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

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри, к.т.н., доцент
___________ Святослав ЮЦКЕВИЧ
«____» ____________ 2023 р.

КВАЛІФІКАЦІЙНА РОБОТА

ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ «МАГІСТР»

ЗІ СПЕЦІАЛЬНОСТІ

«АВІАЦІЙНА ТА РАКЕТНО-КОСМІЧНА ТЕХНІКА»

Тема: «Розробка елементів системи керування повітряного судна з полімерних композитних матеріалів»

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Київ 2023

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
DEPARTMENT OF AIRCRAFT DESIGN

PERMISSION TO DEFEND
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"___" _______________ 2023

QUALIFICATION PAPER

FOR A MASTER'S DEGREE

ON SPECIALITY

"AVIATION AND AEROSPACE TECHNOLOGIES"

Topic: "Development of aircraft control system elements from polymeric composite materials"

Fulfilled by:	___________	**Mykhailo MOVCHAN**
Supervisor: **PhD, associate professor**	____________	**Sviatoslav YUTSKEVYCH**
Labor protection advisor: **PhD, associate professor**	____________	**Katerina KAZHAN**
Environmental protection adviser: **PhD, associate professor**	___________	**Lesya PAVLYUKH**
Standards inspector **PhD, associate professor**	___________	**Volodymyr KRASNOPOLSKII**

Kyiv 2023

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Аерокосмічний факультет
Кафедра конструкції літальних апаратів
Освітній ступінь «Магістр»
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Освітньо-професійна програма «Обладнання повітряних суден»

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ЗАВДАННЯ

на виконання кваліфікаційної роботи здобувача

МОВЧАНА МИХАЙЛА ІГОРОВИЧА

1. Тема роботи: «Розробка елементів системи керування повітряного судна з полімерних композитних матеріалів», затверджена наказом ректора від 20 вересня 2023 року № 1853/ст.

2. Термін виконання роботи: з 25 вересня 2023 р. по 31 грудня 2023 р.

3. Вихідні дані до роботи: необхідність розробки елементів системи керування з полімерного композиційного матеріалу.

4. Зміст пояснювальної записки: вступ, оглядова частина, яка містить опис про системи керування та її ключеві елементи, також відомості про авіаційні матеріали матеріали, їх властивостей та економічної доцільності, основна частина, яка містить розробку матеріалу для виготовлення тяг керування, окремі розділи, присвячені питанням охорони праці та навколишнього середовища.

5. Перелік обов'язкового графічного (ілюстративного) матеріалу: слайди презентації, графіки.

6. Календарний план-графік:

№	Завдання	Термін виконання	Відмітка про виконання
1	Огляд літератури за темою дипломної роботи.	25.09.2023–05.10.2023	
2	Побудова плану та написання частини роботи.	06.10.2023–15.10.2023	
3	Виготовлення зразків та проведення серії експеремиентів.	16.10.2023–29.10.2023	
4	Аналіз отриманих результатів та проведення повторних експеремиентів.	30.10.2023–12.11.2023	
5	Написання розділів по охороні праці та навколишнього середовища.	13.11.2023–26.11.2023	
6	Написання та оформлення пояснювальної записки.	27.11.2023–10.12.2023	
7	Подача роботи для перевірки на плагіат.	11.12.2023–17.12.2023	
8	Попередній захист кваліфікаційної роботи.	18-19.12.2023	
9	Виправлення зауважень. Підготовка супровідних документів та презентації доповіді.	20.12.2023–24.12.2023	
10	Захист кваліфікаційної роботи.	25.12.2023–31.12.2023	

7. Консультанти з окремих розділів:

Розділ	Консультант	Дата, підпис	
		Завдання видав	Завдання прийняв
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Охорона навколишнього середовища	к.т.н., професор Леся ПАВЛЮХ		

8. Дата видачі завдання: 25 вересня 2023 року

Керівник дипломної роботи ____________ Святослав ЮЦКЕВИЧ

Завдання прийняв до виконання ____________ Михайло МОВЧАН

NATIONAL AVIATION UNIVERSITY

Aerospace Faculty
Department of Aircraft Design
Educational Degree "Master"
Specialty 134 "Aviation and Aerospace Technologies"
Educational Professional Program "Aircraft Equipment"

APPROVED BY
Head of the department,
PhD, associate professor
_________ Sviatoslav YUTSKEVYCH
"___" ________________ 2023

TASK

for the qualification paper

MYKHAILO MOVCHAN

1. The topic of the work: "Design of elements of the coating system of a damaged ship from polymer composite materials", approved by the order of the rector dated 20 June 2023, dated No. 1853/st.

2. Period of work: since 25 September 2023 till 31 December 2023.

3. Output data before work: the need to develop control system elements from a polymer composite material.

4. Place of explanatory note: introduction, overview part, which contains a description of the control system and its key elements, as well as information about aviation materials, their properties and economic feasibility, the main part, which contains the development of a material for the manufacture of control rods, separate sections on labor and environmental protection.

5. List of mandatory graphic (illustrative) material: presentation slides, graphics.

6. Thesis schedule:

№	Task	Time limits	Done
1	Review of literature on the topic of the thesis.	25.09.2023–05.10.2023	
2	Building a plan and writing part of the work.	06.10.2023–15.10.2023	
3	Making samples and conducting a series of tests.	16.10.2023–29.10.2023	
4	Analysis of the obtained results and repeated experiments.	30.10.2023–12.11.2023	
5	Execution of the parts, devoted to environmental and labor protection.	13.11.2023–26.11.2023	
6	Writing and formatting an explanatory note.	27.11.2023–10.12.2023	
7	Submission of the work to plagiarism check.	11.12.2023–17.12.2023	
8	Preliminary defense of the thesis.	18-19.12.2023	
9	Making corrections, preparation of documentation and presentation.	20.12.2023–24.12.2023	
10	Defense of the qualification paper.	25.12.2023–31.12.2023	

7. Special chapter advisers:

Chapter	Adviser	Date, signature	
		Task issued	Task received
Labor protection	PhD, associate professor Katerina KAZHAN		
Environmental protection	PhD, professor Lesya PAVLYUKH		

8. Date of issue of the task: 25 September 2023

Supervisor: ____________ Sviatoslav YUTSKEVYCH

Student: ____________ Mykhailo MOVCHAN

РЕФЕРАТ

Кваліфікаційна робота «Розробка елементів системи керування повітрянного судна з полімерних композитних матеріалів» містить:

92 сторінки, 39 рисунки, 16 таблиць, 16 літературних посилань

Об'єктом дослідження в кваліфікаційної роботі є розробка елементів системи керування повітрянного судна з полімерних композитних матеріалів.

Предметом дослідження є основна система керування повітрянного судна, різновиди цієї системи та ключові елементи, а також використання полімерних композитних матеріалів у системі.

Метою кваліфікаційної роботи є аналіз системи керування повітряним судном, вивчення її компонентів, розгляд особливостей та властивостей полімерних композитних матеріалів, а також виготовлення зразків та випробування їх міцності.

Методи дослідження та розробки включають в себе виготовлення зразків матеріалів, проведення серії випробувань на міцність, аналіз отриманих даних.

Робота містить аналіз основної системи керування повітряним судном, розгляд варіантів використання полімерних композитних матеріалів у конструкції, проведення випробувань на міцність, а також аналіз отриманих результатів.

Новизна отриманих результатів полягає в представленні експериментальних даних про міцність цих матеріалів.

Практична цінність роботи полягає в можливості впровадження отриманих результатів у практику авіаційних конструкторських підрозділів, а також в навчальних програмах, пов'язаних з проектуванням повітряних суден та використанням полімерних композитних матеріалів у авіабудуванні.

Система керування літака, полімерний композитний матеріал, рулева тяга керуваня, випробування на міцність.

ABSTRACT

Qualification work "Development of aircraft control system elements from polymeric composite materials" contains:

92 pages, 39 figures, 16 tables, 16 references

The object of research in the qualification work is the development of elements of the control system of an aircraft made of polymer composite materials.

The subject of research is the main aircraft control system, types of this system and key elements, as well as the use of polymer composite materials in the system.

The purpose of the qualification work is to analyze the aircraft control system, study its components, consider the features and properties of polymer composite materials, as well as to manufacture samples and test their strength.

The research and development methods include the manufacture of material samples, a series of strength tests, and analysis of the data obtained.

The work includes an analysis of the main control system of the aircraft, consideration of options for using polymer composite materials in the structure, strength tests, and analysis of the results.

The novelty of the results is the presentation of experimental data on the strength of these materials.

The practical value of the work lies in the possibility of implementing the results obtained in the practice of aircraft design units, as well as in training programs related to aircraft design and the use of polymer composite materials in aircraft construction.

Aircraft control system, polymer composite material, control rod, strength testing.

CONTENT

INTRODUCTION

Aviation stands as an indispensable facet of global existence today, encompassing a myriad of functions facilitated by aircraft. From aerial photography and video capture to the transportation of passengers and cargo, agricultural operations, scientific research endeavors, and military missions, the versatility of aircraft is evident. Notably, the aviation industry, particularly concerning flight control systems, is characterized by exacting standards to ensure the dependability and efficacy of both civilian and military aircraft. Achieving optimal aircraft performance necessitates the utilization of meticulously developed materials.

Aviation materials, tailored for their specific roles, can be broadly categorized into structural materials, distinguished by their mechanical properties, and non-structural materials, characterized by specific physical and chemical attributes. In terms of composition, aviation materials are further classified into metallic, non-metallic, and composite materials. These materials must meet various operational requirements, ranging from heat resistance to low-temperature performance, as well as resilience against factors such as wear, corrosion, fuel, oil, and fire.

Within the realm of aviation materials, distinct classes further subdivide into numerous groups, each serving a unique purpose. Metal alloys and coatings represent one category, while non-metallic aviation materials span a spectrum that includes plastics for structural and radio engineering applications, fibrous materials, paints and enamels, adhesives, lubricants, optical materials, decorative materials, ceramic and metal-ceramic materials, elastomeric materials, and working fluids for on-board systems. Additionally, the scope extends to encompass radio-transparent and radio-absorbing materials, underscoring the intricate and diverse nature of materials essential to the composite applications within aircraft, particularly in their flight control systems.

PART 1. ANALYSIS OF COMPOSITE MATERIALS APPLICATION IN THE ELEMENTS OF AIRCRAFT CONTROL SYSTEM

1.1. Features of airplane mechanical control system design

The flight control system is a critical component in the realm of aviation, serving as the interface between the pilot and the aircraft. Its primary function is to translate pilot inputs into precise and controlled movements of the control surfaces, such as ailerons, elevators, and rudders. This sophisticated system plays a pivotal role in ensuring the stability, maneuverability, and overall safety of an aircraft throughout various flight phases. As advancements in technology continue, modern flight control systems integrate innovative features, enhancing both pilot control and the overall efficiency of airborne operations.

A standard aircraft control system typically comprises three principal components:

- the stick or yoke,
- control surfaces actuators, and
- the linking mechanism connecting the stick or yoke to the control surfaces actuators.

The stick or yoke serves as the primary tool for pilots to manipulate the control surfaces, such as ailerons, elevators, or the rudder, thereby controlling the aircraft's flight path.

To delve into the specifics of the stick or yoke, this section initially introduces the classification and types of flight control systems to underscore the importance of stick or yoke design in the functionality and performance of flight control systems.

Aircraft control systems, or flight control systems, fall into two main categories: Primary flight control system and Secondary flight control system [1]. These systems play crucial roles in ensuring proper aircraft control during flight and, to some extent, enhancing aircraft performance.

The Primary flight control system can be further divided into three distinct subsystems, each characterized by the relative direction of control motion [1]. These subsystems include the lateral control system, longitudinal control system, and directional control system. Each subsystem is responsible for controlling specific aircraft components. Control surfaces or components controlled by these subsystems include:

- Lateral control: ailerons, spoilers, differential stabilizer.
- Longitudinal control: elevator, stabilizer, canard.
- Directional control: rudder.

The lateral and longitudinal control systems directly connect to the aircraft stick, while the directional control system links to the rudder pedals. Manipulating the stick causes movement in different control surfaces, resulting in varied aircraft movements.

The Secondary flight control system can also be subdivided into three different systems, categorized by the control method and its impact on the aircraft's performance. These systems include the trim control system, high lift control system, and thrust or power control system. Components or mechanisms controlled by these systems include:

Trim control: lateral, longitudinal, and directional primary flight control systems.

High lift control: trailing edge flaps, leading edge flaps.

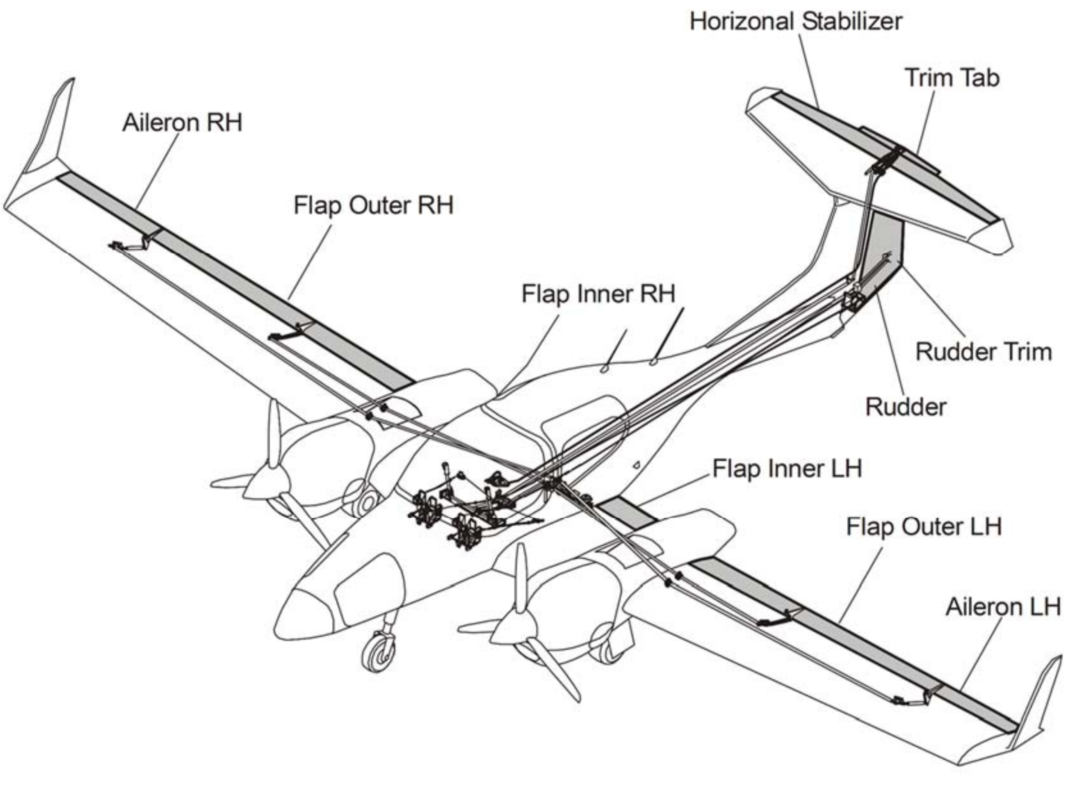

Fig.1.1. Primary and secondary flight control

Typically, the secondary flight control system is not operated directly by the aircraft's stick or yoke; instead, they are controlled using separate buttons, dials, and throttle levers in the aircraft's cockpit. However, the secondary flight control system may indirectly influence the performance of the primary flight control system. For instance, increasing engine thrust can necessitate greater force to move elevators due to increased distributed loading, depending on the aircraft's specific flight control system, as discussed in the following sections.

Flight control systems can be broadly categorized into two types:

- reversible flight control systems and
- irreversible flight control systems.

The key distinction lies in the interchangeability of control between the stick or yoke and the control surfaces. Traditional aircraft designs predominantly feature reversible flight control systems. However, contemporary aircraft control systems often adopt irreversible configurations or a combination of both, integrated into a unified flight control system. The following sections delve into these two types of flight control systems, outlining their respective advantages and disadvantages.

Reversible flight control systems are systems wherein the movement of cockpit controls, particularly the stick or yoke, prompts corresponding movement of the control surfaces and vice versa [1]. Typically, reversible flight control systems employ cables, push-rods, or a combination of both, constituting what is known as a mechanical flight control system.

Mechanical flight control systems are commonly mechanized using cable linkages, push-rods, or a combination of both (Fig.1.1).

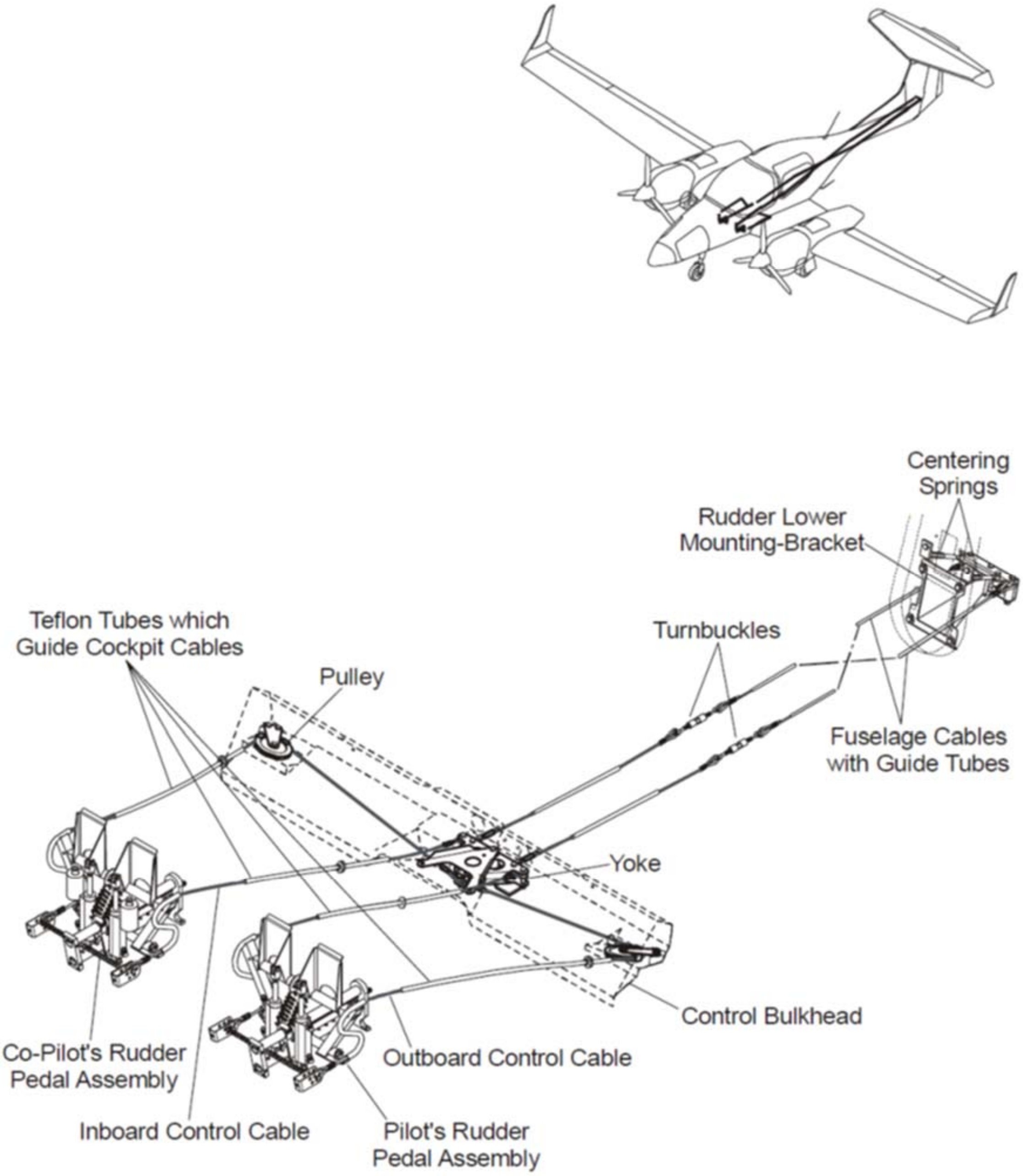

Fig.1.2. Linkages of flight control system

In this system, the aircraft's stick is directly linked to control surfaces through cables or push-rods. Notably, smaller aircraft may lack amplification for the pilot's exerted force on the stick, presenting significant design challenges [1] associated with this type of flight control system like:

- Friction and wear. Resulting from rubbing between rod linkages or cables and pulleys.

- Greater weight. Rod linkages, constructed from robust metals, contribute to increased weight to withstand pilot forces.
- Cable stretching. Over time, cables may stretch due to use and changes in atmospheric temperature.
- Handling qualities. Larger aircraft may necessitate greater pilot force, potentially insufficient for effective control.
- Fluttering. Control cable fluttering can increase vibrations and instability in the aircraft.
- Jamming. Occasional jamming or partial jamming may occur, requiring considerable force from the pilot to overcome the issue.

However, the mechanical flight control system also presents advantages [1]:

- Simplicity and reliability. Cable or push-rod flight control systems are simple to design, operate, and are reliable.
- Lower costs. These systems have lower costs as they do not require advanced technology, complex systems, or specially designed components.
- Relatively maintenance-free. Despite wear issues over time, the system is robust, reliable, and does not demand frequent checks and maintenance.

Designing a reversible flight control system involves careful consideration of mechanical design requirements to ensure compatibility among the stick, actuators, and linking components under operating conditions. Key considerations include system elastic deformation, system friction, kinematic feasibility, cable stretch and slack, push-rod buckling, aerodynamic balance, and mass balance.

1.2. Airworthiness requirements for flight control system

The flight control system must operate smoothly and positively according to its intended function. It should be designed to continue functioning and respond appropriately to commands, ensuring the airplane's recovery even in various attitudes or flight conditions resulting from operating or environmental factors.

Each element of the flight control system must be designed to minimize the chance of incorrect assembly, potentially leading to system failure. If practical, distinctive and permanent markings may be used to avoid assembly errors, considering the potential consequences of such mistakes.

The airplane must undergo analysis or testing to demonstrate its capability for safe flight and landing after any single failure, any combination of failures that are not extremely improbable, and any failure or event resulting in a jam of a flight control surface or fixed pilot control. The pilot should be able to counteract the effects of probable failures, with additional failure conditions having a combined probability of 1/1,000 or less in the presence of a jam.

In the event of all engines failing, the airplane must remain controllable in flight, allowing for approach, landing, and ditching flares. Additionally, during the ground phase, the airplane should be stoppable.

The airplane's design must include indicators to alert the flight crew when the primary control means are approaching the limit of control authority.

If the flight control system has multiple modes of operation, the airplane must provide appropriate alerts to the flight crew when entering any mode significantly altering or degrading the normal handling or operational characteristics.

Flight control systems must be designed to allow swift selection of different positions without waiting for the completion of the initially chosen movement. The system should smoothly arrive at the final selected position without requiring further attention. Movements following the initial selection and the time taken to allow the required sequence should not adversely affect the aeroplane's controllability.

Compliance must be demonstrated through the evaluation of the closed-loop flight control system to ensure no features or characteristics restrict the pilot's ability to recover from any attitude. If applicable, open-loop flight control systems should also undergo evaluation. For airplanes with flight control envelope protection, attitudes outside the protected envelope should be considered [2].

The applicant should consider relevant flight dynamic parameters, including pitch, roll or yaw rate, vertical load factor, airspeed, and angle of attack (non-exhaustive list).

Parameters should be considered within the limit flight envelope associated with the aeroplane design limits or the flight control system protection limits.

The intent is to minimize the risk of incorrect assembly of flight control system elements, addressing potential safety effects. Configuration control is not within the scope of CS 25.671(b) [2].

Assess potential effects of incorrect assemblies, classifying the severity of associated failure conditions.

For catastrophic, hazardous, or major failure conditions, physical prevention means in the design should be the norm. If impractical, distinctive and permanent marking may be used, subject to EASA agreement.

Failure conditions classified as minor or with no safety effect are considered not to have a significant safety impact.

Examples of Significant Safety Effects [2]:

- Out-of-phase action.
- Reversal in the sense of control.
- Interconnection of controls between two unintended systems.
- Loss of function.

1.3. Forces that act on the elements of the control system

The maximum and minimum pilot forces specified in this paragraph are assumed to act on the appropriate control grips or pads, simulating flight conditions. These forces are then reacted at the attachment point of the control system to the control surface horn [2].

In the control surface flight loading condition, the air loads on movable surfaces and corresponding deflections must not exceed those resulting from any pilot force within specified ranges. Two-thirds of the maximum values for aileron and elevator may be used if hinge moments are based on reliable data. This criterion considers the effects of servo mechanisms, tabs, and automatic pilot systems.

The limit pilot forces and torques are as follows [2]:

Aileron:

- Stick: Maximum 445 N (100 lbf), Minimum 178 N (40 lbf)
- Wheel: Maximum 356 DNm (80 D in.lb), Minimum 178 DNm (40 D in.lbf)

Elevator:

- Stick: Maximum 1112 N (250 lbf), Minimum 445 N (100 lbf)
- Wheel (symmetrical): Maximum 1335 N (300 lbf), Minimum 445 N (100 lbf)
- Wheel (unsymmetrical)†: Maximum 1335 N (300 lbf), Minimum 445 N (100 lbf)

Rudder:

- Maximum 1335 N (300 lbf), Minimum 578 N (130 lbf)

Critical parts of the aileron control system must be designed for a single tangential force with a limit value equal to 1.25 times the couple force determined from these criteria.

Unsymmetrical forces must be applied at one of the normal handgrip points on the periphery of the control wheel.

For airplanes equipped with side stick controls designed for forces applied by one wrist and not by the arms:

1. Components Between Handle and Control Stops:

PITCH: Nose Up 890 N (200 lbf), Nose Down 890 N (200 lbf)

ROLL: Roll Left 445 N (100 lbf), Roll Right 445 N (100 lbf)

2. Other Components of Side Stick Control Assembly (Excluding Internal Electrical Sensor Components):

PITCH: Nose Up 556 N (125 lbf), Nose Down 556 N (125 lbf)

ROLL: Roll Left 222 N (50 lbf), Roll Right 222 N (50 lbf)

1.4. Features of aviation materials use in structures and equipment

In modern aircraft structures, high-strength aluminum, magnesium and titanium alloys, steels, including high-strength alloyed and corrosion-resistant steels, and composite materials are most widely used.

The correct choice of material for structural elements can significantly improve the weight and flight-tactical characteristics of an aircraft, as well as reduce material costs for its production and operation. When choosing a material, its mechanical properties are taken into account (tensile strength, yield o, fatigue resistance under various stress cycles, elastic modulus E, wear resistance, viscosity, etc.), thermophysical and chemical properties (linear expansion coefficient a. thermal conductivity l. corrosion resistance, etc.), density r. the cost and scarcity of raw materials, the degree of development in production, technological properties (ductility, weldability, casting qualities, machinability by cutting), which determine the possibility of using the most productive production processes - stamping, pressing, casting, welding, etc. When choosing a material for structural elements also take into account their shape and size, magnitude and nature of the load (constant, impact, cyclic), and thermal loading. the presence of holes, differences in sections and other stress concentrators in structural elements. However, the greatest attention when choosing a material is paid to meeting the requirement of ensuring the necessary strength and rigidity of the structure with the least weight, ensuring weight advantage or weight efficiency of the material.

The weight efficiency of a material, determined by its specific strength σadd/ρ (the ratio of permissible stresses to density) and specific rigidity E/ρ (the ratio of the elastic modulus of the material to its density), is different for different types of deformations. Different criteria for tension are σв/ρ, in case of general loss of stability in compression - E/ρ, in shear - τв/ρ, in case of loss of stability in shear, in bending and torsion and, under repeated loads - σ_{max}/ρ (the values of σadd at a given fatigue life of the structure are taken equal to σmax).

The profitability of a material, taking into account its cost, is determined by the ratio of the specific strength σ_{add}/ρ to the cost of 1 kg of material and, for example, $\sigma_{в}/\rho a$. What characteristics do structural materials have?

Aluminum alloys are alloys characterized by high σ_{add}/ρ and E/ρ values comparable to alloy steels, high fatigue resistance and good technological characteristics. The latter allows them to be processed by stamping, rolling, forging and cutting, and for some of them, welding. They are divided into wrought (for the production of sheets, profiles, stampings, forgings by deformation) and cast (for shaped castings) alloys. Their main characteristics are given in Table 1.1.

Table 1.1

Comparative Characteristics of Materials Used in Aircraft Structures [3]

	$\rho \cdot 10^{-3}$, g/sm^3	σ_B, MPa	E, GPa	$\frac{\sigma_B}{\rho} \cdot 10^{-7}$	$\frac{E}{\rho} \cdot 10^{-7}$,(sm/c)^2 ρ
Aluminum alloys:					
Wrought	2,7	400...550	72	14,8...20,4	2,65
Casting	2,7	200...500	72	7,4...18,5	2,65
Magnesium alloys:					
Wrought	1,8	200...340	45	11,0...18,7	2,50
Casting	1,8	200...270	45	11,0...15,0	2,50
Titanium alloys:					
деформируемые	4,5	500...1300	120	11,0...29,0	2,68
Casting	4,5	630...860	120	14,0...19,0	2,68
Steel:					
Carbon	7,8	420...650	210	5,4...8,3	2,70
Alloy	7,8	800...1600	210	5,4...20,6	2,70
Heavy duty	7,8	1600...2400	210	20,6...30,6	2,70
Composite materials	1,4...2,6	500...1300	35...250	40...60	2,5...10,0

Deformable aluminum alloys. Alloy D16 is duralumin of the Al-Cu-Mg system.

They are used for the manufacture of skins, stringers, spars, frames, ribs, and control system parts. It has good ductility, which makes it possible to widely use stamping for the manufacture of power elements of the airframe. Weldability is poor, but can be machined well.

Alloy D19 remains operational up to higher temperatures than D16 (t H 250 °C) and has slightly higher σ_B/ρ characteristics compared to it. Used to make sheathing and rivets.

AK4-11 alloy is a heat-resistant forging alloy (t up to 350 °C), used for the manufacture of monolithic panels for supersonic aircraft.

AK6 alloy is forging aluminum, used for the manufacture of hot-stamped and forged parts, brackets of complex shapes, rocker arms, monolithic panels of subsonic aircraft.

B95 is a high-strength alloy of the Al-Zn-Mg-Cu system, used for skins and parts of the airframe's power structure (spar belts). Weldability is poor.

Alloys AMts, AMg2 and AMg6 of the Al-Mn and Al-Mg systems are excellent for welding and are used for the manufacture of containers, fuel tanks and pipelines.

Alloys V65, D18P, D19P and AMg5 are used for the manufacture of rivets.

Sintered aluminum alloys produced by powder metallurgy methods allow parts made from these alloys to operate up to t = 500 °C. These alloys are well welded and machined, and have high corrosion resistance.

Cast aluminum alloys. AL4, AL9 - structural alloys for casting parts of complex configurations operating at temperatures up to 200 °C.

AL5, AL19 are heat-resistant alloys for cast parts operating at temperatures up to 250 and 300 °C, respectively.

VAL5, VAL10 are high-strength alloys for casting highly loaded parts operating at temperatures up to 200 and 250 °C, respectively.

Al-Li alloys have lower density, higher σ_B/ρ and E/ρ values, and good weldability, which, as experience in the use of these alloys in welded structures (for example, the fuselage of the MiG-29 aircraft), makes them very promising in aircraft construction .

Magnesium alloys are 1.5 times lighter than aluminum alloys, can be easily machined, can be welded, and have good casting qualities. Disadvantages: low corrosion resistance, insufficient ductility at normal temperatures, low melting point (fire hazard).

MA2-1 is used for the manufacture of forged and stamped parts of complex shapes operating at temperatures up to 150 °C (manhole covers).

MA-8 is used for the production of sheet skins for ailerons, rudders, flaps, etc.

VM65-1 is used for loaded parts of control systems, stamped wheel drums, brackets, rockers.

ML5 is a casting alloy for the manufacture of wheel drums, steering wheels, pedals, and seat frames.

Titanium alloys have high specific strength, heat resistance, and good corrosion resistance (the surface oxide film is stable up to t = 550 °C). They are used for the manufacture of welded assemblies and stamped parts operating at t = 300...500 °C, skins (OT4-1, VT5, VT20), power parts of the airframe frame, landing gear parts (VT22), rods, rockers. Alloys OT4, VT5, VT20 are weldable. They are used mainly in the form of sheets. Alloys VT5, VT6, VT16 - increased strength, used for volumetric stamping. Alloys VT5L, VT6L, VT20L – casting .

The E value of titanium alloys is half that of steel, and where the requirement of rigidity is more important, they are inferior to alloy steels **[3]**.

Steels are alloys of iron and carbon. For the manufacture of lightly loaded frame parts and internal equipment, carbon steel grades 20, 45 are used. Steels 30KhGSA and 30KhGSNA are alloyed. They are used to make critical welded assemblies, cold and hot-stamped parts, frames, spars, rockers, levers, brackets, and chassis parts. Steel 30KhGSA is also used for the manufacture of bolts and rivets. Steel 30KhGSNA is very sensitive to stress concentrators.

Steel 12X18H10T - chromium-nickel, for welded and stamped sheet parts, used for the manufacture of cladding. Weldable with all types of welding.

VNS-2 and SN-2 steels are high-strength, corrosion-resistant, for welded assemblies and stamped sheet parts operating at temperatures up to 400 °C.

CH-4 steel is corrosion-resistant, for the manufacture of honeycomb panel elements from thin sheets, tape and foil, it is well welded, stamped and soldered.

VNS-5 steel is a high-strength, corrosion-resistant steel for power-machined parts (spars, frames, sub-engine frames). Steel is ductile, welds well and has high impact strength.

Ya1T steel has high heat resistance and is used for the manufacture of cladding.

Steel 35KhGSA - foundry, for the manufacture of frames, brackets, forks.

Table 1.1 shows the mechanical characteristics of structural materials at t = 15 °C. However, at a certain temperature, an intensive decrease in mechanical characteristics begins, including Gv (Fig 1.3) and E, which requires an increase in mass or a transition to more heat-resistant materials to compensate. Knowing that the temperature during aerodynamic heating changes according to the formula T = = TH(1 + 0.18 M2)*, where H is the flight altitude, we can plot the dependence T = f (M) on the same graph (see Graph 1.1) (curve 7) and identify working areas I...IV for various materials depending on the flight speed (M number).

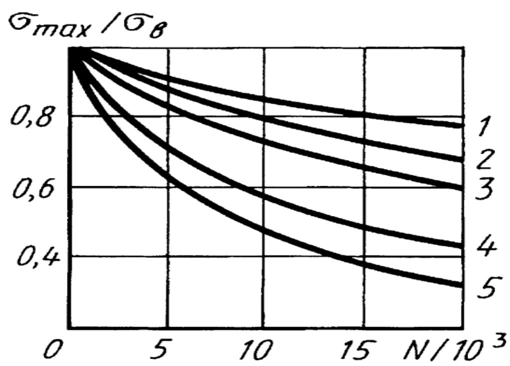

Fig 1.3. Dependence of the stress in parts on the number of stress cycles [3]

In schedule 1.2 shows the decrease in strength under repeated loads (fatigue resistance) for various materials (1 - D16 alloy; 2 - 30KhGSA steel, Gv = 1200 MPa; 3 -

V95 alloy; 4 - 30KhGSA steel, Gv = 1800 MPa), as well as influence of stress concentrator (5 - for steel 30KhGSA with Gv = 1800 MPa). To increase fatigue resistance in critical structural elements, it is necessary to reduce the stresses acting in them, although this is associated with an increase in their mass. In order to increase fatigue resistance, various types of surface hardening (hardening, protective coatings) are widely used.

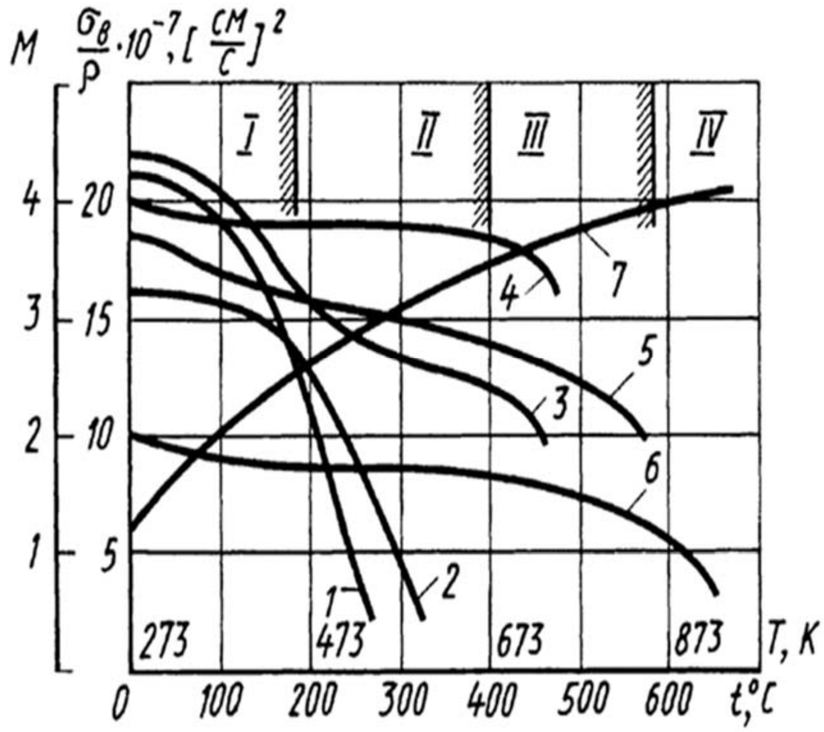

Fig. 1.4. Dependences of individual strength personal materials sв/r on temperature T(in kelvins) (curves 1...6) and temperatures T from the number M (curve 7). [3]

In Figure 1.2: 1, 2 - aluminum alloys V95 and D16; 3 — titanium alloy VT6; 4 — alloy steel 30KhGSA; 5 — corrosion-resistant steel VNS-2; 6 - heat-resistant steel; areas of application: I—aluminum alloys; II - alloy steels and titanium alloys; III - corrosion-resistant steels; IV - heat-resistant alloys, including Ni and Co.

Composite materials (CM) are structural materials consisting of a matrix (base) with reinforcing material distributed in it. Glass, carbon, boron, and organic fibers can be used as reinforcing materials. The metal base for CMs operating at temperatures up to 250...300 °C is aluminum and magnesium alloys, at higher temperatures (450...500 °C) - titanium alloys, at even higher temperatures - nickel alloys. Resins are widely used as a basis in polymer CM, in particular epoxy resin, polyester resin, and phenol-formaldehyde resin.

Composite materials have a wide range of properties, surpassing the materials discussed above in specific strength, rigidity and fatigue resistance (Table 1.2.1). This makes it possible to reduce the weight of the aircraft structure by 20...30%. CMs have low sensitivity to stress concentrators, good corrosion resistance, radio transparency and other characteristics. All this led to the fact that CM began to be used to make the skin of the wing, empennage, rudders and ailerons, slats, radio-transparent fairings, three-layer panels, partitions in cabins, hoods, landing gear doors, fairings and more. Foreign companies are attempting to develop aircraft entirely from composite materials. However, CMs also have a number of disadvantages: instability of characteristic values and anisotropy of properties, low interlayer shear strength, and complexity of embedding.

The properties of CM can be synthesized by changing the types of matrix and reinforcing fibers, their volumetric ratio, the number of layers, the orientation of the reinforcement relative to the acting loads, mixing different types of fibers, and others.

When analyzing the material of construction, the following points must be taken into account:

- for tensile elements, glass or organic fibers are most appropriate (the former are also cheaper, and the latter have a lower density);
- boron plastics have higher compressive strength, and carbon fiber plastics also have greater rigidity;
- the greatest strength and shear rigidity are achieved by the direction of fiber reinforcement ± 45°;
- the highest impact strength, toughness and crack resistance are found in organoplastics (carbon plastics are the most fragile);
- the most heat-resistant are carbon fibers and boron fibers (t = 500...900°C);
- lighter structures made from composite materials may turn out to be more profitable even with the high cost of the composite materials themselves, since, by reducing the weight of the airframe, they can reduce fuel consumption, increase the target load or flight range. The latter leads to an increase in aircraft efficiency.

1.5. Aplication of polymer composite materials in aircraft

Composite material (composite, CM) is an artificially created inhomogeneous solid material consisting of two or more components with a clear interface between them.

Characteristic features of composite materials:

- The composition and form of the components are determined in advance;
- Components are present in quantities that ensure the specified properties of the material;
- CMs are heterophase systems obtained from two or more components with different functions.

Composite materials consist of:

- matrices (matrix materials can be inorganic and organic binders, polymers, ceramics, metals and their alloys, which are in a solid crystalline or amorphous state);
- reinforcing element (fibrous or layered materials of various nature, as well as finely dispersed powdery particles or larger grains act as reinforcing strengthening components;
- in structural composites, the reinforcing elements usually provide the necessary mechanical characteristics of the material (strength, stiffness, etc.), and the matrix (or binder) ensures the joint work of the reinforcing elements and their protection from mechanical damage and an aggressive chemical environment.

Structure of composite materials(form of stiffener elements)

According to the mechanical structure of the compositions, they are divided into several main classes:

1) Fibrous. In fibrous composites, the load-bearing capacity is provided mainly by fibers, and the matrix provides the required arrangement of fibers in the material (Fig. 1.5), transfers loads to fibers, protects fibers from harmful effects of the environment, such as aggressive environments, high humidity, icing, high or low temperatures.

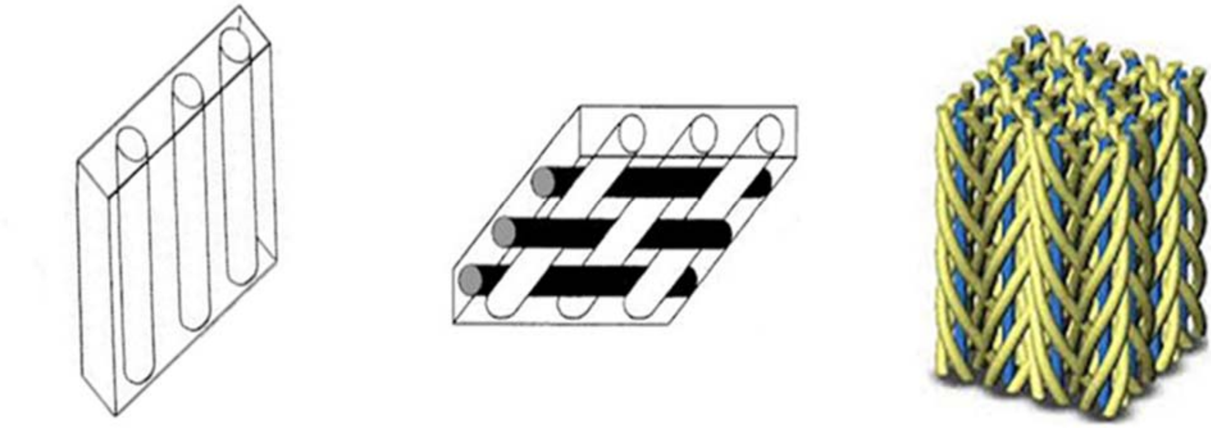

Fig. 1.5. Fiber composites

2) Layered. Layered composites represent a "puffcake" type structure, where a variety of materials act as layers. For example, it can be fabric, unidirectional or randomly reinforced fibrous composites. Most often, layered composites represent a set of layers with different directions of laying fibers (Fig. 1.6). The advantage of layered composites is their ability to provide a complex set of required properties, such as, for example, increased strength and stiffness under specified types of loading, as well as low coefficients of thermal expansion in specified directions.

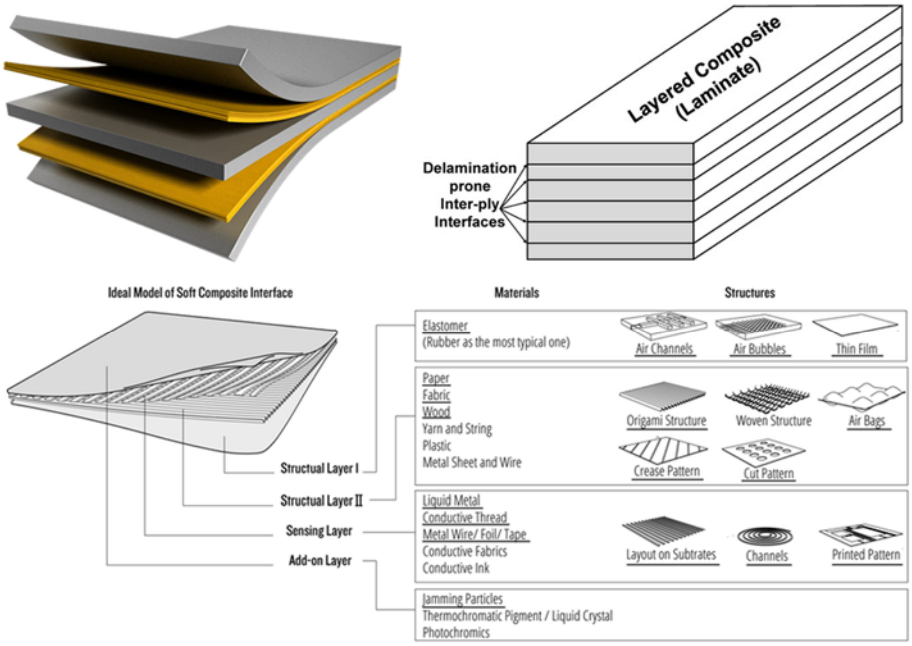

Fig. 1.6. Layered composites.

3) Particle-reinforced composites

Particle-reinforced composites consist of a matrix and microparticles evenly distributed in it - it can be: mica, quartz, glass, silicon dioxide, calcium carbonate, titanium dioxide and other materials (Fig. 1.7). Unlike fibrous composites, in these materials, the matrix, and not the filler, is responsible for the load-bearing capacity of the structure.

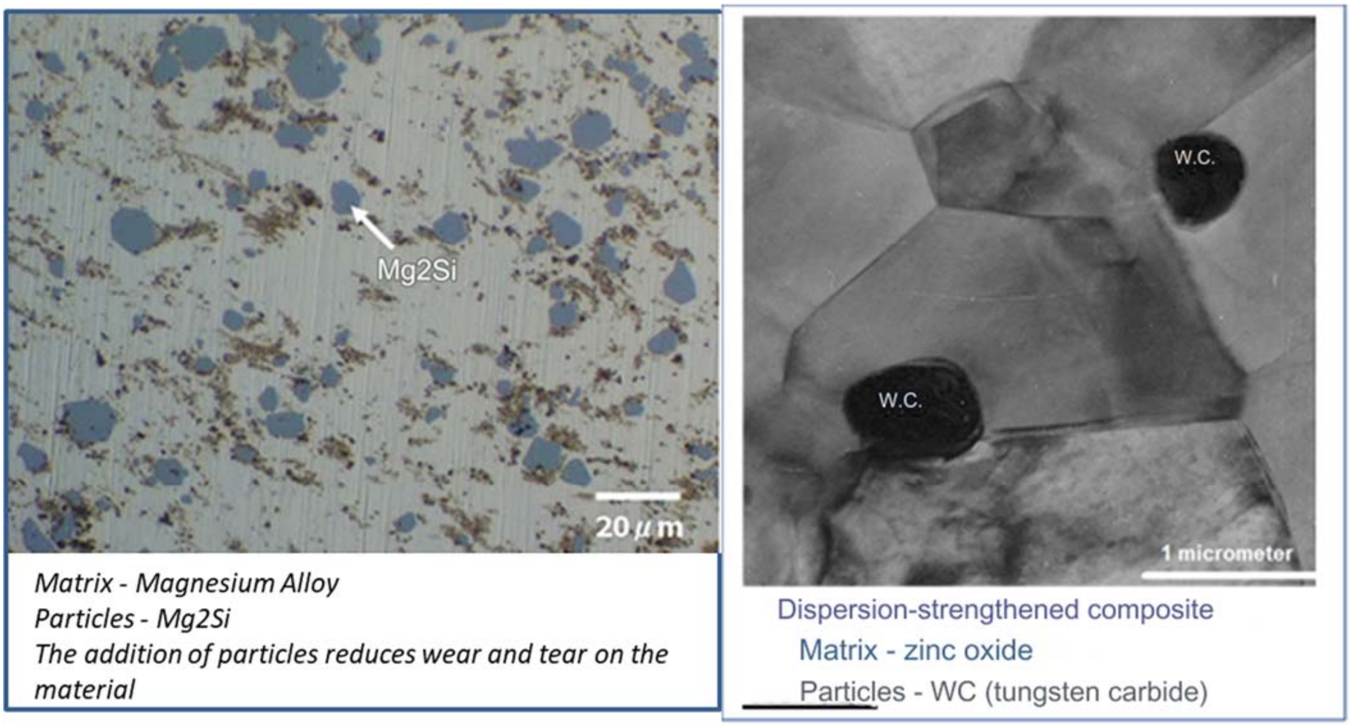

Fig. 1.7. Particle-strengthened omposites.

In composites reinforced with particles, their size is greater than 1 μm, and the content is 20-25% (by volume).

Dispersion-reinforced composites include everything from 1 to 15% (by volume) of particles smaller than 1 micron in size. It is known that the highest strength of dispersion-reinforced composites is achieved with a particle size of 10 to 500 nm with an average distance between them of 100 to 500 nm and their uniform distribution in the matrix.

Nanocomposites are composite materials in which the average size of the filler particles does not exceed 100 nm, and the volume fraction of the filler in these materials is very small - about 2-5% (Fig. 1.8). At the same time, nanocomposites combine the advantages of the constituent components: light weight, flexibility, good processability, increased impact resistance and wear resistance. In addition, these materials are very promising in terms of thermal, electrical, and optical properties. This is due to the fact that the ratio of the surface area of the nanoparticle to its volume is very high, which ensures better chemical interaction between the matrix and the filler. Therefore, the indicators of composites reinforced with nanoparticles significantly exceed the indicators of the same materials reinforced, for example, with fibers or microparticles.

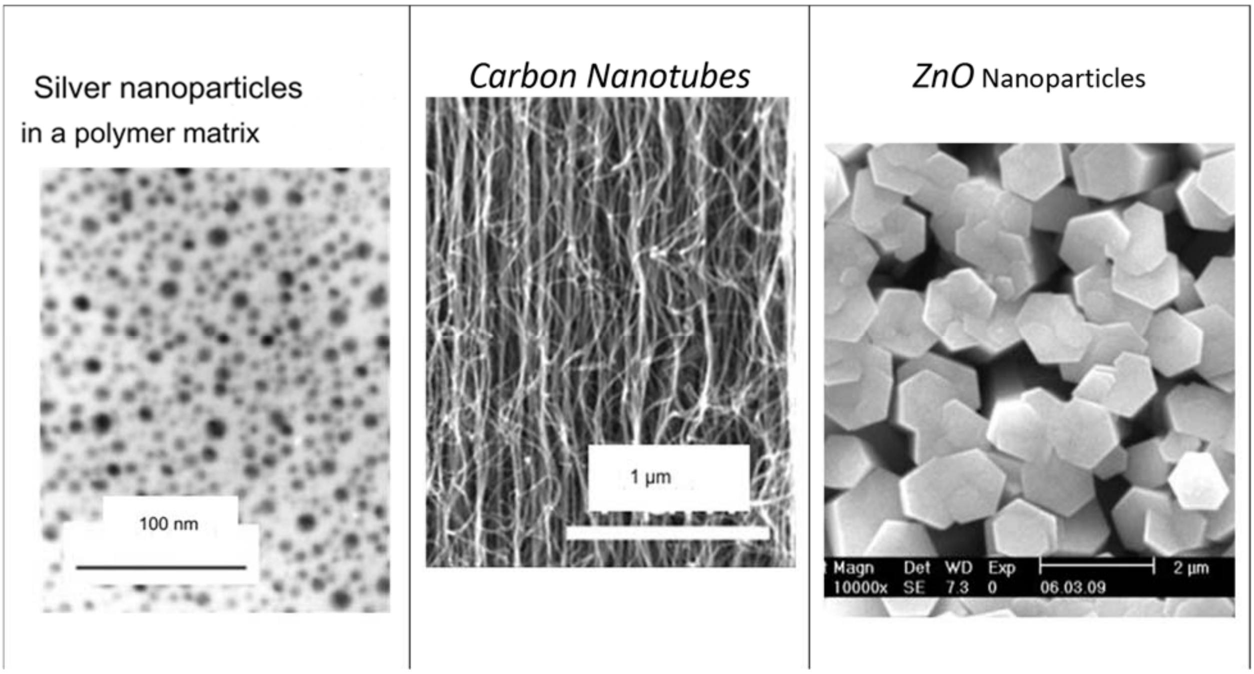

Fig. 1.8. Nanocomposites.

4) Sandwich composites (three-layer panels)

In sandwich composites, two thin but rigid panels are connected to each other with the help of a light filler, the thickness of which significantly exceeds the thickness of the panels being joined (Fig. 1.9). The main advantage of sandwich composites is excellent bending resistance at low weight.

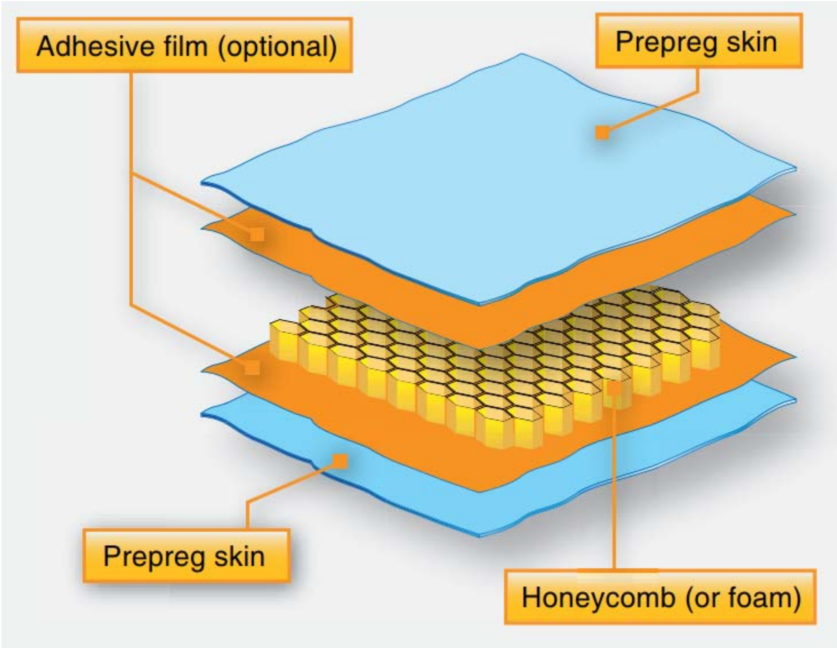

Fig. 1.9. Sandwich composites

1.6. Modern methods of manufacturing tie rods for aircraft

Epsilon Composite has developed and manufactures a full range of adjustable rods for transmitting structural forces or movements in cars or aircraft (Fig. 1.10).

Fig. 1.10. The tie rod is made of carbon fiber.

These adjustable rods are commonly used in the aerospace industry as structural components, for attaching equipment, or for flight control. Steering rods are manufactured using the pultrusion method (Fig. 1.11) without adhesive joints, which guarantees the reliability of the resulting parts in order to ensure flight safety.

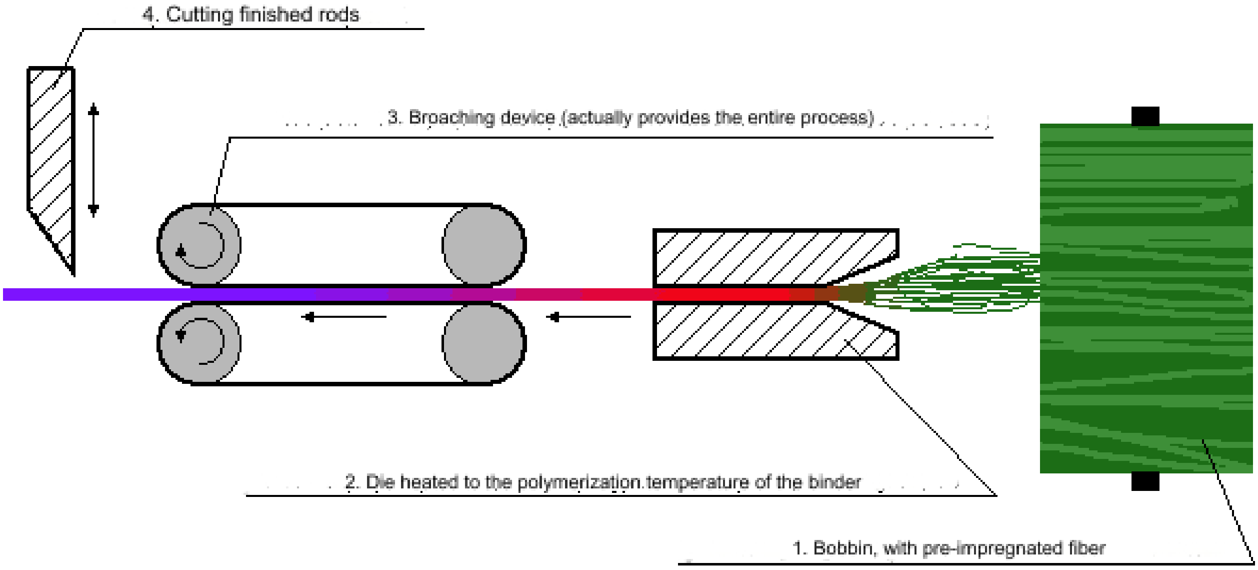

Fig. 1.11. Pultrusion manufacturing method.

The German company CirComp GmbH has also developed control rods for small aircraft (Fig. 1.12) made of carbon fiber, which should help save up to 40% of weight compared to aluminum rods. The following requirements were presented to them:

- ultimate tensile and compressive load 8 kN;
- length 990 mm;
- maximum outer diameter 28.60mm.

Fig. 1.12. Carbon fiber tie rod for small aircraft.

Tests were carried out on a special machine for tension and compression at a speed of 5 mm/min. The following results were obtained (fig. 1.13).

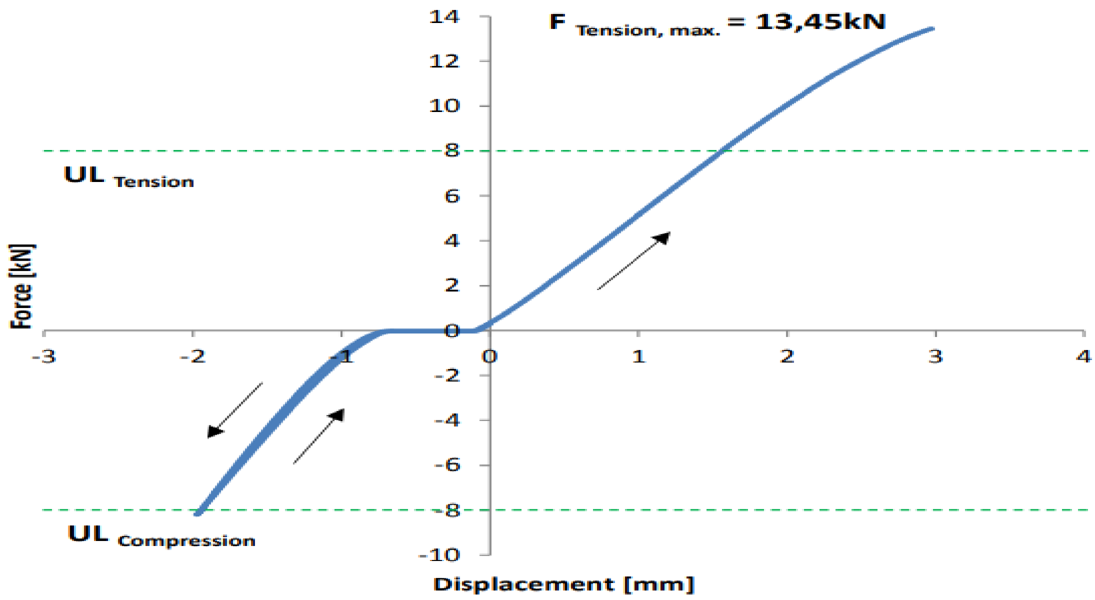

Fig. 1.13. Load versus elongation graph for expansion and compression.

Conclusion to the Part 1

This section provides a comprehensive overview of the main aircraft control systems and the diverse materials employed in their construction, ranging from traditional aluminum alloys to advanced polymer composites. The focus on the critical component of the control system, namely the control rod, emphasizes its significance as a thin-walled tube with tips, where the judicious selection of materials plays a pivotal role in ensuring both reliability and weight efficiency. As we delve deeper into the intricacies of these systems and materials, it becomes evident that the optimal choice of materials for the control rod is paramount, directly impacting the overall performance and safety of the aircraft. This groundwork lays the foundation for the subsequent sections, which will further explore the nuanced aspects of aircraft control systems and delve into the specific considerations influencing material selection.

PART 2. DEVELOPMENT OF A STEERING ROD MADE OF COMPOSITE MATERIAL

2.1. Development of a material for a control rod made of a polymer composite

Polymer composite materials are usually two-phase, that is, they consist of two components - a matrix (resin) and reinforcing elements (fabrics, fibers, rovings). Having many advantages over aluminum alloys, it is not always possible to achieve the desired characteristics. Different fillers that are added to the resin during the manufacturing process allow to vary the characteristics of composite products. For example, microspheres allow to reduce the density and give volume, plasticizers allow to reduce the viscosity during production and reduce the fragility of the finished product.

Fibrous polymer composites, unlike metals, are anisotropic - their mechanical characteristics are not the same depending on the application of the load, they perfectly resist such loads as tension applied in the plane of the reinforcement and very poorly resist compression, while particle-reinforced composites best resist compressive loads

During the development of the rod of the control rod from a composite material, the idea arose to increase the resistance to compressive load by adding reinforcing particles to the matrix. Aluminum oxide (Al_2O_3) with a fraction of 50 μm was used as a filler (Fig. 2.1).

Fig. 2.1. Aluminium oxide.

For the first experiment, 4 samples (tubes) were made from fiberglass as a matrix, epoxy resin with a filler content of 0, 10, 15, 20% relative to the volume of the matrix (Fig. 2.2), the ratio of the matrix to the reinforcing element is 1.1/1 for compression test with dimensions of 28x120 mm. The purpose of the experiment: is it possible to increase the compressive strength, if so, and to establish the optimal percentage of the filler.

Fig. 2.2. Specimens for compression tests.

For tensile testing, 4 samples (plates) were made with 0, 10, 15, 20% filler, dimensions 270x18mm and thickness 2mm (Fig. 2.3).

Purpose: To determine resistance to tensile loads depending on the percentage content of the filler.

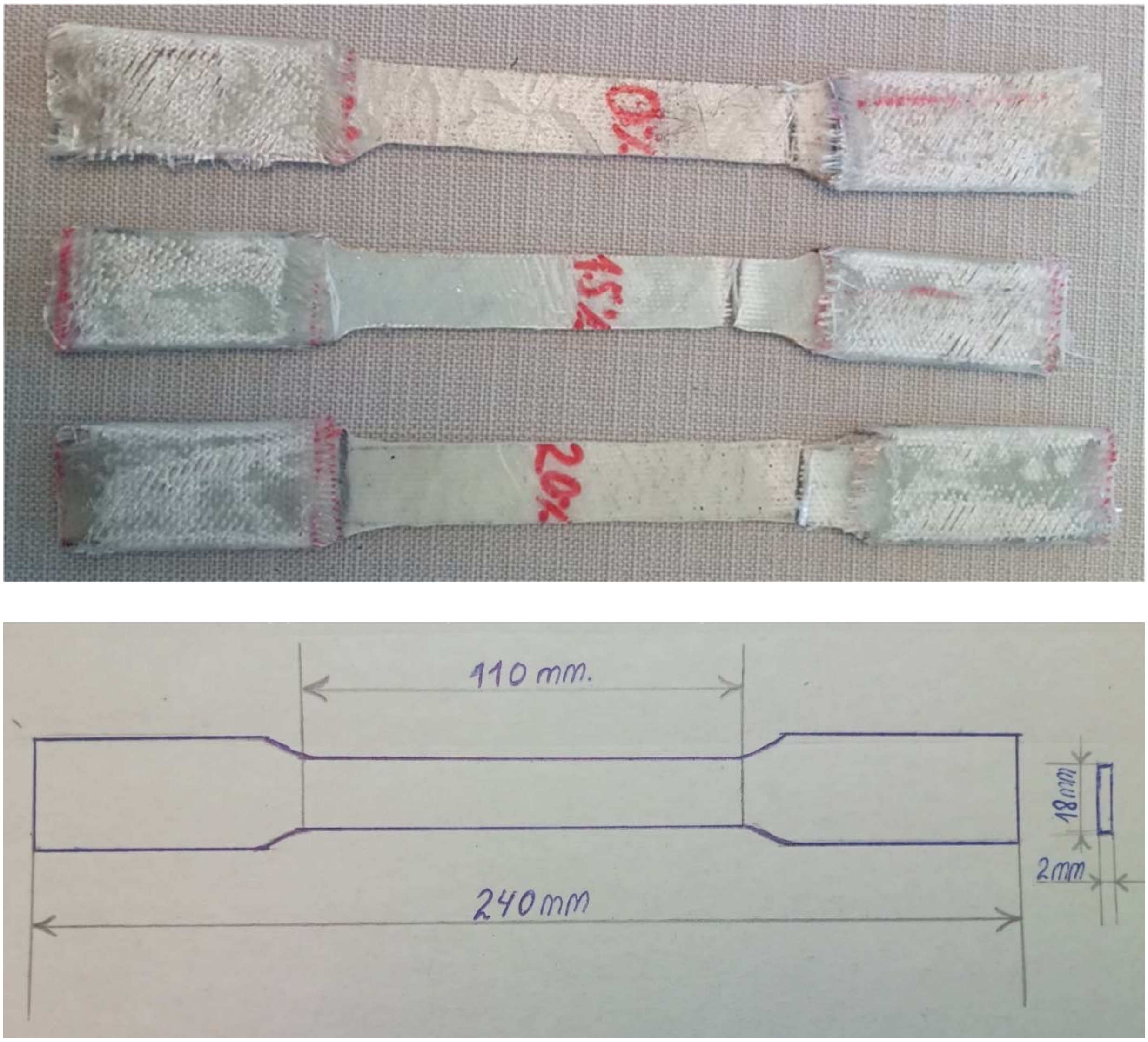

Fig. 2.3. Tensile test specimens.

2.2. Testing equipment

Mechanical testing was conducted utilizing a servo-hydraulic test machine equipped with the digital control system Bi-00-202V, enabling the examination of specimens under static load conditions. The structural and functional architecture of the installation comprises four key components (Fig. 2.4):

- Software (MTL – Windows);
- Personal computer (PC);
- Digital-to-analog converter 2350-Controller;
- Test machine.

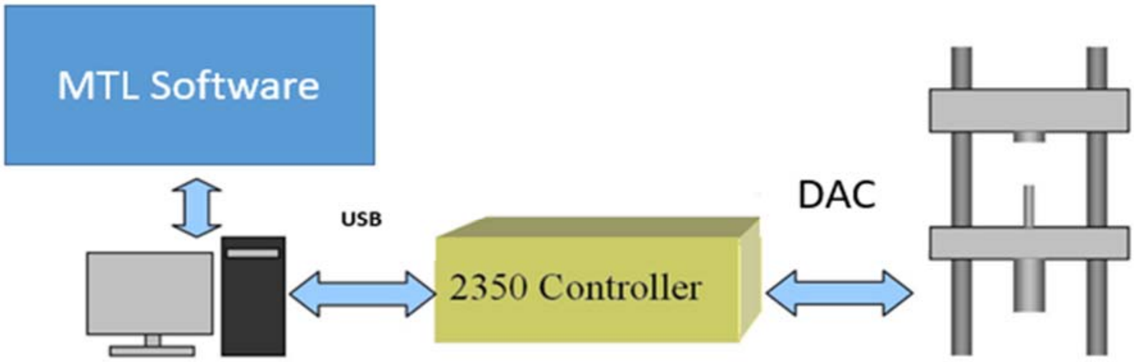

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Fig. 2.4. Architecture of Bi-00-202 V test machine.

The design of the test machine, depicted in Figure 2.5, features a robust structure formed by the base, columns, and upper traverse. A strain gauge (4) is affixed to the upper fixed traverse, and the specimen load is induced by the movement of the rod of the executive mechanism (3). The test program code specified in MTL-Windows is transmitted from the PC to the DAC 2350-Controller via a USB connection as a digital signal. This controller converts the input digital signal into command analog and digital signals, subsequently overseeing the hydraulic system's control of the rod's movement (3) in the executive mechanism.

Three channels facilitate information exchange to control the testing machine:

- Channel for the movement of the rod of the executive mechanism with a working range of ±50 mm and an accuracy of 0.001 mm.
- Load channel with a working range of ±25 kN and an accuracy of 0.001 kN.

- Extensometer channel with a working range of ±0.5 mm and an accuracy of 0.0001 mm.

The extensometer, employed for registering small deformations (Figure 2.6), enables the specimen to be loaded through one of the three channels, designating it as the active control channel. The other two channels operate in an information transfer mode, tracking the test parameters. The MTL–Windows software interface displays the signal indicating specimen loading.

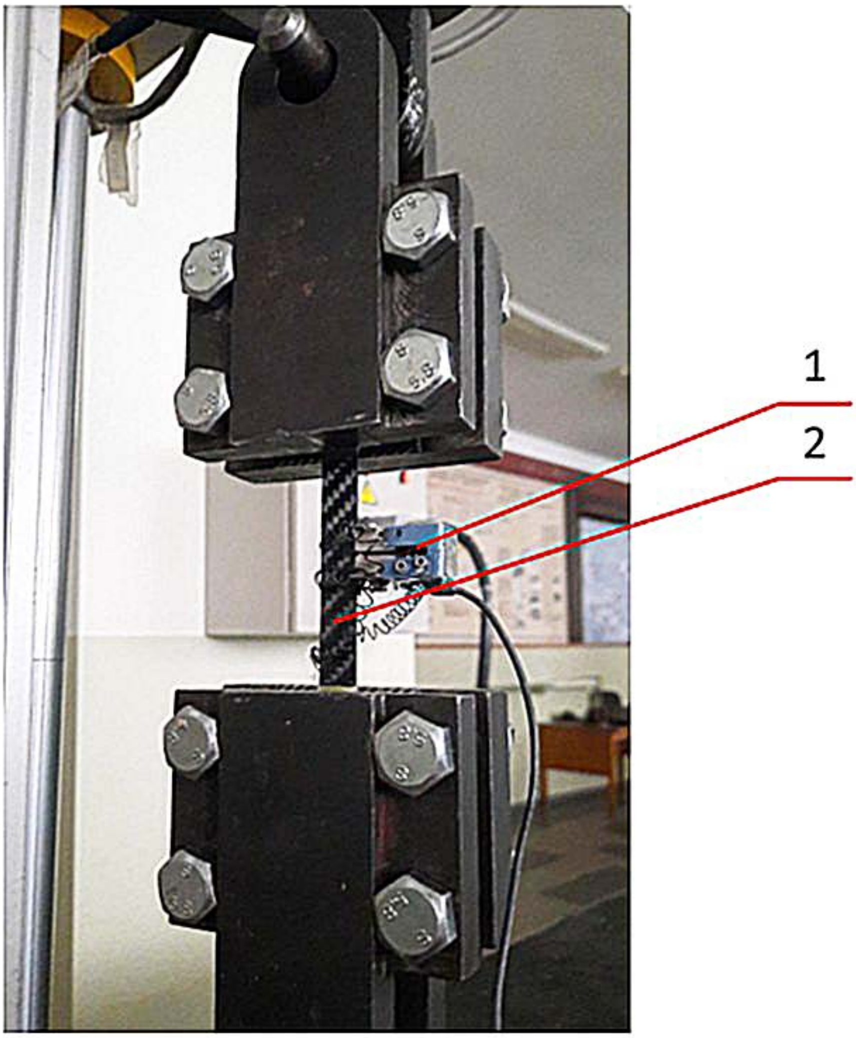

Fig. 2.5. The method of attaching an extensometer to a flat specimen

1 – specimen; 2 – extensometer

The formation of signals in the control channels involves transmitting analog signals from the rod position sensor, force meter, and extensometer to the DAC 2350-Controller. These analog signals are then converted into a digital format, sent to the PC, and finally displayed on the MTL-Windows software interface

The signal indicating specimen loading is visually presented on the MTL–Windows software interface. Signal formation in the control channels follows this process: analog signals from the rod position sensor, force meter, and extensometer are transmitted to the DAC 2350-Controller. This controller converts these analog signals into a digital format, which is then sent to the PC for display in the MTL-Windows software interface.

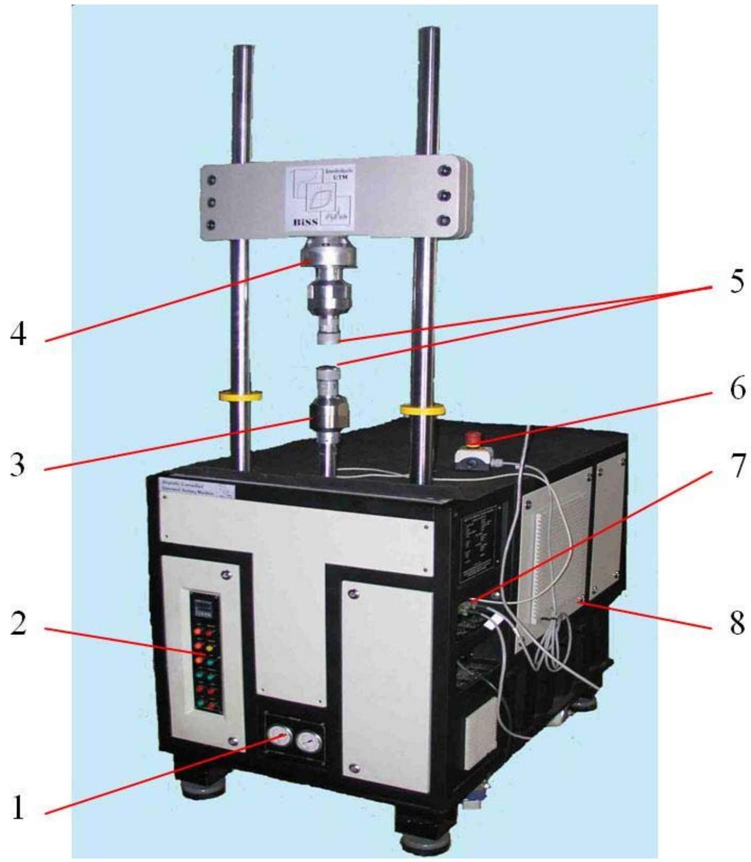

Fig. 2.6. The test machine

1 – pressure gauges of the hydraulic system; 2 – electrical power; 3 – actuator; 4 – dynamometer, 5 – specimen clamps, 6 – emergency stop button, 7 – ports for connecting control devices, 8 – DAC 2350-Controller.

The information received from the three control channels can be used to form or change the control signal of the active control channel.

2.3. Test resuts

The following information was obtained from these tests:

Sample without filler content (Fig. 2.7).

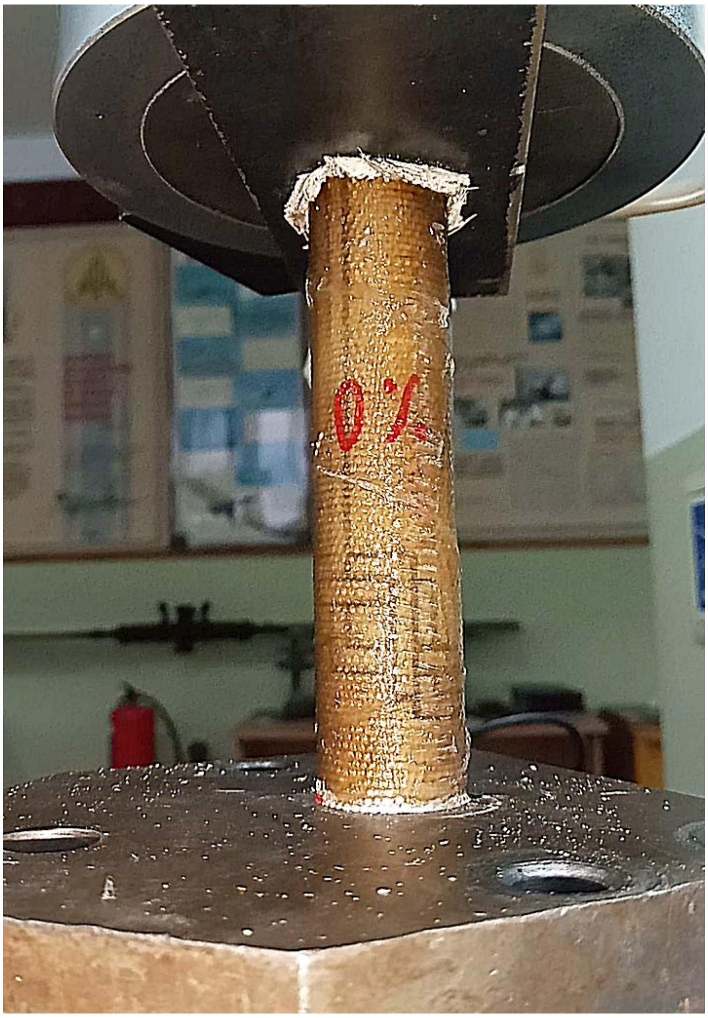

Fig. 2.7. Specimen for compression test.

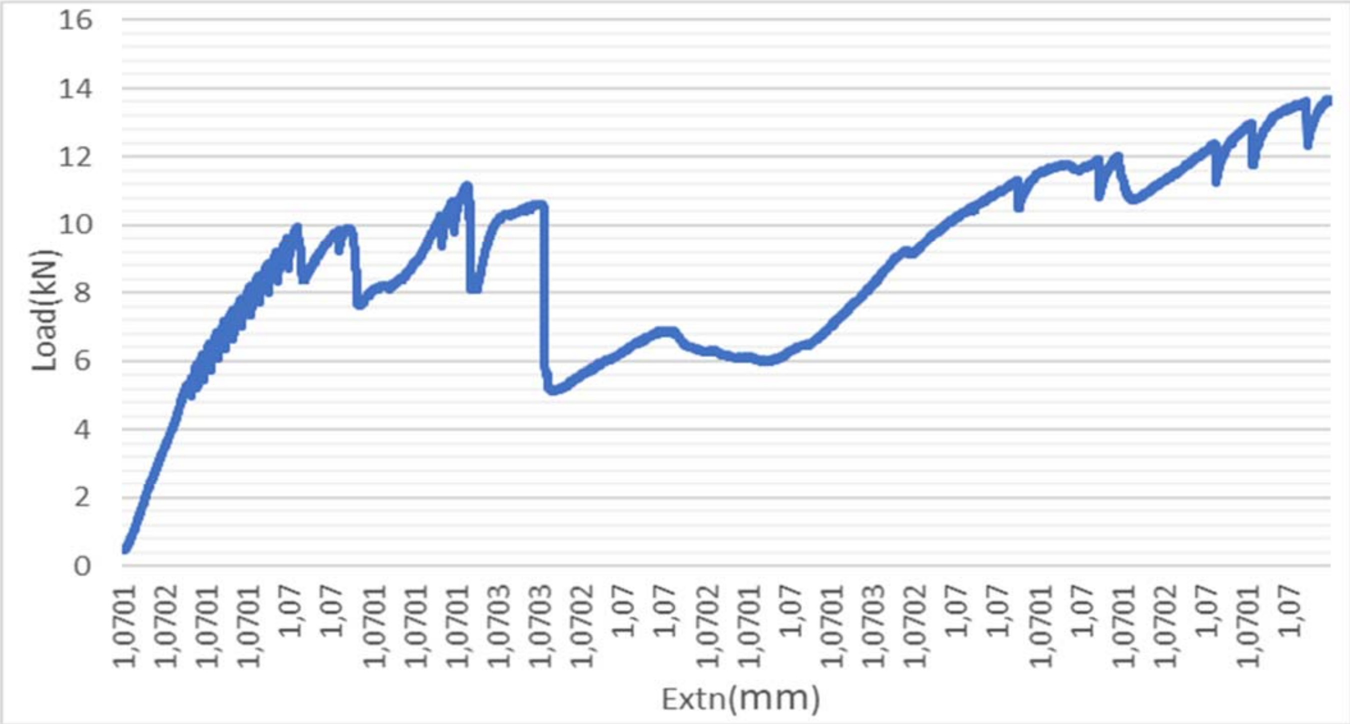

Fig. 2.8. Dependence of elongation on load. Sample without reinforcing particles. Table 1 in Appendix 1.

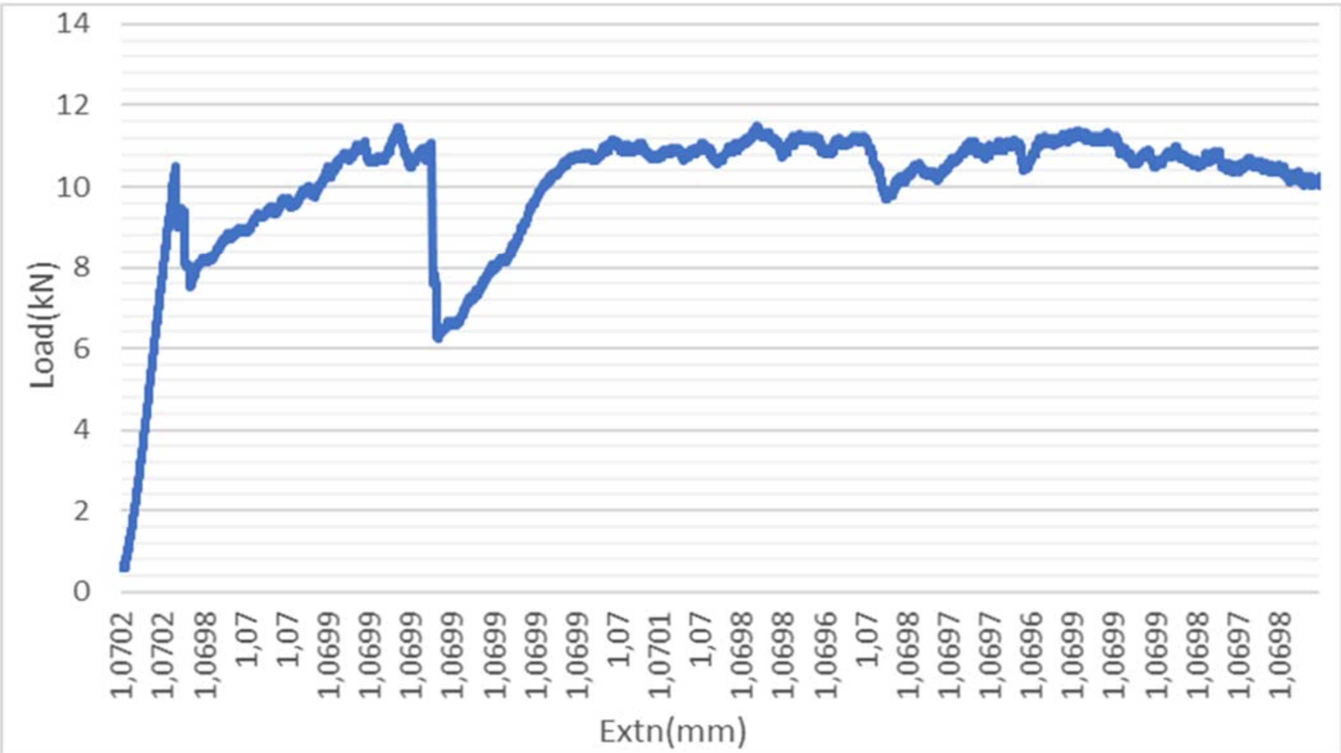

Fig.2.9. Dependence of elongation on load.

Sample with 10% reinforcing particles.Table 2 in Appendix 1.

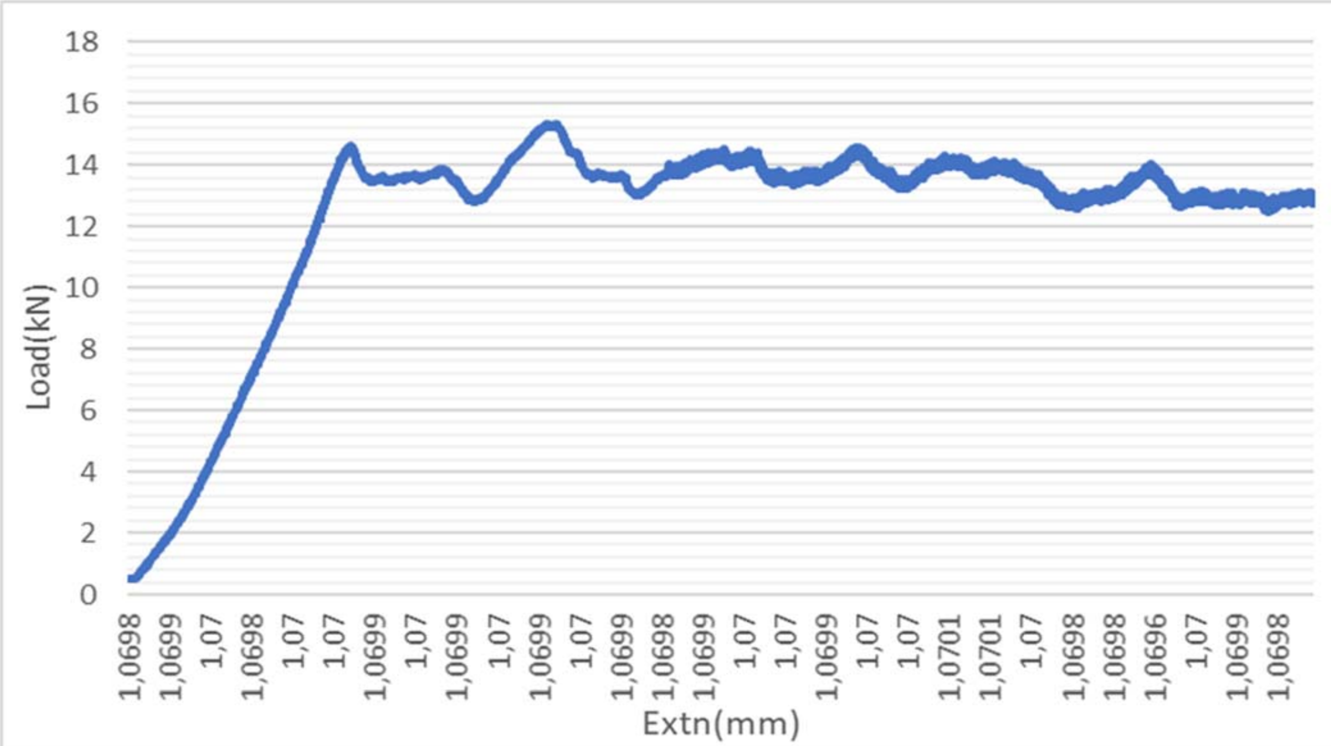

Fig. 2.10. Dependence of elongation on load.

A sample with a content of 15% amplifying particles. Table 3 in Appendix 1.

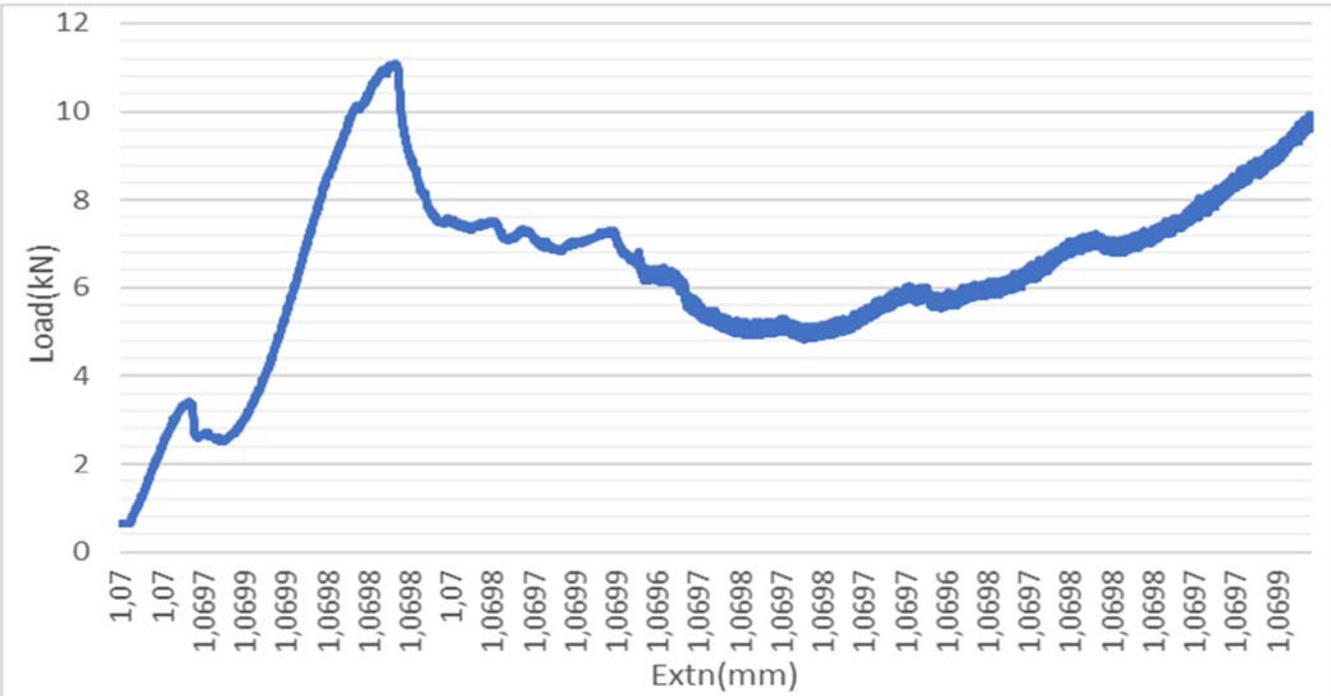

Fig. 2.11. Dependence of elongation on load. A sample with a content of 20%

amplifying particles. Table 4 in Appendix 1.

So, from this experiment, it was possible to determine what resists best compression of a sample with a filler content of 15%.

For tensile testing, 4 samples (plates) with dimensions of 270x18 mm and thickness of 2 mm with a filler content of 0, 10, 15, 20% were made.

Purpose: To determine the resistance to tensile loads depending on the content of the filler.

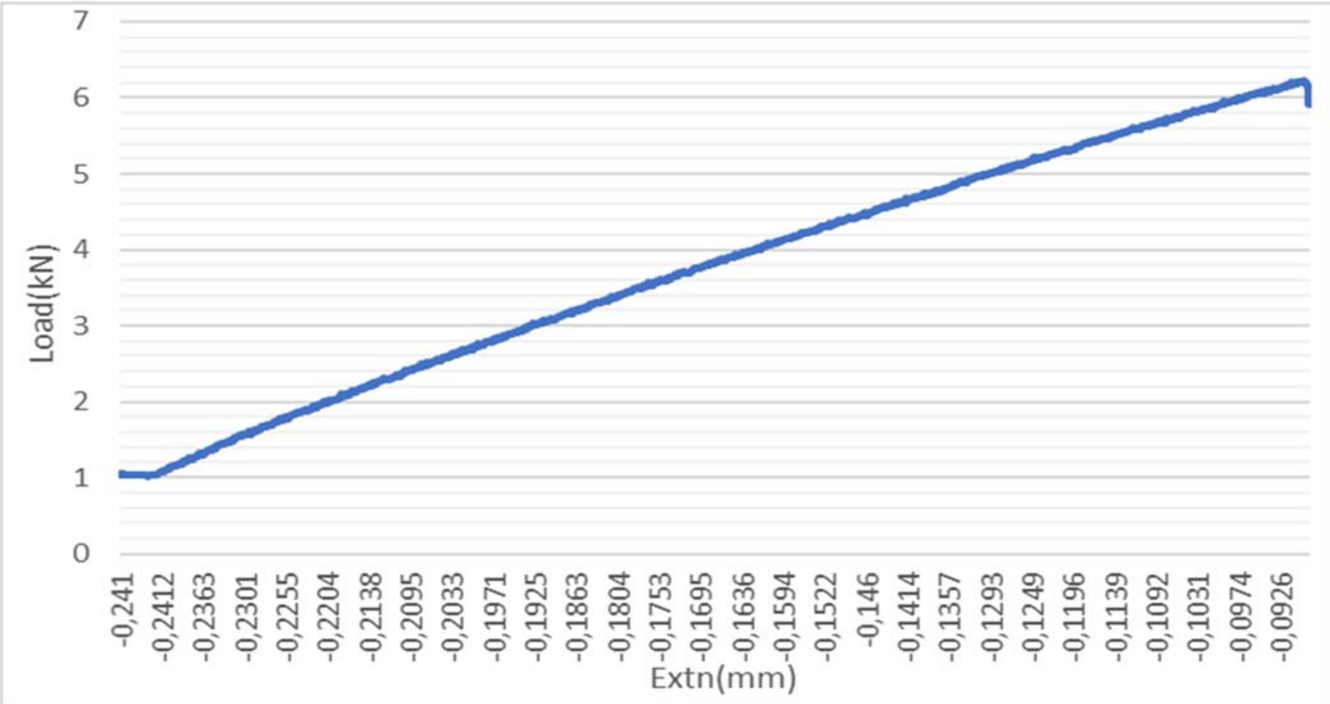

Fig. 2.12. Dependence of elongation on load. Sample beof contentin reinforcing particles. Table 5 in Appendix 1.

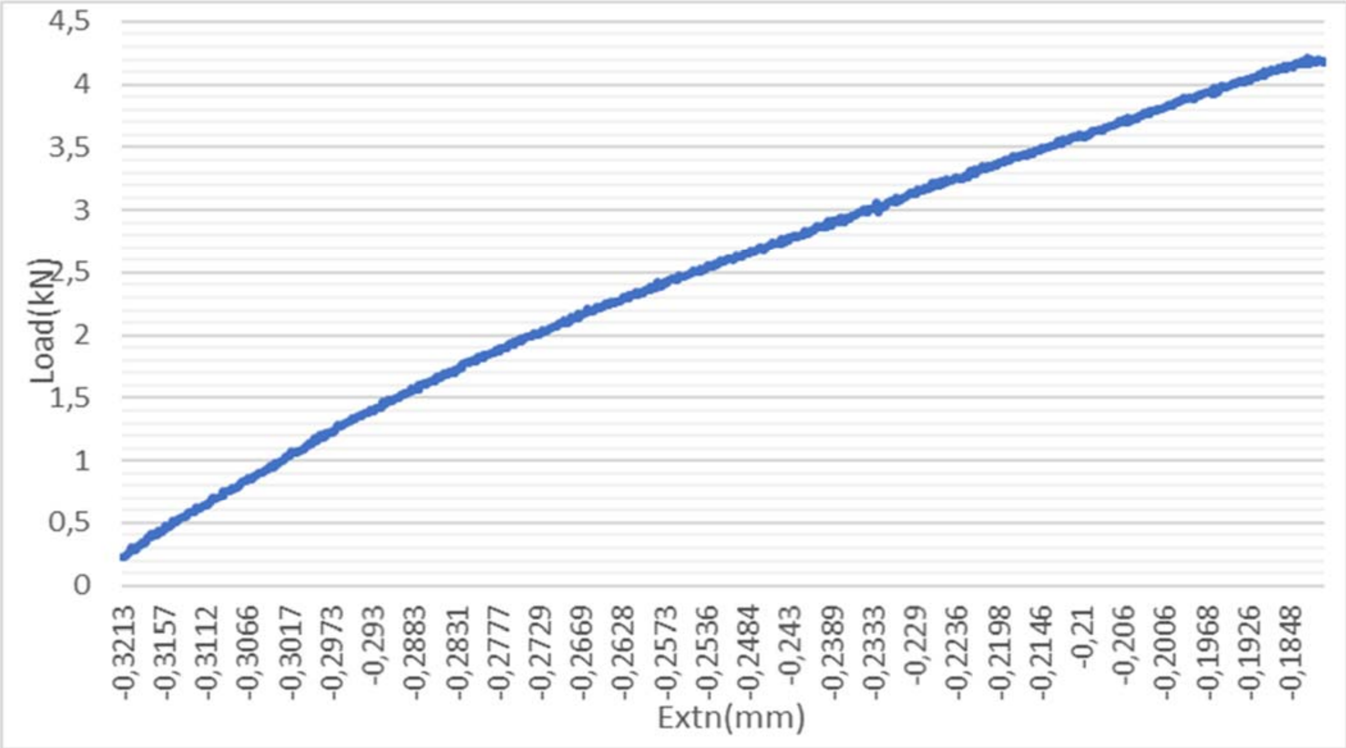

Fig. 2.13. Dependence of elongation on load.

A sample with a content of 10% reinforcing particles. Table 6 in Appendix 1.

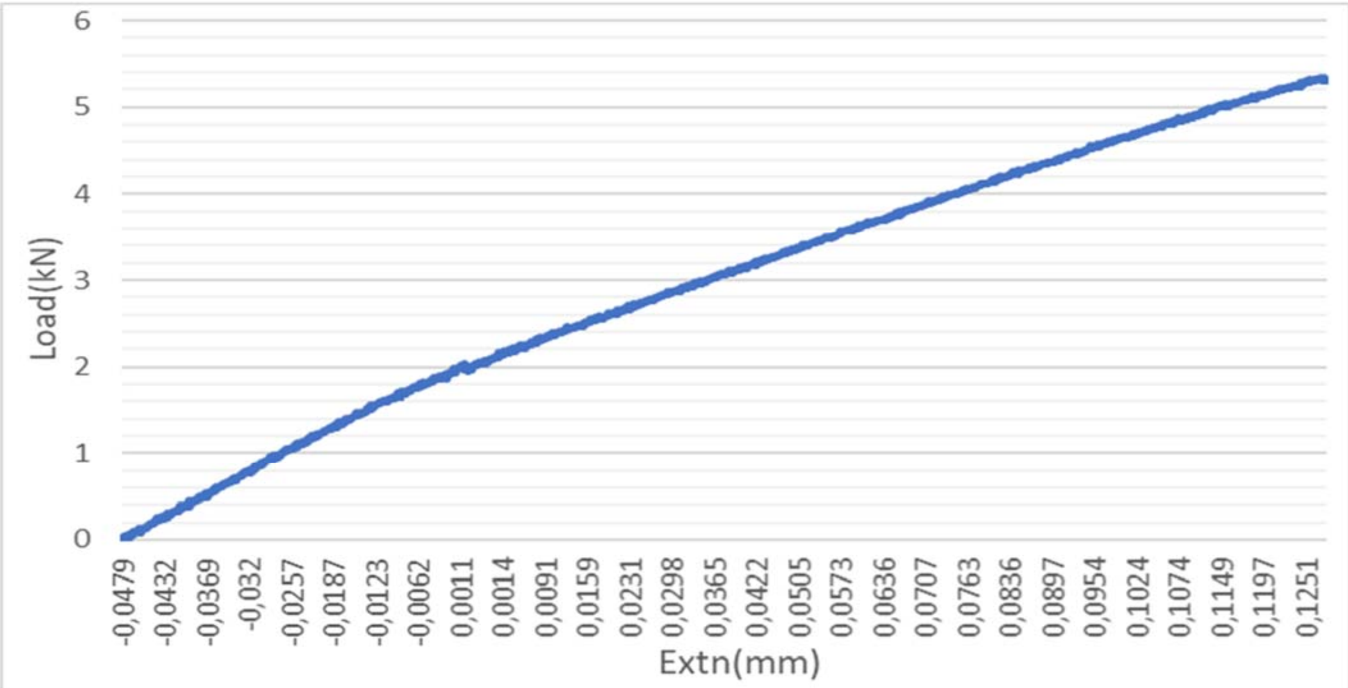

Fig. 2.14. Dependence of elongation on load.

A sample with a content of 15% amplifying particles. Table 7 in Appendix 1.

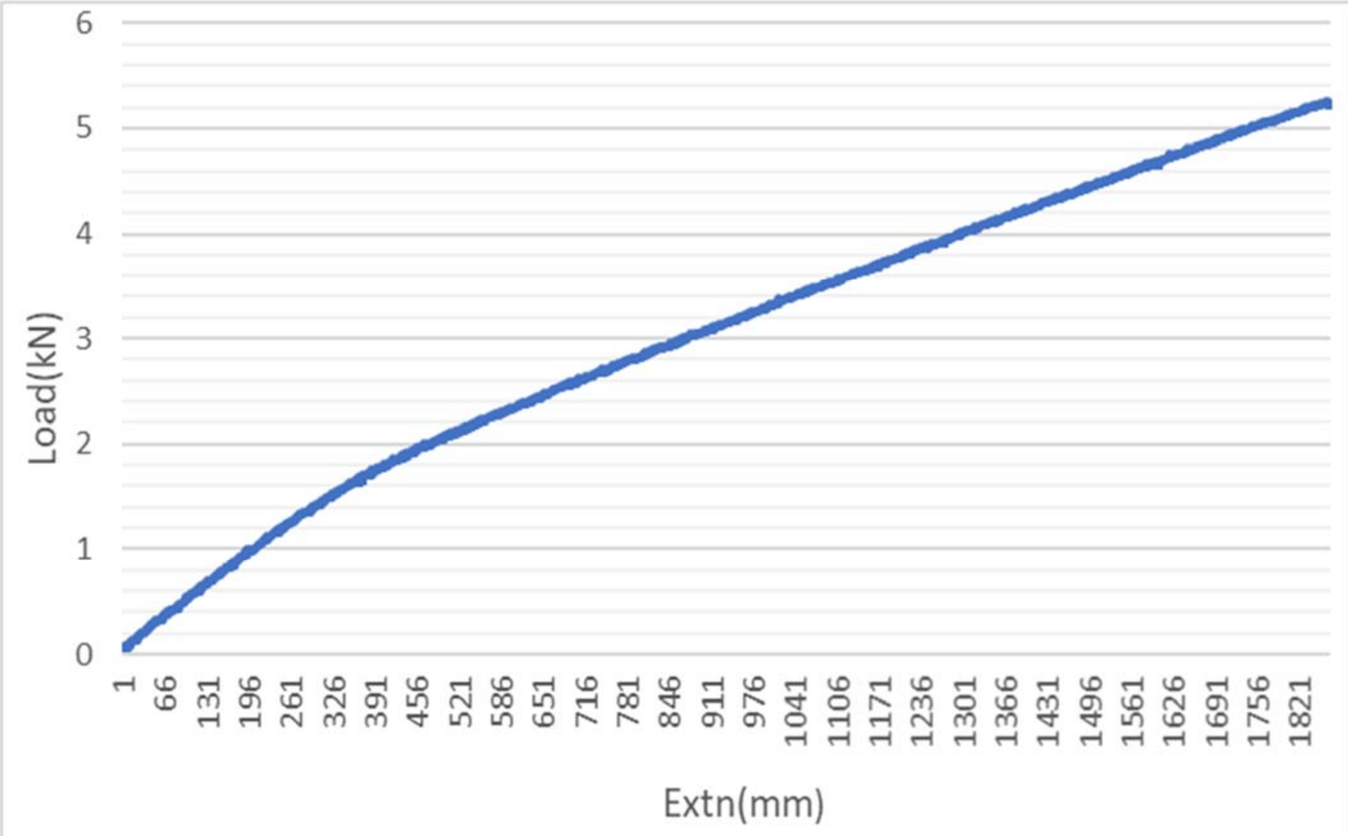

Fig. 2.15. Dependence of elongation on load.

A sample with a content of 20% amplifying particles. Table 8 in Appendix 1.

Let's summarize the obtained data. So, table 2.1 summarizes the results of the first tests: for compression, the force at which the destruction of the material begins is indicated, for tension, the load at which the sample breaks occurs is indicated.

Table 2.1

The fate of amplifying particles in %	Compression Load(kN)	Stretching Load(kN)
0%	-11.560	6.218
10%	-11.468	4.169
15%	-15.079	5,347
20%	-10.912	5,255

Having determined the best ratio of the filler, it was decided to repeat the experiment by making samples from a higher quality matrix. Epoxy resin Larit L - 285 was used as a matrix. For a repeated compression experiment, 2 samples (tubes) with a diameter of 28 mm and a length of 120 mm with a filler content of 0% and 15% were made.

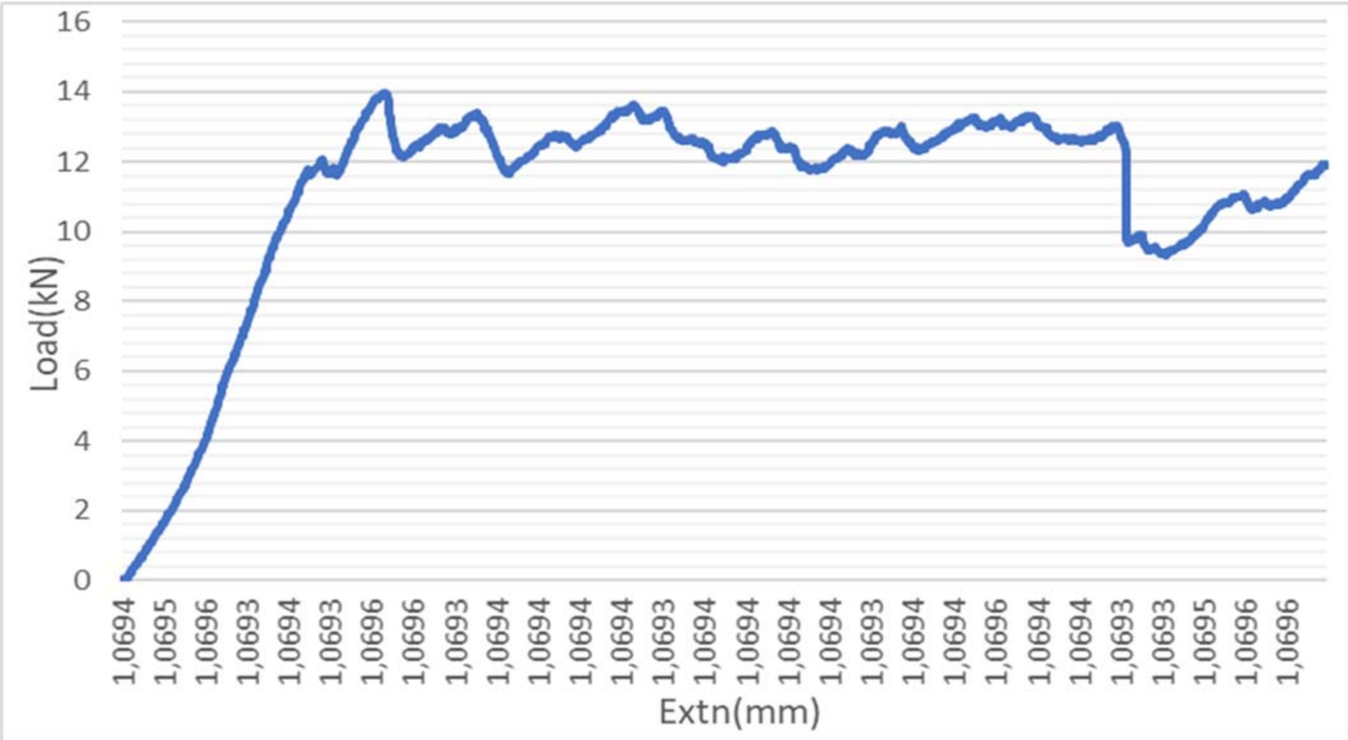

Fig. 2.16. Dependence of elongation on load.

Sample bewith contentin reinforcing particles. Table 9 in Appendix 1.

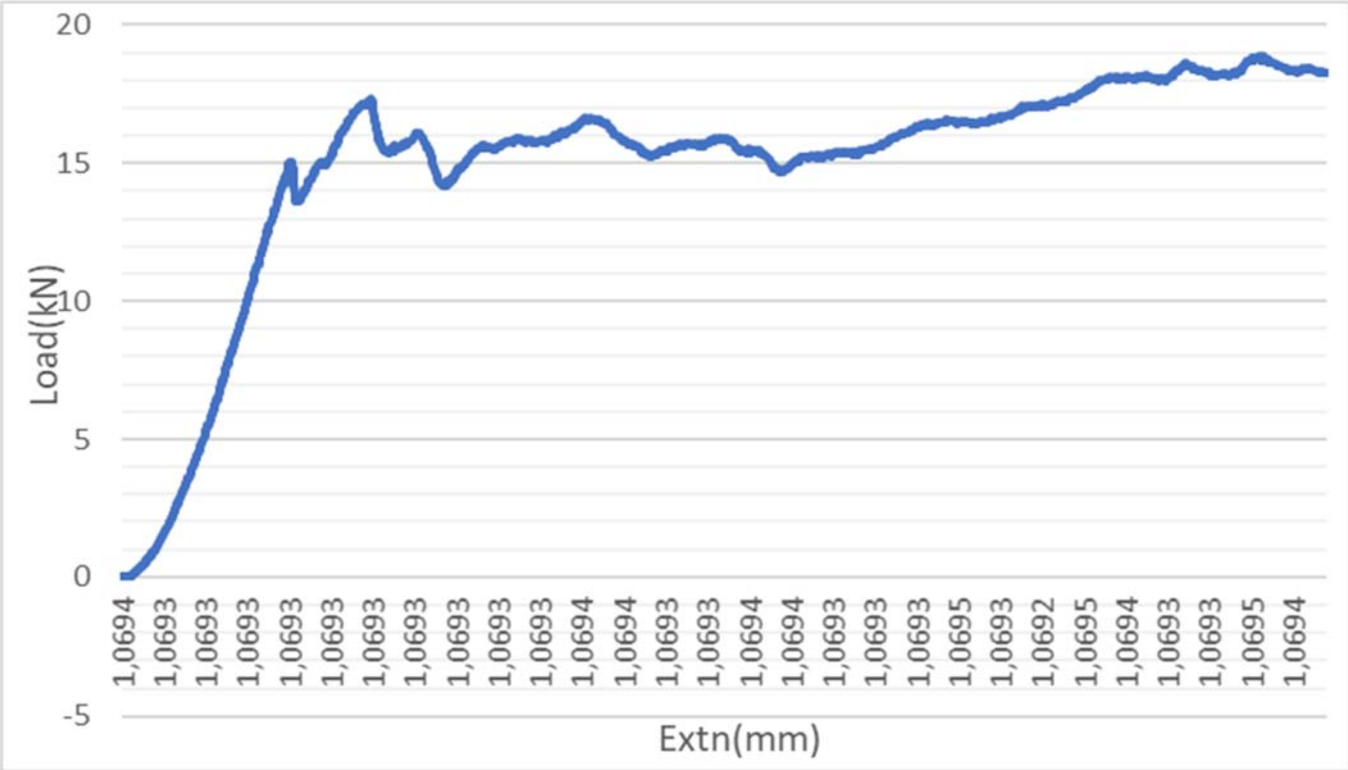

Fig. 2.17. Dependence of elongation on load.

A sample with a content of 15% amplifying particles. Table 10 in Appendix 1.

For tensile tests, two plates with dimensions of 270x18 mm and thickness of 2 mm with 0% and 15% filler content were made.

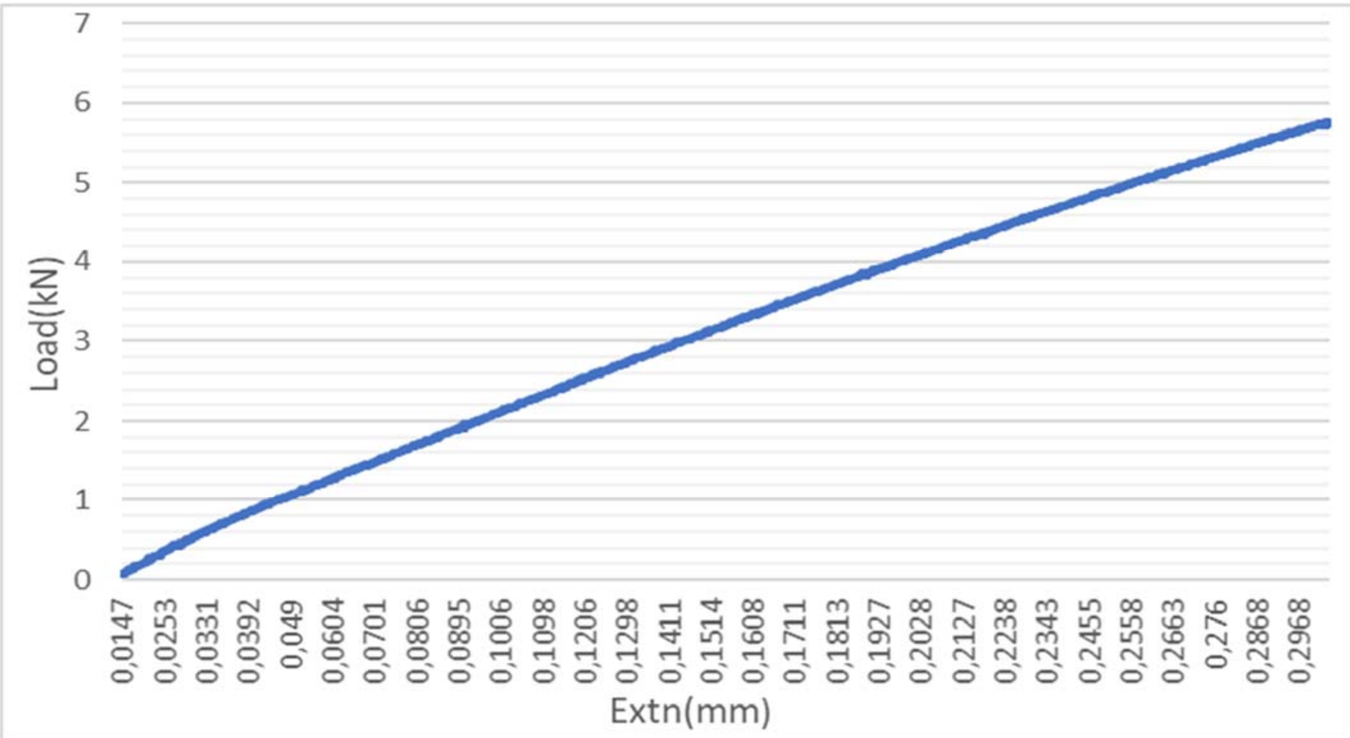

Fig. 2.18. Dependence of elongation on load.

Sample bewith contentin reinforcing particles. Table 11 in Appendix 1.

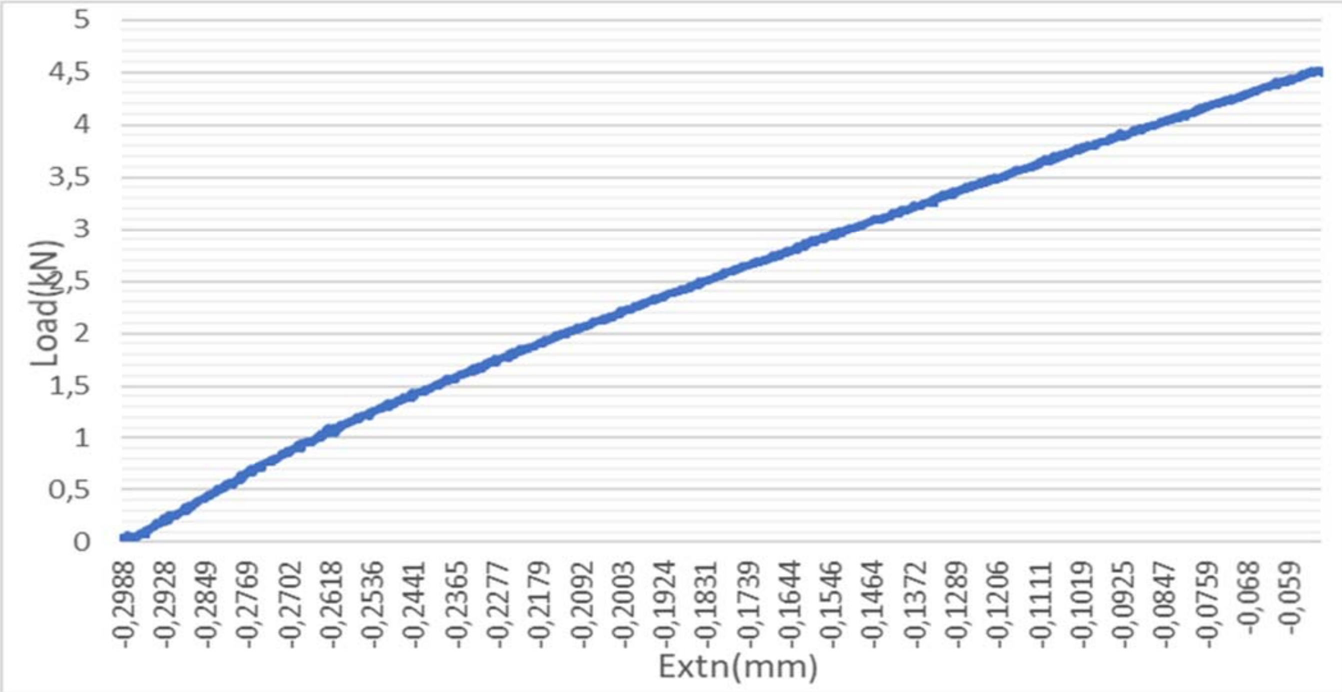

Fig. 2.19. Dependence of elongation on load.

Sample containingohms of amplifying particles 15%. Table 12 in Appendix 1.

Let's summarize the obtained data. Thus, Table 2.2 summarizes the results of the second series of tests: for compression, the force at which material destruction begins is indicated, for tension, the load at which the sample breaks occurs is indicated.

Table 2.2

The fate of amplifying particles in %	Compression Load(kN)	Stretching Load(kN)
0%	-14,325	5,761
15%	-17,57	4.519

Conclusion to the Part 2

The experimental phase of this study has yielded significant advancements in the development of a three-component composite material designed for the construction of aircraft control rods. The findings demonstrate a notable enhancement in compressive load resistance, with the newly formulated material exhibiting an 18% improvement over its non-reinforced counterpart. This outcome underscores the effectiveness of incorporating reinforcing particles in achieving superior performance under compressive forces, a crucial factor in the structural integrity of the control rod. Importantly, the introduction of the filler has been carefully balanced to ensure that tensile load resistance remains largely unaffected, emphasizing the material's versatility and ability to withstand varying stress conditions. These promising results pave the way for further exploration and application of the developed composite material in aircraft control systems, setting the stage for subsequent discussions on the practical implications and potential advancements in aerospace engineering.

PART 3. ENVIRONMENTAL PROTECTION

Introduction

A serious problem with the widespread use of polymer composite materials (PCMs) is recycling. Currently, solving the problem of recycling PCM is a priority materials science task, since the creation and implementation of new materials certainly leads to the generation of waste. Taking into account the specific properties of PCM, such as resistance to external environmental influences, the problem of their disposal is primarily of an environmental nature.

3.1. The influence of polymer composites on the environment

Modern industrial processes and technologies require an increasing use of composite materials, which are highly durable and lightweight. However, it is also important to consider their impact on the environment. Composite materials made from synthetic polymers and reinforced with fibers can have various impacts on the ecosystem and human health.

One of the problems associated with composite materials is their low biodegradability. Such materials can remain in the environment for decades and sometimes centuries. Figure 3.1 shows the burying of composite wind generator blades in the ground that have exhausted composite materials can release soot and other toxic substances that can have a negative impact on human and animal health.

Fig.3.1. Burying wind turbine blades in the ground.

Another problem is the use of certain components in the production of composite materials. Some contain toxic substances such as lead or mercury, which can leach into the environment and accumulate in living things. This can cause various diseases and organ dysfunction.

One of the most environmentally harmful composite materials is fluorocarbons, which contain carbon fluoride. They are potent greenhouse gases and, if released into the atmosphere, can cause depletion of the ozone layer.

3.2. Methods for processing polymer composites

One of the options for processing used polymer composite products is to give them a second life, namely to use them where the requirements are not so high. For example, wind generator blades can be cut into sheets for further use (Figure 3.2). Fiberglass used for the manufacture of wind generator blades has excellent noise-reducing properties and can therefore be used where necessary.

Fig.3.2. New application of wind turbine blades.

The main way to solve the problem of PCM disposal is their recycling. The positive side of recycling is that it produces additional useful products for various industries and does not re-polute the environment. For these reasons, recycling is not only an economically feasible, but also an environmentally preferable solution to the problem of recycling composite materials under modern legislation.

Particularly difficult is the recycling of PCM reinforced with continuous fiber fillers, both because of their high strength characteristics and because of the problems of recycling recycled waste.

All methods of recycling reinforced PCM are united by the need to destroy the matrix (binder) in order to release the reinforcing filler (fiber), with the resulting output of various processed products. Currently, three disposal methods are conventionally considered: physical, chemical and thermal (Fig. 3.3).

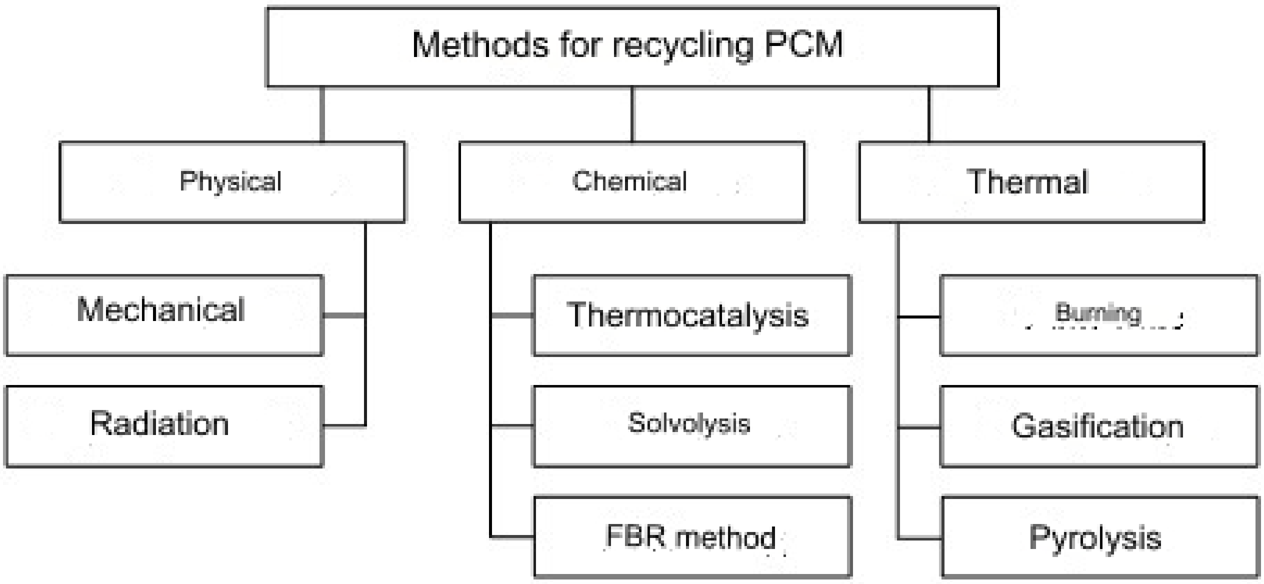

Fig. 3.3. Disposal Methods.

The main promising physical methods of processing at present are mechanical and radiation. The mechanical method includes grinding, crushing and grinding, the main product of which is recyclate (product of PCM recycling) of varying degrees of grinding. The technological design of mechanical processes can be varied - from conventional shredders and grinders to an air zigzag shredder-separator. To describe grinding processes, the grinding theory of P.A. is used. Rebinder, which lies in the fact that the work of destruction of a material consists of the work spent on overcoming elastic and plastic deformations, as well as the work required to form a new surface. The general principle of radiation methods is based on the destruction (destruction) of a polymer matrix under the influence of high-energy radiation.

Among the physical methods, mechanical is the most common (Fig. 3.4). The main advantages of mechanical processing methods are the comparative simplicity of technological design, versatility - applicable for any PCM and polymers, simultaneous processing of fibers and polymer binder, as well as the absence of harmful emissions and fumes. The disadvantages of the mechanical method include high energy intensity, difficulty in controlling the size of crushed plastics, non-neutralized polymer binder, reduction in the mechanical properties of crushed reinforced plastics, limited secondary use of recycled materials; alternatively, crushed material can be used together with crushed stone when pouring foundations. Another example of machines for processing (separation) of aluminum composite panels (Fig. 3.5)

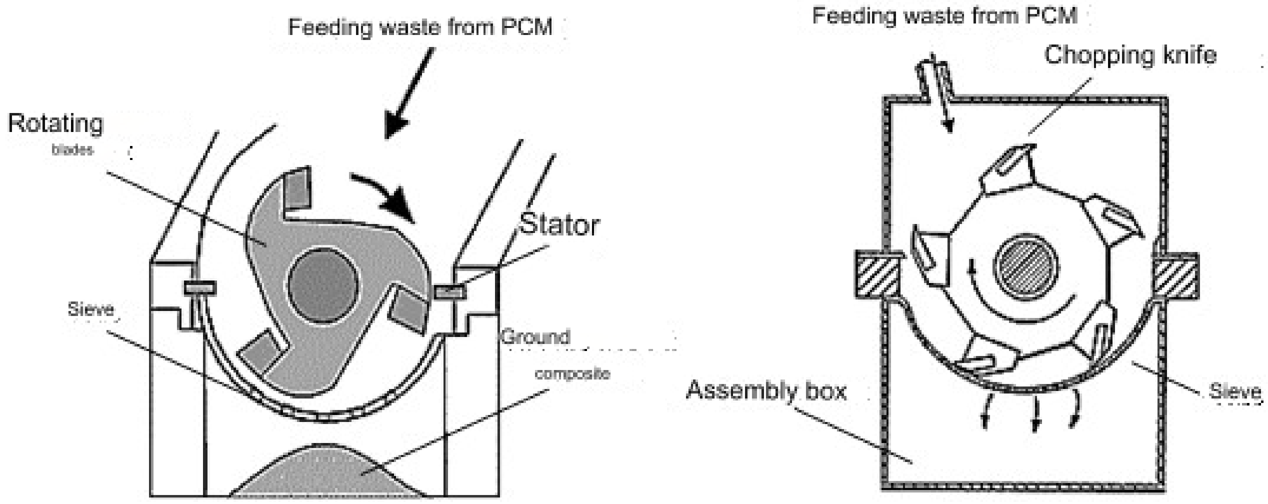

Fig. 3.4. Diagrams of mechanical shredders for polymer composite materials.

Fig. 3.5. Aluminum composites processing machine.

The advantage of the radiation method is its versatility - under the influence of high-energy radiation, almost all polymer matrices are destroyed, while the filler remains intact (for carbon fibers only). The disadvantages of the method are the excessive radiation load on the environment and humans, and the disposal of predominantly thin-layer reinforced plastic waste (up to several millimeters). Research in this direction is underway and, although it is premature to talk about the effectiveness of the approach, it is assumed that despite the inherent disadvantages of this method, in the future it may become one of the main methods for recycling certain types of reinforced plastics due to its energy efficiency and destruction of polymers.

Research is presented on the recycling of PCM using chemical methods based on depolymerization (chemical destruction) of the polymer binder, the output product of which is fiber. In this direction, the main promising methods are thermal catalysis, solvolysis and oxidation in a fluidized bed process (FBP).

In the case under consideration, solvolysis is a special case of thermocatalysis and is distinguished by the fact that in the process of solvolysis, various liquids (supercritical water, alcohols) with catalysts in the form of alkali metal salts are used as a medium for depolymerization of the matrix, and in the case of thermocatalysis, any other media are used.

The advantages of thermocatalytic methods are: low energy consumption, high selectivity of the process for polymer binders (90–98%) and preservation of the properties of the reinforced filler.

The main disadvantages of thermocatalytic methods for processing waste composite materials are: the difficulty of controlling the technological process of processing reinforced plastics with subsequent disposal of harmful reagents and decomposition products of the polymer matrix, the complexity of the technological equipment due to the need to carry out the process at high pressures (up to 3.5 MPa, in some cases – up to 29 MPa), as well as the selectivity of reagents for depolymerization of the binder, for each recycled binder it is necessary to select the composition of the initial reagents.

The processing of carbon fiber reinforced plastics using the solvolysis process is most widespread in Japan. In particular, the Hitachi Chemical company has achieved particular success in this area - the process is carried out at low pressure (up to ~2 at) and a temperature of no more than 200°C. The advantages of this method are: the comparative simplicity of the hardware design, the energy efficiency of the recycling process, and the fact that the decomposition products of the epoxy binder can be used in the re-synthesis of epoxy resins. The output products are fiber and depolymerized epoxy binder.

Interesting results were also obtained within the framework of project 7 of the European Union target program EURECOMP (2009–2012), which is aimed at the development of physicochemical processes for the utilization of PCM, in particular solvolysis. The solvolysis process has been found to remove up to 90% of the resin, resulting in the formation of recovered fiber and a liquid fraction (chemical substance), the composition of which has potential commercial value, in particular substances such as benzoic acid, benzaldehyde, isopropyl phenyl ketone, methyl ethyl ether, methyl isobutyl ether, benzene and acetaldehyde. A schematic diagram of the process of recycling reinforced PCM by solvolysis is presented in (Fig. 3.6).

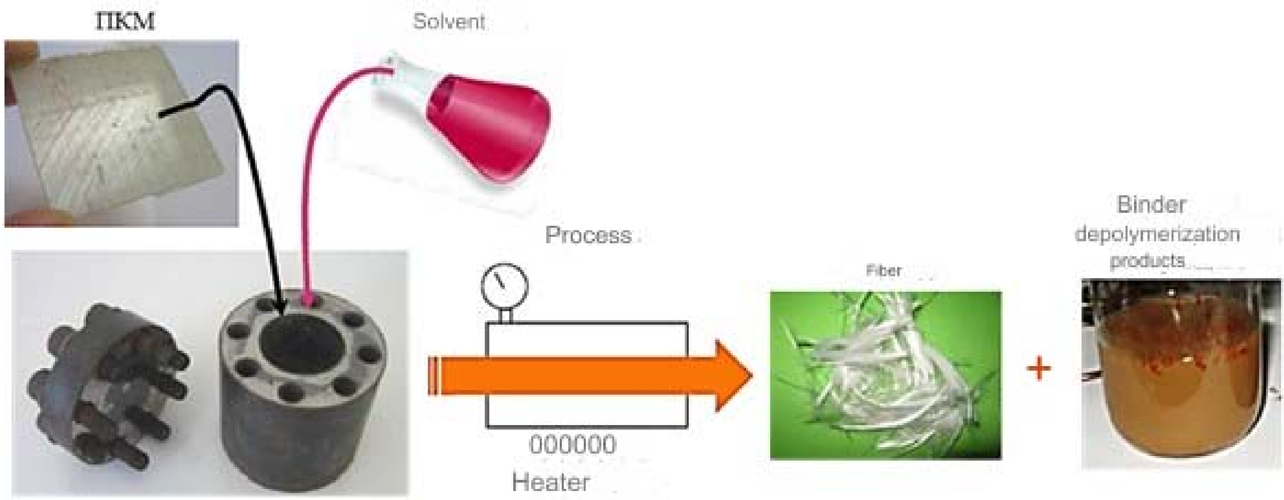

Fig. 3.6. Conventional scheme for recycling polymer composite materials (PCM) using the solvolysis method.

In addition, an assessment of the technological stages of the process and its environmental impact showed its competitiveness compared to existing processing technologies such as pyrolysis. A feature of the recycling of reinforced PCM by the solvolysis method is the requirement that the filler be chemically inert to the reagents, and therefore, only carbon fiber reinforced plastics and some types of fiberglass plastics can be recycled. PCM containing other fillers must be tested for chemical resistance to selected reagents. Figure 3.7 shows images of 1 and 20 L solvolysis reactors created within the EURECOMP project.

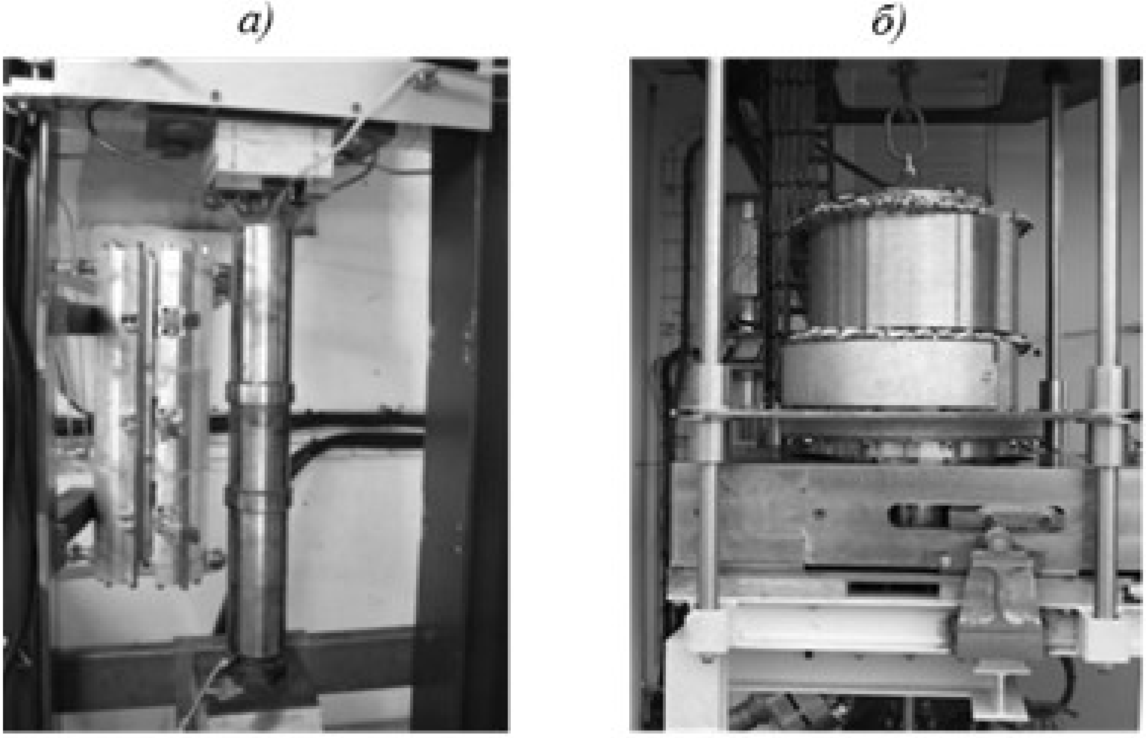

Fig. 3.7. Type of solvolysis reactors created within the framework of EURECOMP project with a capacity of 1 (a) and 20 l (b).

A special case of thermal catalysis is fluidized bed oxidation, developed at the University of Nottingham under the name fluidized bed process (FBP), the general process diagram is shown in Figure 3.8.

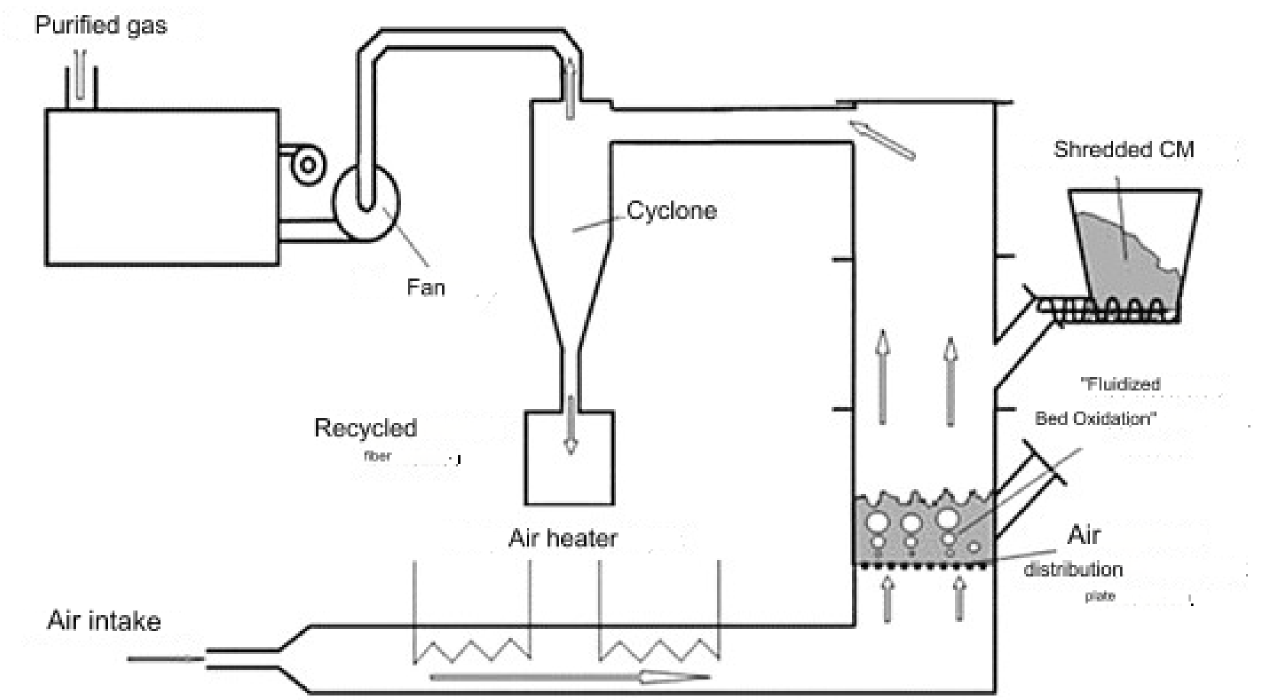

Fig. 3.8. Fluid bed oxidation process diagram with cyclone.

The essence of the technology is as follows. Recyclable reinforced PCM is placed in a bath with a solid dispersed filler, for example sand, and then hot gas (heated to a temperature of 450 to 550°C) enriched with oxygen (air) is supplied. The heated gas passes through a layer of sand, which oxidizes the polymer binder, then the hot air flow carries the fibers and oxidation products of the polymer binder away from the reaction zone. The fibers in the cyclone are separated from the oxidation products of the polymer binder. The under-oxidized compounds of the polymer binder are completely oxidized in the combustion chamber. Using this process, you can deal with various PCM contaminants - any organic materials (polymers, paints, foams) are oxidized, and metals (metal wire, fasteners and inserts) remain in the fluidized bed.

Figure 3.9 shows a comparison of the mechanical properties of recycled and virgin carbon fibers obtained by processing carbon fiber reinforced plastics using pyrolysis, fluidized bed oxidation (FBP), and solvolysis. It can be seen that the most promising method for recycling waste from PCM (carbon fiber plastic), in which the loss of strength and stiffness of the fiber is insignificant (~2–3%), is solvolysis, followed by pyrolysis and oxidation in a fluidized bed.

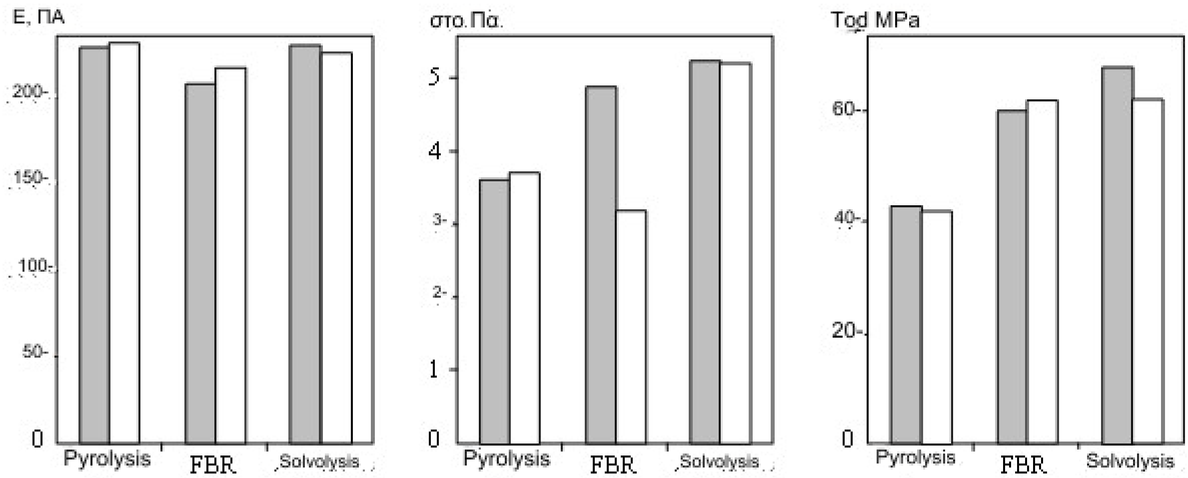

Fig. 3.9. Comparison of mechanical properties (E – modulus of elasticity; σB, τSDV – tensile and shear strengths, respectively) of carbon fibers (■ – initial; □ – recycled) obtained by various processing technologies (FBP – fluidized bed oxidation).

Among the thermal methods for recycling PCM, depending on the oxygen content, one can distinguish combustion (with an oxygen content close to or exceeding the stoichiometric value), gasification (with a lack of oxygen) and pyrolysis (lack of oxygen). The method of burning PCM is a process of its elimination. This method is impractical since the only product that can be used in this process is heat. In addition, combustion leads to environmental pollution (air and water), so this disposal method is prohibited in many countries of the European Union.

The gasification method is the process of decomposing PCM to produce synthesis gas, which is used to produce thermal and electrical energy. The disadvantage of both combustion and gasification is the destruction of the most valuable components of PCM and the high probability of the release of harmful gases into the atmosphere.

Currently, the most common method for recycling reinforced plastics is pyrolysis. Pyrolysis is conventionally divided into low-temperature (from 300 to 500°C), the products of which are fiber, as well as oils and solids - products of the decomposition of the polymer binder; medium temperature (from 500 to 800°C), the products of which are fiber, oils and gases, and, to a lesser extent, solids; high-temperature (from 800 to 1500°C), the main products are fiber and pyrolysis gases, the yield of solids and oils is insignificant. The pyrolysis process is carried out in the absence of oxygen, often in an inert gas environment - nitrogen. A schematic diagram of the process is presented in Figure 3.10.

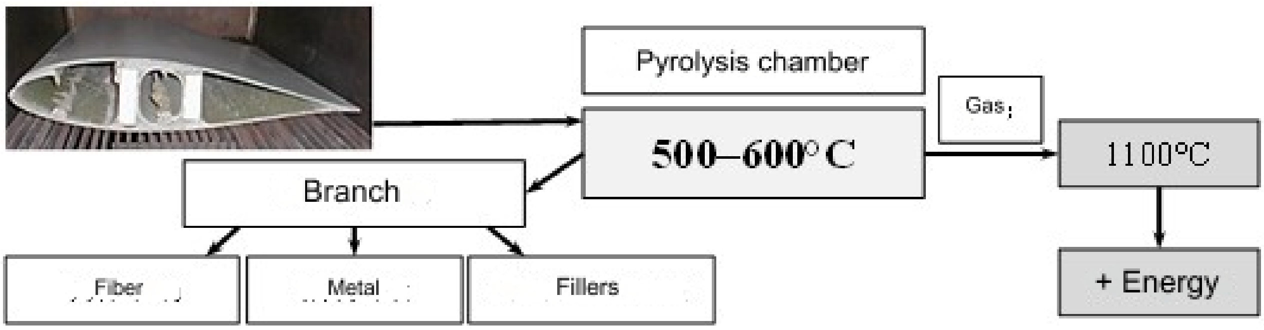

Fig. 3.10. Diagram of the pyrolysis process of reinforced plastics.

The hardware design of the pyrolysis process is almost identical to the process in the oil industry and differs only in the heating method. Heating is carried out using microwave radiation, high-frequency currents, an electric arc, or combined methods using coolants.

The advantages of pyrolysis include high fiber yield with an optimized process, the use of heat from the decomposition of the polymer binder, the versatility of the equipment, good adhesion of the epoxy binder to recycled reinforced plastic fibers and wide commercial applications. The disadvantages of the process include the uneven heating of the reactor working area and, as a result, the decomposition of the binder may be incomplete, as well as the need to neutralize pyrolysis gases that contain compounds of hazardous substances.

Only plastics with heat-resistant fillers, such as fiberglass and some brands of carbon fibers, can be recycled by pyrolysis. In the case of carbon fiber reinforced plastics, it is necessary to select the technological parameters of pyrolysis, since with an unoptimized process, the properties of carbon fibers can decrease by 30–40%.

Pyrolysis is also a promising method for recycling organoplastics. With low and medium-temperature pyrolysis, it is possible to obtain not only raw materials for the production of activated carbon, but also to extract flammable pyrolysis gases and oils that are suitable for recovery. The method is most widespread in Germany, Great Britain, the USA, Belgium, France and other Western European countries.

Criteria for assessing PCM recycling methods:

1 – preservation of filler properties at a level of at least 80%;

2 – the possibility of using decomposition products of the polymer binder;

3 – environmental safety of the technology;

4 – energy efficiency of technology;

5 – possibility of recycling waste products.

Conclusion to the Part 3

The analysis of the experience of recycling polymer composite materials shows the relevance of work in this direction. In the field of PCM recycling, it is advisable to use a different recycling method for each type of filler: for fiberglass - this is pyrolysis and, to a lesser extent, thermal catalysis; for carbon fiber reinforced plastics – these are thermocatalysis, solvolysis and pyrolysis; for organoplastics this is low- and medium-temperature pyrolysis, possibly thermocatalysis, but this method requires further study. In the future, when creating polymer binders that will be used in PCM as a matrix, provide a technology for their utilization by thermocatalytic methods (thermocatalysis and solvolysis).

PART 4. LABOR PROTECTION

Introduction

Occupational safety, as a field of practical activity, is aimed at creating safe and harmless working conditions. At the current stage of production development, it is becoming more and more important. The creation of safe and harmless working conditions in production requires significant material costs, implementation of knowledge and solutions of scientific research works in the field of labor protection. So far, there is still a big gap between what we know about methods and means of labor protection and what is implemented in production. Professionally trained specialists should reduce this difference to a minimum, not only in the field of ecology and environmental protection, but also in the field of ensuring safe, harmless, healthy working conditions in production. Therefore, the role of knowledge on labor protection by engineering and technical workers is very important. Basic knowledge on labor protection issues is laid down in the process of training future specialists.

Labor protection is: A system of legal, socio-economic, organizational-technical, sanitary-hygienic and medical-prophylactic measures and means aimed at preserving the life, health and working capacity of a person during work. Labor protection is a complex scientific discipline in which issues of labor legislation, industrial sanitation, safety technology and fire safety are organically connected.

Solving the tasks of the Fundamentals of Occupational Safety is based on the achievements of ergonomics, scientific organization of work, technical aesthetics, hygiene and physiology of work, psychophysiology, as well as scientific disciplines that determine the development of technical progress.

4.1. Analysis of harmful and dangerous factors of the employee

Due to their unique physico-chemical, technological and consumer properties, polymer materials are widely used in all spheres of life in modern society. Particularly promising is the use of some types of synthetic resins (polyester, epoxy), which do not require complex equipment and significant energy costs. But at the same time, harmful volatile substances (phenol, ethylene glycol, acetone) are released.

For example, a very common epoxy resin, approved according to the correct technology, is considered absolutely harmless under normal conditions, its use is very limited, since during curing in industrial conditions, several sol fractions remain in the epoxy resin - a soluble residue. It can cause serious harm to health if it is washed with solvents and gets inside the body. In unapproved form, epoxy resins are quite poisonous and can harm health. But the most harmful are many hardeners, including the most common hardeners at room temperature — amines.

Epoxy resins are mutagenic, and certain components of some resins have been shown to be carcinogenic. The epoxy ring itself can have these properties to a certain extent, since it is able to bind to DNA. Some resins cause allergies in some people. The most often observed harmful effect of epoxy resins is irritation of the body's integuments. As hardeners of epoxy resins, amines are most often used, which also show toxicity and an irritating effect. The toxicity of less viscous resins is usually higher than more viscous ones. Inhalation of concentrated epoxy vapor, if frequent over a long period of time, may cause irritation of the respiratory tract. Contact of concentrated epoxy resin vapor with sensitive skin areas, such as the eye area, may cause swelling or itching.

Contact of polymer resins with unprotected skin is the most common type of resin and hardener exposure. Even minor skin contact, with frequent repetition, can cause chronic health problems. In isolated cases, with prolonged or repeated contact, the skin can absorb harmful components of the resin. The most common reaction is contact dermatitis or skin inflammation (Fig. 4.1).

Fig. 4.1. Hand dermatitis.

Both the resin and the hardener can cause acute contact dermatitis. Discomfort can be quite severe, but usually disappears when contact with the irritant stops. Repeated skin contact with resins or hardeners can cause chronic dermatitis, which is milder but lasts longer. If left untreated for a long time, it can lead to eczema, a form of dermatitis that can include bumps, blisters or itching. Dust from sanding incompletely cured epoxy can also cause dermatitis if it comes in contact with the skin.

Hardener burns are not typical. Mixed epoxy is unlikely to cause burns. By themselves, WEST SYSTEM and PRO-SET resins and hardeners are moderately corrosive. If left on the skin, they can cause severe irritation and mild chemical burns. Chemical burns develop gradually, initially causing irritation and mild pain. A burn can discolor and leave a small scar on the skin. The time required for the hardener to form a burn depends on the area of contact and the concentration of the hardener. When the hardener is mixed with the resin, the hardener is diluted and less harmful. Although mixed epoxy is less caustic, never leave it on the skin. It hardens quickly and is quite difficult to wash.

Microplastic

During the production of products from polymer composite materials, they are also subjected to mechanical processing: cutting, drilling, milling, grinding, polishing, while micro and nano particles of the material are formed in Figure 4.2, which are immediately lifted up by local swirling air flows, even though they heavier than him.

Fig. 4.2. Microplastics of polymer composites

Microplastic is not a specific type of plastic, but any type of plastic fragment less than 5 mm in length. Microplastics with particle sizes from 100 nm to 5 mm are considered dangerous for the environment. These fragments enter ecosystems from a variety of sources, including cosmetics, clothing and industrial processes, and are also produced by the breakdown of larger plastic particles. Microplastics accumulate in the environment in large quantities, especially in aquatic and marine ecosystems. Plastic decomposes slowly, usually hundreds or even thousands of years. This increases the likelihood of microplastics entering and accumulating in the bodies and tissues of many organisms.

Entry of microplastics and nanoplastics into the human body through breathing is one of the main ways of penetration of these plastic particles into the human body (Fig. 4.3).

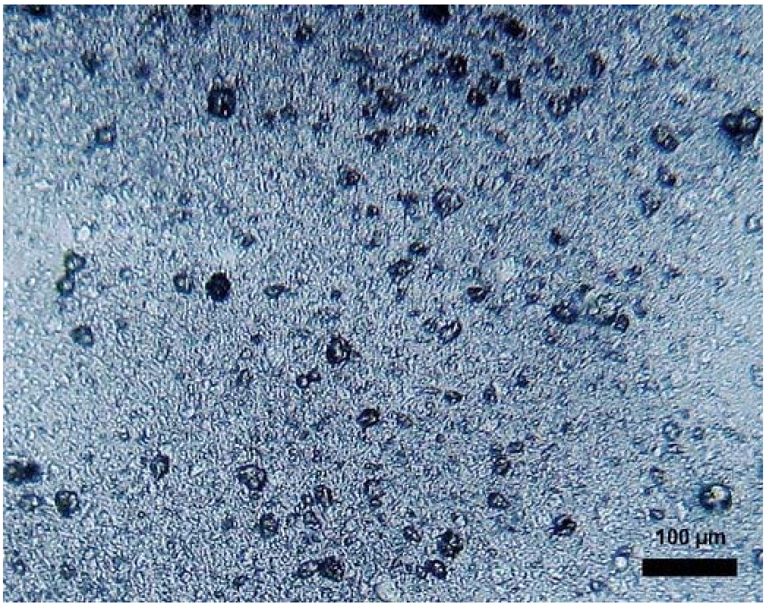

Fig. 4.3. Microplastics in the human body (blood)

From various experimental data, it was documented that the concentration of microplastics in indoor air was higher than in outdoor air. It has been estimated that atmospheric microplastics can persist in lung fluid for a total of 180 days without changes in surface area. Inhaled nanoplastics can travel to the brain and cause neurodegenerative diseases such as Alzheimer's disease and even primary brain tumors. Food and water sources contaminated with microplastics are also one of the main sources of human exposure to microplastics. The results of the study indicate that plastic particles, entering the human body, can move through it together with the blood and settle in various organs, swallowed microplastic particles damage internal organs, and also release dangerous chemicals inside the body - from bisphenol A (BFA), which has a negative effect on endocrine organs, to pesticides. This disrupts the body's protective functions and stops the growth and reproduction of cells. Microplastic particles can lead to the formation of blood clots. Many components of plastic have a negative effect on the endocrine system.

Electrical hazard

An important characteristic of fibrous polymer composites is their electrification, which in many cases determines the safety of their use. Static electrification is the occurrence of electric charges of different signs, which occurs when two bodies are separated, in particular, one or two of them may be polymer materials. The sign and magnitude of charges from their surface depends on many factors. Under certain conditions, especially with repeated disconnection of contacts and a low rate of flow of charges, the difference in electric potentials can reach significant values - several thousand volts. These conditions often arise during frictional contact of polymeric materials with counterbodies, their mechanical processing/processing, movement of non-conductive liquid and gas media relative to them. When a significant potential difference is reached, an electric discharge occurs, which can cause unpleasant or even dangerous effects: a feeling of electric shock when the discharge passes through the human body, mutual repulsion of polymer surfaces or dispersed particles during their processing, ignition of combustible gases, vapors or dust suspension, and other consequences.

The strength of the electric current flowing through a person is the main factor that determines the result of an electric shock. The value of the voltage under which a person found himself and the resistance of his body affect the result of damage to the person only to the extent that the voltage and resistance of the person determine the value of the electric current flowing through the person. If the strength of the electric current increases, the danger of injury to a person also increases. There are several human states that occur at certain current values:

Perceptible current - an electric current with a power of 0.6 to 1.5 mA, which causes a perceptible irritation when passing through the body;

Non-releasing current – an electric current that, when passing through a person, causes irresistible convulsive contractions of the muscles of the arm in which the current-conducting part is clamped. At a current of 3-5 mA (50 Hz), the entire hand that touches current-conducting parts is irritated, at 8-10 mA the pain covers the entire hand, and at 15 mA the spasms of the hand muscles become insurmountable, and the pain is unbearable. At the same time, a person cannot open the hand in which the current-conducting part is clamped;

Limit fibrillation current – the smallest value of fibrillation current. Its value ranges from 100 mA to 5 A for 50 Hz current and from 300 mA to 5 A for direct current. The duration of exposure to electric current largely determines the outcome of the injury, because as the duration of exposure increases, the amount of current through the human body increases, then the protective function of the body decreases, and the probability of the current affecting the heart muscle when it is in the most vulnerable state increases.

In the manufacture of composite products, starting with the production of constituent components and ending with post-processing, operation and repair, electrical equipment, manual and stationary power tools with a voltage of 220V, 380V and higher are used. Electric current with this voltage can cause the following injuries:

Electric burn – the most common electrical injury (fig. 4.4.a). This is a current burn in networks up to 2 kV and an arc burn. The temperature of the arc can be up to 3500 °C. In turn, the action of an electric arc can cause metallization of the skin, which is the result of penetration of metal vapors deep into the skin, when the part of the body is close to the place of its formation (fig. 4.4.b);

Electric signs are gray or pale yellow spots. The configuration of the electric sign corresponds to the shape of the current-conducting part, which was touched by a person (fig. 4.4.c);

Electric shock - the result of this irritation and subsequent inhibition is paralysis of cardiac activity, breathing and electric shock.


Fig. 4.4. a – Electrical Burn. Fig. 4.4. b - Electrometallization of the skin.

Fig. 4.4.c - Electrical Injury - Electrical Sign.

4.2. Development of labor protection measures (according to the most unfavorable factors at this workplace)

Protection against volatile substances

Ventilation of industrial premises (buildings, factories, shops, factories) is a rather complex design task - there is no universal method for it. Formation of the microclimate in the production premises directly with the support of the appropriate temperature and humidity regime in the premises. At manufacturing enterprises, during technological processes, polluting substances are released into the air surrounding the workplace: solid particles, gases, vapors, fogs and liquid aerosols. There is also a problem with the release of heat and water vapor.

Air pollution can cause:

- risks for human health and safety due to their irritating, allergenic, toxic, carcinogenic, radioactive, flammable and explosive properties;
- discomfort and malaise;
- explosions and fires as a result of exceeding permissible concentrations of flammable, explosive components;
- Rapid wear, damage and failure of equipment.

In this regard, it is necessary to create proper working conditions in factory shops. It is important to ensure not only the optimal air temperature, which corresponds to physical efforts and the season, but also to maintain the concentration of pollutants at a safe level.

To cite the worker's respiratory organs, it is necessary to use personal protective equipment against harmful vapors and gases, for example, a respirator or gas mask (Fig. 4.5).

Fig. 4.5. Personal respiratory protective equipment.

There are known cases when ignoring elementary ventilation in the workplace and personal protective equipment led to fatal consequences at work.

The use of industrial ventilation helps to solve these problems (Fig. 4.6). Its main task is to remove or dilute polluting substances formed during technological processes as efficiently and quickly as possible, to increase the comfort of employees' stay by improving air quality. For greater safety, the workshop must be equipped with a system of sensors for the concentration of harmful vapors and gases.

Fig. 4.6. Ventilation for the removal of harmful and flammable gases and vapors.

Some companies producing polymer composites follow an ecological approach. During resin polymerization, flammable gases such as acetone are released, which are captured and stored in cylinders with the help of special equipment, and then used as fuel for personal needs.

Dust protection

Atmospheric air contains approximately 75.5% nitrogen, 23.2% oxygen, 1.28% argon and other substances. It is the amount of impurities in the air that determines the quality of the air. The main harmfulness, which is always included in the composition of the air, in one or another amount, is dust. Suspended particles that are in the air in liquid or solid form are called dust. Exceeding the maximum allowable amount of dust contained in the working area of the room can lead to deterioration of human well-being, and with prolonged exposure, the development of chronic diseases and deterioration of health can be observed. Therefore, it is necessary to monitor the air quality and prevent its pollution above a certain level. It follows that in order to ensure the necessary parameters of the microclimate inside any type of room, as well as to meet technological and sanitary requirements, it is necessary to maintain clean air. For this, it is necessary to organize air purification. It is divided into two main types:

1. Cleaning the air supplied to the room by the ventilation system. At the same time, the supply air should be cleaned already in the case when its dust content exceeds 30% of the dust limit in the working area of the room.

2. Cleaning of exhaust air removed from the room. At the same time, to ensure the cleanliness of the air in the working area of the room, air intake should be organized in the places of its greatest pollution (Fig. 4.7).

Fig. 4.7. Dust collection directly at the cutting point.

In some types of production, dusty air may contain dust, which is a product of production. The capture of this type of dust carries not only an ecological, but also an economic burden.

3. Also, for better cleaning of the air from dust, especially if there are toxic particles, it is necessary to use internal air cleaning with the help of special equipment (Fig. 4.8).

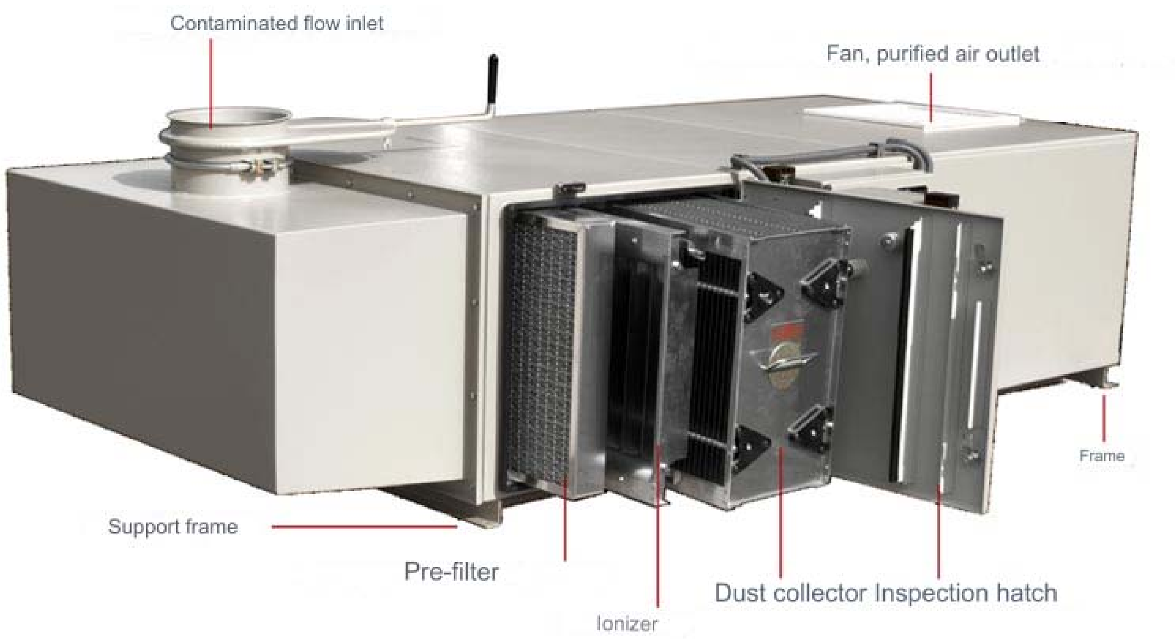

Fig. 4.8. Device for internal air filtration of a robotic room.

Table 4.1

Maximum permissible concentrations and hazard classes of volatile substances in the air of the robotic zone.

Name of substance	Concentration mg/m^3	Hazard Class
Cyclohexanone oxide	1	3
Fiberglass	2	3
Glass dust	2	3
Carbon composite materials	3	3
Fiberglass dust	5	
Glass composite based on polyester resin	5	3
Aramid fiber	5	3
Dust carbon	6	4
Styrene	30	3
Acetone	200	4

In order to reduce the emission of harmful dust into the surrounding air during the mechanical processing of polymer composites, it is necessary to apply hydraulic irrigation of the working edge with a special liquid during cutting and milling, and during grinding and polishing, use special pastes (Fig. 4.9).

Fig. 4.9. The use of special liquids and pastes in mechanical processing of polymer composites.

Protection against electric shock

The issue of reducing the electrification of polymer materials, including fibrous polymer composites, is very important. Different methods are used to reduce the electrification of polymer material:

selection of the least electrified polymer matrix, taking into account other operational requirements for it;

introduction of electrically conductive dispersed fillers into the polymer matrix, for example, carbon black, conductive carbon or metal fibers;

applying electrically conductive coatings or an electrically conductive surface layer to the surface of polymer products;

using antistatic surface treatments of the polymer product (corona discharge treatment, flame or other oxidation treatment) to change the electrification characteristics and/or increase the surface conductivity;

by increasing the electrical conductivity of the environment and other ways.

To protect against electric shock from electrical installations and electrical tools, consider general measures:

Blocking - electrical and mechanical blocking devices are used in electrical installations where the danger of contact with current-carrying parts is high.

Application of insulation - insulation of conductive parts of electrical installations, and in special cases double or reinforced, prevents the appearance of current on metal non-conductive parts of electrical equipment, flow to the ground, and also provides protection of a person from the impact of electric current during an accidental. its contact with current-carrying parts. The following types of insulation are distinguished. Working insulation – electrical insulation of current-conducting parts electrical installation, which ensures its normal operation and protection against electric shock. Auxiliary insulation - insulation provided as auxiliary to the working insulation to protect against electric shock in the event of damage to the working insulation. Double insulation - insulation consisting of working and auxiliary insulation. Reinforced Insulation - Improved working insulation that provides the same degree of protection against electric shock as double insulation.

Protective grounding - an auxiliary electrical connection with the ground or its equivalent of non-conductive metal parts that may be under voltage is called protective grounding. The purpose of protective grounding is to reduce the contact voltage between the body of the electrical installation and the ground to 42 V, and less, which occurs as a result of damage or breakdown of the insulation of current-carrying parts. Protective grounding should be separated from grounding to protect against static and atmospheric electricity discharges. The auxiliary connection to the earth of the neutral points of the windings of generators, power and measuring transformers, arc extinguishing devices and other circuits to ensure the normal operation of electrical installations is called operational grounding. Grounding for protection against static and atmospheric electricity discharges is carried out to discharge these charges into the ground.

4.3. Fire Security

Unlike metals, polymer composite materials are very flammable, their synthetic resins burn especially well (fig. 4.10). The burning of polymer materials during a fire is accompanied by abundant smoke.

Fig. 4.10. Excellent combustion of polymer composite (fiberglass reinforcing element, matrix resin Larit L-285).

The formation of smoke in the process of decomposition and burning of materials is associated with chemical processes of destruction and oxidation occurring under the influence of temperature, as well as with physical processes. This fire hazard occurs at all stages of production: manufacturing of components, production of finished products, operation, repair and disposal.

A significant factor that restrains the introduction of various polymer materials is their fire hazard, due to flammability and accompanying processes. The fire hazard of materials and products made from them is determined in technology by the following characteristics:

1) flammability, that is, the ability of the material to ignite, support and spread the burning process;

2) smoke formation during combustion and flame action;

3) toxicity of combustion products and pyrolysis (decomposition of substances under the influence of high temperatures);

4) fire resistance of the structure, that is, the ability to preserve the physicomechanical (strength, stiffness) and functional properties of the product under the influence of elevated temperatures.

In turn, flammability is a comprehensive characteristic of a material's ability to resist the influence of factors that stop burning. It includes the following values (fire hazard indicators):

1) flash point or self-ignition;

2) speed of burning and spread of flame on the surface;

3) parameters characterizing the conditions under which a self-sustaining combustion process is possible, for example, the composition of the atmosphere (oxygen index) or temperature (temperature index).

It should be noted that the above indicators of fire hazard and flammability are often contradictory and the improvement of one of the properties may be accompanied by the deterioration of others. In addition, the introduction of additives that reduce the fire hazard of polymeric materials, as a rule, leads to the deterioration of physical and mechanical and other operational properties, as well as to an increase in the cost of the material.

Synthetic polymers do not behave when heated similarly to metals, natural stone or a typical representative of a natural polymer such as wood. When the temperature rises (in case of fire), before the stage of decomposition, synthetic polymers go through the stage of a highly elastic state. The material softens and loses strength under all types of static load. In addition, at this stage, intensive release of volatile products begins, which intensifies the burning of the material.

Fire Prevention & Fire Protection

The fire protection system is a set of organizational measures and technical means aimed at preventing the effects of dangerous fire factors on people and limiting material damage from it. Fire protection at enterprises is ensured by a number of measures:

- to prevent fire, the production premises must be equipped with a fire alarm system;
- use, if possible, non-flammable and non-flammable substances and materials instead of fire-hazardous ones;
- limiting the number of combustible substances and their rational placement on the territory of the enterprise;
- isolation of the combustible medium;
- using fire extinguishing means that limit the size of the fire and ensure its extinguishing. For this purpose, it is necessary, first of all, to determine: permissible and unacceptable types of fire extinguishing means;
- using constructions of objects with regulated limits of fire resistance and flammability;
- evacuation of people. It should be completed before the appearance of the maximum permissible levels of dangerous fire factors established by sanitary norms and standards;
- using means of collective and individual protection of people. They ensure the safety of people during the entire period of action of dangerous and harmful fire factors. Collective and individual protection is carried out in cases where the

evacuation of people is difficult or impractical;

- anti-smoke protection, which excludes the possibility of fumigation of storage facilities for collective protection of people and their evacuation routes during the entire evacuation period.

The greatest risk of a fire occurring at the stage when there is a high probability of spontaneous combustion is the preparation and polymerization of synthetic resin, so fire extinguishers and a container with sand should be nearby (Fig. 4.11).

Fig. 4.11. Fire shield in the production room near the fire hazard of the workingearth.

Conclusion to the Part 4

Therefore, in the production of products from polymer composite materials, it is necessary to comply with general and special requirements at all stages of production to ensure a safe and comfortable working area for employees, ignoring the requirements for labor protection can cause severe damage to employees and the environment.

CONCLUSIONS

In conclusion, this qualification papaer has covered main aspects of aircraft control systems, materials selection, and the development of composite materials for control rods. The initial section underscored the significance of optimal material choices for control rods, highlighting their impact on reliability and weight efficiency in aircraft performance. The subsequent experimental phase showcased a noteworthy 18% improvement in compressive load resistance for a newly formulated three-component composite material, emphasizing the successful incorporation of reinforcing particles without compromising tensile load resistance. These promising results open avenues for further exploration and application of the developed composite material in aircraft control systems.

Furthermore, the exploration of polymer composite material recycling methods revealed the importance of tailored approaches based on filler types. Recommendations include pyrolysis for fiberglass, thermocatalysis, solvolysis, and pyrolysis for carbon fiber reinforced plastics, and low- to medium-temperature pyrolysis, possibly thermocatalysis, for organoplastics. Looking ahead, the creation of polymer binders for PCM matrices should consider technologies enabling their thermocatalytic utilization, aligning with sustainability goals.Ultimately, this work emphasizes the critical need for adherence to general and specific requirements in the production of polymer composite materials to ensure a safe working environment. Neglecting labor protection requirements can lead to severe consequences for both employees and the environment, underscoring the importance of responsible production practices at all stages.

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Appendix 1. The test data.

Compression Tests

Table 1

Filler-free sample

Time(secs)	Load(kN)	Extn(mm)	Set Point(mm)
0.4	0.436	1.0702	30.584
10	2.369	1.0700	29.818
15	3.384	1.0703	29.402
19	4.406	1.0702	28.986
30	5.689	1.0701	28.153
34	6.070	1.0701	27.748
40	7.372	1.0700	27.327
50	8.515	1.0701	26.495
60	9.463	1.0700	25.668
70	8.835	1.0701	24.831
80	9.397	1.0700	24.004
90	7.910	1.0700	23.172
100	8.277	1.0700	22.345
110	9.130	1.0700	21.519
127	10.672	1.0701	20.030
10	10.492	1.0700	19.274
90	9.824	1.0702	12.634

110	11.560	1.0701	10.976

Table 2

Sample with 10% filler

Time(secs)	Load(kN)	Extn(mm)	Set Point(mm)
0.4	-0.654	1.0700	-19.920
2	-1.110	1.0702	-20.008
4	-2.391	1.0700	-20.172
6	-3.955	1.0700	-20.336
8	-5.673	1.0700	-20.506
10	-7.436	1.0700	-20.670
12	-9.055	1.0699	-20.835
14	-10.520	1.0700	-20.999
16	-9.359	1.0698	-21.168
20	-8.117	1.0698	-21.502
30	-8.905	1.0700	-22.329
50	-9.970	1.0699	-23.988
70	-11.468	1.0698	-25.652
80	-6.281	1.0699	-26.478

Table 3

Sample with 15% filler content

Time(secs)	Load(kN)	Extn(mm)	Set Point(mm)
0.9	-0.513	1.0700	2.217
2	-0.837	1.0700	2.129
4	-1.525	1.0698	1.965
6	-2.181	1.0698	1.801
10	-4.028	1.0698	1.467
15	-6.707	1.0699	1.051
20	-9.514	1.0699	0.635
25	-12.831	1.0701	0.219
30	-13.625	1.0700	-0.192
35	-13.678	1.0699	-0.608
40	-13.814	1.0700	-1.024
45	-12.944	1.0697	-1.434
50	-14.541	1.0698	-1.850
55	-15.079	1.0699	-2.266
60	-13.673	1.0699	-2.682
65	-13.006	1.0701	-3.098
70	-13.982	1.0699	-3.525
75	-14.253	1.0699	-3.936
80	-13.973	1.0698	-4.341

Table 4

Sample containing 20% filler

Time(secs)	Load(kN)	Extn(mm)	Set Point(mm)
0.2	-0.645	1.0699	5.283
2	-0.934	1.0698	5.228
3	-1.328	1.0698	5.146
6	-2.582	1.0699	4.899
8	-3.237	1.0699	4.730
10	-2.666	1.0699	4.565
15	-2.692	1.0700	4.149
20	-4.387	1.0696	3.733
30	-9.566	1.0698	2.907
35	-10.912	1.0699	2.491
40	-8.225	1.0700	2.075
45	-7.495	1.0699	1.659
50	-7.432	1.0698	1.243
55	-7.118	1.0700	0.832
60	-7.020	1.0698	0.416

Tensile test

Table 5

Sample without filler

Time(secs)	Stroke(mm)	Load(kN)	Extn(mm)
0.3	-45.446	1.025	-0.2420
2	-45.348	1.359	-0.2351
3	-45.271	1.626	-0.2287
5	-45.101	2.069	-0.2178
10	-44.691	3.148	-0.1885
15	-44.275	4.144	-0.1578
20	-43.853	5.085	-0.1276
25	-43.432	5.957	-0.0982
26	-43.306	6.218	-0.0891

Table 6

Sample containing 10% filler.

Time(secs)	Stroke(mm)	Load(kN)	Extn(mm)
0.1	-44.620	0.229	-0.3212
1	-44.538	0.526	-0.3144
2	-44.461	0.786	-0.3086
4	-44.302	1.317	-0.2953
6	-44.132	1.771	-0.2816
8	-43.952	2.168	-0.2679
10	-43.799	2.501	-0.2542
14	-43.459	3.155	-0.2283
18	-43.142	3.768	-0.2032
20	-42.890	4.210	-0.1824

21	-42.868	4.169	-0.1854

Table 7

Sample containing 15% filler

Time(secs)	Stroke(mm)	Load(kN)	Extn(mm)
9	-41,762	0,179	-0,0454
15	-41,554	0,764	-0,0323
20	-41,401	1,238	-0,0206
30	-41,067	2,025	-0,002
40	-40,749	2,653	0,0217
50	-40,416	3,32	0,0478
60	-40,071	3,944	0,0727
70	-39,753	4,519	0,0958
80	-39,425	5,074	0,1173
85	-39,25	5,347	0,1272

Table 8

Sample with 20% filler content

Time(secs)	Stroke(mm)	Load(kN)	Extn(mm)
0.1	-33,431	0,062	-0,3831
5	-33,283	0,551	-0,3738
10	-33,108	1,035	-0,3635

20	-32,796	1,822	-0,339
30	-32,467	2,371	-0,309
40	-32,128	2,91	-0,278
55	-31,646	3,648	-0,234
65	-31,312	4,122	-0,2052
75	-30,967	4,594	-0,1761
85	-30,644	5,05	-0,148
89	-30,485	5,255	-0,1348

The second series of compression tests.

Table 9

Sample without filler

Time(secs)	Load(kN)	Extn(mm)	Set Point(mm)
0.1	-0,443	1,0694	18,984
1	-0,667	1,0693	18,935
2	-1,025	1,0692	18,853
5	-2,221	1,0694	18,601
10	-4,922	1,0693	18,185
15	-8,495	1,0693	17,775
17	-10,086	1,0693	17,594
20	-11,622	1,0696	17,358
21	-12,197	1,0696	17,271

24	-12,186	1,0693	17,025
26	-13,048	1,0693	16,86
30	-14,325	1,0693	16,532

Table 10

Sample containing 15% filler

Time(secs)	Load(kN)	Extn(mm)	Set Point(mm)
1	-0,461	1,0694	19,384
3	-1,007	1,0693	19,225
5	-1,893	1,0694	19,055
7,5	-3,499	1,0694	18,853
10	-5,371	1,0693	18,639
12,5	-7,59	1,0693	18,437
15	-9,897	1,0694	18,229
17,5	-12,495	1,069	18,015
20	-14,746	1,0691	17,813
22,5	-14,396	1,0693	17,605
25	-15,449	1,0691	17,402
27,5	-16,731	1,069	17,189
30	-17,57	1,0691	16,986
32,5	-15,927	1,0693	16,773
35	-16,172	1,0693	16,565

Second series of tensile tests

Table 11

Filler-free plate

Time(secs)	Stroke(mm)	Load(kN)	Extn(mm)
1	-36,491	0,071	0,0142
4	-36,419	0,282	0,0247
15	-36,02	1,064	0,05
20	-35,877	1,302	0,062
30	-35,549	1,895	0,0898
40	-35,232	2,465	0,1171
50	-34,898	3,025	0,1459
60	-34,569	3,56	0,1738
70	-34,224	4,091	0,2028
80	-33,907	4,596	0,2323
90	-33,573	5,085	0,2614
100	-33,244	5,552	0,2893
105	-33,08	5,761	0,3043

Table 12

Plate with 15% filler content

Time(secs)	Stroke(mm)	Load(kN)	Extn(mm)
1	-40.229	0.048	-0.2978
5	-40.098	0.408	-0.2859
10	-39.939	0.846	-0.2703

30	-39.282	2.152	-0.2036
40	-38.938	2.739	-0.1675
50	-38.615	3.311	-0.1316
60	-38.275	3.836	-0.0975
70	-37.958	4.360	-0.0629
73.4	-37.837	4.519	-0.0521