friction for micro- and nano-scale objects where surface area forces dominate inertial forces.

The origin of kinetic friction at nanoscale can be explained by thermodynamics. Upon sliding, new surface forms at the back of a sliding true contact, and existing surface disappears at the front of it. Since all surfaces involve the thermodynamic surface energy, work must be spent in creating the new surface, and energy is released as heat in removing the surface. Thus, a force is required to move the back of the contact, and frictional heat is released at the front.

Angle of friction

For the maximum angle of static friction between granular materials. For certain applications it is more useful to define static friction in terms of the maximum angle before which one of the items will begin sliding. This is called the angle of friction or friction angle Θ is the angle from horizontal and $\mu_s$is the static coefficient of friction between the objects. This formula can also be used to calculate μ_s from empirical measurements of the friction angle [10].

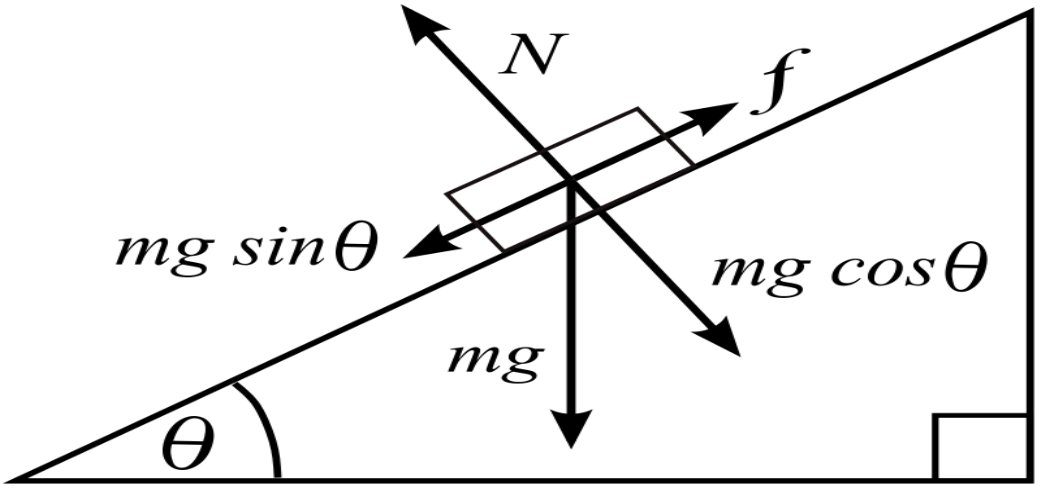


Figure 1.14 – Angle of friction θ, when block just starts to slide

The normal force is defined as the net force compressing two parallel surfaces together; and its direction is perpendicular to the surfaces. In the simple case of a mass resting on a horizontal surface, the only component of the normal force is the force due to gravity. In this case, the magnitude of the friction force is the product of the mass of the object, the acceleration due to gravity, and the coefficient of friction. However, the coefficient of friction is not a function of mass or volume; it depends only on the material. For instance, a large aluminum block has the same coefficient of friction as a small aluminum block. However, the magnitude of the friction force itself depends on the normal force, and hence on the mass of the block [11].

If an object is on a level surface and the force tending to cause it to slide is horizontal, the normal force between the object and the surface is just its weight, which is equal to its mass multiplied by the acceleration due to earth's gravity, g. If the object is on a tilted surface such as an inclined plane, the normal force is less, because less of the force of gravity is perpendicular to the face of the plane. Therefore, the normal force, and ultimately the frictional force, is determined using vector analysis, usually via a free body diagram. Depending on the situation, the calculation of the normal force may include forces other than gravity.

Coefficient of friction

The coefficient of friction (COF), often symbolized by the Greek letter μ, is a dimensionless scalar value which describes the ratio of the force of friction between two bodies and the force pressing them together. The coefficient of friction depends on the materials used; for example, ice on steel has a low coefficient of friction, while rubber on pavement has a high coefficient of friction. Coefficients of friction range from near zero to greater than one. It is an axiom of the nature of friction between metal surfaces that it is greater between two surfaces of similar metals than between two surfaces of different metals hence, brass will have a higher coefficient of friction when moved against brass, but less if moved against steel or aluminum.

Fluid friction

Fluid friction occurs between fluid layers that are moving relative to each other. This internal resistance to flow is named *viscosity*. In everyday terms, the viscosity of a fluid is described as its "thickness". Thus, water is "thin", having a lower viscosity, while honey is "thick", having a higher viscosity. The less viscous the fluid, the greater its ease of deformation or movement.

All real fluids (except super fluids) offer some resistance to shearing and therefore are viscous. For teaching and explanatory purposes it is helpful to use the concept of an in viscid fluid or an ideal fluid which offers no resistance to shearing and so is not viscous.

Lubricated friction

Lubricated friction is a case of fluid friction where a fluid separates two solid surfaces. Lubrication is a technique employed to reduce wear of one or both surfaces in close proximity moving relative to each another by interposing a substance called a lubricant between the surfaces.

In most cases the applied load is carried by pressure generated within the fluid due to the frictional viscous resistance to motion of the lubricating fluid between the surfaces. Adequate lubrication allows smooth continuous operation of equipment, with only mild wear, and without excessive stresses or seizures at bearings. When lubrication breaks down, metal or other components can rub destructively over each other, causing heat and possibly damage or failure.

Skin friction

Skin friction arises from the interaction between the fluid and the skin of the body, and is directly related to the area of the surface of the body that is in contact with the fluid. Skin friction follows the drag equation and rises with the square of the velocity.

Skin friction is caused by viscous drag in the boundary layer around the object. There are two ways to decrease skin friction: the first is to shape the moving body so that smooth flow is possible, like an airfoil. The second method is to decrease the length and cross-section of the moving object as much as is practicable.

Internal friction

Internal friction is the force resisting motion between the elements making up a solid material while it undergoes deformation.

Plastic deformation in solids is an irreversible change in the internal molecular structure of an object. This change may be due to either (or both) an applied force or a change in temperature. The change of an object's shape is called strain. The force causing it is called stress.

Elastic deformation in solids is reversible change in the internal molecular structure of an object. Stress does not necessarily cause permanent change. As deformation occurs, internal forces oppose the applied force. If the applied stress is not too large these opposing forces may completely resist the applied force, allowing the object to assume a new equilibrium state and to return to its original shape when the force is removed. This is known as elastic deformation or elasticity.

Radiation friction

As a consequence of light pressure, Einstein 1909 predicted the existence of "radiation friction" which would oppose the movement of matter. He wrote, “radiation will exert pressure on both sides of the plate. The forces of pressure exerted on the two sides are equal if the plate is at rest. However, if it is in motion, more radiation will be reflected on the surface that is ahead during the motion (front surface) than on the back surface. The backward acting force of pressure exerted on the front surface is thus larger than the force of pressure acting on the back. Hence, as the resultant of the two forces, there remains a force that counteracts the motion of the plate and that increases with the velocity of the plate. We will call this resultant 'radiation friction' in brief.”

Rolling resistance

Rolling resistance is the force that resists the rolling of a wheel or other circular object along a surface caused by deformations in the object or surface. Generally the force of rolling resistance is less than that associated with kinetic friction. Typical values for the coefficient of rolling resistance are 0.001. One of the most common examples of rolling resistance is the movement of motor vehicle tires on a road, a process which generates heat and sound as by-products.

Braking friction

Any wheel equipped with a brake is capable of generating a large retarding force, usually for the purpose of slowing and stopping a vehicle or piece of rotating machinery. Braking friction differs from rolling friction because the coefficient of friction for rolling friction is small whereas the coefficient of friction for braking friction is designed to be large by choice of materials for brake pads.

Triboelectric effect

Rubbing dissimilar materials against one another can cause a build-up of electrostatic charge, which can be hazardous if flammable gases or vapours are present. When the static build-up discharges, explosions can be caused by ignition of the flammable mixture.

Belt friction

Belt friction is a physical property observed from the forces acting on a belt wrapped around a pulley, when one end is being pulled. The resulting tension, which acts on both ends of the belt, can be modeled by the belt friction equation [12].

In practice, the theoretical tension acting on the belt or rope calculated by the belt friction equation can be compared to the maximum tension the belt can support. This helps a designer of such a rig to know how many times the belt or rope must be wrapped around the pulley to prevent it from slipping. Mountain climbers and sailing crews demonstrate a standard knowledge of belt friction when accomplishing basic tasks.

Work of friction

In the reference frame of the interface between two surfaces, static friction does not work, because there is never displacement between the surfaces. In the same reference frame, kinetic friction is always in the direction opposite the motion, and does negative work. However, friction can do positive work in certain frames of reference. One can see this by placing a heavy box on a rug, then pulling on the rug quickly. In this case, the box slides backwards relative to the rug, but moves forward relative to the frame of reference in which the floor is stationary. Thus, the kinetic friction between the box and rug accelerates the box in the same direction that the box moves, doing positive work. The work done by friction can translate into deformation, wear, and heat that can affect the contact surface properties (even the coefficient of friction between the surfaces). This can be beneficial as in polishing. The work of friction is used to mix and join materials such as in the process of friction welding. Excessive erosion or wear of mating sliding surfaces occurs when work due to frictional forces rise to unacceptable levels. Harder corrosion particles caught between mating surfaces in relative motion (fretting) exacerbates wear of frictional forces. Bearing seizure or failure may result from excessive wear due to work of friction. As surfaces are worn by work due to friction, fit and surface finish of an object may degrade until it no longer functions properly.

Aircraft brakes

From a broad view, dry sliding contact of solid surfaces includes many different combinations of mating couples. Some of these mating surface couples are: metals in vacuum, oxidized metals, solid film lubricants and viscoplastic materials. In aircraft, some seals, air bleed door seals and bearings general elements of an aircraft disk brake after being run in a simulated rejected takeoff. The disks are welded together. This example is offered to illustrate a beneficial use of dry sliding contact. That this was not dry sliding since liquid metal was being produced during the braking action. That, experience dry sliding contact are: brakes, engine, shaft.

Although aircraft brakes have achieved a high energy absorption per pound of weight, considerable work is continuing to improve life and reduce weight. As an example of energy absorption DC-8-60 which has a kinetic energy of 55X was obtained by engines weighing 12 400 kg (27 200 pounds) and on a rejected take LO6 Newton meters (40.6~10~ foot pounds) at takeoff speed of 160 knots. This energy level off must be absorbed by brakes weighing 1030 kg. As compared to engine weight this is 12 times more pound, however, the brakes'on1.y have to live through one rejected takeoff the brakes into one solid mass.) aircraft braking energy requirement has increased from 1950 to present, (In a rejected takeoff it is not uncommon to melt [13, 14].

1.4 Protecting from friction and wear by composites usage

Use of polymer matrix composites in modern aeroengines

The use of polymer matrix composites (PMCs) in aerospace application dates from the early 40s, the large-scale carbon fibre production of the early 70s making them serious competitors with metals for complex lightweight structures. Complete airframes can now be produced in PMCs, and they are essential to modern helicopters. Temperature requirements limit their use in aeroengines, but most of the nacelle of a modern aero gas turbine is PMC, a component that accounts for around 25 % of the weight and 20 % of the cost of the power plant. Other PMC parts in current engines include fan blades, outlet guide vanes, bypass ducts, nose cone spinners, core engine fairings, annulus fillers and variable guide vane rings.

Materials technology is of fundamental importance to the gas turbine engine. The ultimate efficiency of the engine is limited by operating temperature and, consequently, it requires materials with high temperature capability. The incessant drive to reduce emissions is compounding this need. Engine weight is another important factor, impacting on fuel consumption and military aircraft agility, thus stimulating the demand for low-density materials.

Rolls-Royce Venture into Carbon Fibre Reinforced Composites

The introduction of carbon fibre in the 60s saw Rolls Royce's first major exercise in incorporating composites into engines, with the Hyfil fan blade for the RB211. At that time, Rolls Royce's confidence in using a relatively new and, in hindsight, unproven material for a major rotating component was based on the fact that it had a thorough understanding of the material at the laminate level. Lacking, however, was sufficient experience to translate that knowledge into the fan blade application within the timescale imposed by the RB211 program. Problems with manufacturing repeatability and bird impact resistance eventually resulted in the switch to a titanium component. Events such as this are extremely costly. In a fiercely competitive marketplace, engine development costs need to be tightly controlled, and risks minimized to ensure profitability. This tends to drive a design culture that is predominantly evolutionary. In this environment, a change of material for a component from a familiar alloy to a composite will only occur when the metallic part has reached a limit in terms of weight and/or cost or temperature capability.

A good example of this evolutionary process is the way in which PMCs have been increasingly used in engine nacelles. Driven by the need to reduce weight in relation to existing aluminium designs, composites were first applied to relatively simple parts such as the RB211 524 cowl doors. Applications spread progressively in this region of the engine to the extent that PMCs now dominate the nacelle. A logical extension of the technology has occurred in by-pass ducts for both military (General Electric F414) and civil (Rolls-Royce Tay) engines [15].

New Engine Projects

Step change engine designs, which are the optimum vehicles to target for application of new materials technology, occur relatively infrequently. For example, both Rolls Royce's Trent and General Electric's GE90 were launched in the early 90s only after their previous engines, the RB211 524 and CF6, respectively, had served them well for over 15 years in their various marques. The reason that such vehicles provide excellent opportunities to increase composite penetration is that engine launch is preceded by a detailed development program, the cost of which is spread across all components.

Postcertification qualification of components in new materials on an ad hoc basis, by contrast, is prohibitively expensive.

This issue is typified by the glass-reinforced epoxy fan nose spinner now used on all Rolls Royce civil engines (figure 1.15). Although this appears to be a relatively straightforward component in terms of materials and manufacturing process, entry into service and the realization of the cost and weight benefits had to wait until the costs of the certification test program (cyclic fatigue and bird impact) could be borne by the launch of the next variants of the RB211 engine.

Figure 1.15 – Rolls-Royce fan nose spinners

The use of carbon-fibre-reinforced epoxy fan outlet guide vanes is a more recent example of the need for an opportunity to secure a composite application, figure 1.16. Although proven in terms of materials and manufacturing process, and having survived limited engine exposure, this specific application awaits the launch of a new engine design to reap the potential cost and weight benefits. Further qualification testing to clear this component for service operation would include extensive strain gauge surveys under forward/reverse thrust and cross-wind loads followed by the standard 150 hour ‘modification approval’ engine test costing in excess of US $1.5million, obviously unjustifiable for this component alone.

Figure 1.16 – A carbon fibre reinforced epoxy Trent fan outlet guide vane

Design parameters

As already indicated, the appropriate materials and manufacturing process technologies for many of the potential PMCs are already in place. From the designer's point of view, the transition from working with isotropic materials to composites would appear at first sight to be relatively straightforward. With a wide range of matrix types covering temperatures up to 300 °C and a selection of reinforcing fibres in different strengths and stiffness to choose from, the designer would appear to have a material for every occasion within this temperature regime. The stumbling block, however, is that he will often find having carried out an initial design that, unless the component was a 'repeat' of a previous composite part, there are a number of unknowns about its potential behavior in the engine. Some of these unknowns, or engine integration issues, are likely to carry a high risk. In such cases, the risk can only be eroded by technology demonstration, commitment to which will be granted on the basis of the balance between perceived risk and potential payback.

Ceramic Matrix Composites

Ceramic-based composites comprising both ceramic fibers and matrix offer potential applications at temperatures beyond the best metals. With the benefit of experience gained with polymer composites, erosion of the concerns regarding the airworthiness of these materials has been tackled by a progressive introduction of 'fail safe', modestly loaded, static parts in military bench engine tests. Exhaust nozzle petals in

SiC/SiC have been demonstrated successfully on the EJ200 engine and afterburner flame holders in SiC/alumina have survived rigorous evaluation on a military demonstrator engine. Following these successes, a full size combustor barrel in SiC/alumina material has emerged unscathed from a high pressure, high temperature rise, military cycle rig test. To date, the most complex application of CMC technology in the aeroengine industry is the Rolls-Royce exhaust guide vane manufactured by advanced textile handling procedures involving weaving or knitting followed by chemical vapour infiltration [17].

Metal Matrix Composites

Turning finally to MMCs, the system of most relevance to aircraft engines is continuous ceramic fibre-reinforced titanium. A prime aeroengine application of MMCs will be in compressor discs and drums, in which the very high performance of the fibres can be exploited to give substantial reductions in weight (in excess of 70 %) without the need to introduce the fibres into complex shapes. Savings in weight come from the elimination of the usual metal central web and hub, the hoop strength and stiffness being provided instead by a ring of reinforcing silicon carbide fibres, (figure 1.17).

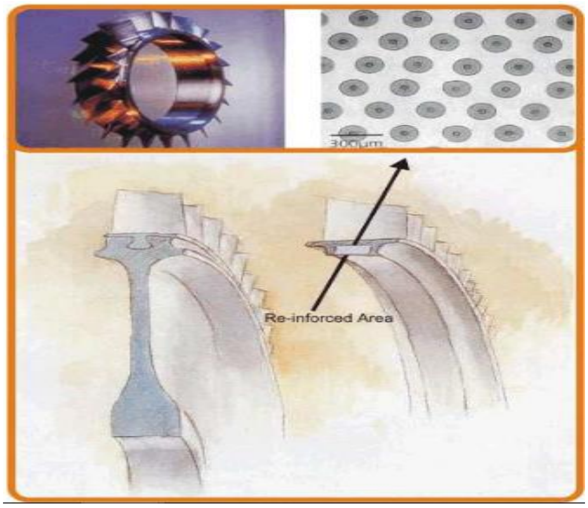


Figure 1.17 – Metal matrix composite bladed ring

There are general physical principles that determine engine efficiency. According to the Carnot thermodynamic cycle, the mastered gas temperature determines the level of perfection of an aircraft engine. Currently, the materials that are used in the turbines, workable at temperatures of 1100 °C maximum. In order for them to continue operating at higher gas temperatures, they must be cooled. This complicates the design and requires the selection of air from the compressor, which significantly reduces the efficiency of the engine. Modern composite materials (CM) are capable of providing higher operating temperatures for turbine components with significantly lower cooling losses or even no cooling at all. We are trying to apply for this purpose high-temperature CM, mainly ceramic (CMC). If metal materials that are currently used in turbines have a specific weight of about 7.5 … 8 g / cm^3, then for KKM the specific weight is 3 … 3.4 g / cm^3, that is, the weight of the product is halved. And any weight reduction is a reduction in fuel consumption, increased reliability.

Not less effect from the use of CM in the cold part of GTE. At present, the trend is that the efficiency of the engine increases with increasing bypass ratio, and in this case, the fan becomes increasingly large. But the weight of the fan is about 30 … 40 % of the weight of the entire engine. The PD-35 fan blades, for example, have a length of about 1.1 m, the inlet fan diameter is 3 m, and in this case the use of metals leads to unacceptable weight gain.

Even if a much smaller blade for a PD-14 engine fan is made of solid titanium, it will weigh 11 kg. The mass of the current hollow titanium blade – 8 kg, and carbon fiber – 5.5 kg. But this is not only a saving of 2.5 kg on each blade, of which there are about 20 in the fan. Since these are rotating masses, as a result of their reduction, the load on the disk and the shaft decreases, the impact on the body decreases when the blade is broken, the turbine can make it less powerful. It is estimated that every kilogram of the mass savings of the fan leads to a reduction of 3.75 kg of the mass of the entire engine. And if the engine is lighter, the load on the wing is reduced and it can also be lightened.

In general, when replacing metals with KM, the weight of individual parts decreases by 10 … 50 %, the durability of the catch increases by 5 … 25 %, and the efficiency of the engine increases by 3 … 8 %.

Boro-aluminum composite material (boro-aluminum). Boron fibers are used as the reinforcing filler of this composite material, and aluminum alloys are used as the matrix. Boro-aluminium is 3.5 times lighter than aluminum and 2 times stronger than it, which makes it possible to obtain significant weight savings. In addition, at high temperatures (up to 430 °C), the boro-aluminum composite material has a twice as large value of specific strength and rigidity as compared with titanium, which makes it possible to use it for airplanes with flight speeds of M = 3, whose designs currently used titanium.

Boro-aluminum composites were used in the design of the tail section of the F-111 aircraft, and Lockheed used these composites in the construction of the caisson of the center section of the C-130 Hercules aircraft.

Currently, the boro-aluminum composite material is widely used in the construction of aircraft engines. For example, the company Pratt & Whitney used it in the manufacture of fan blades of the first and third stages of the TJE JT8-D, TF-30, F-100, and the General Electric Company used the blades of the engine fan J-79 (figure 1.18), which allows to get about 40 % weight savings of these elements.

Figure 1.18 – Boro-aluminum fan blades of the first and third stages in engine J-79

Boroplastiks contain boron fibrous materials as a reinforcing filler. The filler is used in the form of a monofilament (diameter 90 … 200 μm, σ_{rast} = 2500 … 4000 MPa, elastic modulus 380 … 420 GPa), tows of several such threads, braided with auxiliary glass or organize thread, as well as fabrics and tapes in which boron threads or strands are intertwined with other threads. Boroplastic binders are epoxy resins, polyamides or other polymers, mainly thermosets.

Boroplastic materials are characterized by high modulus of elasticity, fatigue strength and other mechanical properties, low creep (up to 0.2 %) in the direction of orientation of the filaments. With prolonged (up to 10 years) exposure to water, lubricants, and atmospheric factors, the mechanical properties of boroplastics are reduced by no more than 10 … 15 %. The level of operating temperatures and the service life of products are determined by the heat resistance of the binder. Some properties of boroplastic materials substantially depend on the geometrical parameters of the filaments. Thus, with an increase in their diameter, the density and strength of boroplastics under tension decrease and the compressive strength increases. To increase the bonding strength of the filler with a binder, boron yarns are etched in HNO3 (tension, shear strength of epoxy boroplastic increases 2–fold). The impact strength of boroplastics can be improved by introducing glass or other fibers into their composition; this reduces the cost of boroplastic [18]**.**

Carbon fiber/epoxy composites are used as a substrate. A polyimide bond coating was prepared and deposited by a thermal evaporation technique onto the polymer composite substrate. The NiCr alloy was used as a top coating deposited by a flame spray technique. The coatings were spread with two configurations, a coating with a bond coat (with polyimide) and a coating without a bond coat (without polyimide). Wear rate measurements for both coated and uncoated samples were performed by a pinon-disc technique. The results shows that PMCs with NiCr coatings had enhanced wear resistance as compared with the uncoated PMCs, and this was due to high hardness and wear resistance of the NiCr alloy. The wear rate increases much more with increasing temperature than it did for the coated PMCs at room temperature. The coated PMCs with bond coats (with polyimide in the bond coat) had lower friction coefficients than the coated PMCs without bond coats (without polyimide in the bond coat), and this was due to a significant increase in interface adhesion. The wear and friction resistance of all the coatings improved significantly with heat treatment. The worn surfaces and oxidation of the NiCr layer were observed by the scanning electron microscope (SEM) with X-ray diffraction (XRD).

Major advances have been made in nickel alloy design over the past thirty years but many of the improvements in high temperature strength have been made at the expense of oxidation and hot corrosion resistance. Friction, corrosion and wear are the most common factors that cause engineering failures Wear is the progressive loss of material from a surface. Among the different types of wear, abrasive wear and adhesive wear normally occur more often than other types. Abrasive wear is due to hard particles or hard protuberances forced against and moving along a solid surface One technique commonly used to improve coating adhesion and durability is the use of bond coats that are interleaved between a coating (topcoat) and a substrate with vastly different coefficients of thermal expansion. Bond coats sandwiched between high-quality flame-sprayed, wear-resistant coatings (top coats) and PMCs substrates have substantially improved the wear resistance of PMCs

Chromium and titanium carbide based powders

Protective coatings operating under conditions of abrasive and erosive wear, corrosion at temperatures up to 700 °C. Recommended for protection of parts of power equipment (boilers, gas turbines, internal combustion engines), forging equipment, crushing rollers, dies for hot pressing, bearing shells, etc.

Basic properties:

- Material utilization factor – 0.7 … 0.8;
- Microhardness HV300 – 710 … 1100;
- Strength of adhesion with steel, MPa – 29 … 32.

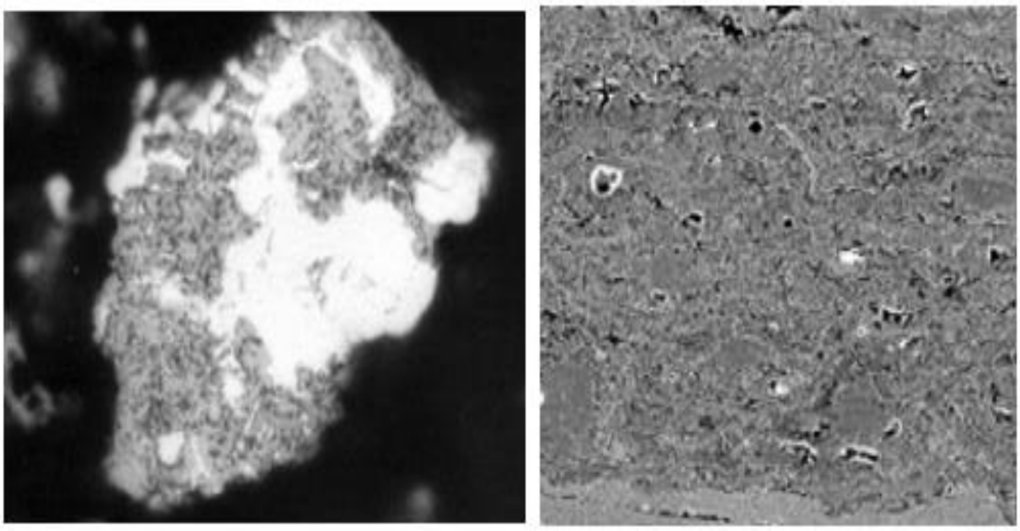


Figure 1.19 – Chromium carbide powder and coating.

Thermostructural composite materials are characterized by mechanical properties, making it possible to create structural parts that retain their mechanical properties at high temperatures. They consist of a compacted fiber carcass and a refractory matrix that fills, at least partially, the pores of the fiber carcass. The choice of materials for fibers and matrix, as a rule, is focused on carbon and ceramics.

Examples of thermostructural composite materials include carbon / carbon composites (C / C) and ceramic matrix composites (CMC), such as C / SiC or SiC / SiC (carbon fiber or SiC framework and silicon carbide matrix), or C / C-SiC (carbon fiber skeleton and a matrix of carbon and silicon carbide mixture), or C / Si-BC (carbon fiber skeleton and self-healing matrix), or C / C-SiC-Si (composite C / C, siliconized during the reaction with Si).

The invention relates to the creation of protective coatings designed to improve the resistance to wear by friction at high temperature (between 500 °C and 1000 °C or higher) of composite materials with a ceramic matrix (CMC), in particular including silicon carbide.

It has been found that these CMC materials exhibit friction wear resistance at extreme high temperatures for some applications, for example for the primary moving sash (control or accompanying) of the ejection nozzle of a turbojet engine.

It should be particularly noted that the results are significantly improved when the mixture is deposited on the outer layer of the part, including silicon carbide (SiC) and / or boron carbide (BC).

It was found that, according to the considered application, the mixture can be located on the entire outer surface of the part or on its part. For example, in the case of an engine nozzle diffuser, the mixture can only be located on surfaces exposed to friction, especially those that relate to the outer or inner surface of the movable flaps of the diffuser.

Ceramic refractory material mainly introduced into the mixture belongs to the group of substances, including alumina silicates (especially mullite, as well as silimanite), aluminum silicates and alumina.

Thermostructural detail of a composite material with a ceramic matrix, characterized in that it contains a protective coating against wear, which is an enamel containing refractory silica and alumina, and having a thickness of about 200 microns, and the enamel additionally contains a filler that forms an additive that changes the emissivity coated areas.

1.5 Repairing surface damage

The most common types of damage to the surface are abrasions, scratches, scars, dents, cuts, and pits. Minor surface damages may be repaired by applying one or more coats of room-temperature catalyzed resin to the damaged area. More severe damages may be repaired by filling with a paste made from room-temperature resin and short glass fibers. Over this coated surface, a sheet of cellophane may be applied, extending 2 or 3 inches beyond the repaired area. Starting in the center of the repair after the cellophane tape is in place, all of the air bubbles can be removed and excessive resin eliminated by lightly brushing by hand or using a rubber squeegee toward the outer ridge of the repair. The resin should be allowed to cure at room temperature, or if necessary, the cure can be hastened by the use of infrared lamps or hot sandbags. After the resin has been cured, the cellophane should be removed and the excess resin sanded off; then, the entire repaired area should be lightly sanded to prepare it for refinishing [19].

The opposite facing is shimmed and backed up with a mold, and the core material is inserted as previously described. The outer repair plies are soaked in the resin and laid over the damaged area. An extra layer of thin cloth is laid over the repair area to extend one-half inch over the undamaged facing. The repair area is then covered with a sheet of cellophane to apply pressure, and then it is allowed to cure. The inner facing is then replaced in the same manner as the outer facing. After the inner repair has been cured, the entire repair area should be sanded to the original contour and prepared for refinishing.

Foam core

When the puncture penetrates the entire wall, the damaged core and face laminates should be removed to one-fourth inch past the perimeter of the hole on the inner face. A plaster support is made to replace the removed core, conforming to the curvature of the inside layer of the inner face. After repair to the inner face has been completed, the plaster support should be removed and the repair continued on the opposite side.

Strength Restoration

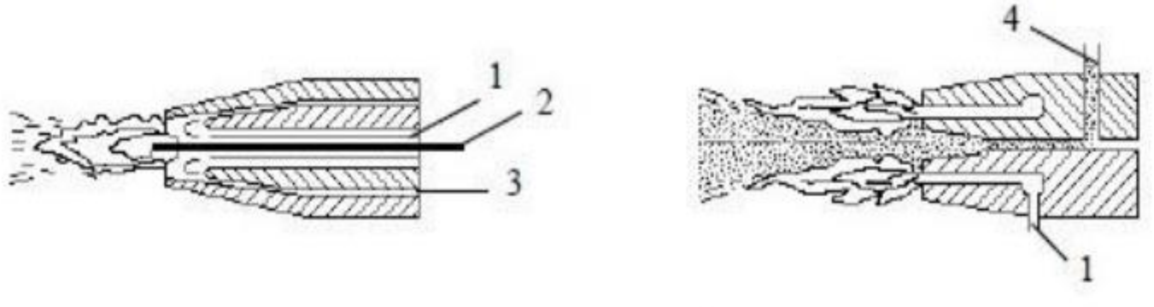
Full strength repairs are desirable and should be made unless the cost is prohibitive or the facilities are inadequate. Less than full strength repairs are sometimes allowed on secondary structures that are lightly loaded, stiffness-critical structures designed for limited deflections rather than for carrying large loads (doors), or structures designed to a minimum thickness requirement for general resistance to handling damage (fuselage skins). Repair manuals for specific aircraft frequently “zone” the structure to show the amount of strength restoration needed or the kinds of acceptable standard repairs. Repair zones help to identify and classify damage by limiting repairs to the load-carrying requirements. Repair zone borders indicate changes in load-carrying requirements due to changes in the structure, skin thickness, ply drop-offs, location of supporting members (ribs and spars), ply orientation, core density, size, and type of materials. Damage in one zone may be repairable; whereas the same type of damage in an adjacent zone may not be repairable [20].

Spraying coatings

Spray Coating for Worn Repair parts, for imparting heat and corrosion resistance, high anti-friction properties. For spraying uses various metals, alloys, ceramics. Spraying can be done in several layers, including with use of various materials. Materials used for spraying are prepared in the form of rods, wire and powder. The sprayed material is melted, and its particles with high speed are sent to the surface of the parts. The connection of coatings with these details occurs both due to mechanical and molecular bonds. The following are performed before coating. preparatory operations: cleaning and degreasing; mechanical grinding processing; special treatment for improvement adhesion of the sprayed material; insulation of surfaces not subject to dusting. To improve the adhesion of the sprayed metal can application of pre-shot blasting, mechanical machining (for example, threading, grooving, etc.), deposition of refractory metals, electro spark or chemical treatment. Different methods are used for spraying the spread of which received gas-plasma, detonation and plasma.

Flame spraying

The melting of the sprayed material during the gas-plasma spraying carried by heat generated by burning a mixture of combustible gas (acetylene) and oxygen. Spraying metal particles is made a stream of combustion products or compressed air (Figure1.20). This way used for spraying low-melting metals.



a – spray head for wire (rods) b – spray head for powder;

1 – gas mixture; 2 – wire (rod); 3 – compressed air; 4 – powder

Figure 1.20 – Schematic diagram of the gas-plasma spraying

Detonation spraying

Detonation spraying based on energy use detonation of a combustible mixture ignited by an electric spark. The speed of movement of the particles of the sprayed material while significantly higher than with the gas-plasma method, which allows to obtain higher quality coatings. Detonation installations coatings are used to apply particularly hard, wear-resistant and heat-resistant coatings from carbides of refractory metals. Detonation - a process that proceeds at high speed, about 2 kilometers per second. Instead of a cartridge in the “gun” the gas is set on fire mixture. For example, wear a worn part chrome-nickel alloy. Then grind and process the part, and she will be like new. It is also possible to spray alloys on parts, which cannot be applied by conventional means, for example, carbide-tungstic alloy. Detonation spraying is the only way applying this alloy on small parts. With detonation spraying to heat and accelerate the sprayed The material uses the energy of the products of detonation gas-oxygen fuel. Propane-butane is usually used as a combustible gas mixture. Detonation coating is a discrete process It is carried out by consecutive performance of the following operations included in a single cycle (shot):

– filling the detonation gun with an explosive gas mixture;

– feed powder into the barrel of the gun;

– explosion of a gas mixture in the barrel.

The composition of the explosive mixture and the degree of filling the barrel significantly affect the energy characteristics of detonation products. From the percentage of fuel, oxidizer and diluent, as well as their volume depends on:

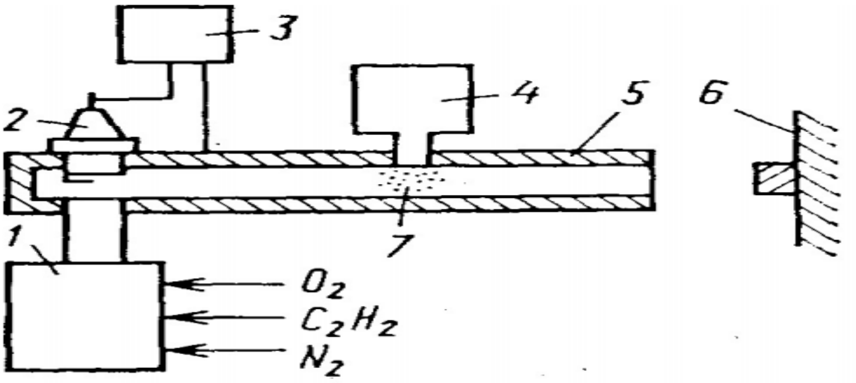
– the amount of heat released during detonation;

– the degree of thermal dissociation of detonation products;

– chemical activity of detonation products in relation to applied material;

– temperature and flow rate from the barrel of the powder.

Due to the high speed of the sprayed particles (600 … 1000 m / s), detonation coatings have a density close to that of sintered material and high adhesion. Detonation spraying allows you to spray a wide range of materials: metals and their alloys, oxides, carbide-based hard alloys. At the same time heating sprayed products are negligible. Detonation spraying due to its discrete nature is very economical, but not too productive comparison, for example, with high-speed flame spraying). As a rule, it is economical to spray surfaces more than a few square centimeters. Distinctive feature of detonation spraying – cyclical the nature of the powder feed to the surface of the workpiece with speed exceeding the speed of sound. Cyclic spraying process get using detonation installations, schematic diagram which are presented in figure1.21. In general, detonation installations consist of a supply unit 1. spraying powder, including powder feeder and dosing device; unit 2, which serves to form the required gas mixtures and filling the barrel of a detonation unit with a given speed; the block of the firing 3 and the igniter 2, designed to initiate explosion of the working mixture; stem 5, which is a pipe with a diameter 20 … 50 mm, length 1 … 2.5 m and intended for directional Blast wave propagation towards the open end of the barrel [21].



1 – supply unit; 2 – igniter; 3 – the block of the firing;4 – supply unit; 5 – barrel;
6 – transfers sprayed parts; 7 – surface particles.

Figure 1.21 – Diagram of detonation devices

The principle of the installation is as follows. From block 1 gas the mixture is fed into the barrel 5. Simultaneously from the powder feeder through the metering device is injected in given portions by gas - nitrogen or air - fine powder in the gas mixture immediately before its ignition, then igniter 2 is set on fire gas mixture. As a result of ignition and movement through the channel combustible mixture it explodes with a significant release quantities of heat and the formation of a detonation wave, which accelerates and transfers sprayed parts 6 to the surface particles 7 at a rate determined by the geometry of the trunk and the composition of the gas. The process of forming coatings detonation spraying complex and poorly understood. In many ways, it is similar to the process plasma spraying. Similarity lies in the fact that the adhesion of particles with the substrate and between themselves can occur in the molten, melted and solid states. Coupling durability is provided mainly due to spraying molten and melted particles that spread and crystallize on the surface substrate due to chemical interaction. In the same time detonation spraying process in contrast to continuous plasma is cyclical, telling powder particles higher speed, which determines the features of the mechanism of formation of coatings. In detonation spraying, the particle velocity, in contrast to plasma spraying (100 … 200 m / s) reaches 400 … 1000 m / s. Therefore, besides thermal activation, a significant effect on the mechanism and plastic formation kinetics of the deposited layers 64 deformation in the collision zone of the particles and the substrate. However, the main contribution in the formation of coatings during spraying introduces thermal activation. Experience of using various methods of spraying, including detonation, shows that to obtain a satisfactory adhesion of the powder particles to the base is necessary so that their significant part was transported to the substrate in molten or melted condition. Experimental studies on the formation process detonation coatings show that the state of the particles located in a two-phase flow, heterogeneous. In the beginning and in the middle flow they are in a molten or melted state, and the temperature in contact with the substrate reaches their melting point. In this case, due to the heat released when the particles hit the substrate, having a speed of ~ 400 m / s, the temperature in the contact zone rises approximately 100 °C.

When spraying powder materials with a melting point, exceeding the melting point of the base metal, occurs melting the last. So, for example, when coating from aluminum oxide AlOz and powdered hard alloys on corrosion-resistant steel last fused and mixed with sprayed molten powder particles, thereby increasing adhesion strength. Increased adhesion, as with other methods gas thermal spraying, promotes pre-shot blasting sprayed surface treatment. In this case, it is possible to receive strong bonds between the sprayed material and the substrate having hardness higher than HRC 60. When spraying the first layer, it is possible the occurrence of pores. When spraying the second layer of powder particles deform and condense the crystallizing first layer that contributes to the elimination or reduction of porosity. This phenomenon characteristic of detonation spraying, it is called the effect of hot shock pressing. Larger particles from the end (tail) of less concentrated flows have lower speed and are applied to the surface of the substrate most often in unmelted form. When forming the coating such particles play a dual role: useful - remove defective areas previously applied coating, increasing its density and physico-mechanical properties; harmful - with a significant increase kinetic energy of large particles in the coating may appear cracks and even its complete detachment. These phenomena can be regulated changing the rate of fire of the installation and the granulation of the sprayed 65 powder. In terms of materials and equipment used process detonation spraying is quite simple. Main factors the nature of detonation spraying is determined by gas mixture, powders, barrel installation. However, the use of these factors in the process deposition associated with the change and management of a number of characteristic each of these parameters. For a gas mixture, this is the composition of the gas mixture; dose of gas mixture in one shot; the composition of the gas mixture in the trunk between shots. For powder - the chemical composition of the powder; spray granulation powder; the location of the powder in the barrel at the time of ignition of the mixture; particle size distribution. The barrel is characterized geometric parameters: diameter and length. In turn, the listed parameters generate other parameters characterizing the final state of the process: concentration, particle temperature and velocity; chemical composition of the medium; temperature substrate surface. Thus, the process of detonation spraying is complex and the quality of coating formation depends on aggregate of numerous parameters, their maintenance in optimal the limits [22, 23].

Table 1.1 – Modes of applying detonation coatings of some materials

Material	Attitude O_2/ C_2H_2	Depth Downloads powder, mm	Distance Spraying, mm	Hitch powder, mg	Granulation, um	Length the trunk	Diameter the trunk, mm
Al_2O_3> 99 %	2,5	750	150	50	20 … 40	2	20
WC+8-20%Co	1,2	300	150	200	1 … 5(mech.) 10 … 20 (homog.)	1.6	16
75% Cr_2C_3+25 % NiCr	1,2	300	100	200	40 … 50	2	20

In serial production, maintaining optimal modes multi-parameter process is possible with the installation in automatic mode. In detonation spraying, you can get coatings from any materials, refractory compounds, oxides, etc. To obtain wear resistant coatings with the aim of restoring parts apply oxide aluminum AlOz, self-fluxing alloys PG-SR, SNGN, VSNGN (65 % WC and 35 % SNG). To improve wear resistance, tungsten carbides WC are used. Titanium TiC, Cr_2C_3 chromium, CrB_2 chromium boride with additives of 8 … 20% Ni or Co. In detonation spraying, it is practically possible to obtain layers considerable thickness, but have the greatest strength of adhesion sprayed coatings with a thickness of 0.2 - 0.4 mm (130 … 160 MPa). Therefore most efficiently restore parts with little wear. The rate of detonation spraying is 1 … 5 shots per give me a sec. The thickness of the coating in the center of the metallization spot applied per shot, depends on the dose of powder supplied to the barrel, and usually makes 8 … 20 microns at the area of a covering of 4 … 6 cm 2 When spraying self-fluxing alloys are usually used powders with a diameter particles 7 … 70 microns. Roughness after detonation Coating is, as a rule, Ra = 3: 4 microns.

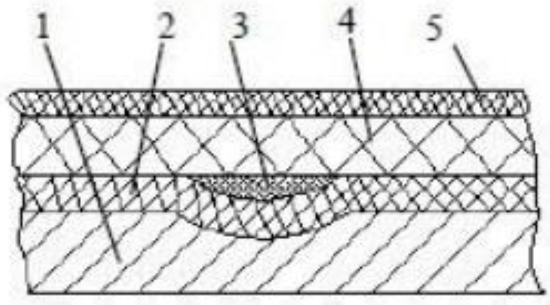
Plasma spraying

For coating by plasma spraying are applied special plasma torches and powerful electric generators. The temperature of the plasma reaches 15000 °C. This method allows to obtain coatings from such refractory materials like tungsten, molybdenum, refractory compounds intermetals, ceramics. When plasma spraying coatings for melting and transfer powder on the restored (hardened) surface of the part is used thermal and dynamic properties of the plasma jet. Plasma spraying is based on the ability of gases under certain conditions goes into a state of plasma, which is a ionized gas flow at high temperatures. Highest Argon plasma has a temperature (15000 … 30000 °C). When excited an electric arc gas supplied to the arc burning zone is ionized under high temperature, high gas pressure and thermal emission of electrons from the cathode surface. Along with positive and negatively charged by ions in the gas contains electrons and neutral atoms, in the collision of which the process of understanding is activated. Plasma has high electrical conductivity, therefore, the voltage in the plasma jet is low and the current is high. High plasma conductivity contributes to the formation around it significant magnetic field. Magnetic field lines force the plasma shrinks, causing it to stretch and take shape cord.

The plasma flow rate reaches 9000 m / s at the nozzle exit, and gas burner, tg 90 m / s. Plasma gas not containing oxygen, allows to obtain coatings without oxides.

For ignition of an electric arc use a high-frequency spark from an oscillator included in the circuit or short-circuit the burner electrodes with graphite rod. At the same time, plasma-forming gas is supplied, and after plasma formation - sprayed powder. Argon is the most widely used plasma gas. nitrogen or mixtures thereof. The use of argon (in addition to its significant cost and scarcity) does not provide sufficient efficiency and process performance due to low heat transfer rate from plasma to particles, short plasma jet length and significant temperature difference across the jet section. This worsens the melting of the particles the sprayed material, and, as a result, the quality of the applied coatings. A promising direction in the field of plasma coatings is use as air plasma gas or its mixtures with other gases. The use of air improves stability and the duration of the continuous operation of the plasma torch. At the same time with this is observed stabilization of the current and the process as a whole, which ultimately this results in higher quality coatings. Coating properties depend on heating temperature and flight speed particles at the moment of contact with the substrate. Higher flight speeds powder particles and the temperature of its heating in the plasma jet provide higher, than at earlier considered methods of a dusting, physicomechanical properties of the coating and a higher degree of its adhesion with surface details. In addition, the plasma spraying process has high performance, the ability to use for coatings wide range of materials, high spraying ratio (up to 95 %) and the ability to fully automate the process. Plasma spraying as coating materials uses powdered alloys and wire. Most often for spraying used durable nickel based powder alloys or iron-based high carbon. Such alloys possess high technological and service properties. Powdered alloys on the basis of nickel brand PG-HN80SR2,PG-HN80SRS and others have such valuable properties as low melting point (950 … 1050 °C), good fluidity, ability to control hardness in a wide range of NCS 35 … 60. The presence of self-fluxing properties. However, such alloys have a high the cost. The disadvantages of iron-based alloys include their higher melting point (1250 … 1300 ° C) and no properties to self-fluxing. Plasma spraying can apply protective thermal coatings from ceramic materials (aluminum oxide HA85 or HA8, dioxide PCR-90 zirconium, etc.) at the bottom of the piston and cylinder head. Surface preparation before spraying does not differ from that described earlier preparation in the section flame spraying.

Protection using lacquer coatings (paintwork) - the main way protect parts from corrosion, as a rule, multilayer (up to 7 layers) paintwork. The materials used to create paintwork, depending on destination, divided into primers, putties, varnishes and paints. Primers are designed to be applied as first layer, therefore, they must have good adhesion. Putty, intended for leveling surface irregularities should have a high viscosity. They are usually applied on pre primed surface. Varnishes and paints are used as top layers LKP. Paints give the coating the required operational and decorative properties. Lucky designed for paint protection (Figure 1.22).



1 – detail; 2 – ground; 3 – putty; 4 – the main paintwork; 5 – lacquer

Figure 1.22 – The structure of the protective paintwork.

The application of paintwork preceded by the preparation of painted surfaces: removal of remnants of old paintwork, all kinds of pollution, washing and drying. Local deformations are aligned with putty. 70 Putties are applied manually with staples, which are elastic plates of metal, wood, PCB or rubber. Depending on the depth of the defect putty is applied in several layers with exposure after application of each layer to dry it. After drying, each layer is carefully trimmed with sandpaper, washed and dried. On the surface prepared in this way layers of soil and the main paintwork are applied. It uses pneumatic or airless (hydrodynamic) paint sprayers. Airless spray paint spraying is achieved by supplying paint materials under pressure. AT when paintwork is applied to areas that are not available for spraying applied hand brush. A significant part of the total time of applying paintwork - up to 90 % is drying time, which is necessary after the application of each coating layer. Reduced drying time is achieved by using preheating (in drying chambers, infrared radiation, etc.). Painting works are carried out in special rooms. or areas of workshops equipped with powerful ventilation systems. Paint sprayers should be made in special cabins. In the process of drying, when applying paint and varnish materials up to 80 % of paint weights of harmful and explosive solvents. Therefore must strictly adhere to safety measures to protect personnel from poisoning with vapors of paints and varnishes, skin lesions, and fire safety requirements [24].

Conclusions to part 1

Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. It follows, therefore, that high temperature resins are extensively used in aeronautical applications. Two main kinds of polymers are thermosets and thermoplastics.

Thermosets are the most popular of the fiber composite matrices without which, research and development in structural engineering field could get truncated. The most common damage is porosity which is the presence of a void in the matrix.

Friction is the force resisting the relative motion of solid surfaces, fluid layers, and material against each other. It is can be static and kinetic [25].

Carbon fibre reinforced composites and boro-aluminum composites play the main role in power plant repairing.

Spray Coating – main method, for imparting heat and corrosion resistance, high anti-friction properties. For spraying uses various metals, alloys, ceramics. Spraying can be done in several layers to better protection.

PART 2

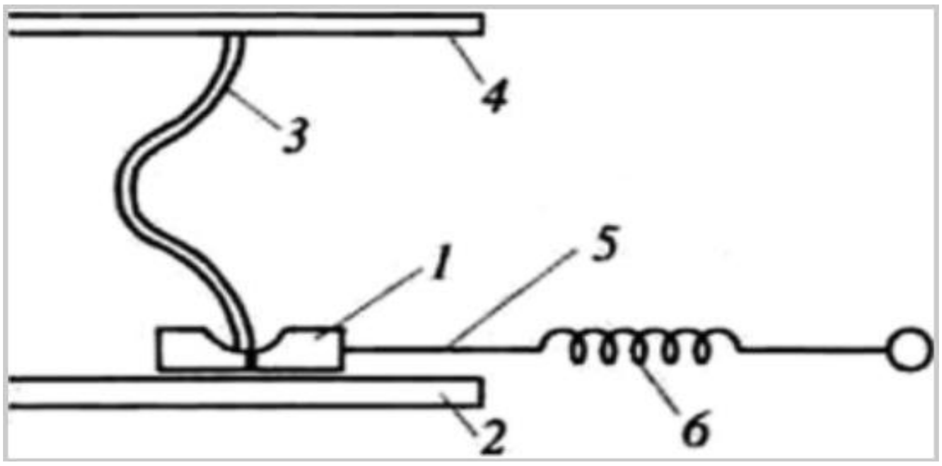
RESEARCH METHODS FOR COMPOSITE MATERIALS FOR FRICTION

2.1 Friction machines

The friction machine is a device for reproducing the tribological process under controlled conditions, providing control of the input and output parameters. The tribological process is carried out between samples from the studied materials of a given shape. The friction machine consists of a drive that performs relative movement of the contacting samples, devices for installing test specimens, devices for loading the friction unit, a device for monitoring output parameters and a number of additional devices (for supplying lubricant to the friction contact, heating the friction unit or creating cryogenic temperatures, to ensure testing in a controlled atmosphere, etc.)

Already the first device used by Amonton to study the process of friction (Figure 2.1) completely falls under the above definition. It includes a loading device (pressure arc 3), a device for moving a moving sample (cord 5, through which a force is applied), a device for controlling the output characteristic (graduated spring 6, which allows to estimate the friction force).

Modern friction machines are much more complicated and provide significantly more information. A friction machine may be specialized, i.e. which allows to investigate the tribological properties of materials under strictly specified conditions (for example, the Amonton device discussed above allows testing only flat samples during translational motion), or universal, allowing testing the tribological properties of materials with varying relative movement patterns. Modern friction machines provide a wide range of test conditions for the tribological properties of materials.



1 – top sample (ironed); 2 – plate; 3 –clamping arc; 4 – fixed beam; 5 – cord; 6 – calibrated spring

Figure 2.1 – Amonton device diagram for studying static friction

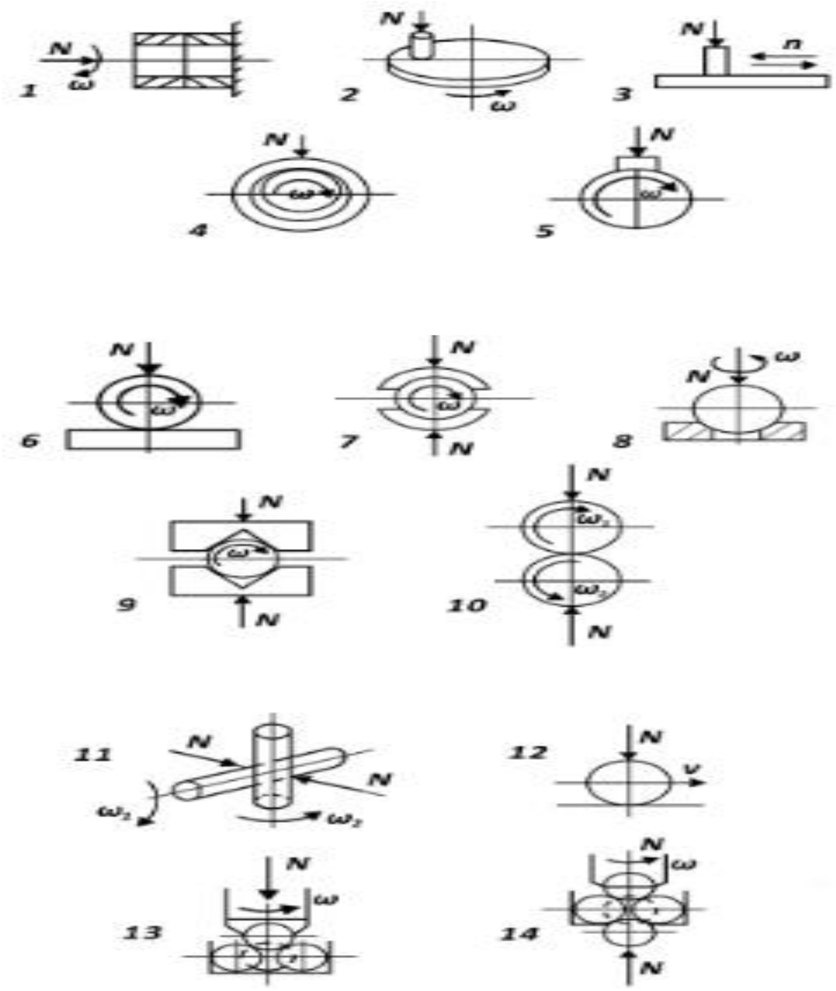
So, both quasi-static and kinetic friction can be reproduced (according to the kinetics of the process), glide at the contact of the rubbing bodies, rolling, rolling with sliding, twisting (according to the kinematics of the tribological process) can be reproduced.

By the nature of the relative movement of the rubbing bodies, the movement can be continuous or intermittent. By the nature of the relative movement reproduce either translational or reciprocating movement. Other combinations of different types of movement are possible, such as friction of a rotating shaft on an oscillating block or reciprocating rotational movement. Friction upon impact, friction in various media, and friction in a wide range of temperatures from cryogenic to hundreds of degrees Celsius can be reproduced.

These modes of the tribological process are implemented on friction machines with various contact patterns of rubbing samples. For contact geometry, the following types of nominal friction contact are distinguished (Figure 2.2). The contact of friction surfaces over a nominal area (Figure 2.2, schemes 1 … 5) is implemented in the following friction schemes.

Face contact rotating and stationary bushings (Figure 2.2, scheme 1). It is widely used in the implementation of the method of assessing frictional heat resistance (ГОСТ 23.210-80), which consists in the fact that the stationary and rotating sleeves are pressed to each other by the ends of a given axial force and increase the temperature of the frictional heating step by step by increasing the rotation frequency of the movable sample. At each of the heating temperatures, the coefficient of friction of the interface is evaluated and the wear of the rubbing bodies is measured. Reproduced on the UMT-1 universal friction machine [26].

Contact of the end face of a stationary cylindrical sample and a rotating disk (Figure 2.2, scheme 2). It is also used in the UMT-1 friction machine. In another version of this scheme, the rotating disk contacts.



1 – rotating and stationary bushings; 2 – cylindrical sample and a rotating disk; 3 – flat specimens; 4 – shaft-bearing; 5 – shaft pattern; 6 – rotating shaft — rectangular bar; 7– two liners; 8 – ring friction; 9 – rotating roller; 10 – two rotating cylinders; 11 – crossed cylinders; 12 – sphere on a plane; 13 – point contact of cone; 14 – point contact of plane

Figure 2.2 – Friction schemes implemented on modern laboratory installations for tribological tests

N – is the load on the friction unit; with angular velocity; V – is the linear velocity; n is the frequency of oscillations of a progressively moving cylindrical sample, so that the trajectory is an Archimedes spiral. This scheme is used in machines for testing wear on the fixed abrasive. The most famous car X4-B, which allows to assess the relative wear resistance of solid bodies in friction on the sandpaper (ГОСТ 17367-71). In parallel, test two samples under the same conditions. One of the samples is the reference one, the second is the one under investigation, and the wear resistance of materials with abrasive wear is judged by the ratio of their wears. Such a presentation of the experimental results eliminates the influence of the quality of the sanding pelt.

Contact of flat specimens, one of which performs reciprocating movement (Figure 2.2, scheme 3). It is carried out in the friction machine 77MT and in the friction machine of the Kishinev Polytechnic Institute. One of the friction schemes implemented in the vibrotribometer 8KU company Optimol (Germany). In the latter case, the upper sample oscillates, and the lower plate is stationary. Another difference of the vibrotribometer from other friction machines performing reciprocating motion is that in these machines the stroke length of the moving specimen is tens of millimeters, and in the vibrotribometer it is tenths and hundredths of a millimeter. Such a difference in stroke length is due to the need to reproduce in the first case the tribological process with a relatively long stroke, and in the second with a sufficiently short (for example, during reproduction of the fretting corrosion process).

The friction shaft-bearing scheme (Figure 2.2, scheme 4) is implemented in serial friction machines of the Ivanovo AO Techpribor: 2168 UMT and II 5080 SMT, as well as in a number of other installations In various embodiments, the rotational or reciprocating motion can be performed. It is used in the selection of compatible construction and lubricants for the bearing pair. The friction shaft pattern is a partial liner (Figure 2.2, scheme 5). It is used in the SMT-1 machine, in a number of earlier models of such SMC-2, MI-1, in the Amsler friction machine. It is used, in particular, in laboratory tests to assess the relative running-ability and sticking resistance of antifriction materials and metal-based coatings under friction in the mode of mixed lubricant according to ГОСТ 23.215-

84.Ii. The linear contact of rubbing surfaces (Figure 2.2, friction schemes 6 … 10) is implemented in the friction schemes which discussed below.

Rotating shaft — rectangular bar (Figure 2.2, scheme 6).One of the most common schemes in tribology. It is used in the Timken friction machine, as well as in a number of techniques implemented on friction machines that perform rotational movement of the shaft (Skoda-Savina machine, MI-1M machine, etc.).

With a Timken machine, with a roller speed of 800 min-1 (or at 3600 min – 1 according to the Ford method), the anti-seize properties of lubricants (according to A8TM B 2509 - greases, according to A8TM B 2782 - industrial and gear oils) or in a wide range of changes in the shaft speed and loads on the friction unit, the anti-wear properties of the oils are examined. The same scheme, according to ГОСТ 23.204-78, is used in the experimental evaluation of the abrasive ability of the processed radial surfaces of a cylindrical sample that wears the flat surface of the reference sample. Linear contact quickly turns into a plane contact [27, 28].

Friction shaft design — two liners (Figure 2.2, scheme 7). The diameter of the shaft is slightly smaller than the diameter of the hole in the liners, so that in this scheme an initial linear contact is made. This scheme is used in the well-known Almen-Wieland oil testing machine (shaft diameter 6.35 mm, hole diameter 0.178 mm larger). Tests on this machine are carried out with a step increase in the load on the friction unit until the seizing occurs.

The sphere – ring friction scheme (Figure 2.2, scheme 8). The rotating ball is in contact with a spherical belt of the same radius, machined or extruded at the intersection of the end and the inner hole of the ring. The belt width is very small (usually 0.2 mm), and therefore the contact in the first approximation can be considered as linear. One of the schemes provided for when testing lubricants by the temperature method according to ГОСТ 23.221-81 and implemented on machines of friction KT-2 and MAST-1.

In the Figure 2.2, **scheme of contact – 9**, the rotating roller is crimped on both sides by the ends of two cylinders of larger diameter with an H-shaped notch with an angle of 90 °. Such a friction scheme is applied in a falex oil friction testing machine. The roller has a diameter of 6.35 mm; the samples are loaded hydraulically. If the contact schemes discussed above are designed to reproduce sliding friction, then Figure 2.2, scheme 10 — **two rotating cylinders** — can perform both sliding and rolling with slippage depending on the direction and magnitude of the angular velocities C0j and from 2. This is one of the most common contact schemes , widely used in modeling friction in gears. Reproduced in various friction machines: in the serial machine SMT-1, previously produced machines SMC-2, Amsler, MI-1M and a number of special roller stands. In some cases, the stands provide an opportunity to change the speed of each roller separately, which allows to obtain different ratios of slip speeds and rolling speeds, to get a clean rolling or a clean slip.

The point contact of the rubbing bodies (Figure 2.2, friction schemes 11 … 14). Generally point contact, by definition, Podolsky, carried out for cylinders, spheres, cones and planes.

The scheme of friction crossed cylinders (Figure 2.2, scheme 7) – is currently used relatively rarely. However, contact circuits made for crossed cones and cylinders, spheres and cylinders, cones and spheres are widely spread. In this case, rotation of one of the elements of the friction unit or both can occur (as in the figure). If one of the samples is still moving progressively, the test will be constantly carried out on a fresh surface. The use of point contact of rubbing bodies during tribological tests in many cases is very rational. Firstly, friction pairs with a point contact allow high contact pressures, characteristic of such friction units as gears, rolling bearings, cam – pusher mates, etc. to be realized. Secondly, such friction pairs do not require burn-in to ensure conformity of the contacting surfaces. Finally, stain wear is easy to control. Of course, it is enough to correctly reproduce friction pairs with a point contact (for example, rolling bearings) on a friction unit model with a point contact. But the most widely tested friction test points with point contact are used in comparative tests of lubricants [29].

Friction of a sphere on a plane (Figure 2.2, scheme 12) is quite common. The relative movement of the elements of this rubbing pair is carried out either according to scheme 2 (i.e., a sphere in contact with a rotating disk, such as, for example, in a DS-1 friction machine), or according to scheme 3 (i.e., a sphere in contact with translational (as in the well-known Bowden-Leben machine), or with a reciprocating moving plate, as in one of the friction schemes implemented in the vibro-tribometer 8KU).

When choosing a test scheme, the possibility of reproduction on a model friction unit of a loaded state, which takes place in a full-scale friction unit, type of motion: translational, reciprocating, rotational (rolling, sliding, sliding), as well as the same temperature mode should be evaluated. The temperature regime is largely determined by the coefficient of mutual overlap (that is, the ratio of the nominal areas on which the friction process is carried out on the contacting samples) determining the distribution of heat fluxes. When using the method of physical modeling, a significant number of these requirements are taken into account automatically. Of great importance is the quality of the working surfaces of rubbing bodies. In comparative tests, the researcher seeks to ensure the same surface quality of the test specimens.

Methods of loading the friction unit should ensure smooth application and stability of the loading mode, regardless of the change in the sample size test process, their beat, the resulting friction moments and their change. These methods are usually fairly simple. If, under the test conditions, each measurement is carried out under constant load, then the friction unit is loaded either with weights (sometimes through a lever), or with a spring-loaded spring, or with hydraulic or pneumatic devices. Thus, the friction unit of a standard four-ball machine, the friction unit of the SRV vibrotribometer, as well as the well-known Skoda — Savina, Timken, etc. units are loaded with weights. in frictional contact, and at other times shock loads occur. This prevents testing under strictly controlled conditions. Therefore, in such cases, use loading devices that have the ability to damping. The most common device with a calibrated spring, Amonton used a flat calibrated spring to load the friction unit. Cylindrical springs are widely used in friction machines with rotating shafts (MI-1M, SMC-2, SMT-1, II-5018, etc.). The above-mentioned Almen-Wieland friction machine is equipped with a hydraulic device for transferring the load to the friction unit. The friction unit of the universal machine UMT-1 is loaded using a membrane pneumatic actuator. There are also installations where loading is carried out by a magnetic head.

The loading schemes discussed above are used for testing under constant loads - at least, constant for specific loading steps. However, there are methods 100 tests involving a change in the load on the friction unit in the process of work according to a certain law. The simplest case of changing the load in the process of testing is provided by the method of evaluation of the extreme pressure properties of machine-building materials (ГОСТ 23.213-83). Measurements are made with a friction scheme - crossed cylinders (Figure 2.2, scheme 11), with the translational movement of one cylinder (or a combination of translational and rotational) relative to the stationary other. The loading is carried out by flat springs, and a linear increase in the load is provided by preloading the spring with fixed wedges, with respect to which the sample and the springs are moving. A simple scheme of continuous loading of the friction unit of a modernized friction machine of the MI type was used by L.Y. Pruzhansky. The loading spring is replaced by a lever on which the tank is suspended, where water is supplied at a constant speed. Great possibilities for loading a friction unit according to a given law are given by the use of a friction unit with a hydraulic or pneumatic drive. More difficult is the implementation of feedback load with any output parameter, for example with wear to ensure constant pressure in the friction contact or with the friction torque. The simplest case of the last feedback is to turn off the machine when the frictional moment in the frictional contact reaches.

2.2 Materials used for the restoration of the gas turbine engine turbine

The working conditions of the turbine blades of the gas turbine engine (GTE) cause high level of static loads, as well as a large range of operating temperatures. The current trend to increase between repairs and general technical resources, as well as a further increase in traction characteristics GTE leads to the expansion of the limits of permissible loads and operating temperatures operation of the blades. To reduce vibration load, the blades are bandaged in the upper part on zigzag-like surfaces. Due to vibration displacement intensive wear of the contact surfaces of the shelves occurs as a result the development of fretting corrosion, which leads to premature release parts out of order. Therefore, the problem of increasing the wear resistance of working blades for GTE turbines are currently highly relevant [30].

To ensure the durability of contact the ends of the turbine blades working in the first place engine D18-T designed high temperature wear-resistant cobalt based alloy – HTN61. Alloy HTN-61 is well fused on nickel alloys and forms solder joints, therefore protection of contact ends can be made both by soldering plates and directly cladding alloy HTN-61, followed by mechanical processing.

Currently, to obtain coatings in internal cavities and perforations turbine blades is the most promising gas circulation method. It is different simplicity of execution, as well as the possibility obtain multicomponent coating outer and inner surfaces of the blades at the same time.

(CrAl) provides surface protection cooling channels and perforation holes patched. On the outer surface is additionally applied condensation diffusion coating SDP2 + VSDP16.The use of complex heat-resistant coating (CrAl) + SDP-2 + VSDP16 and high-temperature wear-resistant alloy HTN-61 for contact the ends of the blades allowed to increase the resource working curtain TJE18 T to 12000hours. Much success in repairing parts associated with the use of self-fluxing powders type PG-U5N. Coatings made from these powders plasma spray, even without further flashing can produce satisfactory quality layer with the required hardness in the range of HRS 20 ... 60.

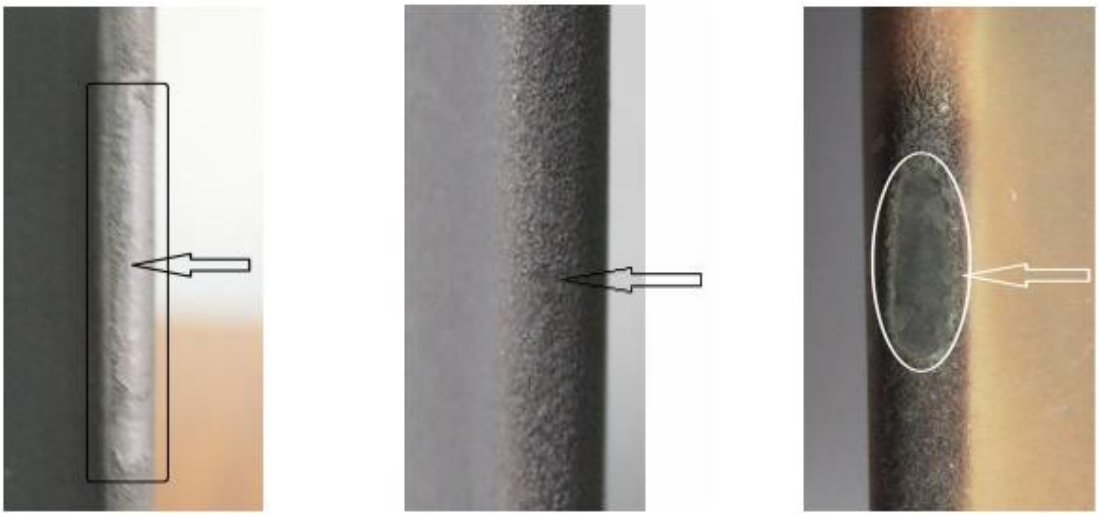
The use of traditional aluminide coatings for blade protection heat-stressed GTE turbines are unacceptable since the start of flashing the interface between the NiAl layer and heat resistant alloy (substrate) occurs at temperatures above 1120 °C. Macroscopically it causes protective surface waviness before the development of its active oxidation. In practice, implemented and widely the following technologies are applied:

– Coating: LPPS (low pressure plasma spraing) for coating application, having in its composition oxides Y, Hf, Si.

– electron beam technology evaporation and vacuum condensation of coatings MeCrAlY;

– VPHET (vacuum plasma high energy technology) which is used for applying two-layer coatings SDP2 / VSDP-16in particular to protect working blades of modern GTE.

For two types of working shovels (RD33 andTK-AI-450-MS) aviation gas turbine engines reviewed features of the degradation of the structure of alloys and protective coatings during operation. Metallographic analysis was performed in cross section of the pen in the area of the characteristic operational damage. Structure blade material and coatings were studied with using raster electronic backscatter electron microscopy (50 ... 3500). The chemical composition of the material in local areas of the blade was determined energy dispersive analysis.



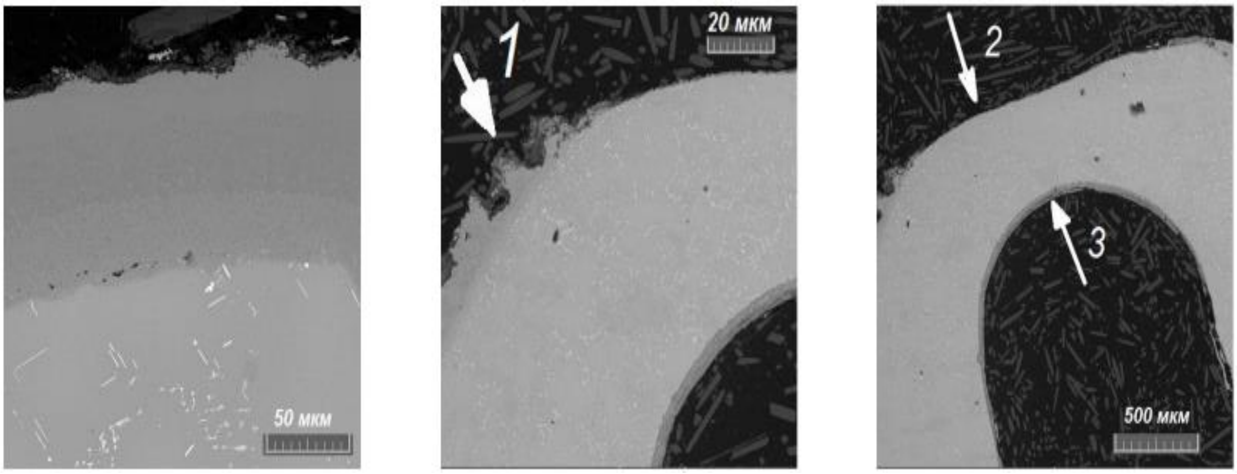
A B C

A – discoloration or peeling of the protective coating;

B – local reflow protective coating;

C – destruction of the coating and erosion of the protected alloy.

Figure 2.3 – Appearance of the overheating zone on working blades of the gas turbine engine RD33



1 – Destruction external coating on the periphery of the burnout;

2 – Erosion of the blade material in the burnout zone;

3 – The degradation zone of the PSC on the inner wall.

Figure 2.4 – Microstructure of heat-resistant protective coating SDP-2 / VSDP-16 (ZhS26-NK alloy) on the track surface of the working blade and the state of the entrance edge in the burnout zone.

To obtain areas of welding and deposited material with minimal defects by improving weldability, as well as improving the performance properties of the blade, the method includes heat treatment with heating to the holding temperature, holding at this temperature, cooling, restoring damaged areas by welding metal or welding, in vacuum to a temperature of 200-950 ° C, and exposure at this temperature is carried out in vacuum for at least 2 hours before the end of degassing and recovery is dislocation metal structure. After welding, mechanical treatment is performed, after which they are strengthened with microbeads, then ion implantation and post-implantation heat treatment are performed. As ions for implantation, Cr, Y, Yb, C, B, Zr ions or a combination of them are used. After implantation, a protective coating is applied using MeCrAlY, where Me is Ni, Co, NiCo or Ni-Pt-Al, by ion-plasma method or by electron beam evaporation in vacuum. A layer of ceramic material with a thickness of 20 … 300 μm is applied to the coating layer; ZrO2-Y2O3 is used as the material of the ceramic layer, and ZrO2-Y2O3 can be used in the ratio Y2O3 - 5 ... 9 wt. %, ZrO2 – the rest [31].

Improving the wear resistance, for example, of compressor blades is achieved by soldering to the retaining shelves of the VTN-1 hardening material, consisting of solid particles of tungsten carbide (relit) and VPr-16 solder on a titanium base as a bond. To implement this process, a special installation has been designed, including a vacuum chamber, a high-frequency device and a vacuum system. When the thickness of the soldered layer is 0.2 … 0.5 mm, it provides almost uniform distribution of tungsten carbide particles. As a result, the compressor blades with a local soldering of the composite material VTN-1 and the worn-out contacting surfaces of the retaining shelves restored by him also increase the service life several times.

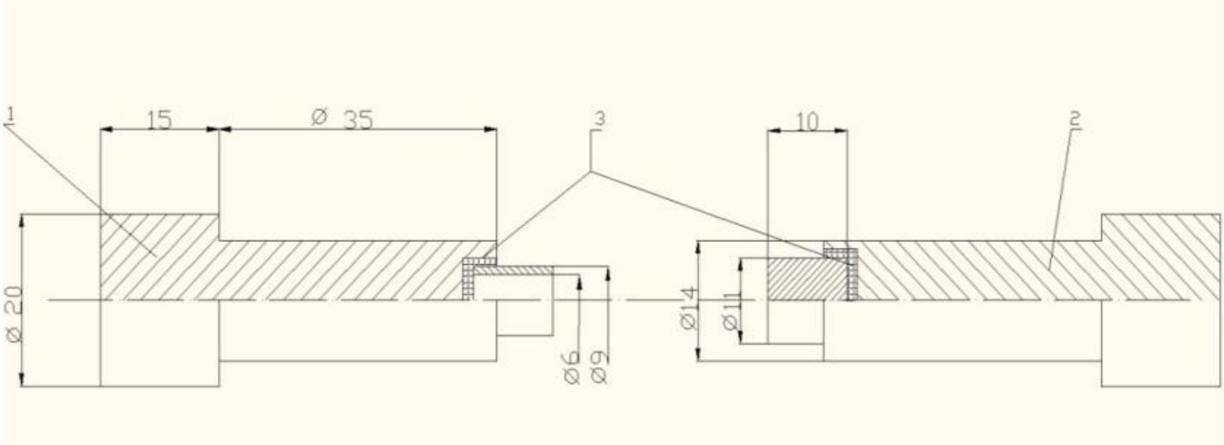
The basis of ensuring the heat resistance and wear resistance of such alloys is the principle of composite reinforcement of a relatively plastic metal matrix using crystals of solid high modulus boride and carbide phases, which is realized in the structure of fused alloy, alloys based on iron and cobalt during their eutectic crystallization. The use of hardened eutectic alloys that combine their properties to work at high temperatures is widely used on a number of aviation engines as materials for strengthening and restoring the contact surfaces of turbine blades, using argon-arcfurnaces and high-temperatures oldering plates. The most common HTN-37, HTN -61, HTN -62 alloys of Co-NbC and Co-(Ti; Nb)-C systems. During several laboratory and operational tests, it was found that the high wear resistance of such alloys significantly exceeds the wear resistance of traditional heat-resistant alloys under high-temperature friting conditions. The trend towards the development of materials to increase the life of engines in the course of time increases, as for modern aviation engines, new requirements for increasing the specific power, performance characteristics of parts, in particular wear resistance of the trunks of the turbine blades. To solve the problems, hot-pressed powder alloys based on cobalt and titanium carbide were developed and proposed for use as high-temperature wear-resistant materials. The principle under lying the creation of wear-resistant materials is based on the possibility of obtaining a powder metallurgy composition composite dispersion strengthened fail-alloys (further powder composite alloys), in whichh refractory fine-dispersed inclusions of the strengthening phase can be artificially introduced into the matrix in the finished state and practically in any the required proportion. Properties of such materials depend on the properties of the matrix and the material of the filler, the quantity, dispersion and the method of introducing the phase of the filler into the matrix.

2.3 Gauging and testing device “MFC-1”

Test for wear resistance Today, there are many techniques and equipment for researching materials in high temperature fretting. They allow to realize a different type of contact between surfaces of friction, methods of heating and the mutual displacement of samples. However, based on the task of the study, it is necessary to create such conditions that would best suit the working conditions of the work of the blades of the GTE on the trampoline racks. Consequently, the samples should contact the plane, provide a relative cyclic load of 40 MPa, the amplitude of vibration displacement - a range of values up to 1 mm. Thus, the most suitable for these requirements is a plant for the study of materials in the fretting MFC-1. To provide the temperature regime, it is additionally equipped with a ring electric oven, thermocouple and millimeter (Figure 2.5).After the test, the average linear depreciation of the samples was measured. The installation allows conducting fringing-corrosion studies infrequency range 10 … 30 Hz at normal pressure up to 40 MPa and amplitude vibrational displacement 0,001 … 2.5 mm [32].

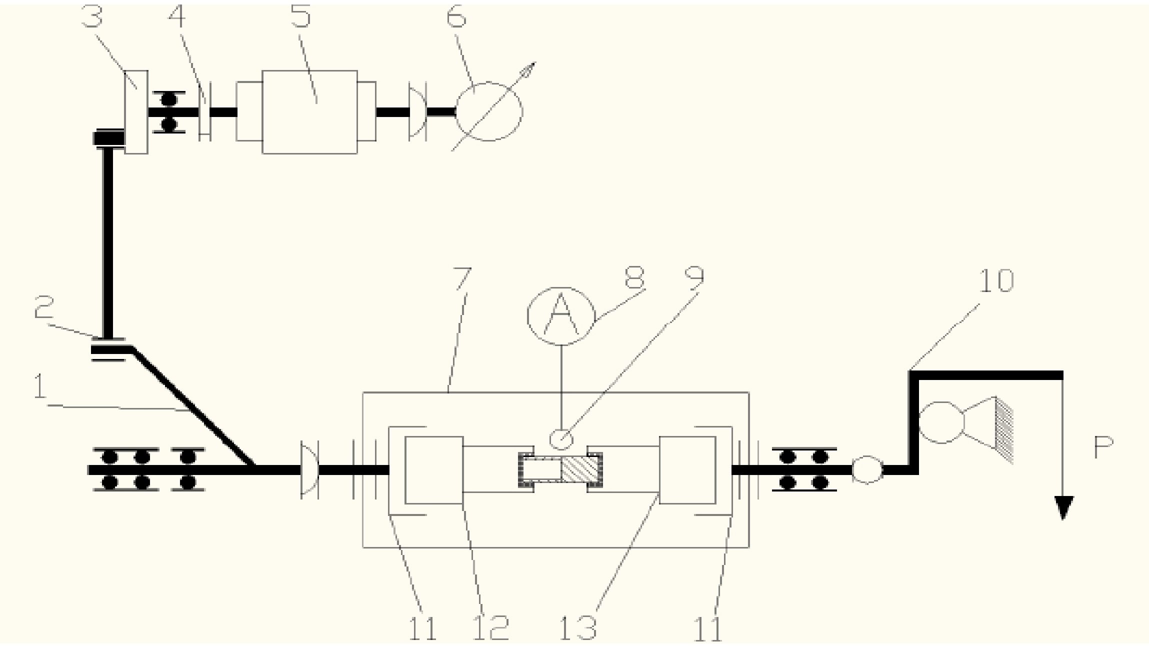
The working steam (Figure 2.6) Is a rolling sample with a ring-shaped hole, to which a sleeve that is pressed against a fixed sample is fastened with a high-temperature solder.

Figure 2.5 – Friction unit of the installation of the MFC-1



1 – movable; 2 – fixed; 3 – solder.

Figure 2.6 – Samples for friction-corrosion tests



1 – horizontal connecting rod; 2 – vertical connecting rod; 3 – adjustable eccentric; 4 – coupling;5 – electric motor; 6 – count of the number of cycles; 7 – electric oven;8 – millimeter; 9 – thermocouple; 10 – lever loading device; 11 – Cheng; 12 – moving sample; 13 – stationary sample.

Figure 2.7 – Principal scheme of installation of MFC-1

Samples for friction-corrosion tests form a ring friction track with a total area of S = 35 mm^2. The width of the friction track is 1.5 mm. The fixed sample is executed in a similar way. The installation allows conducting fretting-corrosion studies in the frequency range of 10 … 40 Hz at a normal pressure of up to 40 MPa and for the amplitude of the vibrational displacement of 0.001 … 2.5 mm. The value of movement of a moving sample relative to a stationary installation with the help of an adjustable eccentric. The exact amplitude of slip in the range 0 … 0.015 mm is controlled by a special screw. The amplitude can be measured using a microscope under stroboscopic illumination, or an inductive converter. The heating of the samples allows to conduct research at temperatures up to 1200 ° C. The elongated specimens and the oven open at the sides ensure that the set temperature is maintained in the friction zone, and at the apertures and in the mounting points of the samples it does not exceed 300 °C (as can be seen from the straw-yellow color of the oxide films formed on the holders) , therefore no additional cooling zing is used. For tests, samples are installed in the hinges. At the same time, the gangs are completely released, the samples are not tucked away. Thus, after loading the sample, the samples are self-centering, after which their final fixation takes place. The rigid fastening in the hinges and the same rigid fastenings themselves zing allow for minimal displacement of the samples in the process of testing, which allows you to withstand the specified load mode accurately. When heated to the operating temperature, the installation is unloaded to prevent grabbing. Establishing a distinct ring of fixing a fixed sample on an adjustable ball bearing allows it to accurately center it with a moving sample. The cut chains allow the samples to be self-aligned. Moving ladder is a ring body that moves fixedly to the table vibrostand. A chink is attached to its moving shaft. The shaft is mounted on two radial-thrust bearings and one stubborn. Its centering on conical and cylindrical surfaces simultaneously allows to maintain its position precisely with respect to the mount of the fixed sample holder, and also to withstand a given position throughout the range of loads and amplitudes. In the process of updating the installation for the possibility of using elongated samples, its base was expanded, that is, the distance between the moving and stationary grandmothers. For this, the stationary grandmother was taken out of the boundary of the vibrostand table and mounted on a cantilevered stove, which did not change the overall design and possible modes of testing the samples on this installation. The specified load on the samples is carried out with the help of a lever device, which allows to create more specific loads. Before the tests, the working surfaces were brought to the same roughness by means of a grinding machine. The linear wear of samples was measured to evaluate the fretting stability [33].

Method for determining the heat resistance of materials Test samples were made from the same materials used for other tests. The method of electro-erosive cutting produced cylinders in height 5 … 10 mm with a diameter of a circle of base 6 mm. The heat resistance test was carried out in an electric oven at a temperature of 1100 °C with a holding time of 50 h with free access to the air chamber. After every 10 hours of testing, samples were cooled and measured mass gain. Heat resistance was determined as an increase in the sample mass per unit area per unit time (g / mm^2 h).

2.4 Samples of composite materials for experiments

For this study, for the purpose of comparison, it was decided to make alloys based on cobalt and nickel alloyed with Cr, Fe and Al.

Choice of filler material The choice of filler for powder alloys is determined by the general requirements for the reinforcing phases of the heat-resistant alloys, namely: the strengthening phase should have high wear resistance, hardness, corrosion resistance in chemically active media, high heat resistance, inertness to the material of the matrix throughout the range of workers temperatures In addition, these compounds should have high levels of cobalt relatedness, which can be estimated from the angle of wetting θ. The magnitude of this angle indicates the ability of the melt to form a stable physical connection with the reinforcing phases. Otherwise, voids in the intergranular space will be formed. Another criterion was the non-deductibility of the filler material and its widespread use in other industries. Such requirements may correspond to a number of refractory compounds. Comparison of their properties can be made according to the data presented in Table 2.1. The results of the analysis of the data of some refractory compounds allows to distinguish from them titanium carbide TiC. Its use for the production of powder alloys will significantly increase the content of the wear-resistant phase, which in turn will increase the wear resistance, heat resistance and hardness of the matrix material both at low and at high temperatures [34, 35].

Table 2.1 – Characteristics of some refractory compounds

№	Compound	Mass gain, mg / cm^2 (T = 1000 ° C)	Max temperature of stable state	Microhardness MPa, x10^3 (P, H)
1	Cr_3C_2	0	1895	18 (15)
2	Cr_7C_3	69,7	1782	18,8 (20)
3	$Cr_{23}C_6$	0	1518	16,6 (10)
4	NbC	11,7	3613	26,2 (5)
5	TaC	39,4	3985	23,8 (5)
6	TiC	1,5	3257	31,7 (5)
7	W_2B_5	2,5	2370	26,6 (3)
8	TiB_2	12	2790	33,7 (3)
9	CrB	0,55	2100	13 (1)
10	Mo_2B_5	1,5	2200	23,5 (5)
11	TiN	25	2950	20 (10)

Thus, on the basis of the analysis of the above data (Table 2.1), it was concluded that the titanium carbide corresponds most to the requirements for the filler of a heat-resisting alloy. It is the most refractory and heat-resistant non-refractory refractory compounds widely used in industry. Modern production methods allow to completely separate carbide of titanium from free carbon, which increases its characteristics. On the other hand, this will prevent the formation of additional chemical compounds in the system, in particular - fusible eutectic with chromium. Powder manufacturers provide a high assortment of dispersion 3 … 3000 microns, which allows you to experiment with the size of carbide impurities in a very wide range. Titanium carbide has a low density (4,92 g / cm^3), which will reduce the mass of blades. As you know, reducing the mass of the disk by 10 % can triple its durability [36].

Production of samples for testing in conditions of high temperature fritting. Alloys were made by hot isostatic pressing of powder mixtures of the corresponding composition obtained by mixing in the planetary mill of the matrix phase base metal powders, the doping elements and the carbide phase powders. The hot pressing modes were selected based on the results of studies on the effect of temperature, pressure, duration of pressing compression on the density and porosity of the received presses. For the comparative evaluation of wear resistance during friction wear, powdered alloys were made on the basis of cobalt and nickel with different volumetric contents of the reinforcing carbide TI phase.

Table 2.2 - Composition of the studied composite materials

№	Compound	Composition of components, vol.%			Type of compound
		Co alloyed	Ni alloyed	TiC	
1	PK-30	70		30	Powder, system Co(Al; Cr; Fe) - TiC
2	PK-40	60		40	
3	PK-50	50		50	
4	PK-60	40		60	
5	PN-30		70	30	Powder, system Ni(Al; Cr; Fe) - TiC
6	PN-40		60	40	
7	PN-50		50	50	
8	PN-60		40	60	

Based on studies on the influence of hot compression conditions (temperature, load, durability) on density, porosity and microhardness of samples by hot pressing method composite alloys based on cobalt and nickel with different contents of titanium carbide were manufactured. It should be noted that for the production of powder samples it was important to achieve their lowest porosity, since wear tests with friction indicate the minimum wear in low-porous powder and foundry alloys [37].

Conclusion to part 2

The friction machine is a device for reproducing the tribological process under controlled conditions, providing control of the input and output parameters. AlloyHTN-61 is well fused on nickel alloys and forms solder joints, therefore protection of contact ends of the turbine blades can be made both by soldering plates and directly cladding alloy HTN-61, followed by mechanical processing. After welding, mechanical treatment is performed, after which they are strengthened with microbeads, then ion implantation and post-implantation heat treatment are performed. As ions for implantation, Cr, Y, Yb, C, B, Zr ions or a combination of them are used. After implantation, a protective coating is applied using MeCrAlY, where Me is Ni, Co, NiCo or Ni-Pt-Al, by ion-plasma method or by electron beam evaporation in vacuum.

The samples should contact the plane, provide a relative cyclic load of 40 MPa. The most suitable for these requirements is a plant for the study of materials in the fretting MFK-1.

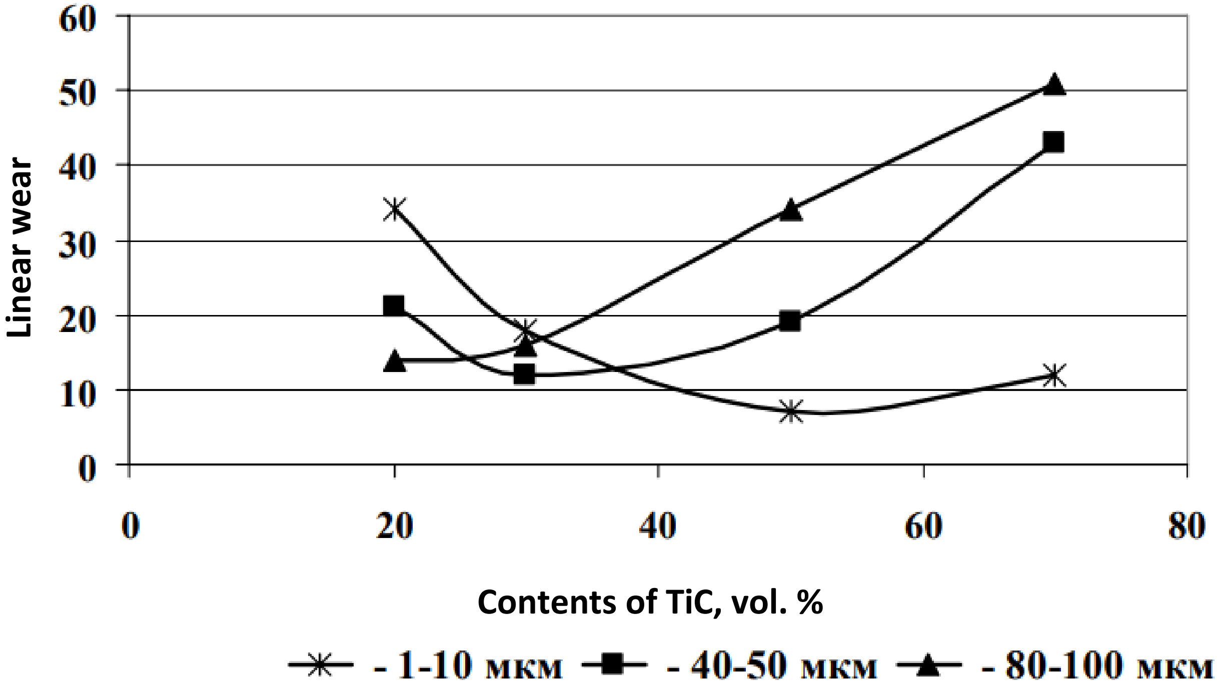
For this study, for the purpose of comparison, it was decided to make alloys based on cobalt and nickel alloyed with Cr, Fe and Al. The results of the analysis of the data of some refractory compounds allows to distinguish from them titanium carbide TiC.

PART 3

FRICTION TEST

3.1 Properties of researched cobalt and nickel alloys

Dependence of wear resistance of composite powder alloys on the content of the reinforcing phase. The wear resistance of composite powder alloys, as shown, depends on the content of the strengthening phase. However, wear resistance depends on the size of the grain. In this part of the dissertation study, the influence of the volumetric fraction of titanium carbide in the alloy on its wear resistance is determined depending on the size of the grain. For this purpose, a series of alloys with a content of filler 30, 50 and 70 % by volume was manufactured. and a grain size of 1 … 10 microns (in powders of this fraction it contains up to 2 … 4 % of TSC crystals with a grain size less than 1 μm, as well as 6 … 10 % of Tis crystals with a grain size of up to 20 μm), 40 … 50 μm, 80 … 100 microns. It is difficult to conduct a study with particles of less dispersion from a technological point of view, due to the difficulty in their grinding and sifting. The test results are shown in figure 3.1.



T = 650 ° C, A = 0.25 mm, P = 30 MPa.

Figure 3.1 – Wear resistance of composite alloys depending on the size and amount of the reinforcing phase

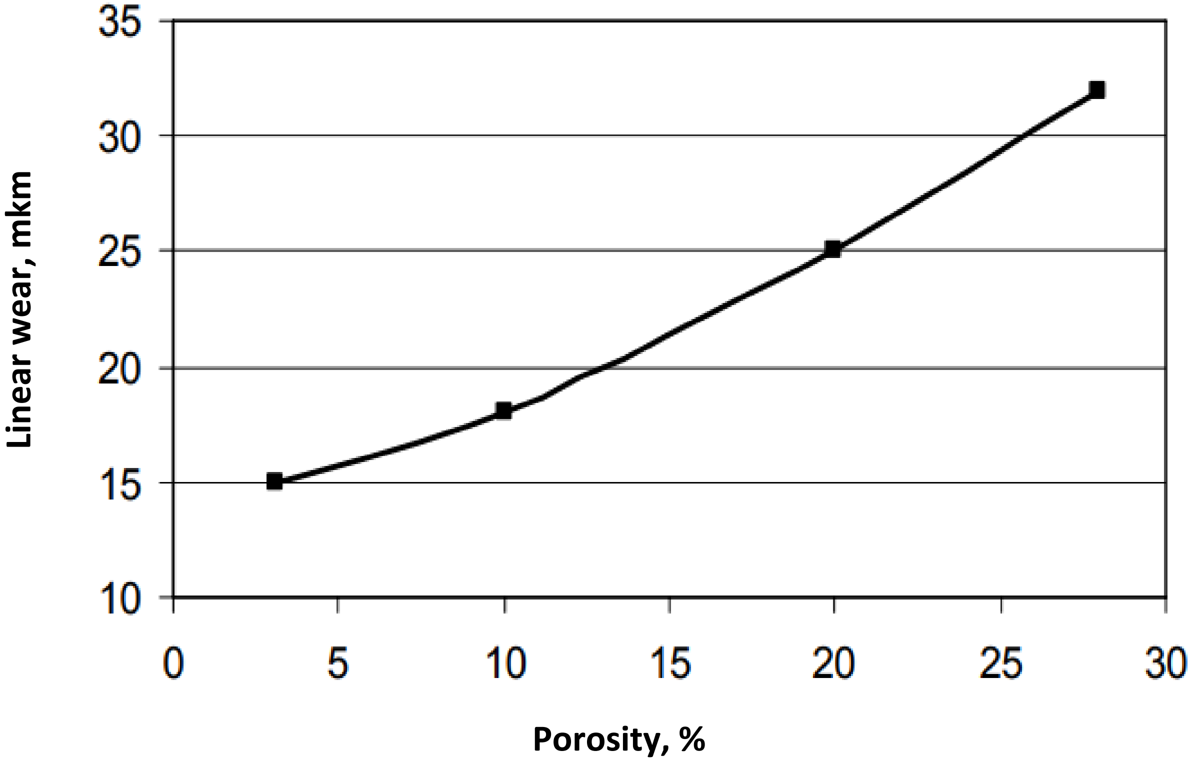
Test base 500 thousand cycles. Thus, with an increase in the content of particles in the size of 1 … 10 microns from 20 to 50 % by volume. The average linear wear has decreased by 3 times. Thus, increasing the filler significantly improves the wear resistance of such material. However, further growth of the content of carbide phases leads to a deterioration of tribological characteristics, which can be associated with the growth of internal stresses in the matrix [39].

High wear resistance of the alloy with 50 % TIS content. can be explained by the fact that the carbide phase covers a significant part of the surface area of the alloy and, as a result, predominant placement of the actual contact areas on carbide grains, which have a high wear resistance at the test temperature. In addition, those grains of less than 1 microns provide a micro content matrix, and grains of 5 … 10 microns and larger (up to 20 microns) perceive the main load of the friction forces. The nature of such dependencies can be explained by the fact that with the increase in the amount of filler in the alloy, the stresses in the matrix, caused by the action of friction forces, increase significantly, the deflection of the strengthening phase takes place. An increase in wear with a decrease in the content of the strengthening phase is due to the fact that the distance between the adjacent particles is large and a significant proportion of the load is perceived as a plastic and non-wear-resistant matrix. This is due to the fact that the distance between the carbides exceeds their average size and they can freely contact the matrix, and this, due to the high stiffness of the TiC, results in abrasive wear of the matrix. Thus, there is a certain volumetric content of the hard filler which has the highest wear resistance for this composition. Growth in the size of the filler significantly changes the nature of the wear curves. For the dispersion of the filler 40 … 50 μm there is an extremum - a segment corresponding to the volume fraction of TiC of 30 … 40 %. Moreover, for some deviation from this value, wear is also small. This change lies within ± 60 % when the content is changed by 10 % vol. As the content of the carbide phase 18 increases, there is a further, but more dramatic increase in the average linear depreciation of the samples. A slightly different nature of wear is characteristic of alloys with the size of carbide grains 80 … 100 microns. Here the extremum is weakly expressed and the minimum wear is observed for the content of titanium carbide 20 % vol. Further increase in the content of the carbide phase dramatically increases the average linear wear of the alloy. In the process of hot pressing there is a deformation of the matrix phase, so that the pores are closed. In this case, the carbide grains do not deform, there is a process of intrusion of the matrix into the space between the grains. Thus, a large grain of carbide complicates this process, in particular the intervals between such grains are sufficiently large, which requires a significant amount of metal bond to close the pores.

For small particles of TiC their high-temperature implantation in plasticized metal occurs, which contributes to the increase of the density of the alloy and the closure of pores. Thus, the main factor causing different intensity of wear due to the change in the grain size of the carbide phase is the increased size and the number of pores formed during the hot pressing process. The results of the conducted research testify. that for each separate fraction of the strengthening phase there is such a correlation of the matrix filler system, in which wear is minimal. Thus, for a fraction of 1 … 10 microns, minimum wear is observed at 50 %, for a fraction of 40 … 50 microns – 30 … 40 % vol. For a fraction of 80 … 100 microns – 20 … 30 % vol. The least wear in high-temperature fretting conditions is with alloys with TiC contents of 50 % vol. and dispersion of carbides of 1 … 10 microns, which also contain grains smaller than 1 microns and grain 10 … 20 microns. The use of powders of titanium carbide of different dispersion provides such an alloy combined micro- and macro-strength, and as a result – high wear resistance.

The effect of porosity on wear resistance of investigated alloys. Wearing of composite powder alloys under conditions of high temperature fretting depends on the method of fabricating the material, structure and properties of the strengthening phase, the uniformity of the distribution of mechanical characteristics in the structure, and so on. For materials of one chemical and quantitative composition, made by methods of powder metallurgy, there is a significant difference in the structure, which consists in different amounts and pore sizes. Pores are mainly local clusters of grains of titanium carbide, between which there is no matrix phase [40].

They significantly affect the distribution of stresses arising in the material under the influence of friction forces, namely - reduce the strength of the material. The research was carried out on samples of the same composition containing titanium carbide in a volume to cobalt matrix ratio of 50/50 but different porosity (3.1, 10.4 and 28 %). The average linear wear was measured to assess wear resistance.



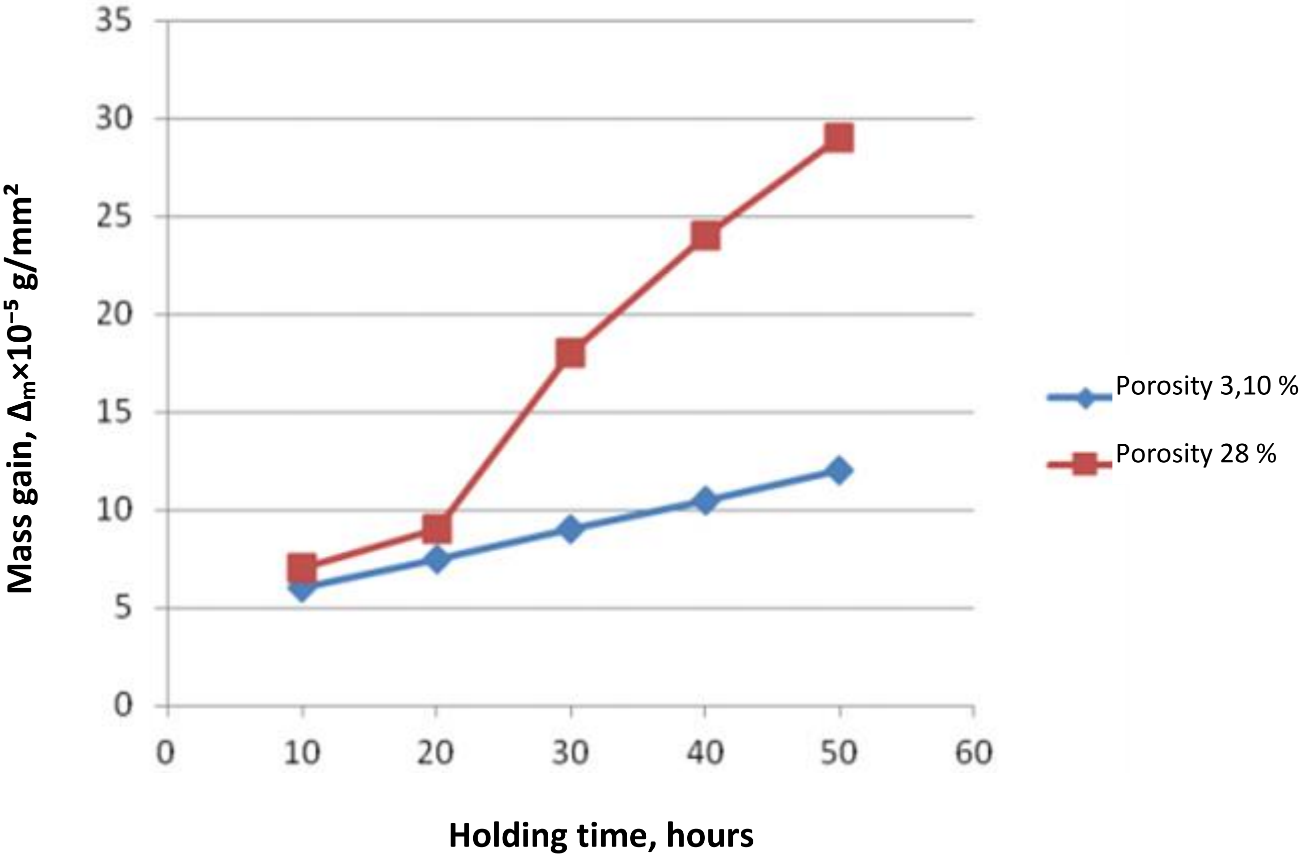
(T = 650 °C, P = 30 MPa, A = 120 µm, 5 × 10^6 cycle)

Figure 3.2 – Average linear wear of powder composite alloys depending on porosity

Thus, the growth of porosity in the material from 3 to 28 % leads to a two-fold increase in the value of linear wear. 20 This can be explained by the fact that the high-porosity material (PC-50 alloy (porosity 28 %) can not effectively redistribute the stresses that result from friction forces inside the material and relax them. In the porous material, the layers of the cobalt matrix are exposed to the external load-shift load elastic deformations, the magnitude of which obviously increases with increasing porosity. These deformations to a large extent are possible due to the presence of pores. This contributes to the accumulation of fatigue damage and the formation of micro cracks, in not always on the verge distribution matrix and carbide phases. Thus, the porous material wear is more intense than low-porosity.

3.2 Influence of porosity on the heat resistance of alloys

Study of the process of contact interaction of heat-resistant alloys under high-temperature fretting conditions showed that an important and necessary property for wear-resistant material is the ability to form a dense oxide film. Its main functions are a barrier for the further penetration of oxygen into the main material, the localization of stresses caused by friction in the surface layer, the protection of the main material from gripping, etc. Partially the ability of the material to form stable oxide layers can be identified with heat resistance in high temperature conditions. Investigation of heat resistance of composite alloys was carried out at a temperature of 1100 °C, weighing of samples was carried out every 10 h of annealing on analytical scales [41].

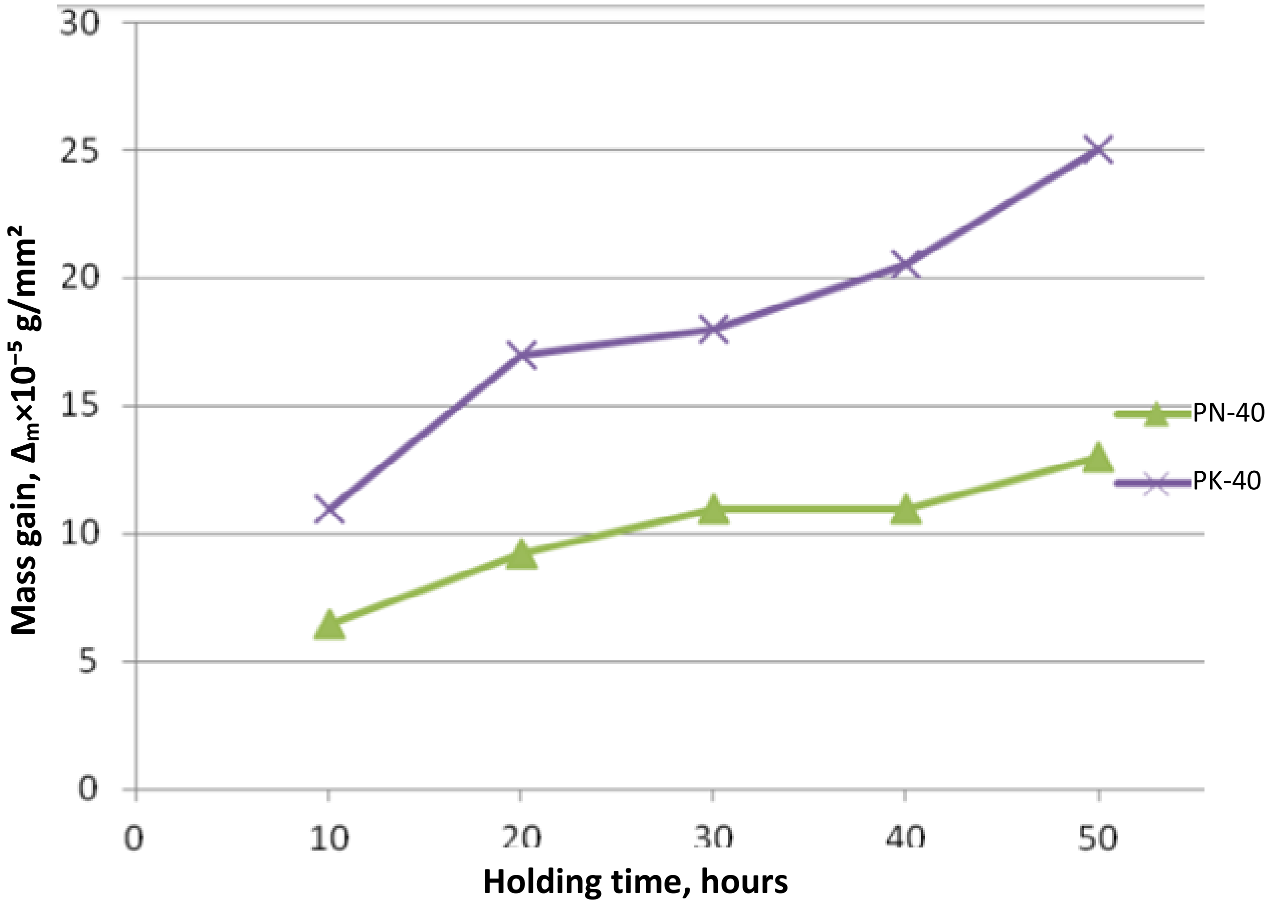


Test temperature - 1100 °C

Figure3.3 – Heat resistance of cobalt alloy PK-50 with different porosity

It can be seen that with increasing porosity the oxidation resistance decreases. This characteristic depends on the properties of the matrix, the filler as well as the state of the surface.

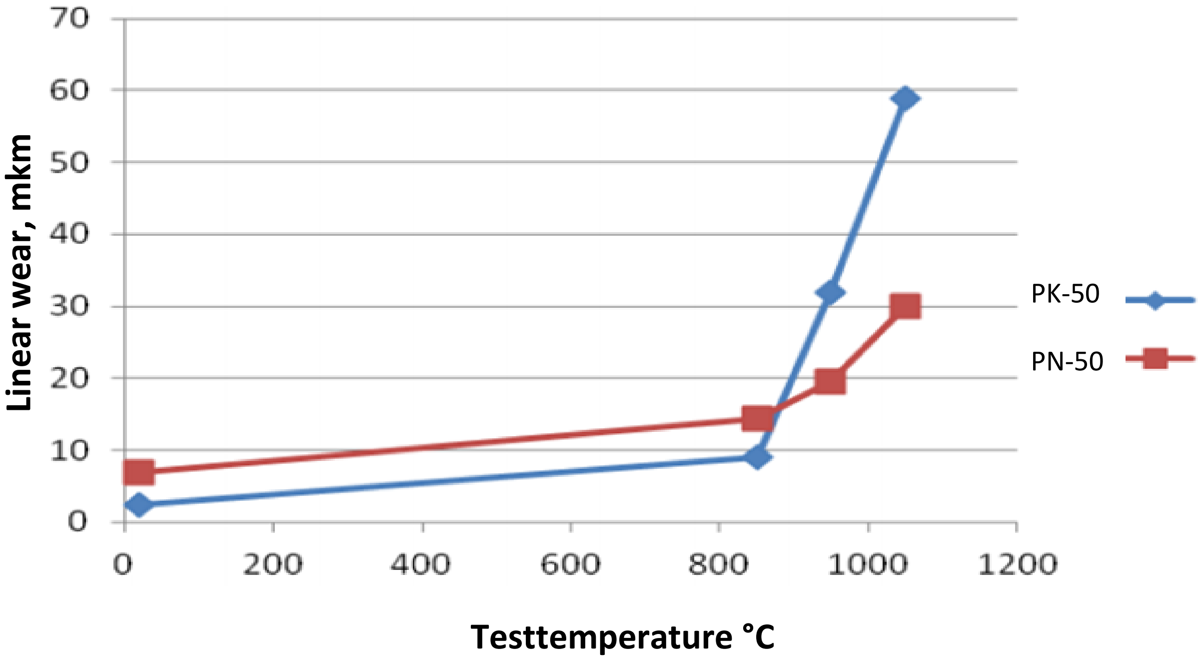
After performing the analysis of the results of the oxidation of objects, we will be able to perform a comparative characteristic of powder alloys on the basis of alloyed Co and Ni components. Characteristic signs of the growth of the mass of alloys using Co and Ni, which are depicted in Figure 3.4, we obtain as a result of annealing in the air at a temperature of 1100 °C with the same content of titanium carbide (40 % vol.).



TiC on the basis of: – nickel (PN-40); based on cobalt (PK-40)

Figure 3.4 – Heat resistance of powder alloys with 40% vol.

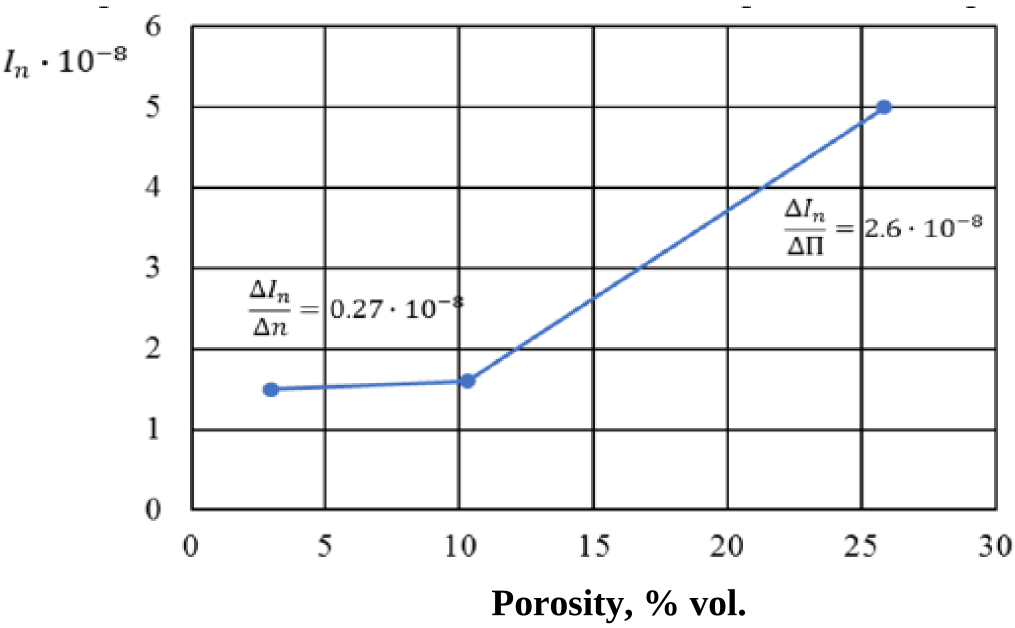
During the experiment, within fifty hours, the weight gain of nickel alloy remains the smallest. It should be noted that the presence of porosity of the structure of the samples under study has little effect on the processes of oxidation of the material. However, despite this effect, the advantage of nickel-based composite material is obvious. In fact, an explanation of this assertion can be characterized by two similar systems - Ni-Cr and Co-Cr. Alloy alloying in such compounds of cobalt and nickel passes the same way. The presence of high chromium concentration in the alloy leads to the formation of a Cr_2O_3 layer, resulting in a slight difference in the oxidation of Co-Cr and Ni-Cr alloys, which can be neglected, which makes it possible to equate the samples. However, the adhesion of scale to cobalt is worse, so during practical use, the heat resistance of Co-Cr alloys is actually lower. Comparison of durability of powder materials, the mixture of which is doped cobalt, nickel, and the strengthening phase - titanium carbide provides an opportunity to determine the relationship of change in their wear at different temperatures and loads. Indicators of average linear wear of investigated materials on the basis of nickel and cobalt with the same content of titanium carbide (50 % vol.) By results of tests in conditions of fretting wear at temperatures of 20, 850, 950 and 1050 °C are shown in Figure 3.5.



TiC on the basis of: – nickel (PN-50); cobalt (PK-50).

Figure 3.5 – Average linear wear of powdered alloys with 50 % vol.

Test conditions: load: A = 120 microns; P = 30 MPa; υ = 30 Hz; N = 1 × 10^6 cycle. Friction pairs of the same name. The wear of nickel alloys in the temperature range from room temperature up to ≈ 900 °C is almost twice as high as in a cobalt-based alloy, but the advantage of wear resistance of a nickel alloy over cobalt is observed at maximum temperatures, namely, the index of wear resistance of nickel alloy is higher at almost 1.6 … 2 times The difference between these indices can be explained by the appearance of adhesion during the oxidation of nickel with a base that exceeds the adhesion of oxidation products of the alloy based on cobalt. The advantage of the melting temperature, heat resistance, durability and machinability of nickel and cobalt powder mixtures can be recommended for the production of alloys to increase the wear resistance of the contact surfaces of the workpiece blades of the GTE. The use of these alloys more efficiently, taking into account the difference in the wear resistance parameters of the alloys on a different basis at different temperatures and different operating modes in the engines and their components.

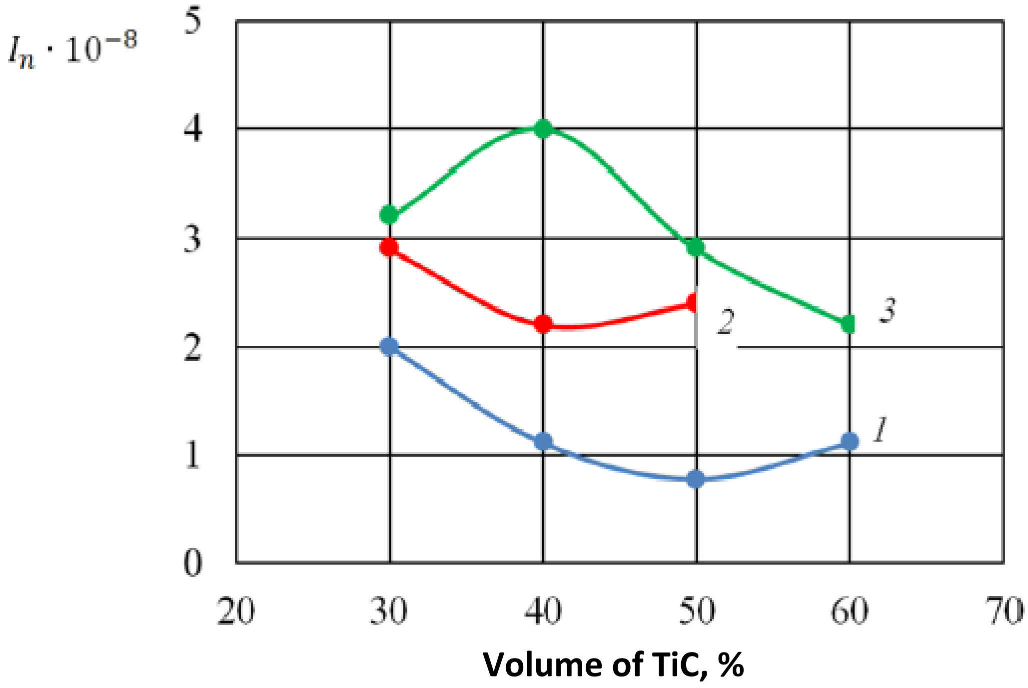


Terms of contact vibroloaded N: amplitude of relative displacement – A = 200 μm, specific contact load – P = 30 MPa, frequency of vibrational displacement – υ = 30 Hz, external temperature – T = 293 K, test base – N = 2×10^6 cycle. Couples of the same name.

Figure 3.5 – Schedule of the dependence of the wear intensity of composite powder alloys PK-50 system Co (Cr; Al; Fe) – TiC from porosity.

In addition, with the use of analytical correlations obtained in the work the values of stress coefficients of composite material were calculated. By the action of normal pressure and frictional force. Calculations were made on an example of a Co-TiC model alloy with an unlined cobalt matrix and the content of TiC in the range of 10 … 80 %. It was assumed that for such voluminous content of the inclusions of the carbide phase and the proportionality of their dimensions with the depth of occurrence points of maximum stress concentration, stress strain state friction loaded surface layer of a heterogeneous composite material can be submitted by a model close to the local distribution model. Leak stresses adopted for an idealized linear reinforced medium [42].

Results of research on wear of studied powder alloys and calculation dependences of maximum stress concentration factors of longitudinal displacement compression (Kr) and longitudinal displacement (K1r) on the volume content in the composition of Co-TiC of carbide inclusions are presented in Figure 3.6 and 3.7.



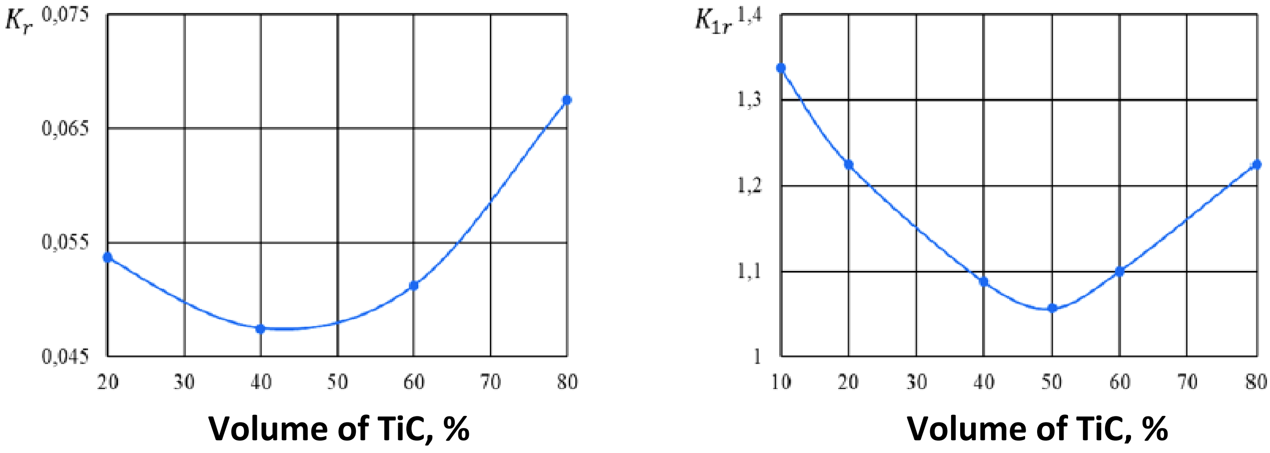
1 – alloys of Ni (Cr; Al; Fe) -TiC system; 2 – alloys of the system HA32-TiC;

3 – alloys of Co (Cr; Al; Fe) -TiC system.

Load conditions: A = 120 μm; P = 30 MPa; υ = 30 Hz; T = 293 K; N = 1×10^6 cycle.

Figure 3.6 – Dependence of wear intensity of composite powder alloys from volume content of TiC

It seems that the highest wear resistance of powder alloys of the studied systems. It is achieved by the content of the carbide TiC phase in the concentration range close to50% vol. The same fields correspond to the minimum values of the concentration of stresses in the model composite from the action of the force of normal pressure and strength friction (Figure 3.7).



a – longitudinal compression Kr; b – longitudinal displacement K1r

Figure 3.7 – Calculated values of maximum coefficients of stress concentration in Co-TiC composite depending on the volume content of TiC

Thus, the obtained results indicate that there is a maximum permissible value of porosity and an optimal concentration of the reinforcing carbide the phases in which the composite powder alloys under study are achieved the greatest resistance to friction wear as can be seen from Figure 3.6 and 3.7. To ensure maximum wear resistance of alloys, their porosity should be as minimal as possible, and the volume content of the inclusions of the strengthening TiC phase to be in the concentration range close to 50 % vol. Obviously, for such the content of the carbide phase is formed most favorably in relation to both the bulk strength of the composite, and the stress-strain state of its friction-loaded surface layers of the correlation and the morphology of inclusions a solid carbide TiC phase and a plastic metal matrix. At the second stage experimental studies of wear resistance of powder composite alloys PK-50, PN-50, HA 32-50 with maximum an acceptable content of titanium carbide when wearing under high-temperature fritting conditions. As in previous studies, the samples were made of hot pressed blanks, the porosity of which did not exceed 10%. The values of mean linear wear of samples of investigated alloys, obtained by results tests, presented in Table 3.1.

Table 3.1 – Results of evaluation of wear resistance of alloys PK-50, PN-50, HA32-50in conditions of high-temperature fritting

№	Material	Average minimum wear, µm, temperature, K *		
		1123	1223	1323
1	PK-50	9,0	32,0	59,0
2	PN-50	14,5	19,5	30,0
3	HA32-50	7.5	12,0	16,5

* – Terms of the vibrating contact load: A = 120 microns; P = 30 MPa; υ = 30 Hz; N = 1×10^6cycle. Friction pairs of the same name.

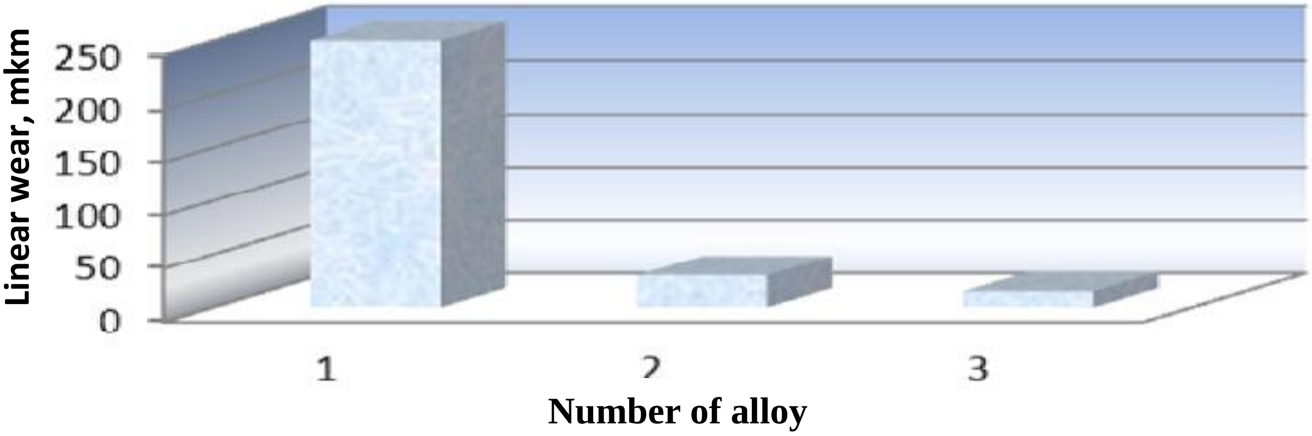
As can be seen from the data obtained (Table 3.1), for the same volume content of the suction carbide TiC phase, the wear resistance of nickel-based powder composite alloys is higher than that of the cobalt-based PK-50 alloy. At the same time, the research showed high heat resistance of powder composite alloys of the Ni (Cr; Al; Fe) -TiC system and the absence of phase and other transformations in these alloys during heating, which indicates the stability of their phase and structural composition [43].

3.3 Results and Topography

During tests we used composites in proportion which is shown in the table below. Some of them are cast alloys, some – powders. During the tests, it was not possible to assess the wear resistance of composite powder alloys with high porosity (№4 and №5). Already at the initial stage of the experiment there were fluctuations of friction within 15-20 % with a frequency of 8-10 seconds.

Table 3.1 The composition of composite alloys

№	**Co, %**	**TiC, %**	**NbC, %**	**Porosity, %**	**Type of compound**
1	80	–	20	–	cast alloy
2	70	30	–	–	cast alloy
3	50	50	–	3,1	powder
4	70	30	–	25	powder
5	50	50	–	28	powder

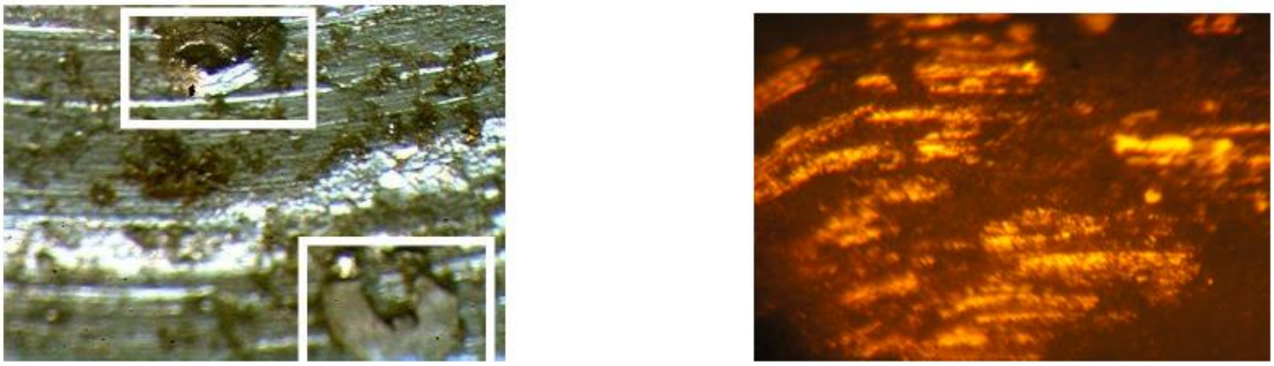


№1 – 250 microns, alloy №2 – 30 microns, alloy №3 – 15 microns

P = 30 MPa; A = 120 μm; υ = 30 Hz; test base = 5×10^6 cycle; T = 650 °C

Figure 3.8 – Results of tests

Through 2×10^6 cycles, the destruction of moving samples was observed on several parts, as well as the separation of the sample from the base parallel to the solder line. This is due to the insufficient ability of the porous material to relax the tension. As a result, a grid of cracks is formed in the near-surface layer. The base cast alloy №1 in friction is prone to the formation of chips (Figure 3.9). On its surface a thin film of oxides is formed, which rapidly collapses. At the same time exposed large areas of the metal, which, in turn, quickly wear out. Likewise, the alloy №2 behaves itself, although the higher content of titanium carbide in the matrix provides much better tribotechnical characteristics. In both cases, the conditions of formation and stability of secondary structures are violated, as a result of which the surface layers of the main material are destroyed [44].

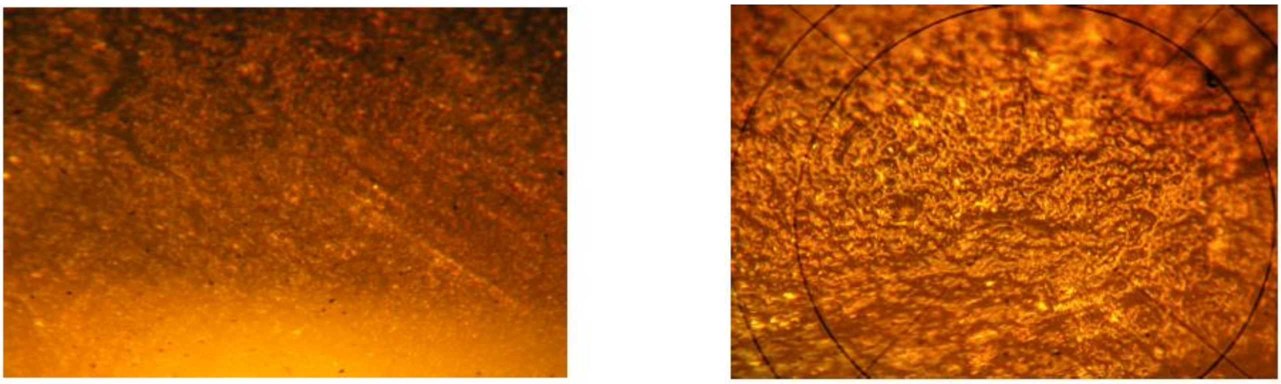


a, ×30 *b*, ×500

a – formation of chips (2×10^6 cycles); b – oxide film is not continuous (5×10^6 cycles)

Figure 3.9 – Topography of the surface of the alloy № 1 after the test

The raft number 3, according to the test results, has the highest durability. This is due to the increased content of carbides and low porosity, which prevents the spread of fatigue cracks inside the material. As is known, structurally heterogeneous material wears out in friction pairs as a whole, as in the process of friction there is a redistribution of the specific load: it increases for more wear-resistant inclusions and decreases for less wear-resistant. Therefore, TIs particles, placed on the sites of actual contact, prevent the destruction of protective oxide films. In addition, these films have a massive texture and a porous surface (Figure 3.10). In these times, at the initial stage of friction, there is accumulation of wear products, which play the role of solid lubricant. All these conditions ensure the stabilization of the wear process and high wear resistance of the material.

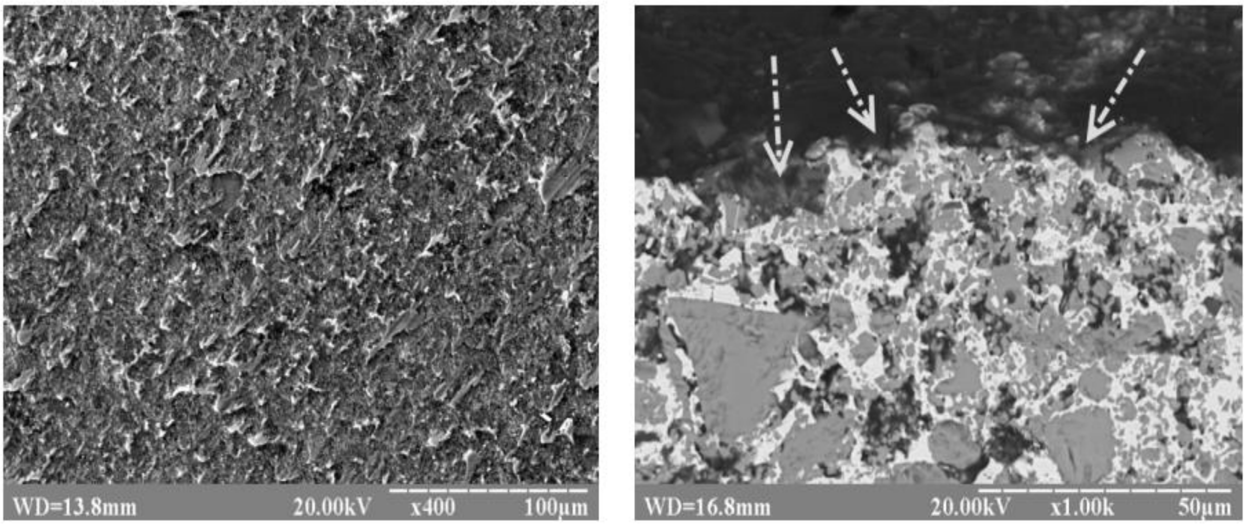


a, ×30 *b*, ×500

a – wear is uniform (2×10^6 cycles); b – porous surface of the oxide film (5×10^6 cycles)

Figure 3.10 - Topography of the surface of the alloy №3 after the test

In porous alloys, the penetration of oxygen into the basic material is facilitated, due to the void, it can penetrate to a considerable depth. In addition, the chemical influence of the internal pores of the pores, that is, the area of interaction increases, as a result of this heat resistance of the material is reduced. Porosity significantly affects the formation of protective oxide layers. In the period of cooking, along with other processes, there is formation and accumulation in the friction zone of wearing products. However, in porous material, wear is first filled with pores on the surface of the friction. In this case, the formation of the separating oxide layer is significantly slowed down and it is land like (Figure 3.1 a). The friction coefficient fluctuation (± 25 … 20 %) may indicate a breakdown of the micro volume of the material from the friction surface. Significant traces of this were detected during the metallographic analysis of samples of the alloy PC-50 (porosity 28 %), under the rubbing track (Figure 3.11 b).



a)   b)

a – topography of a surface of a friction, × 400; b – microscopic deflection of the material in the friction zone

Figure 3.11 – Wearing of porous alloy PK-50 (porosity 28 %)

The nature of the volume internal collapse of the porous alloy as a result of accumulation of fatigue damage and growth of the macro critic is shown in Figure 3.12.

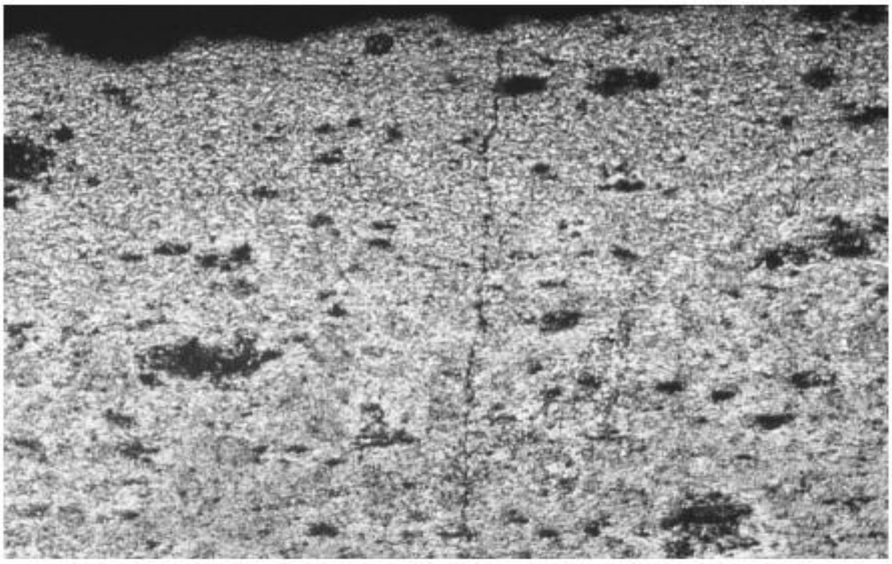


Figure 3.12 – Destruction of porous alloy PC-50 (porosity 28 %) due to friction forces

The crack propagates inside the material from the surface and passes along the boundaries of the pores, which clearly illustrates the effect of their quantity and magnitude on the ability of the porous alloy to work in conditions of external temperature-force alternating load. The pore size in such an alloy considerably exceeds 100 μm, whereas from the point of view of the origin of cracks in the powder alloy, the size of the 6-12 microns is critical. In view of this, further tribological studies were conducted only for low-porous powder and eutectic casting alloys [45].

Conclusion to part 3

It was found that large particles (80 … 100 microns) disappear. Smaller carbide grains (1 … 20 microns) are well bonded to the matrix, effectively reinforcing it, preventing the plastic deformation of the surface layer. This reduces the wear of the alloy, especially in high temperatures. It has been established that the growth of porosity has a pronounced negative effect on these characteristics, namely, when the porosity increases from 3 to 28 %, linear wear increases by 2.3 times, and the heat resistance decreases by 2.4 times. Investigation of the heat resistance of alloys based on nickel and cobalt (under the conditions of an equal number of alloying elements, grains and titanium carbide) showed 1.8 … 2 times better heat resistance and nickel alloys. Wear-resistance (in high-temperature fretting, modernized installation of MFC-1) gave the following results: at temperatures up to 850 °C, cobalt alloy predominates nickel in 1.6 … 3 times, and at temperatures up to 1150 °C – on the contrary: nickel alloy exceeds cobalt in 1,6 … 2 times. High-porous alloys are destroyed due to the weariness destruction already at the initial stage of the test. Alloys with a low content of carbides form a thin oxide film that quickly collapses and blurs the areas of pure metal, which leads to increased wear. PK-50 powdered powder forms a porous oxide film that accumulates wear products, helping to stabilize the friction. The carbide phase takes on a large part of the load, while preventing the destruction of the oxide film. This alloy can be used as a material during the recovery of the contact surfaces of the blades of turbines GTE, as well as during their manufacture.

PART 4

LABOR PRECAUTION

Introduction

For conducting of the experimental investigation for this diploma work we will need the friction machine “MFC-1” to provide friction of a different composite compounds and alloys. The subject of this work is an engineer, who works with machine tool for the friction. For analyzing of the work conditions was chosen a laboratory room in one of the learning campus.

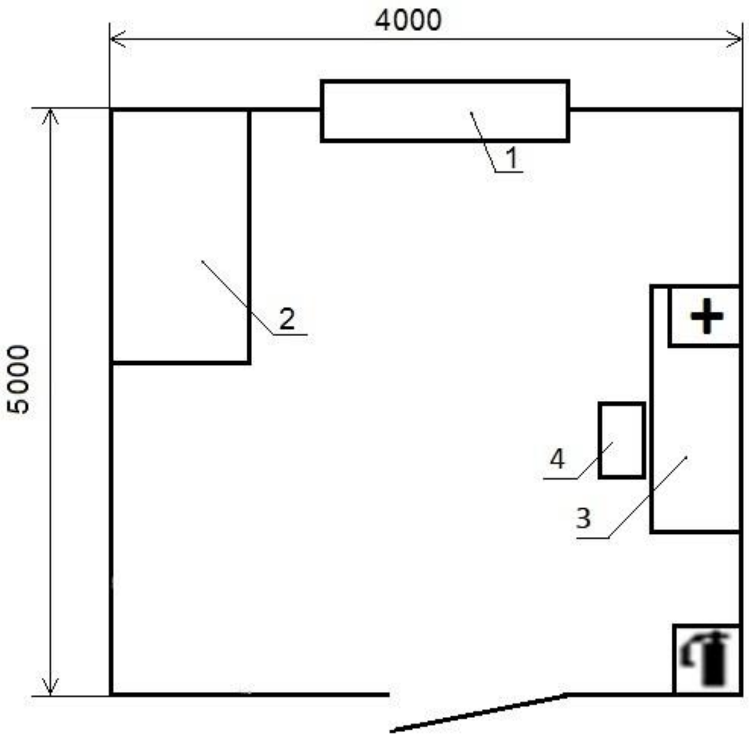
4.1 Organizing of working space

Workplace for investigation is a small laboratory room in campus that is located in the department of designing aircrafts. The room houses one friction machine and one working place.

The linear size of the room – 4m × 5m, height – 3.3 m, area – 20 m^2, amount of space – 66 m^3. All dimensions listed are approved by building codes Ukraine ДБНВ.2.2-28-2010 “Administrative buildings”. Indoors, use mixed lighting. The walls are painted white.

Dimensions of the friction machine “MFC-1” are height – 1200 mm, width – 1500 mm, depth – 1000 mm. The machine is powered by 220V. Work place is a table and chair. Dimensions of the working surface of the table width – 1400 mm, depth – 800 mm, height – 700 mm. Desk chair is lifting swivel and adjustable height and tilt angles the seat and back, as well as the distance back to the front edge of the seat. The width and depth of the seat surface – 400 mm.

The most favorable microclimate in the workplace is the temperature no more than 24 °C, relative humidity should be 40 … 60 % air velocity – 0.2 m / s. To maintain optimal values used ventilation and air conditioning. Noise sources are friction machine “MFC-1”, computer cooling units, multifunction printer, air condition. The room is a first aid kit, Carbon dioxide fire extinguisher to extinguish the fire [46].



1 – in-built air condition; 2 – MFC-1; 3 – table; 4 – chair.

Figure 4.1 – The laboratory room

4.2 The list of harmful and hazardous factors

According to the hygienic standards ГН 3.3.5-8-6.6.1-2002 «Гігієнічна класифікація праці за показниками шкідливості та небезпечності факторів виробничого середовища, важкості та напруженості трудового процесу»:

– moving of unprotected elements of mechanisms, machines and production equipment;

– increased or lowered temperature of surfaces of equipment, equipment and materials;

– increased or lowered temperature, humidity and air flow;

– increased noise, vibration, ultra- and infrasound levels;

– elevated voltage in the electric circuit, the closure of which can occur through the human body;

– elevated level of static electricity;

– sharp edges, bumps and roughness on the surfaces of equipment and tools;

– absence or lack of natural light;

– insufficient illumination of the working area;

– overload (static and dynamic) and neuropsychic factors (mental over-voltage, monotony of labor).

4.3 To carry out methods of decreasing influence of harmful and dangerous

The maintenance organization is responsible for the evaluation of the hazards in the workplace, awareness of personnel and to address safety precautions. The following elements should be taken into account:

– understand the warnings for using specific chemicals as published by the chemical manufacturer. Refer to the Material Safety Data Sheet which accompany the material. This is the primary source of information when determining the risk associated with any substance used in the workplace;

– observe the aircraft/component manufacturer`s warning and cautions in the applicable maintenance data;

– use personal protective equipment (e.g., gloves, respirators, glasses, boots, etc.) to prevent skin, eyes, respiratory and digestive tracts from being exposed to chemicals;

– make sure that sufficient ventilation exist;

– many combination of chemicals are incompatible and may produce toxic fumes and violent reactions. Extreme caution is required to ensure that maintenance chemicals are only mixed in accordance with the specific mixing procedure;

– set up first-aid measures in the workplace (e.g., eye washers, etc.).

For guaranteeing of works safety in operating electro-installations the following organizational arrangements are ought to be fulfilled:

– Appointing of persons, responsible for organization and performance of works;

– Legalization of order or instructions on work performance;

– Realization of admittance on works performance;

– Supervision of works performance;

– Legalization of work finishing, interruptions in work, transposition on other work places.

4.4. Analysis of harmful and hazardous factors

Airborne dust and fibrous particles are the principal source of hazards. These particles are generated by drilling, sanding, routing, or sawing the composite structures. Fine, lightweight fiber particles are easily circulated into the atmosphere, causing skin irritation and inflammation, eye irritation, respiratory system inflammation, pulmonary diseases (black lung), cancer of the lung, and abdominal disorders. Respiratory 5-31 protection is required in those operations where dust exists or is generated. Eye protection, consisting of safety goggles or a face shield, is also recommended for use in work involving any operation where the likelihood of airborne fibers exists.

There is no natural light in this laboratory room, so only artificial light can be. In this room are used fluorescent lamps, that provide workplace illumination of 400-500 lx, which is not enough according to ДБН В2.5-28-2006 «Природне і штучне освітлення.»

In fluorescent lamps an electric current in the gas excites mercury vapor, which produces short-wave ultraviolet light that then causes a phosphor coating on the inside of the lamp to glow. Fluorescent lamps emit a small amount of ultraviolet (UV) light. Fluorescent lamps very fast heated. If a fluorescent lamp is broken, a very small amount of mercury can contaminate the surrounding environment. About 99 % of the mercury is typically contained in the phosphor, especially on lamps that are near the end of their life. The broken glass is usually considered a greater hazard than the small amount of spilled mercury. So we need to change those lamps for new, more safe and bright.

In this laboratory room is installed new ventilation fan, which have enough power for providing normal air exchange, and to take off airborne dust and fibrous particles during experiments [47].

Sensory load (using the screen): To decrease sensory load, the distance from the monitor to the eyes must be at least 50 centimeters. It's best if the top edge of the screen is at the eye level or slightly lower. Every hour should be small break 5-10 minute. To reduce the impact of screen flicker on sight, LCD monitors has to be installed, with refresh rate of 75 Hz. To prevent eye exhaustion exercises for the eyes should be carried out.

During the work shift shall be installed regulated break to provide optimal performance of worker. Time regulated breaks during the work shift should be set depending on its duration, type of work and employment category.

4.5. Calculation of lighting of the working room

Lighting at the workplace is based on ergonomic principles and has to meet safety requirements within the meaning of occupational health and safety .Light has different functions that have to be taken into consideration for comprehensive assessment of a lighting concept in a room. Illumination does not only support the visual perception and therefore the information brokerage, but it is also signified by psychic-emotional and psychic-biological effects. The right light level at the workplace avoids tiredness and lack of concentration. This can be regulated by the illuminance which is measured in Lux (lx). A minimum of 500 Lux is stated for the brightness at computer work stations. Generally speaking, an increase in illuminance boosts the visual performance and positively influences the detailed and fast visual information processing. An illuminance between 500 and 1000 Lux can also be seen as stress-free. Different activities require different levels of light. In general, the more detailed the task, the greater the light requirement. A process control room should be lit at an illuminance of 300 lux, a corridor or walkway may only require 50 lux, whilst studying an engineering drawing may require 750 lux.

750 lx will be taken as the ideal lighting.

Total number of luminaires (N) required to provide a chosen level of illumination (E) at a given surface is:

$$N = \frac{E\ (lx - \ required) x\ Area\ (m^2)}{lumen\ from\ each\ luminaire\ xUFxMF} \qquad (4.1)$$

E – the illuminance level is chosen after consideration of the IES code;

MF – is maintenance or (the light loss LLF) factor.

Utilization factor (UF) – expressed as a number which is always less than unity;

UF = 0.9 (for a modern office building).

Let's say we have a 5 m x 4 m laboratory room we multiply these two numbers together to get an area of 20 square meters. To get the number of lumens we multiply the lux requirement by the area. According the formula 4.1 this gives us

$$20 \times 750 = 15000 \text{ lumens.}$$

We take modern LED lump, which more efficient and safety. Every lamp is - 45W and 5800 lumens.

Light loss factor depends on the maintenance staff of the building, but in general it is taken as 0.8. So we have Total number of luminaires:

$$N = (750\text{lx} \times 20\text{m}^2) / 5800 \times 0.9 \times 0.8$$

$$N=3.59$$

Therefore 4 luminaires will be required to illuminate this workshop to a level of 750 lx. They are located at the same distance from each other forming a square in the middle of the room.

4.6 Fire safety

Category room

The room contains non-combustible substances and materials in the cold, so meet category room for explosion and fire hazard – E.

The type and number of fire extinguishers

The primary means of fire extinguishing is accomplished by set of 2 Dry Chemical Powder fire extinguishers with 9 kg of agent.

Sensor and fire alarm system

A fire alarm system has a number of devices working together to detect and warn people through visual and audio appliances when smoke, fire, carbon monoxide or other emergencies are present. These alarms may be activated automatically from smoke detectors, and heat detectors or may also be activated via manual fire alarm activation devices such as manual call points or pull stations. Alarms can be either motorized bells or wall mountable sounders or horns.

Fire safety equipment carried out in accordance with НАПБА.01.001-2004 rules of fire safety in Ukraine. For fire alarm sensor smoke point is selected SPD-3. The sensor is designed for tracking smoke in an area 20 m^2, so 1 sensors placed in the middle of the ceiling.

Exits

In terms of evacuation figure 4.2 clearly marked evacuation routes, emergency exits, the location of fire insurance and fire alarm.

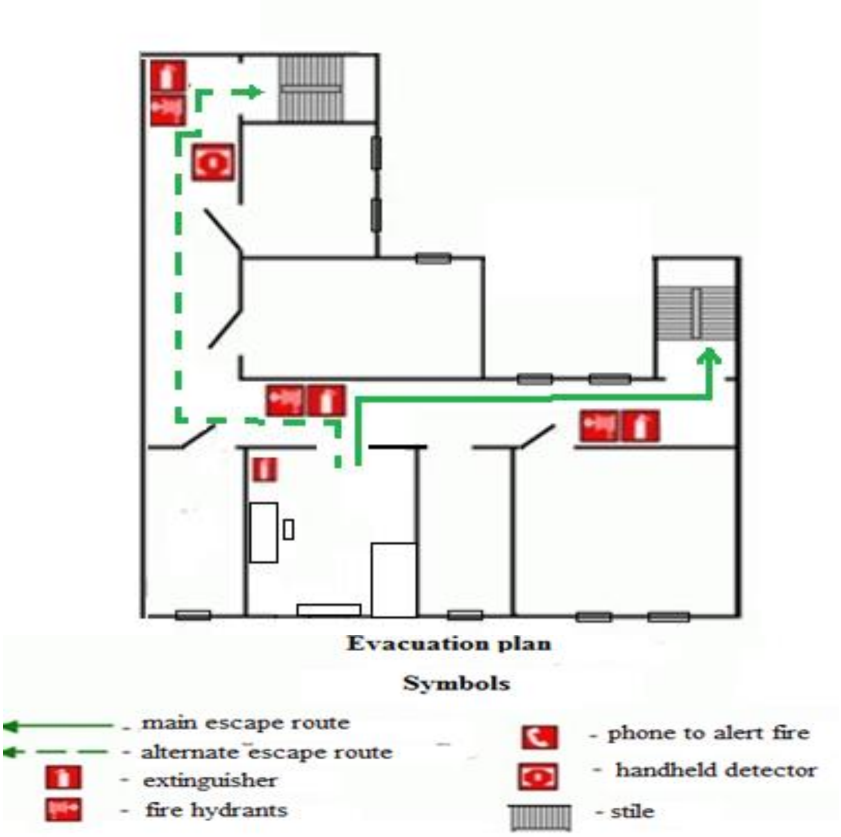


Figure 4.2 – Evacuation plan

The length of the main escape route is 18 m. For evacuation of main way to exit from your room, turn right, pass through the corridor, turn left and go through the steps to the door labeled "Exit". The alternate escape route is 24 m. To escape through this way – turn to the left side corner, pass through the corridor, turn right and go through the steps to the door labeled "Exit".

Conclusion to part 4

For normally operation of the laboratory room the lightning must be changed from fluorescent lamps to LED. Due to this, the illumination will become brighter, it will work clearly, without flickering. The consumption of electricity will be much reduced, and the lamp life will increase. Workplace illumination increase from 400 … 500 lx to 750 lx.

LED bulbs are not harmful, do not blow and do not break. Do not contain mercury. The risk of overheating of the lamps disappears, which affects the improvement of fire safety.

PART 5

ENVIRONMENTAL PROTECTION

The environmental impact of aviation occurs because aircraft engines emit heat, noise, particulates and gases which contribute toclimate changeand global dimming. Airplanes emit particles and gases such as carbon dioxide (CO_2), water vapor, hydrocarbons, carbon monoxide, nitrogen oxides, sulfur oxides, lead, and black carbon which interact among themselves and with the atmosphere.

5.1 Harmful impacts

Noise

Aircraft noise is seen by advocacy groups as being very hard to get attention and action on. The fundamental issues are increased traffic at larger airports and airport expansion at smaller and regional airports. Aviation authorities and airlines have developed Continuous Descent Approach procedures reduce noise footprint. Current applicable noise standards effective since 2014 are FAA Stage 4 and (equivalent) EASA Chapter 4.Aircraft with lower standards are restricted to a time window or, on many airports, banned completely. Stage 5 will become effective between 2017 … 2020. Quantification and comparison of noise effects per seat-distance takes into account that noise from cruise levels usually does not reach the earth surface (as opposed to surface-transportation) but is concentrated on and in proximity of airports.

Water pollution

Airports can generate significant water pollution due to their extensive use and handling of jet fuel, lubricants and other chemicals. Airports install spill control structures and related equipment (e.g., vacuum trucks, portable berms, absorbents) to prevent chemical spills, and mitigate the impacts of spills that do occur. In cold climates, the use of deicing fluids can also cause water pollution, as most of the fluids applied to aircraft subsequently fall to the ground and can be carried via storm water runoff to nearby streams, rivers or coastal waters. Airlines use deicing fluids based on ethylene glycol or propylene glycol as the active ingredient. Ethylene glycol and propylene glycol are known to exert high levels of biochemical oxygen demand (BOD) during degradation in surface waters. This process can adversely affect aquatic life by consuming oxygen needed by aquatic organisms for survival. Large quantities of dissolved oxygen (DO) in the water column are consumed when microbial populations decompose propylene glycol.

Sufficient dissolved oxygen levels in surface waters are critical for the survival of fish, macroinvertebrates, and other aquatic organisms. If oxygen concentrations drop below a minimum level, organisms emigrate, if able and possible, to areas with higher oxygen levels or eventually die. This effect can drastically reduce the amount of usable aquatic habitat. Reductions in DO levels can reduce or eliminate bottom feeder populations, create conditions that favor a change in a community's species profile, or alter critical food-web interactions [48].

Air quality

Ultrafine particles (UFPs) are emitted by aircraft engines during near-surface level operations including taxi, takeoff, climb, descent, and landing, as well as idling at gates and on taxiways. Other sources of UFPs include ground support equipment operating around the terminal areas. In 2014, an air quality study found the area impacted by ultrafine particles from the takeoffs and landings downwind of Los Angeles International Airport to be of much greater magnitude than previously thought. Typical UFP emissions during takeoff are on the order of 10^{15} … 10^{17} particles emitted per kilogram of fuel burned. Non-volatile soot particle emissions are 10^{14} … 10^{16} particles per kilogram fuel on a number basis and 0.1–1 gram per kilogram fuel on a mass basis, depending on the engine and fuel characteristics.

Some 167 000 piston engine aircraft—about three-quarters of private planes in the United States—release lead (Pb) into the air due to leaded aviation fuel. From 1970 to 2007, general aviation aircraft emitted about 34 000 tons of lead into the atmosphere according to the Environmental Protection Agency. Lead is recognized as a serious environmental threat by the Federal Aviation Administration if inhaled or ingested leading to adverse effects on the nervous system, red blood cells and cardiovascular and immune systems with infants and young children especially sensitive to even low levels of lead, which may contribute to behavioral and learning problems, lower IQ and autism.

Radiation explosure

Flying 12 kilometers (39 000 ft) high, passengers and crews of jet airliners are exposed to at least 10 times the cosmic ray dose that people at sea level receive. Every few years, a geomagnetic storm permits a solar particle event to penetrate down to jetliner altitudes. Aircraft flying polar routes near the geomagnetic poles are at particular risk.

Land space for infrastructure

Airport buildings, taxiways and runways take possession of a part of our ecosystem. Most of aircraft movement however is positioned in air at altitude and so away from direct interaction with sensitive nature or human detection. This is opposed to roads, railways and canals being very significant in use of area and dividing of ecological structures while required for surface transportation for as many miles as the distance traveled.

5.2 Pollution by composites

Laminates such as GLARE can typically produce weight savings of between 10 and 15 % with carbon fibre epoxy resin composites saving around 20 % compared to a typical aluminium alloy. The carbon fibre epoxy resin composite could in some cases reduce the weight of a component by up to 40 % compared to aluminium. As the fuel consumption of an aircraft is strongly affected by its total weight so the fuel used during flights can be significantly reduced by increasing the proportion of composites used in the aircraft structure. However, the production, manufacture and final disposal of high performance composites and similar materials used in aircraft requires considerably more energy than metal components such as aluminium alloys. For example, aluminium can be recycled at about 5 % the energy required to refine it from ores. This energy saving, when aluminium is recycled, provides a significant reduction in the energy use of aluminium over its whole lifetime. This illustrates that it is vital to consider the energy and raw materials used and waste products produced at all stages of the lifetime of the material. A more accurate view of the total savings in aviation fuel use and emissions achieved by using the lighter materials can be obtained. Lifecycle assessment (LCA) has been employed to ascertain the effect on the environment in terms of fossil fuel use and emissions of potentially hazardous products when different aerospace materials are used. Aluminium alloy (Al Cu Zn Mg, aerospace grade 7075), the laminate GLARE (which is used by Airbus in A380 and consists of layers of glass fibre-reinforced epoxy resin sandwiched between aluminium foil), and carbon fibre reinforced epoxy resin composites were chosen for comparison. The choice of these materials had the additional advantage of facilitating the evaluation of the software and currently available databases for the LCA. The LCA takes into account all the stages of the material lifetime: raw materials, production and manufacturing, useful life in the aircraft and waste management at the end of the component life. The evaluation of lightweight aerospace materials is vital with the predicted future increase in aviation emissions unless improved technologies are implemented, as illustrated in Figure 5.1.

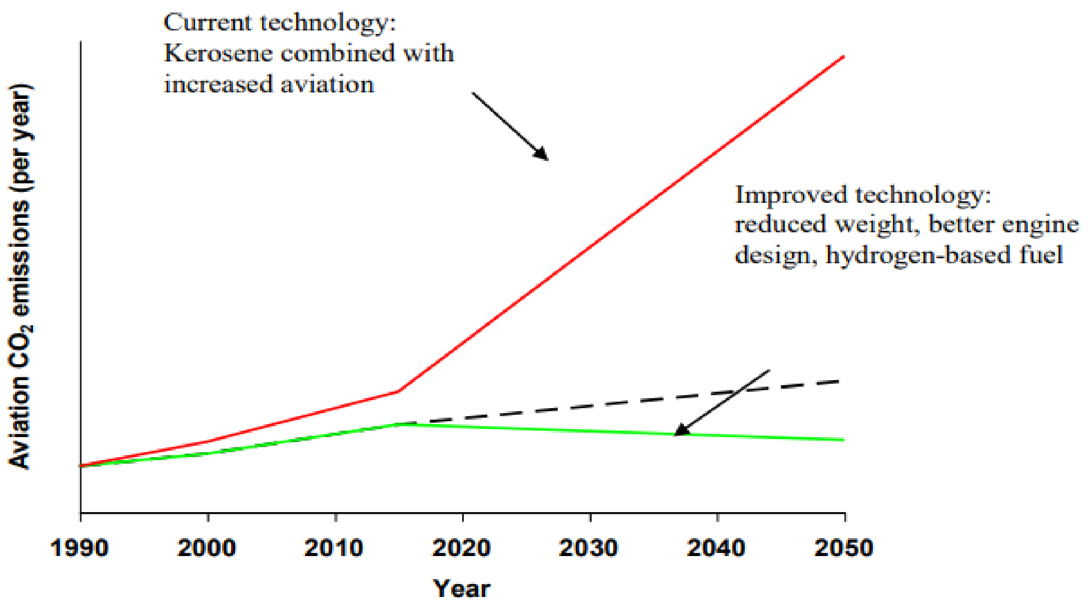


Figure 5.1 – Predicted trends in emissions of carbon dioxide from aviation sources

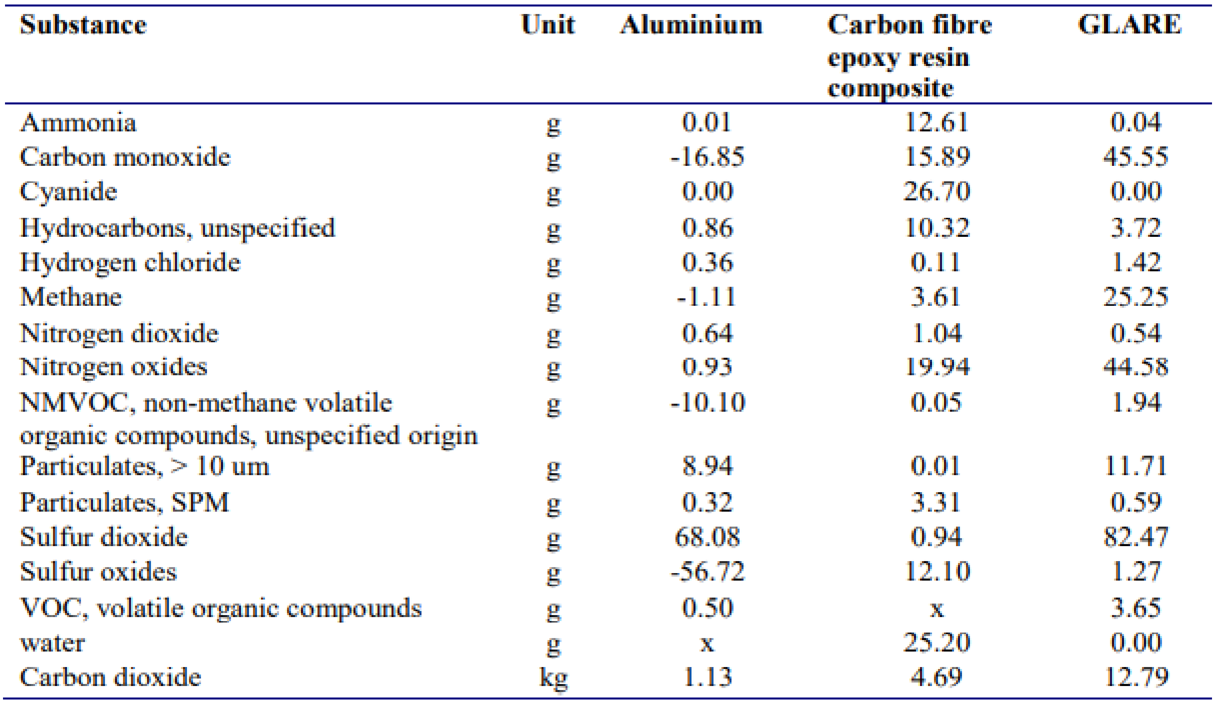
The results of the LCA model contain data concerning the use and production of literally hundreds of chemicals and raw materials that form constituents of the investigated materials. The exact number of items depends on the particular material and the nature of the processes involved in its overall lifetime. The huge amount of data that is concealed within the LCA model provides a challenge to present it in a meaningful way. For the purposes of this study, items of current interest have been extracted from the LCA model for further analysis, such as airborne emissions of substances which influence climate change (known as radioactively active substances) such as carbon dioxide, Sulphur and nitrogen oxides and particulates have been initially selected. It is possible to consider other parameters in this type of study. For example, the emission of volatile organic chemicals or individual named chemicals such as benzene could be considered for a more health-oriented analysis. From time to time it is discovered that a chemical, previously considered to present no risks to human health or to adversely affect the environment, is actually hazardous, possibly carcinogenic or otherwise damaging to human health. Emissions of particulate materials can affect both the environment, contributing to climate change, and can be hazardous to human health. Particulate materials can be particularly damaging to human health if they are produced in the lower part of the atmosphere, around airports for example. When such particulate matter is produced in the atmosphere during flight, they become radioactively active and affect global warming. At the present time there is uncertainty about the effect on climate change caused by water emitted by aircraft. Another complexity arises from the recent development in new materials and structures which may influence the parameters of LCA depending on the size of the carrier, types of engines, payload etc. It is generally accepted that LCA models have to be continuously improved and updated in line with developments in materials, recycling technology, improvements to the databases. This is typified by the recent developments in recycling technology for carbon-fiber epoxy resin composites and glass fiber reinforced polymer composite. Currently these types of composite materials are largely consigned to landfill or incineration after they are stripped from the aircraft at the end of its life. An efficient system for recycling these fiber-reinforced composite materials would markedly improve their impact on the environment during their complete lifetime. The industry recycles carbon fiber reinforced composites although the recovered fibers are currently of lower quality and would not be approved for aerospace use. The LCA models that have been developed in this study have the advantage that they can readily be adapted as will be required to cope with the constantly changing world of aerospace composites [49].

5.3 Life cycle analysis

Method The complete lifecycle of aerospace materials (advanced composites and aluminium alloy) has been investigated to assess and compare the total emissions produced and determine the quantities of raw materials such as fossil fuel. The stages of the material`s lifecycle consisted of: raw materials, production, useful life in the aircraft and disposal at the end of the material`s useful life. However, the details used to model these processes have been especially tailored to reflect the particular nature of the production and other stages of the lifetime of each individual material.

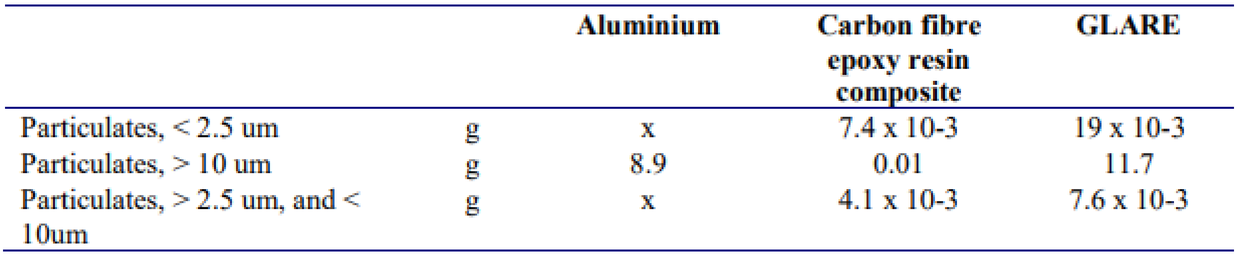
Results and discussion The main two ingredients of carbon fiber epoxy resin composites are epoxy resin and carbon fibers and they are both produced from fossil fuel (oil). Considering the epoxy resin first, this is produced as a liquid and it has to be stored under refrigeration. The process of refrigeration consumes energy which contributes to the overall energy use of the carbon fiber epoxy resin composite. The carbon fiber component begins its life as poly (acrylonitrile) fibers, again originating from fossil fuel. The poly (acrylonitrile) fibers then undergo a high temperature carbonization process. This is carried out in the absence of air. The carbon fibers are then woven into the form required for the component under manufacture; they are effectively mixed with the liquid epoxy resin to form a prepreg. The component is then heated under pressure (autoclaved) to cure the epoxy resin and form the durable, solid carbon fiber epoxy resin component. Other methods of curing have been reported such as using beams of electrons or radiation and electrical resistance and these could be compared in future LCA studies.

The single score is a method of comparing different LCA parameters each having different units. However, according to ISO 14042, this type of representation must be treated with caution as it may be used in a subjective manner. The impact factors can differ according to the software that is used for the calculation. In this work Eco-indicator 99 (E) was employed and it is reported in the literature that this is an acceptable method of calculating impact factors. The data available from the LCA model may be grouped according to use of raw material and emissions to the air, water and ground. There is a large amount of numerical information available for further processing; however, it would not be practical to present the full amount of data. Airborne emissions of radioactively active chemicals and materials such as particulates are shown in Figure 5.2. The results show the level of emissions for production and disposal only. The aluminium data shows significantly lower emissions as the result of the savings gained from the recycling loop. Figure 5.3 shows further information on the sizes of particulates emitted into the atmosphere from the production and disposal stages. The GLARE produces the greatest level of emissions at this stage of processing. However, as the materials are used in the aircraft, the heavier aluminium uses more fuel to travel the same distance and over time in use the aluminium finally produces the highest level of emissions.



Substance	Unit	Aluminium	Carbon fibre epoxy resin composite	GLARE
Ammonia	g	0.01	12.61	0.04
Carbon monoxide	g	-16.85	15.89	45.55
Cyanide	g	0.00	26.70	0.00
Hydrocarbons, unspecified	g	0.86	10.32	3.72
Hydrogen chloride	g	0.36	0.11	1.42
Methane	g	-1.11	3.61	25.25
Nitrogen dioxide	g	0.64	1.04	0.54
Nitrogen oxides	g	0.93	19.94	44.58
NMVOC, non-methane volatile organic compounds, unspecified origin	g	-10.10	0.05	1.94
Particulates, > 10 um	g	8.94	0.01	11.71
Particulates, SPM	g	0.32	3.31	0.59
Sulfur dioxide	g	68.08	0.94	82.47
Sulfur oxides	g	-56.72	12.10	1.27
VOC, volatile organic compounds	g	0.50	x	3.65
water	g	x	25.20	0.00
Carbon dioxide	kg	1.13	4.69	12.79

Figure 5.3 – Comparison of selected airborne emissions for aluminium, glare and carbon fibre epoxy resin composite panels



		Aluminium	Carbon fibre epoxy resin composite	GLARE
Particulates, < 2.5 um	g	x	7.4 x 10-3	19 x 10-3
Particulates, > 10 um	g	8.9	0.01	11.7
Particulates, > 2.5 um, and < 10um	g	x	4.1 x 10-3	7.6 x 10-3

Figure 5.4 – Comparison of airborne emissions of particulates for aluminium, glare and carbon fiber epoxy resin composite panels

Conclusions to part 5

LCA has been used to model and compare the energy use and emissions of aerospace materials: carbon fibre epoxy resin composite, GLARE fibre metal laminate and the standard aerospace grade aluminium alloy. The results have shown that the composites and hybrid materials produce more emissions in the production and disposal stages compared to the aluminium alloy due to the high temperatures involved in the manufacturing of the raw constituents. Further, the emissions results for recyclable materials such as Al are offset by the emissions saved through multiple recycling, the option still not available for advanced synthetic composite materials. However, the total emissions including the operation and use show significantly more favourable environmental trend for composites due to the emissions saved from the lower fuel consumption. The „break even‟ scenario is reached after short time in operation and further use of lightweight structures contributes to long-term emissions saving and pollution reduction. The benefits of using composite materials in energy saving applications are manifold; however, the study also shows potential harm to the environment from using composites in commodity and non-energy saving applications due to their high production and disposal emissions.

GENERAL CONCLUSIONS

On account of the complicated nature of thermal and mechanical loads on turbine blades inadmissible are any mechanical and thermal damages to blades, because it may lead to the break-off of a blade, and consequently to the engine damage, and hence, hazard to flight safety. Some types of mechanical damages resulting from the foreign-matter ingestion are detected after finding damages to the compressor’s first-stage components during pre- or after-flight maintenance, or in the course of the first borescope examination after the event, carried out during periodical maintenance of the engine.

Spray coating used for worn repair parts, for imparting heat and corrosion resistance, high anti-friction properties. For spraying uses various metals, alloys, ceramics.

The use of traditional aluminide coatings for blade protection heat-stressed GTE turbines are unacceptable since the start of flashing the interface between the – NiAl layer and heat resistant alloy (substrate) occurs at temperatures above 1120 °C. Macroscopically it causes protective surface waviness before the development of its active oxidation.

According to the results of experiments in fretting corrosion, wear resistance of materials of matrix-filled type based on Ni (Cr; Al; Fe) -TiS system at temperatures above T = 1123 K exceeds wear resistance of powder alloys led on the basis of doped cobalt with titanium carbide. The maximum permissible value of porosity and the optimum concentration of the strengthening carbide phase amounting to 50 vol. % are established, in which the highest resistance to friction wear is achieved in the composite powder alloys under study, which makes it possible for them to be used for the tribunes of the parts of the hot part of the GTE.

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