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

ДОПУСТИТИ ДО ЗАХИСТУ
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___________ Святослав ЮЦКЕВИЧ
«____» ____________ 2023 р.

КВАЛІФІКАЦІЙНА РОБОТА
ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ«МАГІСТР»
ЗІ СПЕЦІАЛЬНОСТІ
«АВІАЦІЙНА ТА РАКЕТНО-КОСМІЧНА ТЕХНІКА»

Тема: «Порівняльний аналіз перспектив застосування різнорідних композитних матеріалів для силових елементів пасажирської кабіни літака»

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Київ 2023

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

PERMISSION TO DEFEND
Head of the department,
PhD, associate professor
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"___" _______________ 2023

QUALIFICATIONPAPER
FOR A MASTER'S DEGREE
ON SPECIALITY
"AVIATION AND AEROSPACE TECHNOLOGIES"

Topic: "Comparative analysis of the different composite materials application aspects for the structural elements of aircraft passenger cabin"

Fulfilled by:	____________	**Kseniia MELESCHKO**
Supervisor: **PhD, associate professor**	_____________	**Volodymyr KRASNOPOLSKII**
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»
Спеціальність 134 «Авіаційна та ракетно-космічна техніка»
Освітньо-професійна програма «Обладнання повітряних суден»

ЗАТВЕРДЖУЮ
Завідувач кафедри, к.т.н, доцент
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«_____» _____________ 2023 р.

ЗАВДАННЯ

на виконання кваліфікаційної роботи студентки

МЕЛЕШКО КСЕНІЇ РУСЛАНІВНИ

1. Тема роботи: «Порівняльний аналіз перспектив застосування різнорідних композитних матеріалів для силових елементів пасажирської кабіни літака», затверджена наказом ректора від 20вересня 2023 року № 1853/ст.

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

3. Вихідні дані до роботи:кількість пасажирів 250 чоловік, компонування пасажирської кабіни, механічні характеристики різних композиційних матеріалів, конструкція балки підлоги пасажирської кабіни.

4. Зміст пояснювальної записки: вступ, оглядова частина, яка містить опис різних композиційних матеріалів, їх властивостей та економічної доцільності, основна частина, яка містить розробку конструкції балки підлоги пасажирської кабіни, розрахункова частина з результатами моделювань застосування різних видів композиційних матеріалів, окремі розділи, присвячені питанням охорони праці та навколишнього середовища.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу:схема компонування пасажирської кабіни літака, проект балки підлоги для кріплення крісел, результати моделювань в SolidWorks.

6. Календарний план-графік:

№	Завдання	Термін виконання	Відмітка про виконання
1	Огляд літератури за проблематикою роботи. Аналіз різних видів композитів.	25.09.2023 – 01.10.2023	
2	Порівняльний аналіз композитівта традиційних авіаційних сплавів.	02.10.2023 – 15.10.2023	
3	Аналіз варіантів компонування пасажирської кабіни літака та навантаження підлоги.	16.10.2023 – 29.10.2023	
4	Моделювання різних варіантів конструкції балки підлоги.	30.10.2023 – 12.11.2023	
5	Написання розділівпо 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.	18.12.2023 – 19.12.2023	
9	Виправлення зауважень. Підготовка супровідних документів та презентації доповіді.	19.12.2023 – 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
Охорона праці	к.т.н, доцент Катерина КАЖАН		
Охорона навколишнього середовища	к.т.н., професор Леся ПАВЛЮХ		

8. Дата видачі завдання: 25вересня 2023 року

Керівник кваліфікаційної роботи ____________ Володимир КРАСНОПОЛЬСКИЙ

Завдання прийняв до виконання ____________ Ксенія МЕЛЕШКО

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

KSENIIA MELESCHKO

1. Topic: "Comparative analysis of the different composite materials application aspects for the structural elements of aircraft passenger cabin", approved by the Rector’s order № 1853/ст from 20September 2023.
2. Period of work: since 25September 2023 till 31 December 2023.
3. Initial data: number of passengers is 250 people, arrangement of the passenger cabin, mechanical characteristics of various composite materials, the construction of the passenger cabin floor beam.
4. Content: introduction, overview section containing a description of various composite materials, their properties, and economic feasibility, the main section containing the development of the construction of the passenger cabin floor beam, a calculation section with the results of modeling the use of various types of composite materials, separate sections dedicated to occupational safety and environmental protection.
5. Required material: schemes of the arrangement of the aircraft passenger cabin, the design of the floor beam for seat attachment, and the results of modeling in SolidWorks.

6. Thesis schedule:

#	Task	Time limits	Done
1	Review of the literature on the issues of work. Analysis various types of composites.	25.09.2023 – 01.10.2023	
2	Comparative analysis of composites and traditional aviation alloys.	02.10.2023 – 15.10.2023	
3	Analysis of layout options of the aircraft passenger cabin and floor loading.	16.10.2023 – 29.10.2023	
4	Modeling different variations of the floor beam construction.	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 design 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.	18.12.2023 – 19.12.2023	
9	Making corrections, preparation of documentation and presentation.	20.12.2023 – 24.12.2023	
10	Defense of master degree thesis.	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: 25September 2023

Supervisor: ____________ Volodymyr KRASNOPOLSKII

Student: ____________ Kseniia MELESCHKO

РЕФЕРАТ

Кваліфікаційна робота «Порівняльний аналіз перспектив застосування різнорідних композитних матеріалів для силових елементів пасажирської кабіни літака» містить:

111 сторінки, 42 рисунки, 14 таблиць, 43 літературних посилань

В роботі були розглянуті різні види композитних матеріалів, спроектовано балку силової конструкції літака та проаналізовано можливість їх застосування в даній конструкції. Для визначення найбільш придатного матеріалу з точки зору міцності конструкції, а також економічної доцільності його застосування було проведено порівняльний та економічний аналіз і на їх основі запропоновані нові конструктивні рішення.

В дослідницькій частині роботи для підтвердження характеристик міцності та жорсткості обраних матеріалів було використано методи аналітичного розрахунку, комп’ютерного проектування за допомогою CAD/CAM/CAE систем, чисельного моделювання та розрахунку на міцність, а також аналіз напружено-деформованого стану спроектованої конструкції балки та підтверджено її відповідність існуючим нормам.

Результати цієї роботи можуть бути використані в авіаційній галузі та в навчальному процесі авіаційних спеціальностей.

Силова конструкція літака, балка підлоги, композиційні матеріали, розрахунок на міцність, аналіз напружено деформованого стану

ABSTRACT

Qualification paper "Comparative analysis of the different composite materials application aspects for the structural elements of aircraft passenger cabin" contains:

111 pages, 42 figures, 14 tables, 43 references

In this work, various types of composite materials were considered, a beam of the aircraft power structure was designed, and the possibility of their use in this structure was analyzed. To determine the most suitable material in terms of structural strength and economic feasibility of its use, a comparative and economic analysis was performed and new design solutions were proposed on their basis.

In the research part of the work, methods of analytical calculation, computer-aided design using CAD/CAM/CAE systems, numerical modeling and strength calculation, as well as analysis of the stress-strain state of the designed beam structure were used to confirm the strength and stiffness characteristics of the selected materials and confirm its compliance with existing standards.

The results of this work can be used in the aviation industry and in the educational process of aviation specialties.

Aircraft power structure, floor beam, composite materials, strength calculation, stress-strain analysis

CONTENT

INTRODUCTION

In the ever-evolving landscape of aviation, the quest for lighter, stronger, and more efficient aircraft components has been a driving force behind innovation. Among the critical components, the aircraft floor beam plays a pivotal role in ensuring structural integrity, weight reduction, and overall safety. In recent years, the aviation industry has witnessed a remarkable shift towards the adoption of advanced materials, particularly composites, to meet these demands.

Aircraft manufacturers and operators are continually driven to reduce weight, increase fuel efficiency, and improve the overall environmental footprint of aviation. Composite materials, known for their exceptional strength-to-weight ratio, corrosion resistance, and design flexibility, have emerged as a prime contender for replacing conventional materials such as aluminum and steel. The shift towards composites in structural components like floor beams is driven by the need to meet stringent safety standards while concurrently achieving substantial weight reduction and cost savings.

The first part describes into the application of composite materials in the aviation industry. Specifically, we will explore the concept of composites, the various types and characteristics of these materials, and the advantages and disadvantages they offer in comparison to conventional aviation materials. Our aim is to identify which composite material, in theory, is best suited to achieving the objectives of this research.

Second part considers the structural aspects of passenger aircraft, specifically focusing on to the analysis of the aircraft's floor beams. Research will not only encompass an examination of the conventional design and construction of these beams but also involve the innovative process of designing a new beam structure. Will be demonstrated advantages of the newly proposed beam over the traditional design, and conduct an in-depth comparative analysis of the two beam configurations.

In the third section of this thesis, paid attention to the practical aspect of research. Here, the conceptual design of the new floor beam was developed and created solid 3D model of it. This process involves the development of a detailed model for the beam, taking into account all the design parameters and innovative features that have been outlined.

To conduct experimental research within this domain, an engineer necessitates a suitably equipped laboratory or workspace that adheres to state sanitary regulations. These regulations dictate numerous parameters, including air ionization, specifications for high-voltage equipment, and ergonomic criteria for organizing workspaces. The exploration of detrimental factors affecting individuals during the execution of experimental research will be expounded upon, with further details provided in the section on labor protection.

The concluding segment, dedicated to environmental protection, delves into the challenges posed by the impact of hazardous substances on the environment and living organisms during the production of composite materials. Additionally, it explores potential solutions to mitigate these issues.

PART 1. APPLICATION OF COMPOSITE MATERIALS IN THE AVIATION INDUSTRY

1.1. Nature of composite materials

Composite Material (CM) – an artificially created heterogeneous solid material consisting of two or more components – the matrix (plastic base) and filler, with a clear boundary between them. The matrix secures the filler and gives the product its shape, while the filler provides high strength, rigidity, and so on. It is expected that the components of the composite are well compatible and do not dissolve in each other, meaning that the structure of composite materials is not homogeneous [4] (fig. 1.1).

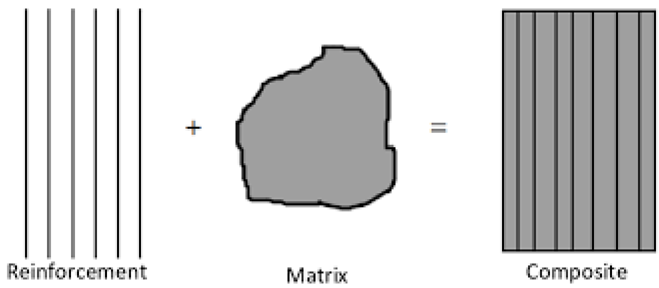

Fig. 1.1. Formation of composite material.

One of the characteristics of composite materials is that their components not only retain their properties but also acquire new ones that they did not have individually. For example, in reinforced concrete, perhaps one of the most well-known composites today, steel reinforcements act as the matrix, and concrete serves as the filler. Structures made of reinforced concrete, including bridge spans, beams, columns, can withstand heavy loads that would cause ordinary concrete to crack. When reinforced concrete undergoes bending, the internal steel framework absorbs the forces and prevents the formation of significant cracks.

Another important point is that concrete is also a composite material: the matrix is gravel and sand, and the filler is cement. Therefore, reinforced concrete is a three-component (or three-phase) composite.

In composite materials, the matrix can be made from metal, ceramics, cement, or polymers. If a composite has several matrices, it is called a polymatrix composite. The filler can be various artificial and natural elements of different shapes: volumetric fabrics, frameworks, sheets, plates, fibers, granules, powder, nanoparticles, and more.

By altering the composition of the matrix and filler, their ratio, the orientation of the filler, different materials with desired properties can be obtained. The filler fibers can be unidirectional or bidirectional (like interweaving in fabric) or arranged chaotically. Additionally, they can be continuous or discontinuous. High-strength composites mostly have an ordered structure. The properties of composite materials are also influenced by the methods of their production, such as temperature, pressure, and more [6].

Initially, composite materials were developed upon the request of the military, primarily for use in aircraft. Today, they are used in various industries. Composites are used in the manufacturing of automobiles and motorcycles, railway objects, airplanes and helicopters, rockets, ships, yachts, submarines, containers for storing various liquids, pipelines, sports equipment (roller skates, skis, bicycles, tennis rackets), medical and household equipment (phone cases, laptops), musical instruments, and more. In other words, if composite materials were to suddenly disappear today, it would lead to a catastrophe for humanity.

Usually, the cost of composite materials is very high, which is related to the complexity of the manufacturing processes, the high cost of the components used, and more. However, when considering the expenses not only for producing composites but also for creating the entire product, cost savings become evident. This cost reduction occurs by reducing the number of technological connectors, parts, and assembly operations in the production of complex structures. The labor intensity of producing products from composite materials can be reduced by 1.5-2 times compared to their metal counterparts.

Fiberglass, or glass-reinforced plastic (GRP), is a polymer composite material in which the filler consists of glass fibers formed from molten inorganic glass. Fiberglass is lightweight, very strong, has low thermal conductivity, high electrical insulating properties, increased sealing and water resistance, and is transparent to radio waves. It allows for the creation of components with complex geometric shapes [7].

Fiberglass is used to manufacture the hulls of small boats, interior linings for public transport, pools, plastic windows, automobile bodies, and water attractions. In the chemical industry, fiberglass is used to make pipelines and containers for transporting and storing acids, salts, and other chemical solutions. Fiberglass is widely used in households, from tables, chairs, panels, and components in refrigerators, washing machines, and microwaves to combs and ballpoint pens.

Carbon fiber-reinforced plastic (CFRP) is used to make individual components for automobiles and even complete car bodies. Formula 1 race cars can reach speeds of over 350 km/h thanks not only to powerful engines but also their low weight. The monocoque (unibody) of a Formula 1 car is made of carbon fiber-reinforced plastic, which is why the total weight of the car does not exceed 600 kg [11].

In carbon fiber-reinforced plastic (CFRP), carbon fibers serve as the filler. These fibers are extremely thin, with a diameter of 0.005-0.010 mm. They are easily bendable but difficult to break. These threads are used to create fabrics of different weaves. These fabrics are layered at various angles and are bound together with a polymer matrix.

In the aerospace and aviation industries, carbon fiber-reinforced plastic has replaced aluminum and titanium alloys. It can withstand high temperatures during launch, extreme pressures from load factor, low temperatures, and the deep vacuum of outer space. Carbon fiber-reinforced plastic is used to manufacture the nose cones of rockets, engine nozzles, and other components of space vehicles that experience extreme aerodynamic stresses [14].

In summary, composite materials are artificially engineered materials that combine different components, such as a matrix and filler, to create a material with unique properties. These materials are known for their strength, durability, and versatility, and they have a wide range of applications across various industries, from aerospace and automotive to construction and consumer products. The use of composites has revolutionized manufacturing and design, offering innovative solutions to complex engineering challenges.

1.1.1. Structure and properties of composite materials

Composite materials can take on various forms, and their fibers can be densely wound to enhance strength if needed. A key feature of composites is their ability to be layered; fibers in each layer can be oriented in different directions, allowing engineers to design structures with unique properties. For instance, a design may allow a structure to bend in one direction while resisting bending in another [4].

Composites exhibit remarkable tensile strength and compression resistance, rendering them suitable for manufacturing aircraft components. The tensile strength stems from the fibrous nature of composites. When subjected to tensile forces, fibers within the composite align with the applied force, resulting in enhanced tensile strength. Effective compression resistance is due to the adhesive properties and stiffness of the system. The role of the resin is to maintain fibers in an upright, columnar arrangement, preventing bending.

In the aerospace field, composites have gained significant popularity due to their ability to provide structural integrity comparable to metallic alloys but at a lower weight, coupled with enhanced corrosion resistance. This leads to improved fuel efficiency and operational characteristics of aircraft.

Aircraft design using composite materials extends to various components, including the fuselage, wings, tail assembly, nacelles, and decorative elements. Carbon-fiber-reinforced polymers are commonly used for lightweight applications, while glass-fiber-reinforced polymers find use in heavier components and nose cones.

The properties of composite materials depend on the composition of components, their combination, quantitative ratios, and the strength of the bond between them. Reinforcing materials can take the form of fibers, cords, threads, tapes, and multilayer fabrics. The content of the reinforcement in oriented materials is 60-80% by volume, while in non-oriented materials (with discrete fibers and filamentous crystals) it is 20-30% by volume. The higher the strength and elastic modulus of the fibers, the higher the strength and stiffness of the composite material.

The properties of the matrix determine the strength of the composition under shear and compression and its resistance to fatigue failure. In layered materials, fibers, threads, tapes, impregnated with a binding agent, are arranged parallel to each other in the plane of arrangement. Flat layers are assembled into plates. The properties become anisotropic. For the material to function effectively in a product, the direction of applied loads must be considered. Materials with both isotropic and anisotropic properties can be created. Fibers can be laid at different angles, varying the properties of the composite materials [6]. The arrangement order of layers in the package thickness affects the bending and torsional stiffness of the material. Reinforcement with three, four, or more filaments is employed. The structure with three mutually perpendicular filaments is the most widely used. Reinforcements can be positioned in axial, radial, and circumferential directions. Three-dimensional materials can come in any thickness, in the form of blocks, cylinders. Volume fabrics enhance tear strength and shear resistance compared to laminated ones. A system of four filaments is built by distributing the reinforcement along the diagonals of a cube. The structure with four filaments is balanced and exhibits increased stiffness during shear in the principal planes. However, creating four-directional materials is more complex than creating three-directional ones.

Composite materials reinforced with high-strength and high-modulus continuous fibers have found the greatest application in construction and engineering. These include polymer composite materials based on thermosetting (epoxy, polyether, phenol-formaldehyde, polyamide, etc.) and thermoplastic binders, reinforced with glass (fiberglass), carbon (carbon fiber), organic (organoplastics), boron (boroplastics), and other fibers; metallic composite materials based on Al, Mg, Cu, Ti, Ni, Co, steel alloys, reinforced with boron, carbon, or silicon carbide fibers, as well as steel, molybdenum, or tungsten wires; carbon-based composite materials reinforced with carbon fibers (carbon-carbon materials); ceramic-based composite materials reinforced with carbon, silicon carbide, and other refractory fibers and SiC. Compositions containing 50-70% of carbon, glass, aramid, or boron fibers have been developed, exhibiting specific strengths and elastic moduli 2-5 times higher than those of conventional structural materials and alloys. Furthermore, fiber-reinforced composite materials surpass metals and alloys in fatigue strength, heat resistance, vibration resistance, sound absorption, impact toughness, and other properties. For example, reinforcing Al alloys with boron fibers significantly improves their mechanical characteristics and allows for an increase in the alloy's operating temperature from 250-300°C to 450-500°C. Wire (W and Mo) and fiber reinforcement of refractory compounds are used to create heat-resistant composite materials based on Ni, Cr, Co, Ti, and their alloys. For instance, Ni-based heat-resistant alloys reinforced with fibers can operate at temperatures of 1300-1350°C. In the production of metallic fiber-reinforced composite materials, the application of the metallic matrix to the filler is primarily achieved through the melting of the matrix material, electrochemical deposition, or spraying. Shaping the products is mainly done by impregnating the framework of reinforcing fibers with molten metal under pressures of up to 10 MPa or by joining foil (matrix material) to the reinforcing fibers using rolling, pressing, or extrusion at temperatures above the melting point of the matrix material [7].

One of the common technological methods for manufacturing polymer and metallic fiber-reinforced composite materials is the growth of filler crystals within the matrix directly during the component manufacturing process. This method is used, for example, in the creation of eutectic heat-resistant alloys based on Ni and Co. The alloying of melts with carbide and intermetallic compounds, which form fibrous or plate-like crystals upon controlled cooling, leads to alloy strengthening and allows for an increase in their operating temperature by 60-80°C. Carbon-based composite materials combine low density with high thermal conductivity, chemical resistance, dimensional stability during rapid temperature changes, as well as an increase in strength and elastic modulus at temperatures up to 2000°C in an inert environment. High-strength composite materials based on ceramics are achieved through reinforcement with fibrous fillers, as well as metallic and ceramic dispersible particles. Reinforcing with continuous SiC fibers enables the production of composite materials characterized by increased viscosity, bending strength, and high oxidation resistance at elevated temperatures. However, reinforcing ceramics with fibers doesn't always lead to significant improvement in their strength properties due to the lack of elastic behavior at high modulus values. Reinforcement with dispersed metallic particles allows for the creation of ceramic-metallic materials (cermets) with increased strength, thermal conductivity, and resistance to thermal shock. In the production of ceramic composite materials, methods like hot pressing, pressing followed by sintering, and slip casting are typically employed. Reinforcement with dispersed metallic particles significantly increases strength by creating barriers to dislocation movement. This kind of reinforcement is primarily used in the creation of heat-resistant chromium-nickel alloys. Materials are produced by introducing fine-dispersed particles into molten metal, followed by conventional processing of ingots into finished products. For instance, introducing ThO_2 or

ZrO_2 into an alloy allows for the creation of dispersion-strengthened heat-resistant alloys that can operate under load at 1100-1200°C (compared to the typical operational limit of 1000-1050°C for regular heat-resistant alloys under the same conditions) [11].

A promising approach to creating high-strength composite materials is the reinforcement of materials with filament-like crystals ("whiskers"), which, due to their small diameter, are virtually defect-free compared to larger crystals and exhibit high strength. Crystals of Al_2O_3, BeO, SiC, B_4C, Si_3N_4, AlN, and graphite with diameters of 1-30 µm and lengths of 0.3-15 mm are of particular practical interest. These fillers are used in the form of oriented yarn or isotropic layered materials similar to paper, cardboard, and felt. Introducing filament-like crystals into a composition can provide it with unique combinations of electrical and magnetic properties. The selection and application of composite materials are largely determined by loading conditions, operating temperatures of components or structures, and technological capabilities. Polymer composite materials are the most accessible and well-established. A wide range of matrix materials including thermosetting and thermoplastic polymers offers a broad choice of composite materials for operation in the temperature range from negative values up to 100-200°C for organoplastics, up to 300-400°C for glass, carbon, and boron-based plastics. Polymer composite materials with polyether and epoxy matrices work up to 120-200°C, with phenol-formaldehyde matrices up to 200-300°C, and with polyimide and silicon-organic matrices up to 250-400°C. Metallic composite materials based on Al, Mg, and their alloys, reinforced with fibers from B, C, SiC, can be used up to 400-500°C; composite materials based on Ni and Co alloys can operate at temperatures up to 1100-1200°C, those based on refractory metals and compounds can withstand temperatures up to 1500-1700°C, and those based on carbon and ceramics can endure temperatures up to 1700-2000°C. The use of composites in construction, thermal protection, friction reduction, radio and electrical engineering, and other fields allows for a reduction in the weight of structures, increased machine and equipment lifespans and power, and the creation of fundamentally new components, parts, and structures. All types of composite materials are used in chemical, textile, mining, metallurgical industries, mechanical engineering, transportation, sports equipment manufacturing, and more [14].

1.2. Classification of composite materials

Composites are multi-component materials composed of a polymer, metal, carbon, ceramic, or other base (matrix) reinforced with fillers such as fibers, filament-like crystals, fine-dispersed particles, and others. By selecting the composition and properties of the filler and matrix (binder), as well as their proportions and orientation, materials with the desired combination of operational and technological properties can be achieved. The use of multiple matrices (poly-matrix composite materials) or fillers of various nature (hybrid composite materials) within a single material significantly expands the possibilities for regulating the properties of composite materials. The reinforcing fillers bear the majority of the load in composite materials [5].

Based on the structure of the filler, composite materials are divided into fibrous (reinforced with fibers and filament-like crystals), laminar (reinforced with films, plates, laminar fillers), and dispersion-reinforced (with fine-dispersed particles) categories. The matrix in composite materials ensures material integrity, stress transfer, and distribution within the filler, while also determining heat, moisture, fire, and chemical resistance.

By the nature of the matrix material, composites can be categorized into polymer-based, metallic, carbon-based, ceramic, and other types of composites.

Composite materials with a metallic matrix consist of a metallic material (often Al, Mg, Ni, and their alloys), reinforced with high-strength fibers (fibrous materials) or fine-dispersed refractory particles that are insoluble in the main metal (dispersion-strengthened materials). The metallic matrix binds the fibers (dispersed particles) into a single entity.

Composite materials with a non-metallic matrix have found widespread application. Non-metallic matrices include polymer, carbon, and ceramic materials. Among polymer matrices, epoxy, phenol-formaldehyde, and polyamide matrices are the most commonly used. Carbon matrices, either coked or pyrolytic carbon, are obtained from synthetic polymers subjected to pyrolysis. The matrix binds the composition, giving it shape. The reinforcing agents are fibers, including glass, carbon, boron, organic, based on filament-like crystals (oxides, carbides, borides, nitrides, and others), as well as high-strength metallic wires, contributing to high strength and stiffness [6].

Composite materials with fibrous fillers (reinforcements) can be categorized by their reinforcement mechanism into discrete, where the ratio of fiber length to diameter is relatively small, and continuous fiber. Discrete fibers are randomly distributed within the matrix. The diameter of fibers ranges from fractions to hundreds of micrometers. The higher the ratio of fiber length to diameter, the greater the degree of reinforcement.

Often, composite materials exhibit a layered structure, with each layer reinforced by a large number of parallel continuous fibers. Each layer can also be reinforced by continuous fibers woven into a fabric, which preserves the initial shape of the final material in terms of width and length. Frequently, fibers are intertwined into three-dimensional structures.

Composite materials differ from conventional alloys with higher values of temporary resistance and endurance limit (by 50 to 10%), elastic modulus, stiffness coefficient, and reduced susceptibility to crack formation. The use of composite materials increases the stiffness of a structure while simultaneously reducing its metal content. The strength of fibrous composite materials is determined by the properties of the fibers; the matrix primarily needs to redistribute stress between the reinforcing elements. Therefore, the strength and elastic modulus of the fibers should be significantly greater than the strength and elastic modulus of the matrix. Stiff reinforcing fibers bear the stress that arises within the composition when loaded, imparting strength and stiffness in the direction of fiber orientation [14].

To strengthen aluminum, magnesium, and their alloys, boron fibers are used, as well as fibers made from refractory compounds (carbides, nitrides, borides, and oxides) with high strength and elastic modulus. For reinforcing titanium and its alloys, molybdenum wire, sapphire fibers, silicon carbide, and titanium boride are employed. Enhanced heat resistance of nickel alloys is achieved by reinforcing them with tungsten or molybdenum wire. Metallic fibers are also used when high thermal conductivity and electrical conductivity are required. Promising reinforcements for high-strength and high-modulus fibrous composite materials include filament-like crystals of aluminum oxide and nitride, silicon carbide, boron carbide, and others. Composite materials with a metallic base exhibit high strength and heat resistance, yet they are not very malleable. However, fibers in composite materials decrease the rate of crack propagation originating within the matrix, and sudden brittle failure is virtually eliminated. Anisotropy in the mechanical properties along and perpendicular to the fibers is a distinctive feature of fibrous composite materials, along with their low sensitivity to stress concentrations. Anisotropy in the properties of fibrous composite materials is taken into account when designing components to optimize properties by aligning resistance fields with stress fields. It's crucial to note that the matrix can transmit stress to the fibers only if there is a strong bond at the interface between the reinforcing fiber and the matrix. To prevent contact between fibers, the matrix should fully encase all fibers, which is achieved with a content of no less than 15-20%. The matrix and fiber should not interact with each other (mutual diffusion should be absent) during manufacturing and operation, as this could lead to a reduction in the strength of the composite material. Continuous refractory fiber reinforcement of aluminum, magnesium, and titanium alloys with boron, silicon carbide, titanium boride, and aluminum oxide significantly enhances heat resistance. A characteristic of composite materials is their low rate of deterioration over time with increasing temperature.

The primary drawback of composite materials with one and two-dimensional reinforcement is their low resistance to interlayer shear and transverse rupture. This deficiency is absent in materials with volumetric reinforcement [15].

In contrast to fibrous composite materials, in dispersion-strengthened composite materials, the matrix is the main load-bearing element, while the dispersed particles impede the movement of dislocations within it.

High strength is achieved with particle sizes of 10-500 nm, with an average distance between them of 100-500 nm and their uniform distribution within the matrix. Strength and heat resistance, depending on the volumetric content of strengthening phases, do not follow the law of additivity. The optimal content of the second phase for different metals varies, but usually does not exceed 5-10% by volume. The use of stable refractory compounds (thoria, hafnia, yttria, complex compounds of oxides and rare-earth metals) as strengthening phases, which do not dissolve in the matrix metal, allows maintaining high material strength up to 0.9-0.95 of the melting point. As a result, such materials are often employed for their high heat resistance. Dispersion-strengthened composite materials can be developed based on most of the metals and alloys commonly used in engineering. Alloys based on aluminum, such as Sintered Aluminum Powder (SAP), are particularly widespread and commonly used in this context.

1.2.1. Organic Matrix Composites

Organic Matrix Composites (OMCs) are a class of advanced materials that combine the properties of organic polymers and reinforcing agents to create structures with enhanced mechanical, thermal, and chemical characteristics. These composites are engineered to capitalize on the unique attributes of both the organic matrix and the reinforcing materials, resulting in materials that are stronger, more durable, and more versatile than either component alone [12].

At the core of OMCs is the organic matrix, which typically consists of a polymer resin. Polymers are long-chain molecules made up of repeating subunits, and they can be tailored to possess a wide range of properties depending on their chemical composition and processing techniques. The matrix provides the bulk of the material's structure and contributes to its overall behavior, including factors such as flexibility, toughness, and resistance to environmental factors.

Reinforcing agents are integrated into the organic matrix to enhance specific material properties. These agents can take the form of fibers, particles, or other structures that are typically composed of materials like carbon, glass, aramid, or natural fibers. Reinforcements are selected based on their desired contribution to the composite's mechanical strength, stiffness, thermal stability, and other performance attributes.

The synergy between the organic matrix and the reinforcing agents creates a material with remarkable capabilities. Organic matrix composites can exhibit exceptional strength-to-weight ratios, making them valuable in industries where lightweight yet robust materials are essential. Their ability to resist corrosion, fatigue, and extreme temperatures further expands their applications in fields such as aerospace, automotive, sporting goods, construction, and more [14].

Manufacturing OMCs involves carefully designing the matrix-reinforcement interface to ensure effective stress transfer between the two components. This optimization can be achieved through various techniques such as layering, weaving, or aligning the reinforcing agents in specific directions to achieve desired material properties.

One of the notable challenges in developing OMCs is achieving uniform dispersion and alignment of the reinforcing agents within the matrix. This is crucial for realizing the full potential of the composite's properties. Advances in material science, nanotechnology, and manufacturing processes have enabled researchers and engineers to address these challenges and create OMCs with increasingly tailored and impressive performance profiles [16].

In summary, Organic Matrix Composites are innovative materials that leverage the strengths of organic polymers and reinforcing agents to achieve improved mechanical, thermal, and chemical characteristics. These composites are driving advancements in a wide range of industries, offering solutions to complex engineering problems where traditional materials fall short.

1.2.2. Metal-Matrix Composites

Metal matrix composites (MMCs) represent engineered combinations of two or more materials, with one of them being a metal. These combinations are deliberately designed to achieve specific properties through the systematic blending of diverse constituents. Traditional monolithic materials face limitations in terms of attainable combinations of strength, stiffness, and density. Engineered MMCs, comprising continuous or discontinuous fibers, whiskers, or particles within a metal matrix, attain exceptional combinations of specific strength and specific modulus [10].

Furthermore, the implementation of systematic design and synthesis procedures permits the creation of distinctive engineering solutions.

- Processing of Metal Matrix Composites:

In the progression of metal matrix composites, three predominant processing methods have been employed:

- High-pressure diffusion bonding;
- Casting;
- Powder metallurgy techniques, which encompass vacuum hot pressing [10].

More specifically, diffusion bonding and casting techniques have been applied to the fabrication of continuous fiber-reinforced metal matrix composites. On the other hand, discontinuously reinforced metal matrix composites are commonly produced through processes involving powder metallurgy and pressure-assisted casting. Notably, for the production of prototype spacecraft components such as tubes, plates, and panels, metal matrix composites like B/Al, Gr/Al, Gr/Mg, and Gr/Cu have been manufactured using diffusion bonding.

- Properties:

Table 1.1 provides an overview of the typical properties exhibited by a selection of continuous fiber-reinforced metal matrix composites. Generally, the measured properties of as-fabricated metal matrix composites align with the analytically predicted properties of each composite. A primary advantage of MMCs over their organic matrix counterparts is their elevated maximum operating temperature. For instance, B/Al maintains beneficial mechanical properties up to temperatures of 510°C, whereas an equivalent B/Ep composite is constrained to around 190°C. Moreover, MMCs like Gr/Al, Gr/Mg, and Gr/Cu display enhanced thermal conductivity due to the substantial contribution from the metallic matrix [13].

Table 1.2 lists the properties of discontinuously reinforced aluminum (DRA) composites which are being currently produced both for spacecraft and commercial applications. DRA is an isotropic metal matrix composite with specific mechanical properties superior to conventional aerospace materials. For example, DWA Aluminum Composites has produced MMC’s using 6092 and 2009 matrix alloys to offer the best combination of strength, ductility and fracture toughness, and using 6063 matrix alloy to obtain high thermal conductivity. Similarly, Metal Matrix Cast Composite (MMCC) Inc. has produced graphite particulate reinforced aluminum composites to offer the optimum combination of high specific thermal conductivity and CTE.

Table 1.1

Material Properties of Unidrectional Metal Matrix Composites for Space Applications.

Properties	P100/6061 AI [0°]	P100/AZ91C Mg [0°]	Boron/ AI [0°]
Volume Percent Reinforcement	42.2	43	50
Density ρ, gm/cm^3	2.5	1.97	2.7
Poisson Ratio ν_{xy}	0.295	0.3	0.23
Specific Heat C_p, J/kg*K	812	795	801
Longitudinal			
Young Modulus,GPa	342.5	323.8	235
Ultimate Tensile Strength, MPa	905	710.0	1100
Thermal Conductivity K_x, W/m*K	320.0	189	–
CTE_x 10^{-6}/K	-0.49	0.54	5.8
Transverse			
Youngs Modulus,GPa	35.4	20.7	138
Ultimate Tensile Strength, MPa	25.0	22.0	110
Thermal ConductivityK_y, W/m*K	72.0	32.0	–

Table 1.2

Material Properties of Discontinuously Reinforced Aluminum Matrix Composites

Property	Graphite AI GA 7-230	AI6092/SiC/17.6p	AI/Sic/63p
Density ρ,gm/cm^3	2.45	2.8	3.01
Young Modulus,GPa	88.7	100	220
Tensile Ultimate Strength, MPa	109.6	406.5	
Compressive Yield Strength, MPa	76.8	461.6	253
Compressive Ultimate Strength, MPa	202.6	-	
$CTE_{(x-y)}$, 10^{-6}/K	6.5-9.5	16/4	7.9
Thermal Conductivity, (W/m*K)	190 150	165	175 170
Electrical Resistivity,Ohm	6.89	-	

Metal-matrix composites find application in various fields, including the Space Shuttle, commercial airliners, electronic substrates, bicycles, automobiles, golf clubs, and diverse other uses, either in active use or during the prototyping phase. While a majority of these composites utilize aluminum matrices, an increasing number of applications necessitate the matrix properties of superalloys, titanium, copper, magnesium, or iron.

Similar to all composite materials, aluminum-matrix composites don't constitute a singular substance but rather a collection of materials with customizable attributes like stiffness, strength, density, thermal conductivity, and electrical properties. The properties can be tailored by adjusting factors such as the matrix alloy, reinforcement material, volume and configuration of reinforcement, reinforcement placement, and the fabrication technique employed. Despite the various adjustments, aluminum composites maintain the advantage of cost-effectiveness compared to most other metal-matrix composites. Additionally, they offer commendable thermal conductivity, high shear strength, impressive abrasion resistance, capability for high-temperature operation, nonflammability, minimal reactivity with fuels and solvents, and suitability for shaping and processing using conventional equipment [13].

Manufacturing methods for aluminum MMCs encompass casting, powder metallurgy, development of reinforcement within the material itself, and foil-and-fiber pressing methods. There is now a consistent supply of high-quality aluminum MMCs available in significant quantities, with leading manufacturers scaling up production and reducing costs.

In the realm of superalloys, composites reinforced with tungsten alloy fibers are in development for components within jet turbine engines designed to function at temperatures exceeding 1,830 °F.

Graphite/copper composites offer customizable properties and endure high temperatures in air, showcasing excellent mechanical attributes, alongside high electrical and thermal conductivity. Their processing is more straightforward compared to titanium, while also having lower density when contrasted with steel. Copper matrices combined with tungsten particles or aluminum oxide particles are employed in heat sinks and electronic packaging.

Titanium combined with silicon carbide fibers is undergoing exploration as potential skin material for the National Aerospace Plane. Notably, stainless steels, tool steels, and Inconel are matrix materials reinforced with titanium carbide particles, and these are transformed into components like draw-rings, suited for high-temperature and corrosion-resistant applications. Compared to monolithic metals, MMCs have:

- Higher strength-to-density ratios;
- Higher stiffness-to-density ratios;
- Better fatigue resistance;
- Better elevated temperature properties;
- Higher strength;
- Lower creep rate;
- Lower coefficients of thermal expansion;
- Better wear resistance;

The advantages of MMCs over polymer matrix composites are:

- Higher temperature capability;
- Fire resistance;
- Higher transverse stiffness and strength;
- No moisture absorption;
- Higher electrical and thermal conductivities;
- Better radiation resistance;
- No outgassing;
- Fabricability of whisker and particulate-reinforced MMCs with conventional metalworking equipment.

Some of the disadvantages of MMCs compared to monolithic metals and polymer matrix composites are:

- Higher cost of some material systems;
- Relatively immature technology;
- Complex fabrication methods for fiber-reinforced systems (except for casting);
- Limited service experience [10].

Numerous metals have been used as matrices. The most important have been aluminum, titanium, magnesium, and copper alloys and superalloys.

1.2.3 Ceramic Matrix Composites

Ceramic matrix composites (CMCs) have garnered increasing popularity as materials suitable for a diverse array of high-performance and protective components. This heightened interest has underscored the need for comprehensive insights into the consequences of employing various machining techniques. Essentially, CMCs are composed of ceramic fibers embedded within a matrix, employing ceramics such as carbon fibers and carbon to construct both the matrix and fibers. These ceramics encompass a broad spectrum of non-metallic inorganic materials, renowned for their frequent deployment under high-temperature conditions. Ceramics exhibit a remarkable range of attributes, including exceptional strength and stiffness even at exceedingly high temperatures, chemical inertness, and low density, among others. Within CMCs, ceramics assume roles as both the matrix and reinforcement materials, with the matrix ensuring smooth functionality while the reinforcement imparts distinct special properties [1].

Ceramic matrix composites are tailored for applications necessitating superior thermal and mechanical attributes, spanning sectors including nuclear power plants, aviation, chemical facilities, space structures, and transportation services. In the realm of advanced aircraft, the augmentation of overall impulse-to-mass ratios for rocket engines becomes paramount, prompting the need for reduced engine structural weight and heightened resistance to component heat. The development of new ultra-high-temperature composites, characterized by resistance to elevated temperatures and low density, has become imperative, providing the foundation for high-performance engine design. The virtues of continuous fiber-reinforced CMCs are widely acknowledged as indicative of a nation's prowess in designing and producing contemporary aircraft, spacecraft, and weaponry. Such CMC materials find utility in diverse aircraft engine configurations, aircraft brake disks, high-temperature gas turbine components, slide bearing elements, hot gas ducts, flame holders, and burner components, with oxide-based CMCs contributing to their fabrication.

Ceramic matrix composites introduce an emerging technology aimed at bolstering the hardness and durability of ceramics in applications typified by extremely high temperatures, as found in engine hot sections. By yielding materials that are stiffer, harder, and lighter, capable of withstanding elevated operating temperatures, CMC materials hold the promise of driving further advancements in productivity and weight reduction. Composite materials also offer the potential to yield novel materials endowed with unique properties absent in conventional materials. Research endeavors have explored into metal nanocomposites and hybrid ceramic substances synthesized through the sol-gel method, alongside quasi-crystalline materials exhibiting separated phases at the nanometer scale, all contributing to the concept of structured ceramic nanocomposites.

CMCs composed of Si_3N_4/SiC and Al_2O_3/SiC systems have demonstrated the potential for advanced airframe design due to their commendable strength-to-weight and stiffness-to-weight ratios. CMCs are frequently employed in intricate sections of aero-engine vanes, with traditional machining serving as a prevalent method for reshaping the materials to meet geometric and assembly prerequisites [1].

Ceramic matrix composites epitomize a category of composite materials wherein ceramics serve dual roles as both matrix and reinforcement. The matrix material ensures cohesion, while the reinforcement imparts distinctive characteristics. fig. 1.1. illustrates various types of composite matrices and the materials adopted in each composite. CMCs were developed for applications demanding elevated mechanical and thermal performance, encompassing domains like aviation, nuclear power plants, land transportation, chemical facilities, and space structures. Within ceramic matrix composites, reinforcement materials such as alumina, aluminasilica, carbon, and silicon carbide are employed. Refractory fibers encompass nanofibers, long fibers, short fibers, particles, and whiskers, sharing a polycrystalline structure akin to conventional ceramics. Although CMCs exhibit reduced susceptibility to crack defects, once fractures initiate, the repercussions can be significant. Ultra-high-temperature, non-oxide ceramics are integrated into matrix materials for specialized applications. Advanced ceramics have seen extensive utilization in the production of ceramic matrix composites, addressing a major drawback of traditional ceramics, which is their brittleness. Prominent non-oxide CMCs encompass carbon/silicon carbide (C/SiC), carbon/carbon (C/C), and silicon carbide (SiC), with their nomenclature often derived from the structure of the fiber and matrix materials employed [3].

- Properties of Ceramic Matrix Composites

Advanced ceramics have a unique number of properties, including high tensile strength under high temperatures, superior corrosion, high hardness, erosion resistance, low density, strong elastic modulus, and reduced coefficients of friction, making them reasonable alternatives for a variety of structural applications as compared with pure metals [21]. Cutting tools, heat exchangers, wear components and coatings are just a few of the current applications of advanced ceramics. But, to use ceramics in new areas like engines and turbines, their reliability and brittleness must be improved. Ceramic matrix composites have the benefit of higher toughness, catastrophic failure resilience, good strength, low weight, low thermal expansion, and capacity which sustains high temperatures for oxidation resistance. Ceramic materials were more resistant to high temperatures as well as harsh environments than metals as well as other traditional engineering materials. Ceramics constitute inorganic non-metallic materials made up of non-metallic and metallic elements bound together by ionic and/or covalent bonds. Thermal shock resistance and toughness are limited in traditional ceramics. the usage of fiber reinforcement in ceramic matrix composites overcomes these problems. Ceramic matrix composites have a number of common features which include (i) high tolerance to thermal shock and creep, (ii) resistance to high temperatures, (iii) excellent corrosion and wear resistance, (iv) intolerance to corrosive chemicals, (v) reinforcement improves fracture toughness, and (vi) at high temperatures, the strength of the material remains high.

- CMC Reinforcing Materials.

Typical reinforcing fiber materials include the following:

- Carbon, C;
- Silicon Carbide, SiC;
- Alumina, Al_2O_3;
- Mullite or Alumina Silica, Al_2O_3-SiO_2 [20].

The fibers can take many different forms, including the more traditional continuous fiber as well as short fibers, particles, whiskers, and nanofibers. These fibers all have a polycrystalline structure like traditional ceramics possess. The reason you do not see glass, organic, or metallic fibers is because CMC fibers must remain stable at temperatures above 1,800 °F.

The reinforcing fibers are just a fraction of the thickness of a human hair – and in the case of nanofibers, are even tinier. They are often woven into a fabric or tape-like material for inclusion in a CMC part. In a typical CMC process, the fibers are coated with a material such as boron nitride and then passed through a matrix slurry bath, resulting in a prepreg tape or cloth.

The majority of current CMC applications use short fiber, whisker, or continuous fiber reinforcement. The use of whiskers and short fibers improves the CMC's resistance to crack propagation and its overall toughness but can result in catastrophic failure. Long, or continuous, fiber reinforcement provides better strengthening than whiskers or short fibers. The use of long fibers also results in better toughness because the fibers can hold the CMC together even after the ceramic matrix has begun to crack, significantly slowing down crack propagation.

CMC Matrix Materials

The list of typical matrix materials in a CMC would be the same as the fiber materials listed above, along with non-oxide ultra-high-temperature (UHT) ceramics used only in special applications [3].

For producing the prepreg tape just discussed above, the fibers would be passed through a slurry bath of binders, solvents, and the matrix material being used (e.g, carbon or silicon carbide). The various layers of prepreg tape are laid up and shaped to form the final part. In most cases, the part then goes through pyrolysis to convert the matrix material to a ceramic, which will be discussed in more detail further on.

1.2.4 Polymer Matrix Composites

Polymer matrix composites (PMCs) are a type of composite material that consists of a polymer matrix reinforced with fibers. The fibers, which can be short fibers or continuous fibers, provide strength and stiffness. The polymer matrix binds the fibers together and transfers loads between them [9].

PMCs offer several advantages over other materials, including:

- Light weight. The low density of the polymer matrix leads to a low composite density compared to metals. This makes PMCs desirable for weight-sensitive applications.
- High specific strength and stiffness. The reinforcing fibers provide strength and stiffness on a per mass basis that can exceed other structural materials like metals.
- Design flexibility. PMC properties can be tailored by changing the type of polymer, type of fiber, fiber orientation and fiber volume fraction.
- Corrosion resistance. The polymer matrix protects the fibers from environmental attack leading to excellent corrosion resistance.
- High fatigue strength. Well-designed PMCs exhibit excellent fatigue resistance compared to metals.
- The polymers used as the matrix phase are generally either thermoplastics, thermosets or elastomers. Thermoplastics have the advantage of recyclability and toughness. Thermosets cannot be remolded after initial forming but offer superior mechanical properties. Elastomers impart toughness and the ability to stretch [9].

The fiber reinforcements are commonly glass, carbon or aramid fibers. Glass provides low cost and high tensile strength. Carbon fiber has very high stiffness and strength for critical applications. Aramid fiber offers strength with low density and high impact resistance.

PMCs do have limitations in extreme temperature environments since the polymers will eventually decompose. The maximum service temperature is typically 300-350°C. The properties of PMCs are also more sensitive to moisture absorption than metals or ceramics [18].

Overall, PMCs offer an excellent balance of properties for structural applications demanding high strength, low weight and corrosion resistance. With continuous research improving polymer and fiber properties, PMCs will continue growing as a material of choice for lightweight structures.

1.2.5. Carbon Fiber Reinforced Polymer Composites

Carbon fiber reinforced polymer (CFRP) composites consist of carbon fibers embedded in a polymer matrix. The carbon fibers provide exceptional stiffness and strength, while being lightweight. The polymer matrix binds the fibers together and transfers load between them. The high specific strength and stiffness of CFRPs make them widely used in weight-critical applications like aerospace structures [2].

CFRPs were first commercialized to serve the defense and aerospace industries. Their outstanding mechanical properties continue to drive adoption in additional markets such as automotive, sports equipment, wind turbines, and civil infrastructure. Ongoing advances in manufacturing techniques aim to reduce costs and expand applications of these versatile composite materials.

Carbon fibers are produced by the controlled pyrolysis of precursor fibers. The main types of precursor fibers are polyacrylonitrile (PAN), pitch, and rayon. PAN-based fibers comprise over 90% of carbon fiber production due to their superior strength and modulus properties. The precursor fibers are oxidized and carbonized at high temperatures to transform the molecular structure into nearly pure carbon. The fibers can then be surface treated and sized to improve matrix bonding.

Carbon fiber properties like stiffness, strength, and thermal conductivity can be tailored based on precursor composition and manufacturing process parameters. The small diameter filaments provide a high strength-to-weight ratio. Individual carbon filaments range from 5-10 microns in diameter while commercial-grade fibers are bundled into tows of 3,000 to 24,000 filaments [8].

Polymer Matrices

The polymer matrix in a CFRP composite binds the carbon fiber reinforcement for efficient load transfer. Thermoset resins including epoxy, polyester, vinylester and phenolic are the most widely used. Epoxies offer a superior balance of mechanical properties and processing characteristics. Thermoplastic polymers can also be utilized including PEEK, PEI, and PPS [18].

The fiber-matrix interfacial bonding strength significantly affects the composite mechanical properties. Applying surface treatments or sizings to the carbon fibers is used to optimize bonding between the hydrophilic fibers and hydrophobic polymer resins.

The properties of CFRPs include:

- High specific strength and stiffness. CFRPs achieve strength-to-weight ratios exceeding aluminum and most other structural alloys.
- Low coefficient of thermal expansion. Closely matches that of concrete, steel and other materials.
- Corrosion resistance. Provides excellent durability in infrastructure applications.
- Electrically conductive. Can be used for lightning strike protection in aircraft.
- Fatigue and impact resistance. Excellent for cyclic loading applications [2].

The combination of properties has resulted in the use of CFRPs for critical structural applications in aerospace, automotive, marine, sports equipment and civil infrastructure. The high cost of carbon fiber is the main barrier to entry, though emerging manufacturing techniques aim to improve affordability. With continued development, CFRPs have potential to displace traditional materials like steel and aluminum alloys in multiple industries.

1.3. Advantages of composites over traditional aviation materials

In the field of aviation and aerospace technology, traditional materials have been in use for many decades, boasting a long history of successful utilization in aircraft construction and various aspects of aviation technology [17]. The primary traditional aviation materials include:

1. Aluminum. It is one of the most widely used metals in the aviation industry. Aluminum is employed in crafting lightweight yet sturdy aircraft structures, including fuselages, wings, and fasteners.
2. Steel. Used where high strength and wear resistance are required, steel is typically used in the production of fasteners, landing gear, panels, and other structural components.

3. Titanium. Renowned for its lightweight properties and high strength, titanium finds its application in manufacturing engine components, fasteners, panels, and other parts that demand durability under heavy loads.

4. Magnesium. A lightweight metal typically employed in small and light aircraft classes, magnesium is used in constructing frames, doors, hatches, and various other components.

5. Wood. Historically utilized in aviation, especially in its early development stages, wood was used for crafting frameworks and coverings, enabling the creation of lightweight and maneuverable aircraft.

6. Glass and Fabric Materials. These materials have been used for aircraft coverings and even in the construction of airships.

7. Corrosion-Resistant Alloys. Utilized to prevent corrosion in aggressive environments, including marine and harsh climatic conditions.

Recognizing the significant advantages of composite materials compared to traditional aviation materials is crucial in the modern aviation industry's development. With increasing demands for lightweight, efficiency, and environmental sustainability in air transportation, composite materials are demonstrating their potential as a vital resource for creating lightweight, strong, and durable structures [19].

In this chapter, the exploration encompasses the key advantages that composite materials offer over traditional aviation materials. Emphasis is placed on critical aspects including weight and density, strength and rigidity, corrosion and oxidation resistance, aerodynamic design, and longevity. A more in-depth discussion of these advantages compared to traditional materials aids in comprehending the significant contribution of composites to modern aviation technology.

- Lightness and Weight:
  - Composite Materials:

Advantages: Composites are created by combining a matrix (typically a polymer material) with reinforced fibers (such as fiberglass, carbon fiber, or aramid fiber). This allows them to achieve an impressive strength-to-weight ratio. They are lighter than most traditional metals like aluminum and steel, which helps reduce the aircraft's weight and improve its productivity and efficiency.

• Strength and Rigidity:

o Composite Materials:

Advantages: Composite materials are characterized by high strength and rigidity at low weight. Reinforced fibers account for a significant portion of their strength, allowing the creation of structures that can withstand significant loads. Their properties can be tailored by changing the type and orientation of fibers, making them versatile for engineering applications.

• Corrosion Resistance:

o Composite Materials:

Advantages: One of the primary advantages of composite materials is their high resistance to corrosion and oxidation. Since they do not contain metallic components that can react with aggressive environments, composites are less vulnerable to corrosion. This makes them particularly popular for use in humid conditions, marine environments, and other aggressive settings.

o Increased Maintenance:

The absence of corrosion resistance requires regular maintenance and protective measures such as anti-corrosion coatings, painting, and routine inspections. This can lead to increased maintenance costs, including the time and resources needed to keep metallic components in good condition.

o Reduced Durability:

Corrosion and oxidation can reduce the durability of metallic materials, especially in aggressive climatic conditions, atmospheric pollutants, and chemically active environments. This may necessitate early removal or repair of components, increasing overall operational and maintenance costs.

o Limited Efficiency:

Weakening of strength and other mechanical properties due to corrosion can limit the efficiency and performance of the aircraft. This can become a constraint in achieving optimal performance and fuel efficiency parameters.

• Aerodynamic Design:

o Composite Materials:

Advantages: Composite materials allow for the creation of more complex and streamlined shapes, contributing to improved aerodynamic efficiency of the aircraft. Smooth surfaces, absence of seams, and structural ribs reduce air resistance and facilitate an efficient airflow around the aircraft.

• Durability:

o Composite Materials:

Advantages: Composites are known for their high durability due to the absence of corrosion and the ability of components to withstand dynamic loads. They are less prone to material fatigue, which can significantly extend the service life of structures.

Table 1.3

Comparison table of composite materials and traditional aviation materials

Characteristic	Composite Materials	Traditional Materials (e.g., Aluminum and Steel)
Weight	Lighter than metals	Comparatively heavy
Strength at low weight	High	High (but higher mass may reduce strength-to-weight ratio)
Overall structure weight	Reduced due to lightness	Higher due to the use of heavy metals
Fuel Efficiency	Reduced fuel consumption	Increased fuel consumption due to higher mass
Aerodynamic Efficiency	Improved due to shapability	Limited due to the weight and geometry of metallic components
Strength	High	High (but higher mass may reduce strength-to-weight ratio)
Rigidity	High	Lower compared to composites
Property adaptability	Change fiber type and orientation	Limited adaptability of metals
Enhanced durability	Yes	Yes
Internal damping	Ability to absorb impact energy	Less ability to absorb impact energy
Corrosion resistance	High	Depends on material and protective measures
Interaction with aggressive environments	Less vulnerable	May require additional protection
Preservation of properties in humid conditions	Yes	Depends on material and treatment
Durability	High	May be reduced due to corrosion and oxidation
Maintenance needs	Less frequent	May require regular maintenance

Continue table 1.3

Aerodynamic design	Improved flexibility	Limited by mechanical properties of materials
Smooth surfaces and absence of seams	Yes	May require additional processing and joints
Potential reduced air resistance	Yes	Yes
Optimization of aerodynamic characteristics	Effective	Limited due to limited flexibility and shaping of metallic components
Durability	High	High but may be limited by corrosion and material fatigue
Corrosion and oxidation resistance	Yes	Limited susceptibility to corrosion and oxidation
Ability to withstand dynamic loads	Yes	Yes
Service life under normal conditions	Long	Long
Service life in aggressive conditions	High	May be shortened due to corrosion and oxidation
Material fatigue impact	Less prone to fatigue	Fatigue impact may reduce service life

1.4. Disadvantages of composite materials

Composite materials, endowed with numerous advantages, make a significant contribution to the modern aviation industry. What has become possible due to excellent strength-to-weight ratio, high corrosion resistance, and the ability to efficiently absorb loads serves as a basis for enthusiasm towards composites. However, the following analysis reveals common drawbacks that must be carefully researched and generalized [15].

1. Complex Manufacturing. The production of composite materials and structures is the most notable limitation. Complexity arises from an extended sequence of processes, including lamination, vacuum infusion, as well as thermal and aerospace treatments. Each of these steps requires not only expensive equipment but also a high degree of expertise.

2. Cost. The cost of composite materials and their structures typically exceeds prices for traditional metallic products. Here, the significant impact comes from the cost of raw materials and enriched technologies required for their production. This can lead to increased overall production costs and higher prices for the end product.

3. Vulnerability to Damage. Despite the aforementioned advantages, composite materials exhibit greater vulnerability to damage from mechanical impacts or loads. In

particular, even minor impacts can lead to the development of invisible cracks or deformations that can significantly affect the overall structural strength.

4. Brittleness. Some composites can be more brittle than traditional metallic materials. The results obtained may change under stress, leading to unpredictable events and worsening the overall safety context.

5. Limited Heat Resistance. Some composite materials may lose strength and stability at high temperatures, creating certain disadvantages for certain aircraft zones subjected to significant thermal stress.

6. Complexity of Repair. Repairing composite structures in case of damage can become excessively complex and labor-intensive. Special skills, equipment, and infrastructure are required for detecting and restoring even minor damages.

7. Moisture Impact. Some composites can be sensitive to moisture and water, leading to a reduction in their mechanical characteristics and strength. This can result in accelerated degradation and reduced durability.

8. Structural Inhomogeneity. The production of composites can lead to structural and compositional irregularities in the material. This can lead to changes in strength and other mechanical characteristics of the structure [16].

The general drawbacks of composite materials in aviation provide an opportunity to focus on the need for further scientific and engineering work. By improving manufacturing technologies, developing effective repair methods, and enhancing reliability, the impact of these drawbacks on the high efficiency and safety of composite materials in aircraft construction can be reduced or neutralized.

1.5. Selection of composite materials for the aircraft passenger floor beam

With the increasing role of aviation in the modern world, there are constant demands for improving and optimizing the designs of passenger aircraft. One of the key aspects in this process is the selection of materials for structural elements, including the floor beam. The material used for the beam determines not only its mechanical characteristics but also the safety, reliability, and overall efficiency of the aircraft.

Among the recent trends in material selection for aviation structures is the use of composite materials, which possess a unique combination of properties: lightweight, high strength, corrosion resistance, and fire resistance. However, there are limitations and drawbacks to the use of specific types of composites that require careful analysis and consideration during selection [11].

The main criteria for comparison will include weight, strength, corrosion resistance, heat resistance, fire resistance, environmental impact, mass production feasibility, and cost.

Within the context of this analysis, a table featuring specific numerical parameters for each material will be utilized, aiding in the facilitation of an objective comparison. By representing key properties of each material in numerical form, the identification of specific characteristics, drawbacks, and advantages becomes achievable within the context of its application in the floor beam [15].

Subsequent analysis and comparison will guide the determination of the most suitable material for the passenger aircraft floor beam.

Table 1.4

Materials comparison table

Parameter / Material	Glass Fiber Reinforced Polymer	Carbon Fiber Reinforced Polymer	Aramid Fiber Reinforced Polymer	Metal Matrix Composites	Aluminum	Steel
Weight, kg	5-8	3-6	4-7	6-10	10-15	15-20
Corrosion Resistance, %	85-90	95-98	90-95	90-95	60-70	30-40
Heat Resistance, °C	120	1500	300	500	300	600
Fire Resistance, °C	250	400	350	300	650	800
Strength, MPa	200-500	300-800	150-450	200-600	100-350	200-800
Manufacturing Technology	Easy	Complex	Complex	Complex	Easy	Complex
Cost, $	150-200	300-500	200-300	250-400	100-150	50-100
Environmental Impact	Low pollution	Low pollution	Low pollution	Low pollution	High pollution	High pollution
Mass Production Feasibility	Mass production	Local production	Local production	Limited production	Mass production	Mass production

The table 1.4, complete with parameters and numerical comparisons of materials, will empower us to draw conclusions regarding which material aligns best with the requirements of efficiency, safety, and cost-effectiveness.

Therefore, by evaluating all the parameters listed in the table, it can be concluded that Carbon Fiber Reinforced Polymer (CFRP) emerges as the best material for the aircraft floor beam. This conclusion is grounded in a comprehensive comparison of materials with respect to crucial characteristics and requirements for the aircraft beam.

Parameters where CFRP performed the best:

Weight: CFRP has the lowest weight among all the materials considered, which is crucial for reducing the aircraft's mass and increasing its fuel efficiency.

Strength: CFRP provides excellent strength and stability, ensuring a high level of safety and reliability for the beam under various flight conditions.

Corrosion Resistance: CFRP high corrosion resistance prevents material degradation due to corrosion, especially in humid and aggressive environments.

Heat Resistance: CFRP can withstand high temperatures up to 1500°C, making it an excellent choice for beam stability during different flight modes.

Fire Resistance: The composition of CFRP, which includes carbon fibers and a polymer matrix, offers a high level of fire resistance, contributing to passenger and crew safety.

Disadvantages of CFRP and their solution:

Cost: The manufacturing cost of CFRP can be higher compared to other materials. However, this cost is offset by its weight and material efficiency, leading to reduced fuel consumption and CO_2 emissions.

Mass Production Feasibility: CFRP manufacturing technologies may not yet be as mass-produced as other materials. However, this is a temporary limitation as developments in this field continue, and mass production will increase.

Other materials considered in the context of choosing a material for the passenger aircraft's floor beam have their advantages, but compared to Carbon Fiber Reinforced Polymer (CFRP), they exhibit certain limitations and drawbacks that diminish their effectiveness and suitability for this application.

• Aluminum:

Weight: Aluminum is lightweight, but CFRP is even lighter, allowing for greater fuel savings and reduced CO_2 emissions.

Strength: Aluminum lacks the same level of strength as CFRP and may not withstand heavy loads under various flight conditions.

• Steel:

Weight: Steel is heavier than aluminum and CFRP, which can lead to increased aircraft weight and fuel consumption.

Corrosion Resistance: Steel is susceptible to corrosion, which can limit the beam's durability and require regular maintenance and repairs.

• Metal Matrix Composites (MMC) and Ceramic Matrix Composites (CMC):

Weight: MMC and CMC have a weight advantage over steel, but they can be heavier than CFRP.

Corrosion Resistance: Depending on the composition, MMC and CMC can also be susceptible to corrosion if the matrix is not corrosion-resistant.

• Organic Matrix Composites:

Fire Resistance: Organic matrix composites may be less fire-resistant, especially compared to CFRP, which can pose a safety risk in case of a fire.

• Polymer Materials:

Heat Resistance: Some polymers may not have the same high heat resistance as CFRP and may not withstand extreme temperatures during flight.

In summary, Carbon Fiber Reinforced Polymer (CFRP) best meets the key criteria for a passenger aircraft floor beam material. Its high strength, lightweight nature, corrosion resistance, heat resistance, and fire resistance outweigh any limitations it may have. By choosing CFRP, optimal safety, efficiency, and durability for beam is ensured in aviation operations.

Conclusion to the Part 1

In conclusion, the first part of this work has provided a comprehensive exploration of composite materials, thoroughly investigating their fundamental aspects, including composition, structure, and properties. The discussion encompassed the classification of composite materials, covering organic matrix composites (OMCs), metal-matrix composites (MMCs), ceramic matrix composites (CMCs), polymer matrix composites (PMCs), specifically focusing on carbon fiber reinforced polymer (CFRP) composites.

Moreover, the analysis highlighted the significant advantages that composite materials offer over traditional aviation materials, underscoring their lighter weight, higher strength-to-weight ratio, corrosion resistance, and design flexibility. However, it also shed light on the drawbacks associated with composite materials, such as their susceptibility to impact damage, delamination, and high manufacturing costs.

An essential aspect discussed was the selection of composite materials for the aircraft passenger floor beam, emphasizing the importance of meticulously considering various factors, including mechanical properties, durability, fire resistance, and overall safety, in the decision-making process.

This in-depth exploration sets the stage for the subsequent parts of this work, laying the foundation for a more detailed examination of the application, performance, and specific considerations in utilizing composite materials for the aviation industry. In the following sections, the focus will be on the practical implementation and the analysis of these materials for the development of a reliable, safe, and efficient aircraft passenger floor beam.

PART 2. THE SUPPORT BEAM OF THE PASSENGER CABIN FLOOR

2.1. Floor beam description

Beams used in the construction of aircraft must meet the specified requirements of strength and stiffness with the smallest mass. In the design of an aircraft, beams work in bending with shear and compression (or tension) at the same time. Therefore, the shape of the section of the beams should be chosen so that the largest part of the mass of the material is located as far as possible from the neutral axis.

2 longitudinal beams, which are the load-bearing element of the cabin floor are considered. They are located along the axis of the aircraft between frames #1 and 5. The beams are equipped with manual and foot controls for the aircraft. Beams -– duralumin, equally strong, U-shaped section 2 mm thick. Beam width – 210 mm, height in the middle – 75 mm and at the ends – 40 mm. From below, the beam is protected by a sheet 0.6 mm thick. The ends of the beams are riveted to frames # 1 and 5 with the help of brackets. The upper plane of the beams, together with the sheets, forms the floor of the cockpit, divided into two parts by a passage [33].

The horizontal passage panel is located along the threshold of frame #5 and has a rigid stamped frame below, riveted with a smooth sheet. The panel is laid on beams of frames #2, 3 and 4 and riveted to them, forming a step 360 mm high from the floor of the cargo compartment. To provide convenient access to units located under the floor, the middle part of the floor in the cockpit between frames #4 and 5 is easily removable [33].

Removable side panels are mounted on screws along the passage, which, when removed, provides convenient access from the cab to the installation sites of the units located under the floor. Ahead of the passage is an easily removable casing that covers the transverse tube for manual control of the aircraft.

To unload the upper fuselage spars in the front of the cabin, a stiffening element is installed, recruited from a sheet with a thickness of 1.5 mm and profiles. The stiffening element is riveted to the spars and frame #1 and simultaneously serves as a panel for installing equipment.

The frame of the floor of the passenger or cargo compartment of the fuselage (fig. 2.1) consists of longitudinal and transverse beams and serves to fasten the floor panels. The transverse beams are structural elements of the frames of the middle part of the fuselage, which are described above.

The longitudinal set of the floor consists of longitudinal beams, diaphragms and walls. The longitudinal beams are installed in seven rows at a distance of 250 mm between the rows. Beams – channel section, made of a sheet 2 mm thick and fixed on the horizontal shelf of the frame with two countersunk rivets. Between frames #5 and 7, the profiles are installed in the transverse direction [37].

The diaphragms are located along the axis of the aircraft and at the sides. They consist of a 0.8 mm thick wall with edges and holes for lightening, riveted with pressed corners. The diaphragms are attached to the vertical posts and horizontal shelves of the frame with the help of rivet-knits. Part of the brackets has stamped holes and springs for screw locks, which are attached to the frame of the floor panel. The diaphragms located at the sides are connected to the frames with additional sheets. The sheets have a side to which the inner lining is attached with screws.

The walls are located along the axis of the aircraft between frames #5 and 7 and at the sides of the fuselage between frames #8 and 9. The walls are made of a sheet 1 mm thick, reinforced with pressed profiles, and riveted with their lower side to the fuselage skin. In the side walls there are holes for the passage of flap control rods.

The flooring consists of separate panels that are laid on the frame, and each of them is attached to it with four spring locks. The panel consists of a sheet of plywood 4 mm thick, lined on both sides with duralumin sheets 0.5 mm thick. Duralumin sheets are glued to plywood with BF-2 bakelite glue and riveted along the contour with rivets. The panel on the outside is covered with cork chips on AK-20 nitroglue to prevent feet from slipping when moving around the cabin [33].

The floor structure is designed for a load of 1000 kgf/m^2. Between frames #8 and 9 there is a hatch for access from the cockpit to the electromechanism for controlling the lower flaps, which is closed by a panel.

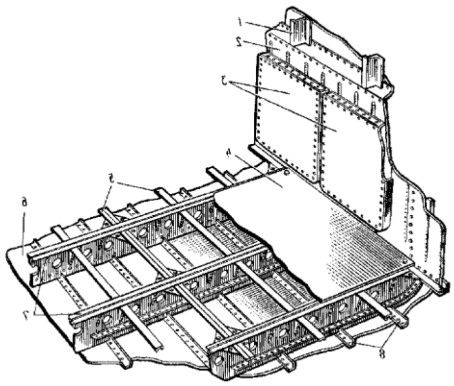

Fig. 2.1. Cargo floor frame:

1 – frame; 2 – side panel; 3 – folding hard seats; 4 – floor panel; 5 – longitudinal beams of the floor; 6 – duralumin sheathing; 7 – frames (cross beams of the floor); 8 – stringer

To secure cargo on the sides of the fuselage, nine mooring brackets are installed (five below and four above the passenger seats) and 13 steel knots with rings that are screwed into nests riveted into the floor frame elements. The side brackets are made of AL4 alloy and are bolted and riveted to the fuselage frames.

Steel knots are an eye bolt with a thread and a ring. The removed mooring rings are stored in a special box cut into the floor panel at frame #15, and their sockets are closed with plugs.

To secure cargo to the aircraft, nine mooring cables and a net are applied. On the right side of the fuselage inside the cargo compartment, marks and inscriptions of the location of the cargo are applied.

A floor is installed along the tail compartment, consisting of separate panels, laid on U-shaped profiles. The panels are similar to those of the cargo compartment and are attached to the fuselage profiles with spring locks [37].

The floor of the tail compartment between the frames was replaced by a light metal track covered with cork chips. The panels are attached to the frames with bolts and anchor nuts.

2.2. New beam description

The objective of the utility model is to develop such a beam design that would have a lower mass and would facilitate its installation in the aircraft structure. In addition, the design of the beam must allow the passage of cables and other communications through it without compromising its strength. This goal is achieved by a new beam made of polymer composite materials, containing spiral intersecting and interconnected rods, characterized in that it is made in the form of a hollow mesh structure having the shape of a rectangular frame with rounded corners in cross section. In addition, in the beam, the spiral ribs are made in the form of spirals of opposite twist with round turns, intersecting and fastened together, connected at the ends by monolithic sections of a woven polymer composite material. [31].

An aircraft floor beam made of polymer composite materials according to claims 1 and 2, characterized in that it is additionally provided with longitudinal and transverse ribs associated with spiral ribs. [34]. (fig. 2.2)

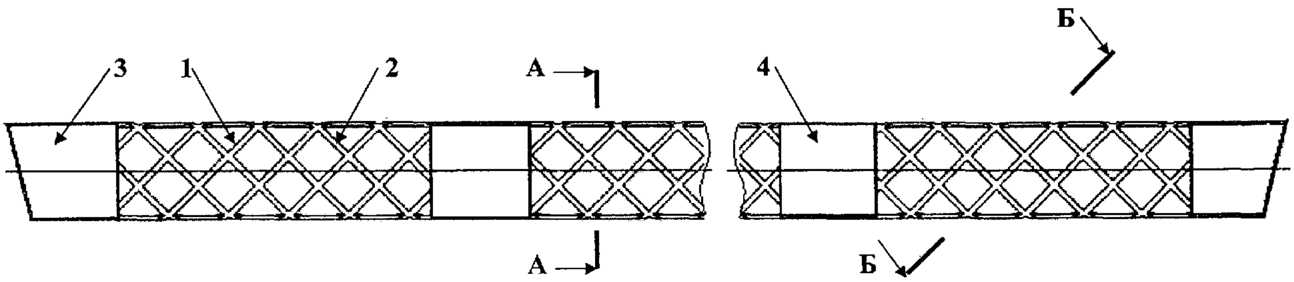

Fig 2.2. Aircraft floor beam made of polymer composite materials:

1– shows a frontal view of a floor beam with a partial cut; 2 –shows section A-A; 3 – shows a fragment of a floor beam with transverse ribs; 4 – shows a fragment of a floor beam with longitudinal ribs on the upper plane.

Also, the design of the floor beam, in contrast to the known ones, is made in the form of a closed mesh structure with a round constant cross-section along the entire length of the part, as a result of which there is a plane on each side of the floor beam, which allows attaching the parts to it with simple fasteners. All intersecting planes of the floor beam have mating radii to prevent sharp bends of the reinforcing fibers of the filler in these places, which reduce their strength [35].

In addition, in the places of future installation of attached parts, in the mesh frame of the floor beam, in contrast to the known ones, there are monolithic sections based on woven fibrous filler, which represent local reinforcement of the floor beam at the attachment points of the attached parts.

These monolithic sections distribute the concentrated loads from the attached parts to the group of ribs with which they intersect, and also allow the attached parts to be attached to it in the least laborious and most structurally simple way, which increases the productivity of fastener manufacturing and the productivity of assembly operations.

The floor beam (fig.2.3) is made in the form of a hollow mesh structure having a cross-sectional shape of a round frame with rounded corners. The beam includes spiral ribs made in the form of spirals of opposite twist with round turns, intersecting and fastened together. In addition, the beam has monolithic sections of PCM based on woven filler associated with spiral ribs. At the same time, monolithic sections serve to connect the ends of the spiral ribs and for docking with the fuselage structure. Monolithic sections are designed for joining the beam with floor elements. The beam is made with longitudinal ribs extending on the upper and lower surfaces. All ribs have a rectangular section and a unidirectional structure, since all the fibers reinforcing them are directed along the axis of the ribs. The location of the transverse and longitudinal ribs is chosen so that each rib in the intersection zone intersects with only one other rib.

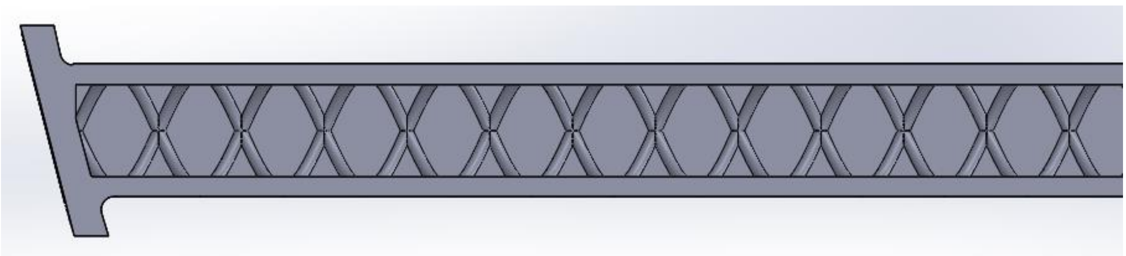

Fig. 2.3. Structure of the beam.

The angle of intersection of the spiral ribs is 45 ± 5° to the longitudinal axis of the beam, because this angle is optimal when the floor beam is loaded with torques, and torque loads are present during all aircraft flight regimes, including during take–off and landing. The transverse ribs are located at an angle of 90° to the mandrel axis, and the longitudinal ribs are parallel to the part axis. Moreover, for technological reasons, the longitudinal ribs are arranged in pairs and symmetrically on opposite flat parts of the floor beam [35].

Longitudinal ribs and monolithic sections both have a closed shape and repeat the cross section of the floor beam. That is, they have the shape of a rectangle with mating radii *R*. Longitudinal ribs have different widths from spiral ribs. The number of longitudinal ribs in a particular floor beam design is determined by the loads acting on it. For some floor beams, the operational loads are such that transverse and longitudinal ribs are not required. In this beam, 2 longitudinal ribs are used, which fully cope with the loads that act on the beam [36].

All helical fins have the same thickness. The longitudinal and ribs also have the same thickness as the spiral ribs. The same thickness is achieved by varying the width of the ribs, because strength calculation optimizes the required cross–section of longitudinal and transverse ribs and, given their thickness, their width is determined.

The floor beam has a layered structure, because its formation is carried out by layers of fibrous filler impregnated with a polymer binder, which is called a prepreg. The ribs are wound with a prepreg in which all the fibers of the filler are parallel and directed along its length, such a prepreg is called unidirectional. Monolithic sections are wound, including fabric-based prepreg and it is called woven prepreg.

Layer structure of one of the unidirectional ribs, including the places where they intersect with two other unidirectional ribs, and the layers of one rib alternate with the layers of other ribs crossing it, forming a single design of parts.

Where the ribs intersect, there are more layers and less resin, and where the ribs intersect, there are fewer layers, which are compensated by the higher resin content.

In places of monolithic sections, after the formation of each first layer of all ribs, the first layer of woven prepreg is laid with a width of a monolithic section. Further, everything is also repeated in layers until the required thickness of the part is formed. As a result, there is a sequential alternation of layers of woven and unidirectional prepregs at their intersections according to a scheme similar to the scheme in fig. 2.2, and in places where there are no ribs, PCM is formed with a woven filler and with a relatively high content of polymer resin, as these places contain fewer layers [33].

The implementation of the proposed design occurs in the following sequence.

A floor beam made of polymer composite materials is wound on a winding machine onto a special mandrel with a layer-by-layer unidirectional prepreg tape for ribs and a woven prepreg tape for monolithic sections, as follows.

First, sequential winding of the first layers of all ribs is carried out in any sequence. Moreover, the chosen sequence on the first layer must also be observed when winding the remaining layers of ribs. For definiteness, it is better to choose the following winding sequence: spiral ribs, transverse ribs, longitudinal ribs.

After winding the first layer of helical ribs, the first layer of longitudinal ribs is wound, and then the first layer of transverse ribs. After that, in places of monolithic sections, one layer of woven prepreg is wound.

The formation of the first layer of helical ribs takes place over several revolutions of the winding machine until the first layers of all helical ribs are formed.

Usually, the formation of one layer of helical fins requires winding with a lead of two or more, depending on the frequency of the helical fins. In this case, intersections of ribs with reinforcement angles of +45° and -45° are formed. Upon completion of the formation of the first layer of spiral ribs, the prepreg tape is cut off and the winding of the transverse ribs is started.

The first layer of the first transverse rib is formed in one turn of the mandrel, after which the prepreg strip is cut and the first layer of the next transverse rib is also formed, and so on. until the completion of the formation of the first layers of all transverse ribs.

The first layers of longitudinal ribs are wound in pairs, as shown in fig.2.3, which shows a mandrel with a floor beam area marked with dash-dotted lines and technological allowances. The winding of the first layer starts from the zone of one of the technological allowances, the winding of the layer of the longitudinal rib is continued in the zone of the part until the prepreg tape enters the zone of the technological allowance from the opposite side of the mandrel. Here, the prepreg tape is wrapped around the mandrel and returned to the part area at the bottom of the mandrel. Further, the winding of the lower rib symmetrically located to the first longitudinal rib continues until it enters the technological allowance zone, from where the winding of the layer of the longitudinal rib began. Here the prepreg tape is cut. The place of beginning and end of winding of the layer of the first pair of the first layer of longitudinal ribs is marked with a line. The next pair of longitudinal ribs is wound in the same way until the winding of all first layers of longitudinal ribs is completed [35].

Then the first layers of monolithic sections are wound with a woven prepreg. The scheme of their formation is similar to the scheme of formation of transverse ribs. The difference is that the woven prepreg tape coincides with the width of the monolithic section and when it is wound, the woven prepreg intersects not only with all the ribs in this zone, but also with the weaves of these ribs. Therefore, in these places in the floor beam there will be the largest number of layers and the lowest content of the binder due to its squeezing into places with a smaller number of layers during the subsequent curing operation of the part.

The smallest number of layers is formed in places where there are no ribs, where a composite material is formed only on the basis of a woven filler, which is compensated by a high content of a polymer binder in it.

Further, everything is also repeated in layers, i.e., on the first layers of spiral, transverse, longitudinal ribs and monolithic sections, the second layers of spiral, transverse, longitudinal ribs and monolithic sections, respectively, are sequentially laid, then the third, fourth layers, etc. until the specified thickness of the part is formed.

The sections of the floor beam between the ribs and the monolithic sections remain unfilled with material and through holes are formed there. After the winding of the part blank is completed, it goes through the molding operation in an oven or autoclave under the influence of the temperature, pressure and holding time required by the technological process until the binder is cured [35].

Thus, a mesh structure is obtained, in which all the ribs and monolithic sections, after the completion of the curing and machining operation to separate the technological allowance, form a single structure of the floor beam.

The claimed of design model implements the main advantages of polymer composite materials (PCM) – almost all elements of the floor beam – unidirectional ribs, work along the reinforcing fibers, except for monolithic sections in places where woven reinforcing fillers are located. Moreover, monolithic sections with woven reinforcing fillers redistribute concentrated loads from the attached elements to unidirectional ribs. Such a design is much lighter than both metal analogues and an I-beam of a PCM floor. In addition, the claimed of design model reduces labor costs for the manufacture of floor beams by eliminating the operation of forming cover layers and eliminating the operation of machining to create through holes, reduces labor costs for the manufacture of fasteners by simplifying the design of assembly structures [33]. Such simplifications make it possible to realize the presence of flat surfaces on the shell and the presence of monolithic sections. Monolithic sections based on woven fillers make it possible to distribute concentrated loads from fasteners in a structurally simple way attached parts to a sufficient number of ribs without causing their overload. Also, the complexity of assembling the floor beam with the parts attached to it is reduced, because fasteners have a much simpler design. For the same reasons, labor productivity in assembly operations increases. Due to the use of plastic woven reinforcements on monolithic sections in this technical solution, it is enough to drill mounting holes in them in these places and install simple structural fastener details, for example, a bolt with a nut. This further simplifies the design of fasteners and reduces the complexity of assembly even more.

2.3. Comparison of traditional and designed beam

1. Traditional Beam (Duralumin)

- The structural floor beam of this design is made of duralumin and features a U-shaped cross-section with a thickness of 2 mm. It runs along the aircraft's axis and supports the cabin floor load. The height of this beam varies from 40 mm at the ends to 75 mm in the middle, with a width of 210 mm. The beam is covered on top with a sheet of duralumin, while a 0.6 mm thick plate protects its underside.
- The beam ends are secured using brackets on frames #1 and #5. For convenient access to subsystems located beneath the floor, the central section of the cabin floor between frames #4 and #5 is designed to be easily removable.

1. Composite Beam (Polymer Composite)

- The structural floor beam of this design is made from polymer composite materials and differs from the traditional beam in several aspects. Its primary goal is to create a lighter and more integrated structure for aircraft use. Additionally, the beam's design should facilitate cable routing and other communications without compromising its strength.

- This beam consists of a hollow lattice structure with a cross-section resembling a rectangular frame with rounded corners. The spiral ribs are designed as counter-rotating spirals with rectangular turns that intersect and connect to each other, linked at the ends by solid sections of polymer composite material.

Summary of all of the above in table 2.1.

Table 2.1.

Comparison of materials

Comparison Aspects	Aluminum Beam	Polymer Beam (CFRP)
Material	Aluminum	Carbon Fiber Reinforced Polymer (CFRP)
Shape	U-shaped, specified dimensions	Mesh-like structure with rounded angles
Weight	Moderate due to aluminum	Much lighter, attributed to the use of composites
Strength	Steel-like strength but heavier	High strength with significantly less mass
Corrosion Resistance	Good	Absence of corrosion issues
Durability	Good	Polymer materials can have a long service life, depending on operating conditions
Beam Ribs	Reinforcement not as significant, simple spiral ribs utilized	Complex opposing spiral ribs and monolithic segments employed, promoting optimal load distribution

These differences enhance the beam's characteristics:

1. Mass Characteristics. The use of polymer composites allows for a significantly lighter beam compared to the duralumin alternative. This leads to a reduction in the overall aircraft weight, enhancing its fuel efficiency.

2. Structural Strength. The hollow lattice construction enables an optimal load distribution, improving the beam's strength. Specifically, reinforced solid sections made of polymer composite material help distribute concentrated loads from attached elements onto a group of spiral ribs, increasing the structure's stability.

3. Communication Passage. The beam's design using polymer composites effectively allows cables and other communications to pass through without compromising its strength.

4. Spiral Ribs. Counter-rotating spiral ribs with rectangular turns contribute to the beam's resistance to torsional loads that might occur during various flight modes.

5. Simplified Assembly. The specifications of the second beam reduce assembly complexity as the use of spiral ribs and solid sections simplifies the structure of fastenings, enhancing assembly productivity.

6. Integrated Structure. With a more integrated structure, the polymer composite beam allows for a reduction in the number of nodes, thereby reducing weight and assembly complexity, improving the aircraft's overall characteristics.

Therefore, the new beam based on polymer composites is a more effective alternative in terms of mass, strength, assembly and functionality compared to the duralumin beam.

2.4. Economic analysis

After examining the structure and peculiarities of beams with aluminum covering and composite beams, we can conduct an economic analysis to determine which of these beams will be more cost-effective in production.

The efficiency and economic feasibility were analyzed based on assessing the production costs, technical durability, technical specifications, material costs, maintenance, and potential operating expenses. The study involved an analysis of economic parameters such as the service life, potential repair and maintenance costs, material expenses, and considerations of factors influencing the overall effectiveness and economic viability of both beam types in the context of their application in aircraft construction [17].

The results of the economic analysis of composite material and aluminum alloy beams will provide the opportunity to compare the effectiveness of using these materials in aircraft construction, which could be significant for decision-making in material selection for aircraft structures (table 2.2).

Table 2.2

Economic analysis

Parameters	Duralumin beam	Beam on the base on CFRP
Cost of material (1 kg)	$100-300	$300-500
Cost of production	$1500	$1000
Overall expenses	$5000	$7000
Labor costs for assembly	$1000	$1000

Continue table 2.2

Integration costs	5-15%	10-20%$
Weight (kg)	8	4
Maintenance and repair costs	$1000	$1000
Service life	30	40

When considering the cost analysis between the two beams, the beam based on CFRP (Carbon Fiber Reinforced Polymer) appears to be more advantageous in several aspects compared to the duralumin beam. Here's a detailed breakdown of the cost benefits and potential savings:

1. MaterialCost:

CFRP-based beam is higher by $200-200 per kilogram compared to the duralumin beam.Opting for the duralumin beam could save $200-200 per kilogram in material costs.

2. Production Cost:

CFRP-based beam is lower by $500 compared to the duralumin beam.Choosing the CFRP-based beam can result in savings of $500 in production costs.

3. OverallExpenses:

CFRP-based beam is higher by $2000 compared to the duralumin beam.Selecting the duralumin beam could save $2000 in overall expenses.

4. IntegrationCosts:

CFRP-based beam is higher by 5-15% compared to the duralumin beam.Opting for the duralumin beam might result in lower integration costs, potentially saving 5-15% of integration expenses.

5. Weight:

CFRP-based beam weighs half as much as the duralumin beam.Choosing the CFRP-based beam could save on transportation costs due to its lighter weight.

6. Service Life:

CFRP-based beam is longer by 10 years compared to the duralumin beam.Opting for the CFRP-based beam could result in long-term savings due to the extended service life.

In summary, while the duralumin beam appears to have lower material and overall production expenses, the CFRP-based beam offers advantages in terms of lower production costs, higher durability with a longer service life, and potential savings in transportation due to its lighter weight.

By choosing the less expensive duralumin beam, potential savings could amount to:

- $200-200 per kilogram in material costs;
- $500 in production costs;
- $2000 in overall expenses;
- 5-15% in integration costs;

Potentially reduced transportation costs due to a lighter weight.

Conclusion to the Part 2

In this part, the attention was focused on the passenger cabin floor structural element. It is shown the development of a new, lighter-weight floor beam for aircraft. The main goal of this study was to innovate the main structure that not only reduces weight but also seamlessly integrates into the aircraft design while accommodating essential cabling and communication pathways without compromising structural integrity.

The utility model proposed in this work presents a novel design, featuring a hollow mesh structure with cross spiral rods interconnected to form a rectangular frame with rounded corners. This innovative beam incorporates anti-twist spiral ribs made from sections of polymer fabric composite material, achieving a balance between weight reduction, strength, and integration capabilities.

A comparative analysis was conducted between the traditional duralumin beam and the engineered CFRP-based beam. While the duralumin beam initially appears more cost-effective in terms of material and production expenses, the CFRP-based beam offers substantial long-term advantages. It exhibits increased durability, a longer service life, and the potential for cost savings in transportation due to its lighter weight.

The economic analysis conducted in this study reveals that opting for the CFRP-based beam, despite initial higher costs, could yield significant benefits over a 10-year period. This includes potential savings in material costs, production expenses, overall expenditures, integration costs, and the possibility of reduced transportation expenses due to its lightweight nature.

In essence, this research demonstrates that while the duralumin beam might seem initially more economical, the CFRP-based beam offers a compelling long-term investment due to its durability, extended service life, and potential savings in various cost categories, ultimately contributing to enhanced efficiency and effectiveness in the aviation industry. Subsequent sections of this thesis will consider the practical application, testing, and specific implications of these findings in the aviation field.

PART 3. 3D MODELING OF THE DESIGNED STRUCTURE

3.1. Calculation of beam

In the design and calculation of a beam, the crucial aspect involves considering the actual forces and deformations that may arise. Thanks to strength calculations, it becomes possible to determine how these forces will actually operate.

At the initial stage of calculations, the scheme of the beam is developed and the forces acting on it are determined (fig. 3.1).

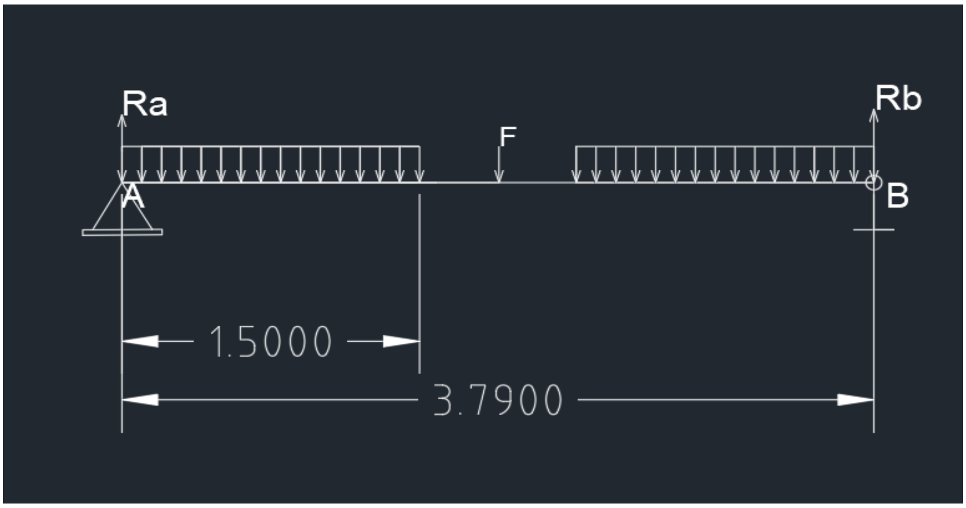

Fig. 3.1. Skim of loading.

Next, it is necessary to specify the input data for the calculation:

L=3.8 m, a=1.5 m, F=4000 H, q=10800 N\m

1. Determination the reaction

$$\sum M_a : -q_a - F\frac{1}{2} - q_a(1-\frac{a}{2}) + R_b l = 0$$

$$R_b = \left(q\frac{a^2}{2} + \frac{1}{2}Fl + q_a l - q\frac{a^2}{2}\right)\frac{1}{l} = \frac{1}{2}F + q_a$$

$$\sum M_b : -R_a l + q_a\left(l - \frac{a}{2}\right) + F\frac{l}{2} + q_a\frac{a}{2} = 0$$

$$R_a = \left(q_a l - \frac{q_a^2}{2} + \frac{Fl}{2} + \frac{q_a^2}{2}\right)\frac{1}{l} = \frac{1}{2}F + q_a$$

$$R_a = R_b = \frac{1}{2}\cdot 4000 + 10800\cdot 1.5 = 2000 + 16200 = 18200H$$

2. Determination Q and M in any section:

$$1)\quad Q = R_a - qx; \qquad M = R_a x - q_a \frac{x}{2}$$

$$X_1 = 0; Q = R_a; M = 0$$

$$X_1 = 0; \quad Q = 18200H; \quad M = 0H$$

$$X_2 = a \quad Q = R_a - q_a \quad M = R_a a - q\frac{a^2}{2}$$

$$X_2 = 1.5; Q = 200; M = \frac{400\times 1.5}{2} + \frac{10800\cdot 1.5^2}{2} = 3000 + 12150 = 15150H$$

$$2)\quad Q = R_a - q_a; \qquad M = R_a x - qa(x - \frac{a}{2});$$

$$X = a; \quad Q = R - q; \quad M = Ra - qa(x - \frac{a}{2});$$

$$X_2 = 1.5; \quad Q = 2000H \quad M = 18200\cdot 1.5 - 10800(1.5\cdot\frac{1.5}{2}) = 27300 - 12150 = 15150$$

$$X_3 = \frac{l}{2}; \; Q = R_a - q_a; \qquad M = R_a x - qa(x - \frac{a}{2});$$

$$X_3 = 1.9; \quad Q = 2000H; \quad M = 18200\cdot 1.9 - 10800\left(1.5\cdot\frac{1.5}{2}\right) = 34580 - 18630 = 15950$$

$$3)\quad Q = R_a - qa - F; \quad M = R_a x - qa\left(x - \frac{a}{2}\right) - F(x - \frac{l}{2})$$

$$X_3 = \frac{l}{2}; \; Q = R_a - qa - F; \quad M = R_a x - qa\left(x - \frac{a}{2}\right) - F\left(x - \frac{l}{2}\right);$$

$$X_3 = 1.9; \quad Q = 200 - 400 = -200H$$

$$M = 18200\cdot 1.9 - 10800\cdot 1.5(1.9 - 0.75) = 15950$$

$$X_4 = l - a; \quad Q = R_a - q_a - F; M = R_a x - q_a(x - \frac{a}{2}) - F(x - \frac{l}{2});$$

$$X_4 = 2.3; \quad Q = -2000H;$$

$$M = 18200 \times 2.3 - 10800 \cdot 1.5\left(2.3 - 0.75\right) - 4000 \cdot 0.4 = 15150$$

4) $Q = R_b + qx; \quad M = R_b x + q_a \dfrac{x}{2};$

$$X_1 = 0; \quad Q = R_a; \quad M = 0;$$

$$X_2 = a; \quad Q = R_a - q_a; \quad M = R_a a - q\frac{a^2}{2};$$

$$X_2 = 1.5; \quad Q = -18200; \quad M = \frac{4000 \cdot 1.5}{2} + \frac{10800 \cdot 1.5^2}{2} = 3000 + 12150 = 15150H$$

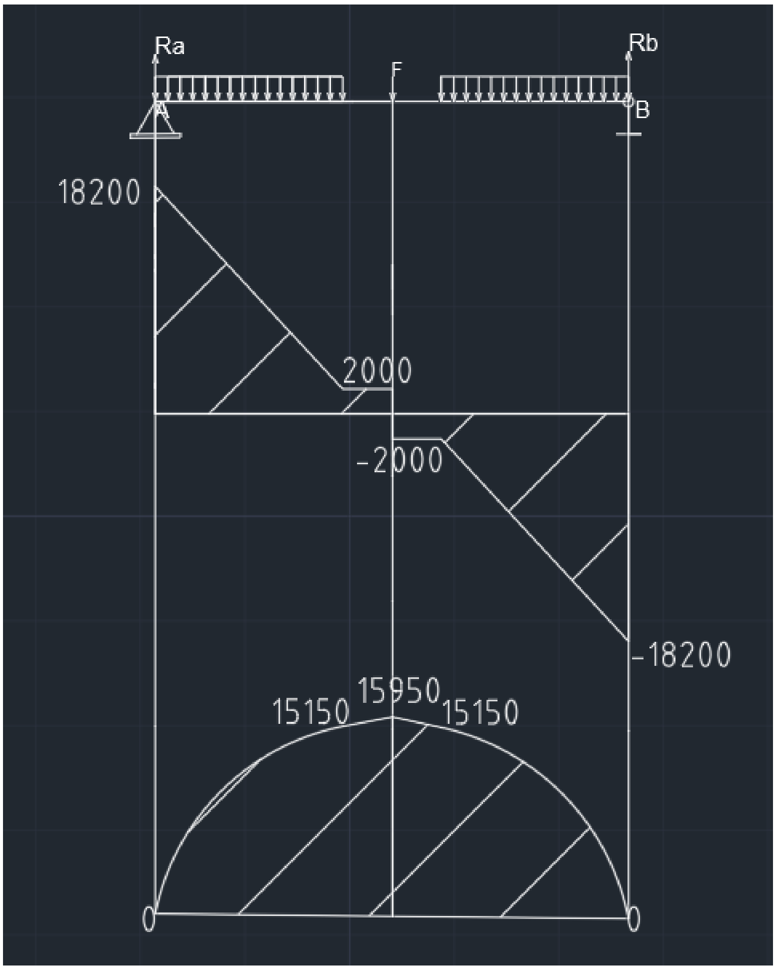

Fig. 3.2. Diagram of stress.

Conclusively, after conducting strength calculations and developing the diagram, it can be inferred that the graphical representation reveals stress levels within the beam that remain within safe thresholds. Consequently, a confident assertion can be made that the beam exhibits no inclination to fracture or malfunction due to an excessive load.

3.2. Unlocking Design Precision: A Comprehensive Exploration of the SolidWorks Program

SolidWorks, derived from the English words "solid" and "works," stands as a leading CAD software package dedicated to automating industrial processes throughout the stages of design and technological preparation for production. Developed by SolidWorks Corporation, initially founded by John Hirschtik, the software became an independent division of Dassault Systèmes (France) in 1997 [40].

Commencing its development journey in 1993 and entering the market in 1995, SolidWorks swiftly became a formidable competitor to products like AutoCAD, Autodesk Mechanical Desktop, SDRC I-DEAS, Compass, and Pro/ENGINEER. It earned the distinction of being the first CAD system to support solid modeling on the Windows platform, utilizing the Parasolid kernel.

Key problem areas addressed by SolidWorks include:

Design Preparation for Production (DPP):

- 3D design of products, accommodating varying complexities and manufacturing specifics.
- Development of design documentation aligned with GOST standards.
- Industrial design, reverse engineering, and communication system design (electrical harnesses, pipelines, etc.).
- Engineering analysis covering strength, stability, heat transfer, frequency analysis, dynamics of mechanisms, gas/hydrodynamics, optics and lighting, electromagnetic calculations, dimensional chain analysis, and more.
- Express analysis of manufacturability during the design phase.
- Data preparation for Integrated Electronic Technical Records (IETR).
- Data and process management at the Computer-Aided Process Planning (CPT) stage.

Technological Preparation for Production (TPP):

- Tooling and technological equipment design.
- Analysis of manufacturability for product design.
- Analysis of manufacturability for manufacturing processes (plastic molding, stamping, drawing, bending, etc.).
- Development of technological processes following industry standards.
- Material and labor rationing.
- Machining, including CNC machine program development, CNC program verification, machine operation simulation, and various machining methods such as milling, turning, turning-milling, electrical discharge machining, laser cutting, plasma cutting, water-jet cutting, punching dies, and coordinate measuring machines [40].
- Data and process management at the Tooling and Fixturing System (TFS) stage.

Data and Process Management:

- Unified digital product model handling.
- Electronic technical and management document flow.
- Collaborative development technologies.
- Facilitation of geographically distributed teams.
- Archiving of technical documentation adhering to GOST standards.
- Project management.
- Data protection using Electronic Data Signatures (EDS).
- Data preparation for Enterprise Resource Planning (ERP) and cost calculation.

SolidWorks comprises both in-house developed software modules and certified software from specialized developers, recognized as SolidWorks Gold Partners. This comprehensive system empowers industries to streamline their design and production processes, ensuring efficiency and compliance with industry standards [40].

3.3. Model of a beam

This section of the work aimed at determining the optimal composite material for a beam structure using the SolidWorks software. After conducting detailed calculations, which verified the beam's capacity to endure the required loads, the subsequent action is to create a three-dimensional model of the beam. The application of simulations through

SolidWorks aims to identify the best composite material for the structure, ensuring not only high strength but also optimal efficiency in operation. At this stage will be systematically analyzed various parameters and material properties, which will be crucial in selecting the material for further work on the construction.

A series of experiments are planned using the capabilities of SolidWorks to detect and compare the characteristics of different polymer materials. The obtained data will aid in determining the most suitable material that meets the requirements of strength, durability, and optimal functionality for use in our beam construction. Conclusions drawn from these investigations will be decisive in material selection and the further development of the structure.

The first step will be to create drawings of the beam and show the integration of the it into airplane fuselage (fig. 3.3-3.4).

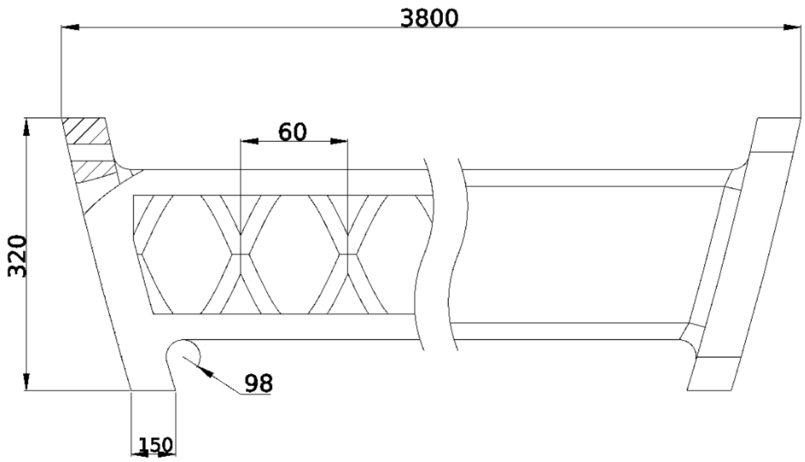

Fig .3.3. Drawing of beam.

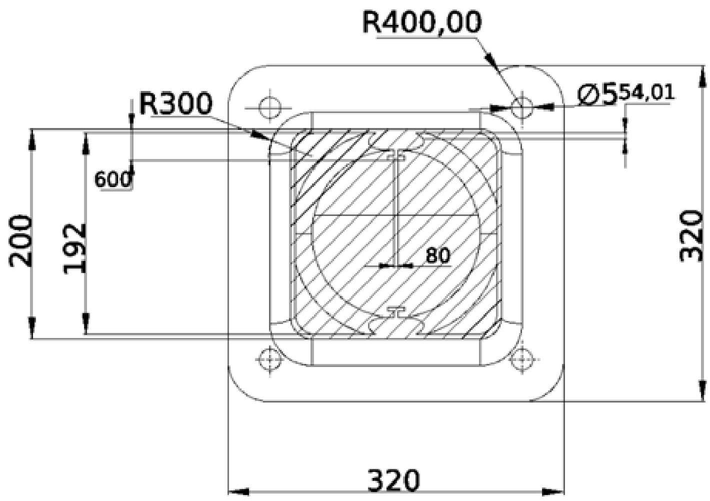

Fig .3.4. Scheme of beam assembly to the frame.

Using 2D drawing of the beam was created the 3D model for farther stress-strain analysis (fig. 3.5). Next step is application of forces that will represent the real loading of the beam (fig. 3.6).

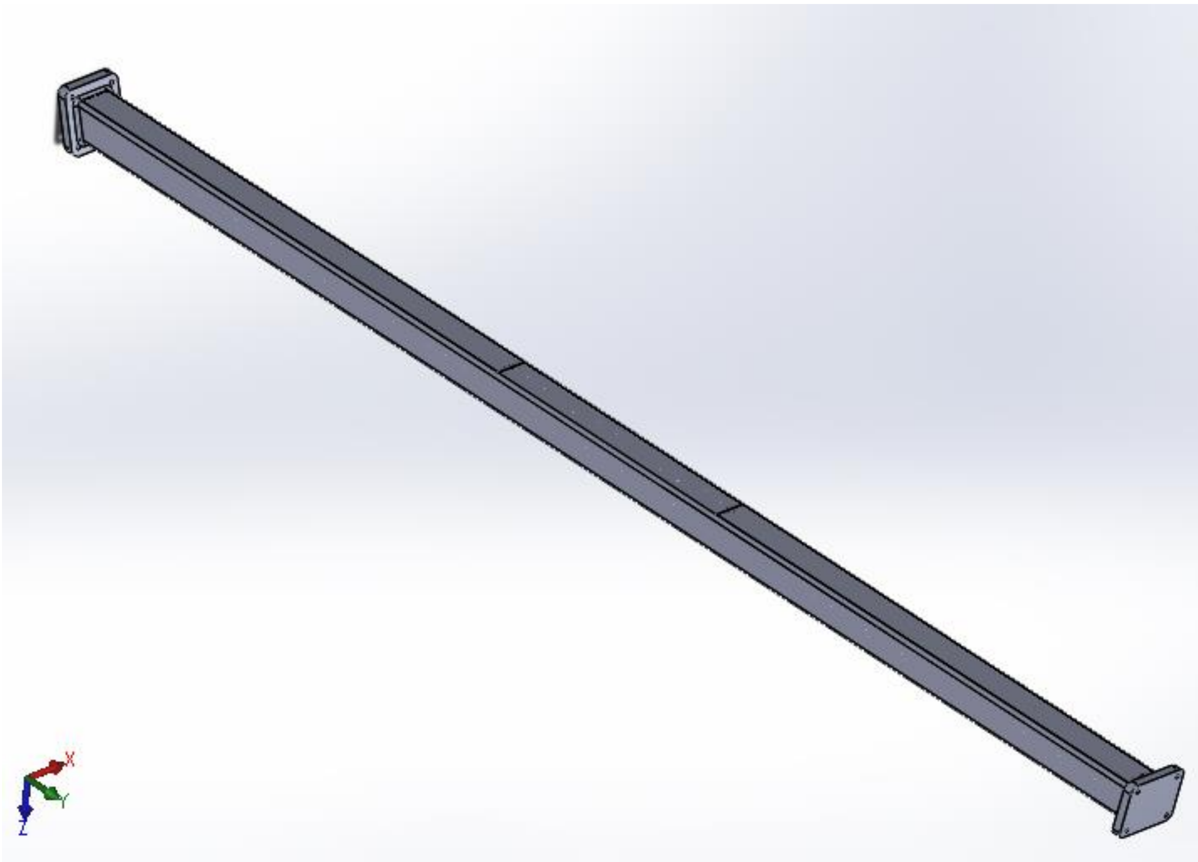

Fig. 3.5. 3D Solid model.

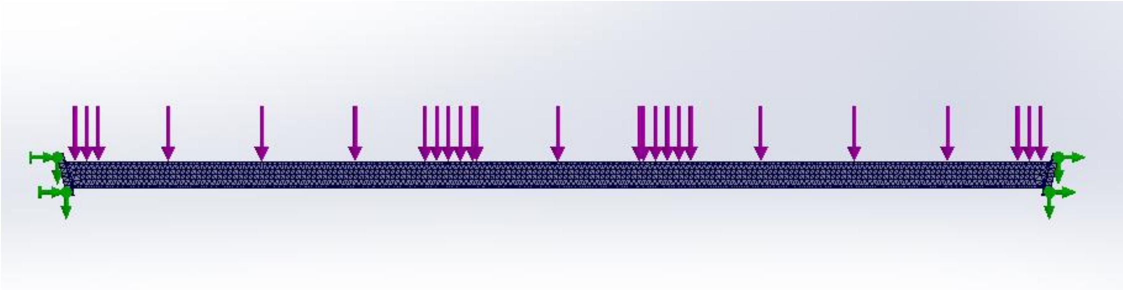

Fig. 3.6. Force application.

As a result of the computer-aided design of the beam, detailed visualization and modeling work was performed in 2D and 3D spaces. Through careful integration of the beam into the fuselage, its exact position and interactions in the system were determined. Taking into account the distribution of forces on the 3D model, the beam is ready for experimental analysis. Having obtained the force distribution scheme, we can proceed to testing the strength of the beam.

3.4. Modelling of different beam materials

Testing with composite materials were performed in the next sequence: Organic matrix composites, metal matrix composites, ceramic matrix composites, polymer matrix composites, and carbon fiber reinforced polymer composites. N/m^2

The mechanical properties of testing materials show in tables 3.1-3.6

Table 3.1

Parameters of Organic Matrix Composites

#	Property	Value	Units
1	Elastic Modulus	15000000000	N/m^2
2	Poisson's Ratio	0.194	N/A
3	Shear Modulus	2500000000	N/m^2
4	Mass Density	1200	kg/m^3
5	Tensile Strength	5000000000	N/m^2
6	Yield Strength	2500000000	N/m^2
7	Thermal Conductivity	1,5	W/(m·k)
8	Specific Heat	1386	J/(kg·K)

After conducting a strength simulation of the beam, the following conclusions can be drawn. The simulation reveals significantly high stress near the attachment point, reaching 3.800e+07 MPa compared to the permissible load of 3.829e+07 MPa (fig. 3.10). Hence, the material at this specific location may experience fracturing, potentially resulting in the failure of the entire structure. The deformation scale equals 27.176.

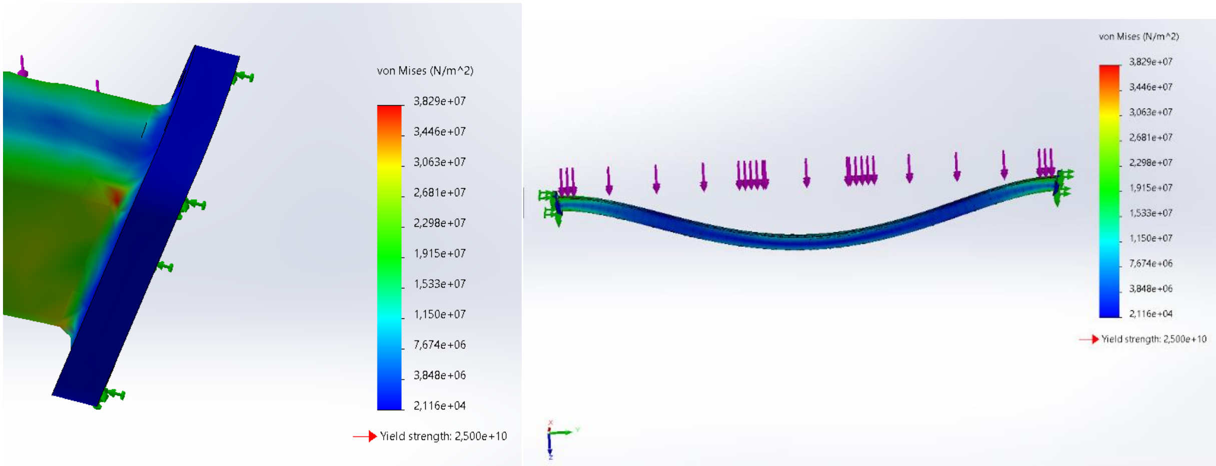

Fig. 3.10. and Fig. 3.11. Result simulation on Organic Matrix Composites.

Table 3.2

Parameters of Metal Matrix Composites

#	Property	Value	Units Metal Matrix Composites
1	Elastic Modulus	100000000000	N/m^2
2	Poisson's Ratio	0.3	N/A
3	Shear Modulus	5000000000	N/m^2
4	Mass Density	3000	kg/m^3
5	Tensile Strength	500000000	N/m^2
6	Yield Strength	400000000	N/m^2
7	Thermal Conductivity	50	W/(m·k)
8	Specific Heat	1386	J/(kg·K)

The simulation reveals significantly high stress near the attachment point, reaching 3.800e+07 MPa compared to the permissible load of 3.829e+07 MPa (fig. 3.12 -3.13).

Hence, the material at this specific location may experience fracturing, potentially resulting in the failure of the entire structure. The deformation scale equals 181.053.

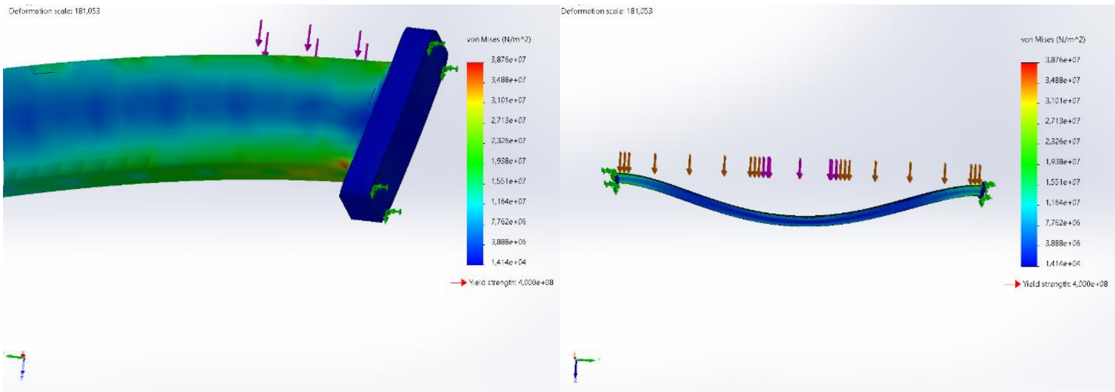

Fig. 3.12 and Fig. 3.13 Result Simulation on Metal Matrix Composites

Table 3.3

Parameters of Ceramic Matrix Composites

#	Property	Value	Units
1	Elastic Modulus	120000000000	N/m^2
2	Poisson's Ratio	0.2	N/A
3	Shear Modulus	300000000000	N/m^2
4	Mass Density	2000	kg/m^3
5	Tensile Strength	350000000	N/m^2
6	Yield Strength	450000000	N/m^2
7	Thermal Conductivity	5	W/(m·k)
8	Specific Heat	1386	J/(kg·K)

The simulation reveals significantly high stress near the attachment point, reaching 3.800e+07 MPa compared to the permissible load of 3.100e+07 MPa (fig. 3.10). Hence, the material at this specific location may experience fracturing, potentially resulting in the failure of the entire structure. The deformation scale equals 216.944.

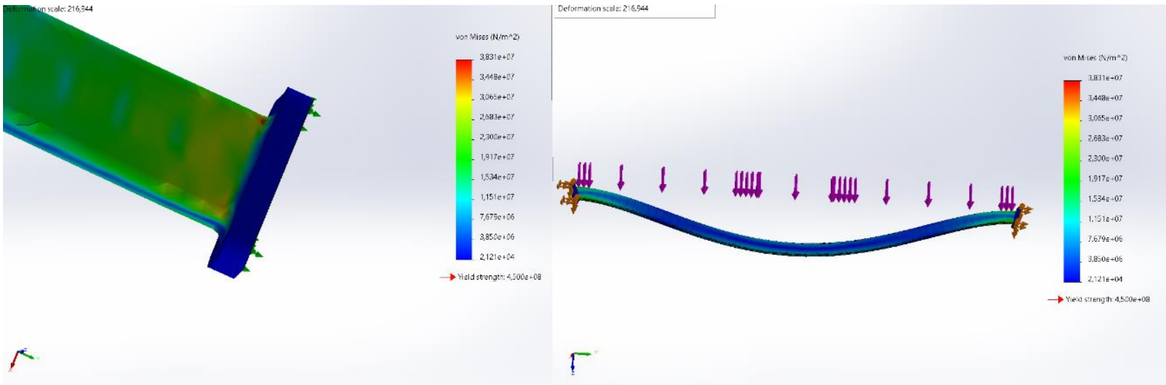

Fig. 3.14. and Fig. 3.15. Result Simulation on Ceramic Matrix Composites

Table 3.4

Parameters of Polymer Matrix Composites

#	Property	Value	Units
1	Elastic Modulus	10000000000	N/m^2
2	Poisson's Ratio	0.33	N/A
3	Shear Modulus	30000000000	N/m^2
4	Mass Density	1500	kg/m^3
5	Tensile Strength	70000000	N/m^2
6	Yield Strength	100000000	N/m^2
7	Thermal Conductivity	0,3	W/(m·k)
8	Specific Heat	1386	J/(kg·K)

The simulation reveals significantly high stress near the attachment point, reaching 3.890e+07 MPa compared to the permissible load of 3.501e+07 MPa (fig. 3.16-3.17). Hence, the material at this specific location may experience fracturing, potentially resulting in the failure of the entire structure. The deformation scale equals 18.1223.

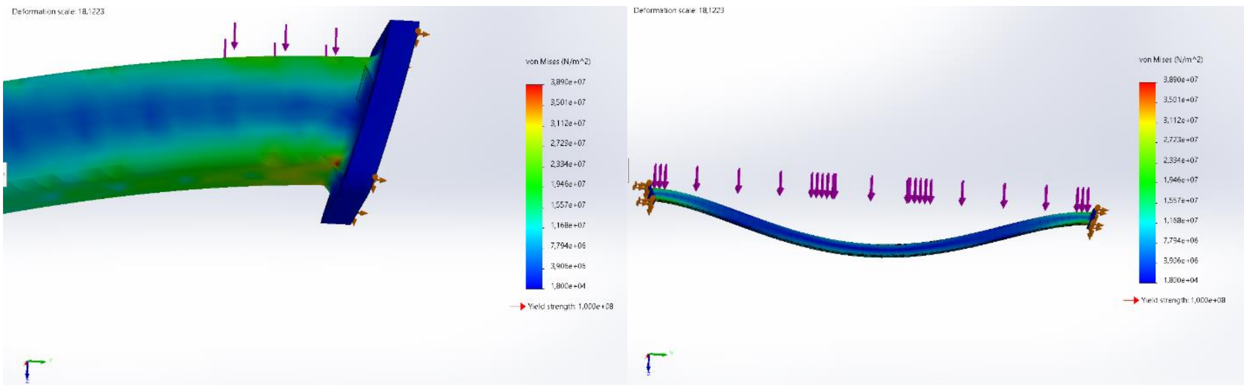

Fig. 3.16. and Fig. 3.17. Result Simulation on Polymer Matrix Composites

Table 3.5

Parameters of carbon fiber reinforced polymer composite

#	Property	Value	Units
1	Elastic Modulus	160000000000	N/m^2
2	Poisson's Ratio	0.194	N/A
3	Shear Modulus	2000000000	N/m^2
4	Mass Density	1600	kg/m^3
5	Tensile Strength	2000000000	N/m^2
6	Yield Strength	2000000000	N/m^2
7	Thermal Conductivity	50	W/(m·k)
8	Specific Heat	1386	J/(kg·K)

The simulation indicates that the highest stress occurs near the attachment zones, reaching 1.915e+07 MPa, which is well within the acceptable limit, considering the maximum allowable load is 3.829e+07 MPa (fig. 3.18). Therefore, the material and the beam's structure adequately withstand the imposed load. The deformation scale is measured at 289.254

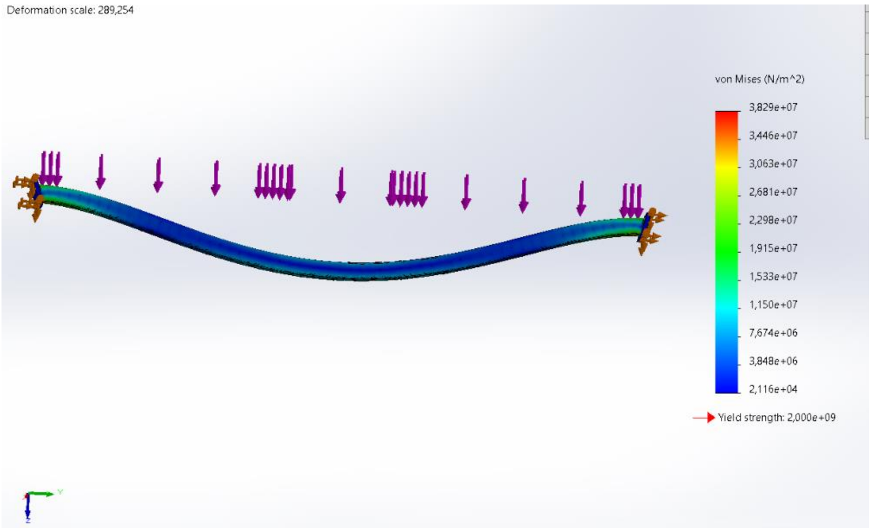

Fig. 3.18. Result Simulation on Parameters of carbon fiber reinforced polymer composite

Table 3.6

Parameters of Aluminum Allot 7075

#	Property	Value	Units
1	Elastic Modulus	719920000000000	N/m^2
2	Poisson's Ratio	0.33	N/A
3	Shear Modulus	26890000000000	N/m^2
4	Mass Density	2810	kg/m^3
5	Tensile Strength	219999997.9	N/m^2
6	Yield Strength	94999999.42	N/m^2
7	Thermal Conductivity	173	W/(m·k)
8	Specific Heat	1386	J/(kg·K)

The simulation indicates that the highest stress occurs near the attachment zones, reaching 3.501e+07 MPa, which is well within the acceptable limit, considering the maximum allowable load is 3.829e+07 MPa. (fig. 3.19). Therefore, the material and the beam's structure adequately withstand the imposed load. The deformation scale is measured at 130.481.

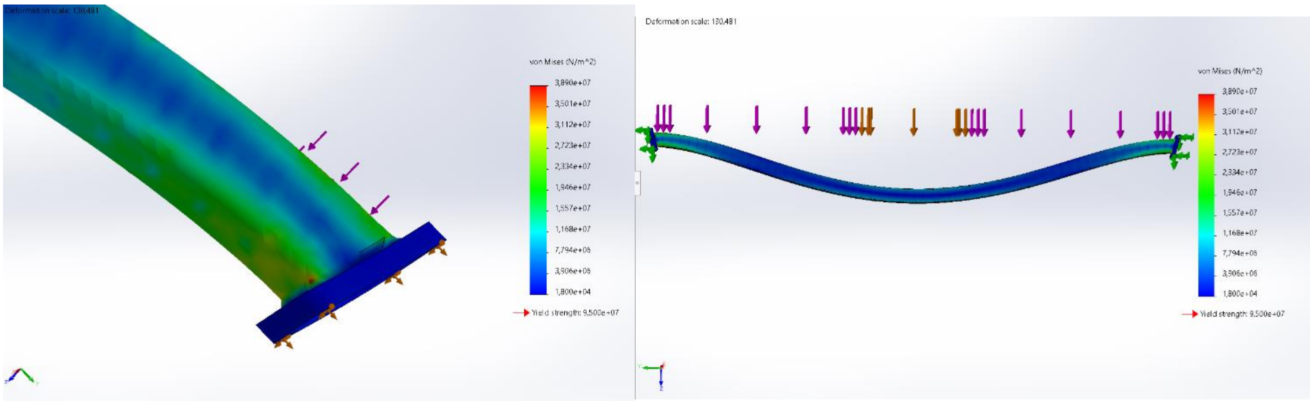

Fig. 3.19. Result Simulation on Aluminum Aloy 7075

3.5. Discussion of the results

Six different materials were selected for the study: Organic Matrix Composites, Metal Matrix Composites, Ceramic Matrix Composite, Polymer Matrix Composite, Carbon Fiber Reinforced Polymer Composites, and Aluminum Alloy 7075. Each material underwent strength testing and deformation measurements according to standard protocols.

Results:

1. Organic Matrix Composites. Significantly high deformation was observed near the attachment point, close to the permissible limit. The deformation scale was relatively low.

2. Metal Matrix Composites. Similar to organic matrix composites, this material exhibited significant deformation near the attachment point, but the deformation scale was higher.

3. Ceramic Matrix Composite: This material showed less deformation within the permissible limit, but the deformation scale was high.

4. Polymer Matrix Composite: The material demonstrated considerable deformation, yet the deformation scale was lower compared to some others.

5. Carbon Fiber Reinforced Polymer Composites: This material exhibited noticeable deformation with a relatively high deformation scale compared to the permissible load.

6. Aluminum Alloy 7075: This aluminum alloy displayed minimal deformation within the permissible limit, but the deformation scale was slightly higher compared to other materials.

Table 3.7

Result of simulations

Material Type	Maximum Deformation at Attachment Point	Permissible Deformation	Deformation Scale
Organic Matrix Composites	3.800e+07	3.829e+07	27.176
Metal Matrix Composites	3.800e+07	3.829e+07	181.053
Ceramic Matrix Composite	3.100e+07	3.800e+07	216.944
Polymer Matrix Composite	3.501e+07	3.890e+07	18.1223
Carbon Fiber Reinforced Polymer Composites	1.915e+07	3.829e+07	289.254
Aluminum Alloy 7075	3.501e+07	3.890e+07	130.481

- Material with the smallest deformation

The material with the smallest deformation scale is the Polymer Matrix Composite. According to the data, the maximum deformation near the attachment point for this material is 3.501e+07, which remains within the permissible limit of 3.890e+07. The deformation scale in this case amounts to 18.1223.

This material, having the smallest deformation scale among the specified materials, may possess certain technical advantages concerning its strength and resistance to loads. Its low deformation scale indicates that the material can withstand loads close to the permissible limit with minimal changes in its internal structure or shape. This could be crucial for certain applications within the aviation industry where structural integrity is paramount.

- The worst material

Based on the provided data, the material most likely to experience breakage is the Ceramic Matrix Composite. The highest deformation near the attachment point for this material reaches 3.100e+07, which approaches but remains below the permissible limit of 3.800e+07. The deformation scale in this case amounts to 216.944.

High deformation near the material's strength limit can potentially lead to breakage. If a material is too close to its strength limit, even minor external forces or loads could result in cracks or fractures. This makes the material less resistant to loads compared to other materials where the deformation scale remains higher or is further from the strength limit.

- The best material

Based on the given data, the best material in terms of strength and deformation under load is the Polymer Matrix Composite. This material has the lowest deformation scale among all the listed materials (18.1223), which remains within the permissible limit, and yet exhibits less deformation compared to other materials. This indicates that the material can withstand loads with fewer changes in its structure and form.

Such a material might be desirable in the field of aviation manufacturing, where strength and the material's ability to endure loads with minimal alterations are crucial.

Conclusion to the Part 3

The comprehensive exploration encompassing the Calculation of Beam, Comparative Analysis of Beam Materials, and the Comparative Analysis post-experimentation has provided profound insights into the behavior of various materials under stress and loading conditions in beam structures.

In the first section, the Calculation of Beam, the theoretical underpinnings were examined, offering a fundamental understanding of the expected performance and behavior of beams under applied loads. This section laid the groundwork for assessing the strength and deformations of various materials used in beam constructions.

The Comparative Analysis of Beam Materials scrutinized diverse materials, highlighting their strengths, limitations, and behaviors under stress. Through meticulous assessment, it was evident that each material displayed unique attributes under loading conditions, shedding light on their suitability for different structural applications. The evaluation facilitated a clearer understanding of the implications and advantages of various materials in the aviation industry, laying the groundwork for further targeted material selection in construction.

The Comparative Analysis after Experiment was instrumental in substantiating the theoretical assumptions with empirical data. The practical examination unveiled crucial performance disparities among the materials under actual loading conditions. The outcomes established a correlation between the theoretical calculations and the real-world behavior of materials. The identification of the Polymer Matrix Composite as the material with the lowest deformation scale, yet within the permissible limits, underscores its potential for resilient structural applications in aviation engineering.

This collective analysis provides a robust foundation for informed decision-making in material selection for beams within the aviation industry. The results outline the significance of not only theoretical estimations but also the critical role of practical testing in comprehending material performance, aiding in the optimization of structural integrity and performance in aviation construction.

PART 4. ENVIRONMENTAL PROTECTION

Environmental protection is now a trend that is being closely monitored in various economic and transport sectors. Air transport has many advantages (e.g. speed and safety) compared to other modes of transport. The environmental impact of aviation is significant, despite the fact that many important aviation organizations regularly assess the level of this impact and take appropriate measures. Air transport also has an impact on air quality, especially in areas with airports, as the majority of emissions from internal combustion engines occur during take-off and landing. To reduce the environmental impact of aviation, aircraft manufacturers are developing new types of engines and using new types of materials in aircraft production. Despite the measures taken to improve aviation safety, aviation accidents are still frequent and also have a negative impact on the environment. Take–off and landing are the most important phases of flight in terms of safety and environmental impact [1]. The environmental impact of aviation has been the subject of many studies. The most significant impact on the air is caused by the combustion of hydrocarbon fuels in the internal combustion engines of vehicles, which produce toxic and carcinogenic substances, as well as substances involved in the global warming of the Earth's atmosphere (CO2, N2O, CH4) [24].

However, air transport not only has a direct impact on the environment through its own transportation services, but also indirect impacts such as air, soil and water pollution in the event of incidents and accidents. Air transportation, and hence aviation technology, is constantly evolving and for various reasons new materials well suited for use in aviation are emerging. Such materials include composite materials, which have become an integral part of aircraft structures. Despite the operational advantages of these materials, composite materials in aircraft construction have disadvantages as well, which are related to the fact that when a composite multilayer structure is used, weakening of the internal structure of this structural material cannot be easily detected. Selected technological aspects of composite materials in aircraft design and construction are highlighted in Dutton et al [8]. The authors discuss important technological differences between composites and metals, differences in manufacturing processes, design procedures and material characterization, in particular the causes and nature of damage that can occur in service. In the context of aircraft accidents and the aircraft structural materials used, heat exposure during an aircraft fire is an important issue.

4.1. Problems and Solutions in the Sphere of Ecology in the Production of Polymer Materials.

Polymeric materials are usually complex systems that utilize a variety of polymeric components. The production of these materials is capable of meeting the needs of various industries, agriculture and households. It is a key challenge in polymeric materials technology. During the manufacture of multi-component polymers and their practical use there are processes of separation of harmful low molecular weight substances. Their content, depending on the operating conditions, can be several percent by weight of polymeric materials. When interacting with polymers, dozens of compounds of different chemical nature can be formed [30].

The production and use of polymers have a direct or indirect impact on the human body through the environment, the production environment and the living environment. After use, polymers and polymer products are often discarded into the soil. As a result of the decomposition process, soil, wastewater and the environment are damaged. The production and use of polymeric materials remains a serious environmental problem.

Polymer production is one of the fastest growing industries. In 2010, global polymer production grew at an average annual rate of 5-6%, reaching 250 million cubic tons. The per capita consumption of polymers in developed countries was 85-90 kg. The interest is driven by the production of polymers, primarily based on a variety of technical materials.

Polymeric materials (PM) with different physicochemical, structural and technological properties based on various plastic and elastomeric components are widely used in various spheres of national economy and medicine. This is due to the formation of waste at all stages of production and processing of polymeric materials. Therefore, the problem of their utilization remains urgent, and their negative impact on human health and the environment is a worldwide problem.

Polymers are divided into three groups depending on the source of waste generation.

Industrial wastes include three main categories:

- Technological wastes;
- industrial house hold wastes;
- domestic wastes [39];

Technological waste due to the production of polymeric materials arises at the stages of their synthesis and processing. These wastes are subdivided into secondary raw materials and technological wastes not suitable for recycling. The latter includes non-removable elements such as fringes, sharp edges and small parts, representing a share of between 5% and 35%. As the main components of the waste are insoluble and retain a quality comparable to the original polymers, recycling does not require specialized equipment and can be carried out in the same plant.

Processing of soluble substances should be carried out without disturbing the technological processes of production, including synthesis and processing, which leads to the formation of technological waste that can be completely eliminated. Waste arising in the production process can be used in the processing of various products, supplementing the range of raw materials.

Depending on the production needs, waste is collected from unused polymer material products in various industries such as agriculture (films, fertilizer bags), automotive (tires), and the packaging industry. Characterized by homogeneity and lower levels of environmental pollution, these wastes are of significant interest for recycling.

Waste of household origin is generated in homes, offices and businesses and then sent to municipal landfills. This waste acquires the status of mixed waste, falling into a new category of waste. The percentage of such waste is 50% of the total waste and their quantity is constantly increasing. However, there are difficulties in their utilization and recycling. This is due to the incompatibility of thermoplastics included in household waste, which requires a step-by-step separation of insulation materials [24].

The volume of industrial and domestic waste is increasing, accompanied by a growing interest in the use of polymeric materials. This interest is predominantly related to the increasing use of polymers in technical and domestic applications such as food, beverage and drug packaging, as well as in operating costs such as polyethylene films, greenhouses, feed production, fertilizer bags, household chemicals, kapron nets, household items, children's toys, sports equipment, carpets, linoleum, vehicles and others.

At the same time, the massive import of polymers from various sectors such as manufacturing, food processing, medicine, cosmetics and others is leading to an increase in polymer packaging waste. These wastes are characterized by unique properties: they do not rot, do not spontaneously decompose, do not accumulate and occupy small areas. However, it also causes damage to people's homes, water bodies and forests.

Burning of polymer waste emits toxic gases, creating favorable conditions for breeding rodents and insects in landfills. Thus, polymer products pose an environmental threat in the context of industrial and domestic waste.

Various measures have been taken to control environmental pollution associated with polymer production. One such approach is thermal recycling of polymer materials, which includes oxidizing them at high temperatures or incineration [24].

However, the value of substances and materials is lost during this process. The combustion of the products produces water and carbon dioxide, which implies that the feedstock, namely monomers, cannot be re-polymerized. In addition, as stated above, the release of large amounts of carbon dioxide into the atmosphere causes undesirable global effects, including the greenhouse effect.

It should also be noted that the combustion of polymers produces toxic volatile air pollutants, which in turn affects water and soil resources.

It is important to note that a large number of additives used in the production of polymers such as dyes, pigments and heavy metals used as catalysts in the synthesis of polyethylene are released into the environment in the form of various compounds. Toxic substances pose a serious threat to public health.

Plastic products may also include fillers, in the form of solid and gaseous substances. Plastics containing such fillers have high strength and rigidity. They are also non-flammable, electrically conductive and have higher coefficients of friction than pure plastic products. If the process of producing and processing fillers requires low energy and financial inputs, the cost of filler plastics can be reduced.

Today, despite previous indifference to nature, people are beginning to realize the tragic consequences. The solution of environmental problems places strict requirements on polymers and their production technologies: polymer production should be environmentally friendly or at least have minimal impact on the environment; used polymers should be recyclable or biodegradable.

4.2. Modern methods of utilization of polymer composite materials

4.2.1. Classification of modern methods of PCM utilization

When reviewing the classification of modern methods of recycling composite materials (CM), three main categories can be distinguished: physical, chemical and thermal methods (see fig.4.20). Among physical methods, in addition to mechanical crushing, radiation methods should be emphasized, which are based on the ability to decompose reacto plastic matrices under the influence of high-energy particle flows. Research in this area is being conducted in the USA [1,2], but difficulties with the technological equipment raise doubts as to whether this approach can lead to the creation of a commercially effective industrial technology.

Chemical methods of CM recycling based on depolymerization of binders are being tried [3,4]. Some progress has been made in this direction, including research carried out at the University of Nottingham [5]. This research is ongoing, including the European and international projects AFRECAR and EURECOMP [39].

An example of successful development of thermo catalytic method of CM processing is the technology developed by Adherent Technologies Inc. (ATI). The resulting fiber is short, but there is a growing global demand for such raw materials, which makes this process commercially promising. However, the disadvantages of the method are the high toxicity of the reagents used and the complexity of the equipment due to the need to carry out the process at high pressures (up to 3.5 MPa in the ATI process [6]).

Traditional thermal methods of municipal waste processing (incineration and gasification) have the disadvantage of destroying the most valuable components of CM (see Table 1). Therefore, more promising are the processes allowing to obtain CM fibers as a recycling product.

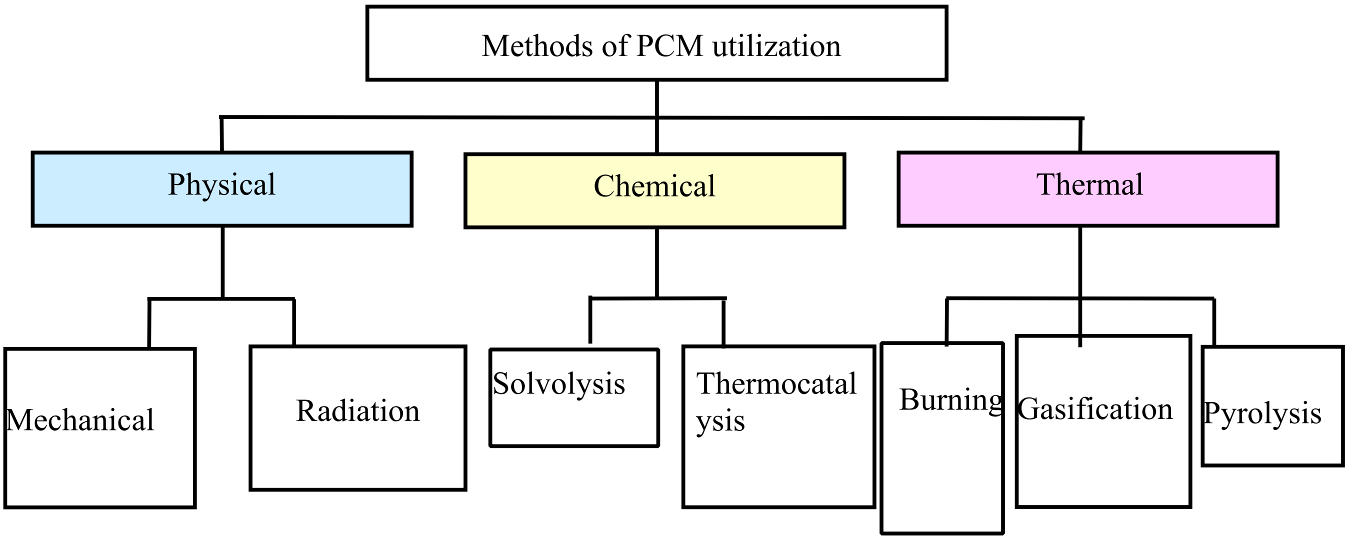

Fig. 4.1. Classification of modern methods of recycling PCM.

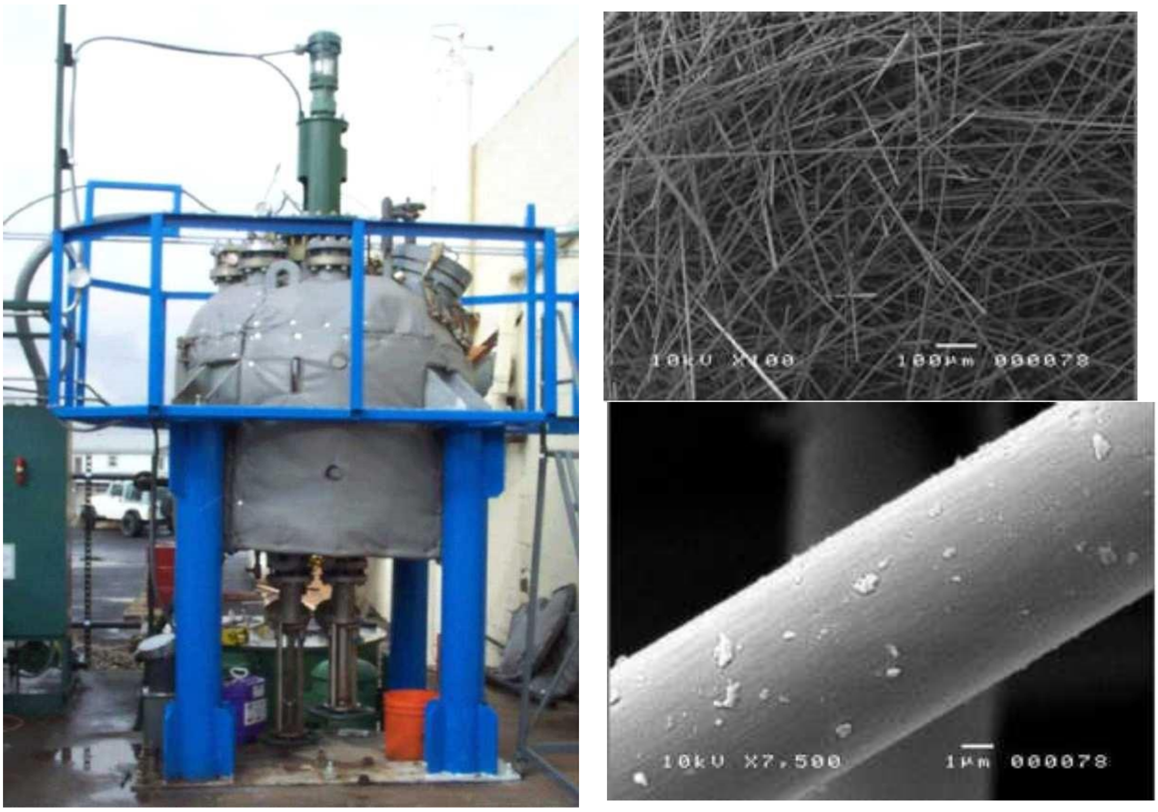

Fig. 4.2. Appearance of the catalytic reactor and carbon fiber obtained during processing using Adherent Technologies Inc. technology.

From a prospective point of view, the recycling of composite materials (CM) by dry pyrolysis seems to be very reasonable. This method involves thermal decomposition of the binder in the absence of oxygen. The product of such processing is fiber. This process can be heated by electric arc, high frequency currents or heat carriers [24].

Depending on the oxygen content, thermal methods for the utilization of composite materials (CM) are classified into three main groups: incineration methods (at oxygen content close to or above the stoichiometric content), gasification (oxygen deficient) and pyrolysis (no oxygen) (see fig. 4.2).

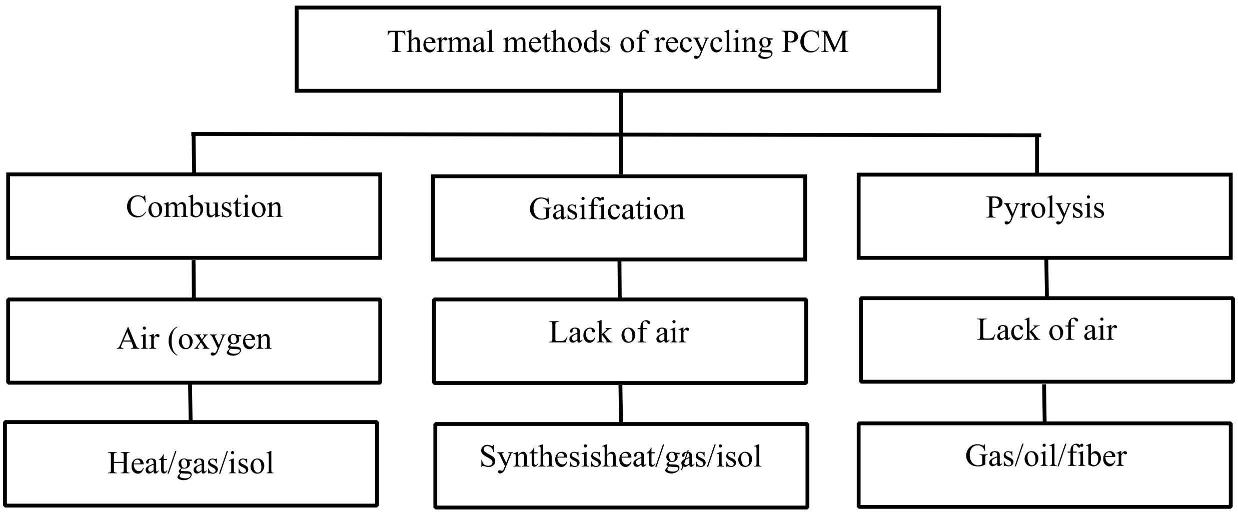

Fig. 4.3. Features and products of thermal methods of PCM utilization

The peculiarities of technological processes lead to the formation of a variety of products during the processing of combined materials (CM). Incineration mainly serves for the elimination of CM, with heat being the only usable product. Nevertheless, in practice, it is difficult to organize efficient combustion of CM, especially in the case of materials based on glass fibers and similar materials. Their combustible content is insufficient to support the combustion reaction.

In this connection, the combustion of CMs is often used as additives in various technological processes, such as cement kilns. Special types of kilns have also been developed for the combustion of CM, such as hearth furnaces, rotary kilns, circulating kilns, fluidized bed kilns, spray kilns and refractory nozzles.

In gasification, the resulting synthesis gas is used to produce heat and electricity. It has been reported that the gas produced from one ton of municipal solid waste by plasma gasification is sufficient to produce more than 1 MW of electricity. However, in the processing of CMs such as FRP, the above characteristics can only be achieved by gasification of carbon fiber-reinforced plastics. For fiberglass, the gasifiable content is found to be insufficient to create a commercially viable process [24].

In both combustion and gasification, there is a disadvantage of destroying valuable CM components. Therefore, processes that produce CM fibers as a final product seem more promising. In this context, the processing of CM by dry pyrolysis - thermal decomposition of the binder without access to oxygen - seems promising. The process is supported using electric arc, high frequency currents or heat carriers. Depending on the process temperature, a distinction is made between low-temperature pyrolysis or semi-coking (450-550 °C), medium-temperature pyrolysis or medium-temperature coking (up to 800 °C) and high–temperature pyrolysis or coking (900-1050 °C).

In addition, the low heat transfer efficiency between the combined materials (CM) and the hot gas acting as the heat transfer medium in this process is a drawback. An additional problem is the formation of dioxins. Current knowledge suggests that they are formed under the conditions of any chemical process of combustion or pyrolysis of organic substances in the presence of chlorine.

European Parliament Directive No. 2000/76/EC of December 4, 2000 on thermal treatment of dioxinogenic waste requires that incineration facilities be operated in such a way that the dioxin generated is kept at a temperature of at least 850 °C for a minimum of 2 seconds. With this in mind, it is worth considering the introduction of high-temperature pyrolysis processes for combined materials that meet these requirements. Such processes can be based on high-temperature pyrolysis in salt or slag melts using plasma heaters to stabilize the melt temperature.

4.2.2. Perspectives of the evolution of technologies for the processing of polymer composite materials (PCM) using high-temperature pyrolysis.

The development of such technologies can be carried out through melt pyrolysis using salts, alkalis or other materials. As noted in [8], a promising system for environmentally safe recycling of polymer composite materials (PCM) includes the following key elements:

- Plasma thermal stabilization of the melt.

- The use of magnetohydrodynamic (MHD) mixing to prevent overheating of the coolant.
- Two-stage gas purification system using emulsion filters that combine the functions of hardening reaction products and pre-purification of exhaust gases [39].

Gas hydrate water treatment system in a closed process water circulation system.

The integration of these technical solutions aims to commercially produce fibers from PCM waste with minimal environmental impact. When changing technological parameters, this equipment can be used for processing various toxic wastes.

This method can significantly reduce the decomposition time of the binder to tens of seconds. It is planned to use plasma heating for thermal stabilization of the melt. The results of studies on the processing of waste aluminum alloys indicate that MHD mixing prevents overheating of the melt. The proposed method also includes an innovative way to purify exhaust gases by combining the functions of high-temperature flow quenching and purification in emulsion filters.

Each element of the technological process has been successfully tested individually, confirming its effectiveness. However, their joint use in a single system has not been considered until now.

There are studies on mathematical modeling of electrically conductive media under MHD conditions. However, studies on plasma thermal stabilization of the melt together with MHD stirring have not yet been carried out. Carrying out such research using mathematical modeling methods can lead to new scientific results and further development of reactors for recycling PCM, as well as equipment for processing toxic waste.

At the moment, there is no information about the processing modes of PCM in melts, which requires experimental research. The results obtained will allow us to evaluate the prospects for using the proposed approach when creating industrial equipment for recycling PCM structures. If the research is successful, it will be possible to create industrial equipment for recycling PCM structures with complete environmental safety and zero emissions of potentially hazardous recycling products.

4.3. Environmental Responsibility in Aircraft Construction: Advantages of Composite Materials for Environmental Protection

Composite materials in the aviation industry have numerous advantages in the context of ecology, compared to other aviation materials. Key benefits include:

1. Low weight: Composite materials such as carbon fibers are characterized by low density compared to traditional metal materials such as aluminum or titanium. This helps to reduce the weight of the aircraft, which in turn reduces fuel consumption and CO2 emissions into the atmosphere.
2. High strength and stability: Composite materials have excellent strength with low weight, which allows you to create lighter, but at the same time very strong structures. This contributes to increasing the service life of aircraft and reducing the amount of waste.
3. Durability and maintainability: Composite materials may be less susceptible to corrosion than traditional metal structures. In addition, they can be easily repaired in the event of damage, reducing the need to replace components and thus the amount of waste.
4. Resource efficiency: Manufacturing composite materials can require less energy and resources compared to manufacturing metal structures. Reducing the amount of resources used contributes to more sustainable and environmentally friendly production.
5. Aerodynamic efficiency: Composite materials allow creating more aerodynamic shapes, which helps to reduce air resistance and fuel consumption.

Table 4.1

Environmental Benefits: Composite Materials vs. Traditional Metals in the Aviation Industry

Criteria	Composite Materials	Traditional Metals
Lightweight	Composites are inherently lightweight, offering fuel efficiency and reduced emissions.	Traditional metals tend to be heavier, contributing to increased fuel consumption and emissions.
Corrosion Resistance	Composite materials exhibit high resistance to corrosion, extending the lifespan of aircraft components.	Traditional metals may corrode over time, requiring frequent maintenance and replacement.
Strength-to-Weight Ratio	Composites provide a superior strength-to-weight ratio, enhancing structural integrity without excess weight.	Traditional metals may require more material to achieve similar strength, leading to increased weight.

Continue table 4.1

Design Flexibility	Composites offer greater design flexibility, allowing for aerodynamic shapes and streamlined structures.	Traditional metals may have design limitations, impacting aerodynamics and overall efficiency.
Recyclability	Some composite materials are recyclable, reducing environmental impact and promoting sustainability.	Traditional metals are often recyclable but may require more energy-intensive processes.
Reduced Emissions	Lightweight composites contribute to lower fuel consumption, resulting in reduced greenhouse gas emissions.	Heavier traditional metals contribute to higher fuel consumption and emissions.
Energy Efficiency	Manufacturing composite materials can be more energy-efficient compared to traditional metal production processes.	Traditional metal production processes may require higher energy inputs, contributing to environmental impact.

Thus, the use of composite materials in aircraft construction can significantly reduce the impact of aviation on the environment, ensuring more efficient use of resources and reducing CO2 emissions.

Conclusion to the Part 4

In general conclusion, it should be emphasized that composite materials are defining a new era in the materials science and manufacturing industry. They turn out to be a key element for solving the challenges of ecology and sustainability in production. The high degree of strength and weight resistance demonstrated by composites ensures their unsurpassed performance in a number of industries, including the aerospace and automotive industries.

Most importantly, composite materials overturn conventional ideas about sustainable development. The ability to recycle and recycle, as well as the energy efficiency of production processes, make them a key tool in creating environmentally friendly and efficient technologies. The use of composites contributes to the reduction of emissions of harmful substances and the consumption of resources, which makes them indispensable in solving environmental problems.

All this indicates the prospects and importance of composite materials in the context of sustainable development. Providing a balance between technical characteristics and environmental aspects, composite materials open new horizons for technological progress, ensuring at the same time efficient development and preservation of the environment.

PART 5. LABORPROTECTION

In modern industrial production, the use of composites is becoming increasingly common, which determines the relevance of occupational health and safety issues in this area. The replacement of traditional materials with innovative composites brings important changes to technological processes and working conditions. Their unique properties and wide range of applications make them a key element in many industries. However, as the popularity of composites grows, so does the importance of health and safety issues in their manufacture.

The production of polycrystalline silicon (PCS) is a complex technological process associated with certain risks to human health. One of the main risk factors is the potential for toxic fumes and dust to be generated during the processing of silicon materials. These chemicals can be ingested by employees through the breath, skin, or improper use of personal protective equipment [22].

In addition, workers' health can be jeopardized by the possibility of thermal injuries associated with high temperatures during some stages of PCM production. Heated equipment and materials create potential conditions for burns and other thermal injuries [1].

It is also important to take into account the possibility of noise pollution in the workplace, which can lead to hearing impairment.

A general health hazard is the possibility of occupational diseases associated with prolonged exposure to harmful substances or hazardous working conditions.

Thus, the production of PCM requires careful risk management and the implementation of effective occupational health and safety measures to ensure the safety and health of employees at all stages of the production process.

5.1. Harmful and dangerous factors when working with PCM

A harmful occupational factor is a factor of the labor process and the production environment, the impact of which on the human body, if hygienic standards are not met, can cause a decrease in performance and deterioration of health, even to the point of occupational diseases [21]. A hazardous occupational factor is a factor of the labor process and the production environment, the impact of which on the human body under certain conditions can lead to injury or other sudden deterioration in health [21].

The following harmful and dangerous factors exist when working with polymer-composite materials:

1. The presence in the air of volatile organic and inorganic components harmful to human health during the processing of composites, such as ethylene oxide, formaldehyde, and carbon monoxide. Inhalation of such substances leads to irritation of the mucous membranes of the mouth, nose, throat and lungs, which can lead to shortness of breath, coughing and other problems. Long-term inhalation of harmful substances can lead to diseases such as pneumonia.

2. Thermal radiation from the heating elements of cylinders, screw extruder working areas, and thermal cabinets for removing moisture from the PCM. Prolonged exposure to the skin can cause redness or even burns. The temperature of the surfaces of equipment and heated equipment with which the employee comes into contact during work should not exceed +45 °C [22].

3. Vibration during equipment operation (PL-32 injection molding machine), which belongs to category 3 - technological vibration that affects a person at the workplace of stationary machines or is transmitted to workplaces that do not have vibration sources [17]. Prolonged exposure to vibrations leads to neurovascular disorders, damage to the osteoarticular and other body systems, changes in the function of the thyroid gland and gastrointestinal tract.

4. Noise during equipment operation. With prolonged exposure to a person's hearing aid, it leads to a decrease in hearing acuity or even loss. The following high-risk objects can be identified in the thesis: equipment for the manufacture of experimental samples from PCM (injection molding machine, thermal cabinets), machines and equipment for the study of characteristics and properties.

5.2. Requirements for process equipment

The requirements for equipment for the production of parts made of polymer-composite materials (PCM) define a set of critical aspects aimed at ensuring the efficiency of production processes and the safety of workers. In particular, the emphasis is on maximum mechanization and automation of work, compliance with safety standards, electrical safety and protection against electrostatic charges. The requirements for ventilation, pneumatic systems, protective fences, and other aspects aimed at ensuring the safety and efficiency of the production process in the conditions of working with CMM are defined in detail. This text thoroughly examines each point of the requirements, focusing on the key aspects of technical and organizational safety in this area [23].

When manufacturing parts from polymer-composite materials (PCM), it is necessary that the equipment provide automation and mechanization of work.

The equipment must comply with safety standards, in particular DSTU 12.2.061:2009, which defines the general safety requirements for workplaces.[23]

The electrical equipment used in production processes must comply with DSTU 7237:2011 regarding electrical safety and explosion and fire hazard classes of premises.

It is important to ensure reliable grounding of the equipment and protection against static electricity in accordance with DSTU 7237:2011 [25].

Places with intense emissions of harmful substances should be equipped with local exhaust ventilation equipped with locking devices.

Protective fences on the equipment must comply with DSTU 12.2.061:2009 [26].

The control system of equipment operated by two or more persons must have a locking device that makes it impossible to start it by one person.

Equipment controls must comply with DSTU 2244-93 [29].

Production facilities must be equipped with safety signs in accordance with the requirements of the Technical Regulations and DSTU ISO 6309:2007 [28].

Lifting mechanisms must be operated in accordance with the requirements of the Rules for the Construction and Operation of Cranes.

Therefore, the requirements for equipment for the production of PCM parts should take into account automation, safety and compliance with standards in all aspects of its operation.

5.3. Measures aimed at organizational and technical protection of employees from harmful and dangerous factors.

Considering all the hazards that workers may face during productioncomposite materials based on epoxy and phenol-formaldehyde resins should be minimizedharmful exposure to hazardous substances that workers may come in contact with and deal withlife safety This can be achieved by creating comfortable conditions for people's activities, protection of people and the environment from the influence of dangerous factors that over legally permissible level. First of all, it is recommended to carry out sanitary and hygienic measures planned to ensure: maintenance of temperature regime and humidity regime [23];

- availability sufficient ventilation;
- the presence of constant control over the dust content generated in the work area,
- mainly in rooms with poor ventilation; performing cleaning of the work area with the aim of avoid dust, which can form an explosive mixture with air and cause a flash explosion explosion [25];
- checking the equipment's serviceability (thermal insulation and waterproofing); implementation of sealing devices and communications;
- continuity and automation of the technological process; maximum reduction the amount of phenol and formaldehyde in resins, mixtures, adhesives, plastics and products made from them.

Since there are companies engaged in the production of composite materials mandatory quality control of manufactured products, then methods are used for this X-ray structural analysis performed on X-ray machines. These studies are dangerous for the human body, therefore, in order to minimize their negative impact during execution, it is important to follow the rules of radiation protection at work:

- research is conducted only in specially equipped rooms and devices and the maintenance of which meets sanitary and technical requirements;
- there should be constant monitoring of the level of ionizing radiation, ozone, nitrogen oxides, which they arise during ionization of X-ray radiation;
- preventing deviations from the established technological process of working with an ionizing source radiation;

- use of special clothing (cotton dress DSTU 12.4.131-83 and DSTU 12.4.132-83, cotton cap, dielectric mat) [25]
- before starting work, it is necessary to make sure that the blocking devices are in good working order, measuring devices, ventilation systems, power supply;
- make sure that protective screens and locks are available and in working order;
- it is necessary to control the strength of the radiation dose in the rooms where the procedures are carried out study of the technical condition and effectiveness of radiation protection equipment, including monitoring radiation power on the surface of installations in all accessible places and workplaces busy [26].

It is important that workers follow personal hygiene measures and use tools

individual protection. When in contact with substances that have a sensitizing and irritating effect onskin, it is necessary to apply [29]:

- gloves: technical rubber (K 20 Sh 20 according to DSTU 20010-74), plastic on a textile basis (typ. "Teplast" red) [23];
- creams, protective ointments and pastes: KHIOT-6, Mikolan ointment, IER-1 paste, "biological" casein paste glove"; protective furacilin paste, film-forming cream, silicone hand cream (hand protection with impossibility, due to the peculiarities of the technological process, to use gloves to protect the skin of the hands, as well as also exposed body parts).
- it is necessary to wash hands after work;
- resins are washed off the skin with a mixture of alcohol, glycerin and ammonia;
- wash off the phenol with soapy water, a weak soda solution; recommended after washing off resins lubricate the skin. In conditions of increased dustiness, we recommend using: protective glasses; Respirators:"Lepestok", "Astra", RPG-67, F-62-Sh, ALINA-200 AVK; gas masks: gas mask of brand A or brand A p filter, CP-5, CP-5M, CP-7 with DPG-1 cartridge, CO brand gas mask; Overalls made of paper fabric; in ISSN 1813-5420 (Print). Energy: economy, technologies, ecology. 2019 No. 3 108 ISSN 2308-7382 (online) when in contact with liquid products, use armbands, aprons, polyethylene shoes, gloves with chlorosulfonated polyethylene or polyvinyl alcohol [22].

It is necessary to conduct a medical examination of employees once a year, to conduct a detailed dynamic examination review; to study sanitary and hygienic working conditions in detail.

Compliance with all rules of labor protection and safety techniques in the manufacture of products from the composite materials mentioned in the article will reduce the risk of damage to the human body, minimize the negative impact of harmful substances in their composition on the health of employees

5.4. Requirements for the placement of production equipment and organization of workplaces

In today's production environment, organizational and technical aspects of ensuring the safety and efficiency of the industrial process are of great importance. In particular, the placement of production equipment is not only determined by design requirements, but also aims to guarantee the highest degree of protection for employees in the event of an emergency. During the design and operation, it is important to comply with safety standards to ensure optimal conditions for employees and high efficiency of the production process. Let's consider the key aspects of equipment placement, ensuring safety, ease of maintenance and compliance with ergonomic standards. Given the importance of these aspects, viona aims to take a systematic approach to workplace organization and safety at work [23].

According to the project documentation, production equipment is located in such a way as to ensure the safe evacuation of employees in case of emergency.

The location of the equipment should guarantee the safety and convenience of maintenance and repair, as well as simplify the transportation of equipment, parts and materials as much as possible.

The organization of workplaces must comply with the requirements of NPAP 25.2-1.35-90. Workplace when performing work while standing. General ergonomic requirements of NPAP 25.0-1.02-13. Workplace when performing work while sitting. General ergonomic requirements" [21].

In places where there is a potential danger to employees, as well as on production equipment that is the source of this danger, it is necessary to place appropriate safety signs, such as warnings about high electrical voltage on the doors of cabinets with control equipment and signs prohibiting access to the movement area of carriages and machine gantries.

When servicing operating equipment, each employee must comply with the requirements of the equipment operating instructions.

Workplaces, aisles and passageways must not be cluttered with equipment, parts and production waste.

The amount of solvents, adhesives, lubricants and binders that are simultaneously present at the workplace must not exceed the standards specified in the technological documentation.

5.5. Coordination of Actions in the Case of an Emergency: Fire at the Enterprise

An emergency situation in the form of a fire at a composites manufacturing facility requires a quick and coordinated response to minimize damage and protect the lives of workers. Here are the actions to consider in such a situation:

1. Call the fire department: It is the employee's responsibility to immediately notify the local fire and rescue services of the fire. Report the exact location and size of the fire [29].

2. Activate fire alarms and evacuation: Fire alarm systems should be activated to notify employees of the threat. Launch an evacuation plan, including evacuation signals and a safe exit route.

3. Provide first aid and evacuation: All employees should know the location of fire extinguishing and emergency evacuation equipment. Employees should assist victims and facilitate their safe evacuation.

4. Use of fire extinguishing equipment: You should use available fire extinguishing equipment, such as fire extinguishers, to attempt to contain and extinguish the fire if it is safe to do so and you are trained to do so.

5. Do not use elevators: In the event of a fire, elevators should not be used. They can get stuck or spread the fire.

6. Prevent chemical leaks: If chemicals are stored or used in the facility, efforts should be made to prevent their leakage or spread by taking appropriate control and containment measures [28].

7. Cooperation with the fire brigade: When the fire brigade arrives on the scene, the employee should cooperate with them by providing important information and assisting in the containment and extinguishing of the fire.

8. Notification to workers and the public: Workers, residents, and other interested parties should be informed of the current situation and given instructions on safe behavior.

9. Investigation and analysis: After a fire, a thorough investigation should be conducted to determine the cause and take steps to prevent similar incidents in the future [28].

The goal is to maximize the safety of life and property of employees in the event of a fire and avoid further negative consequences

Conclusion to the Part 5

In conclusion, the comprehensive exploration of Part 5 on Labor Protection has provided valuable insights into various critical aspects of ensuring a safe and secure working environment. The examination of harmful and dangerous factors associated with working with PCM highlighted the importance of identifying and mitigating potential risks. Furthermore, the detailed requirements outlined for process equipment underscore the significance of maintaining high standards to safeguard employees.

The discussion on organizational and technical measures for protecting employees shed light on the proactive approaches needed to create a secure workplace. This involves not only addressing immediate threats but also implementing long-term strategies to minimize risks. The considerations for the placement of production equipment and organization of workplaces emphasized the need for a well-thought-out layout that promotes both efficiency and safety.

Additionally, the section on coordination of actions in case of an emergency, specifically focusing on fires at the enterprise, underscored the importance of preparedness and a structured response plan. Timely and effective actions during emergencies are crucial in minimizing potential harm and ensuring the safety of all personnel.

In essence, Part 5 underscores the multifaceted nature of labor protection, encompassing everything from understanding potential hazards to implementing preventive measures and emergency response strategies. By adhering to these comprehensive guidelines, organizations can not only comply with safety regulations but also foster a culture of well-being and security for their employees, ultimately contributing to a healthier and more sustainable work environment.

GENERAL CONCLUSION

This work was devoted to a comparative analysis of the prospects for the use of heterogeneous composite materials for the power elements of the passenger cabin of an aircraft, revealing various aspects of the use of modern technologies in aircraft construction. The research includes the study of the nature of composite materials, their structure, classification and specific application in the power elements of the passenger cabin.

In the first section, five types of composite materials are explored and compared, including organic matrices, metal matrices, ceramics, and polymer matrices. Key aspects of selecting composite materials for passenger cabin floor elements are emphasized.

The second section is dedicated to analyzing the support beam of the passenger cabin, including a comparison with traditional construction. A detailed review of the new beam structure is provided, along with an economic analysis. The economic analysis revealed that an aluminum beam is more cost-effective compared to CFRP, confirming the advantages in terms of production, maintenance, and repair.

The third stage involves 3D modeling of the developed structure using SolidWorks, determining the impact of selected composite materials on the properties and efficiency of the beam. The tests indicated that Polymer Matrix Composite (PMC) is the most superior composite material for the aircraft beam due to its minimal deformation under loads.

The fourth and fifth sections address aspects of environmental and occupational safety when using polymer composites in aircraft structure production. The sections provide a comprehensive approach to ensuring safety and sustainability in the production process.

In summary, the study identifies key aspects and advantages of using composite materials for aircraft cabin power elements. Economic and engineering parameter analysis confirmed the cost-effectiveness of aluminum beams over carbon fiber polymer composites. 3D modeling using SolidWorks determined that Polymer Matrix Composite is the most durable material for the support beam. This work contributes to the understanding and development of modern aviation technologies, offering recommendations for further research and innovative solutions in production.

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APENDIX

Appendix A

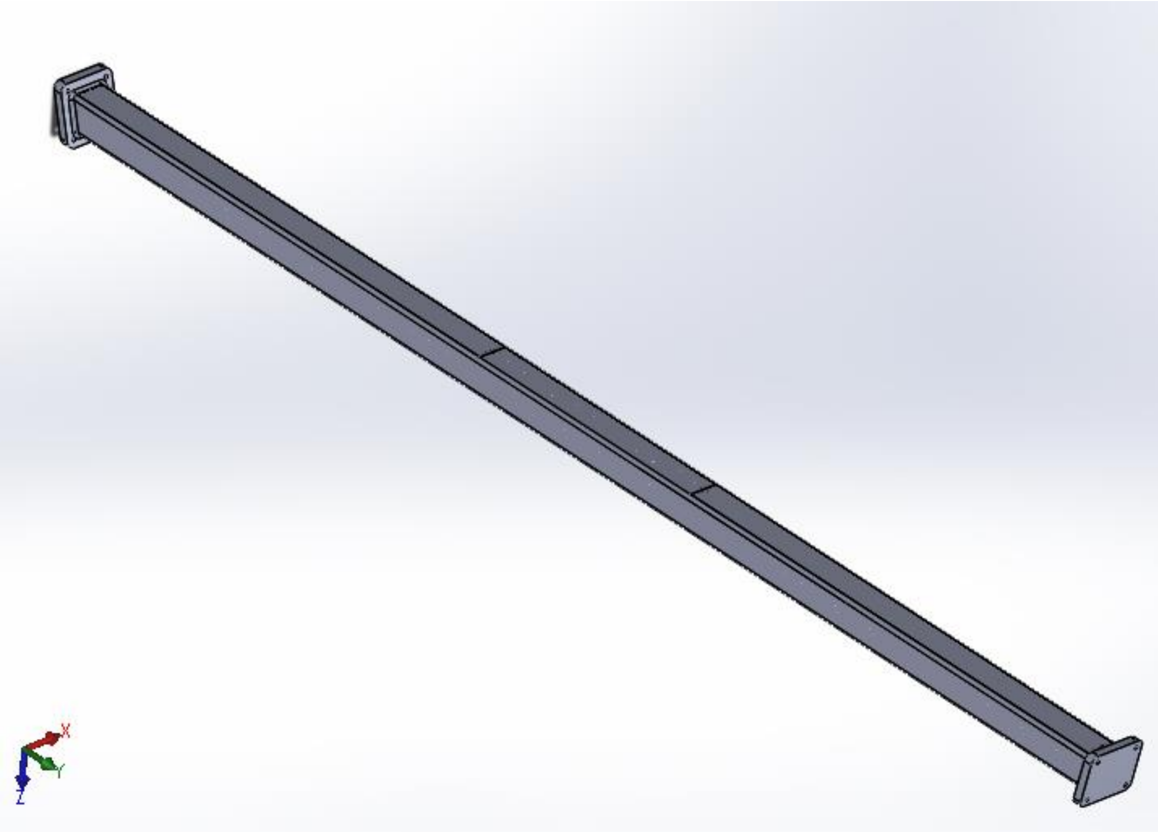

Fig. 1. General view of the beam

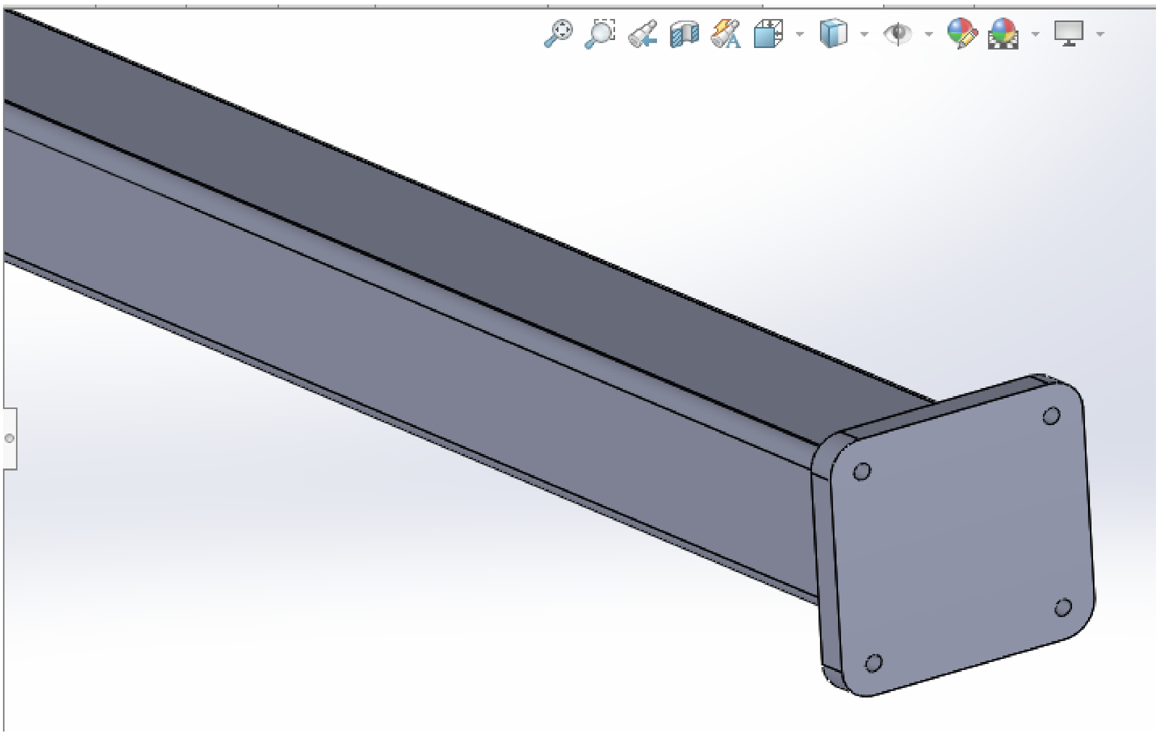

Fig. 2. Fastening the beam to the fuselage

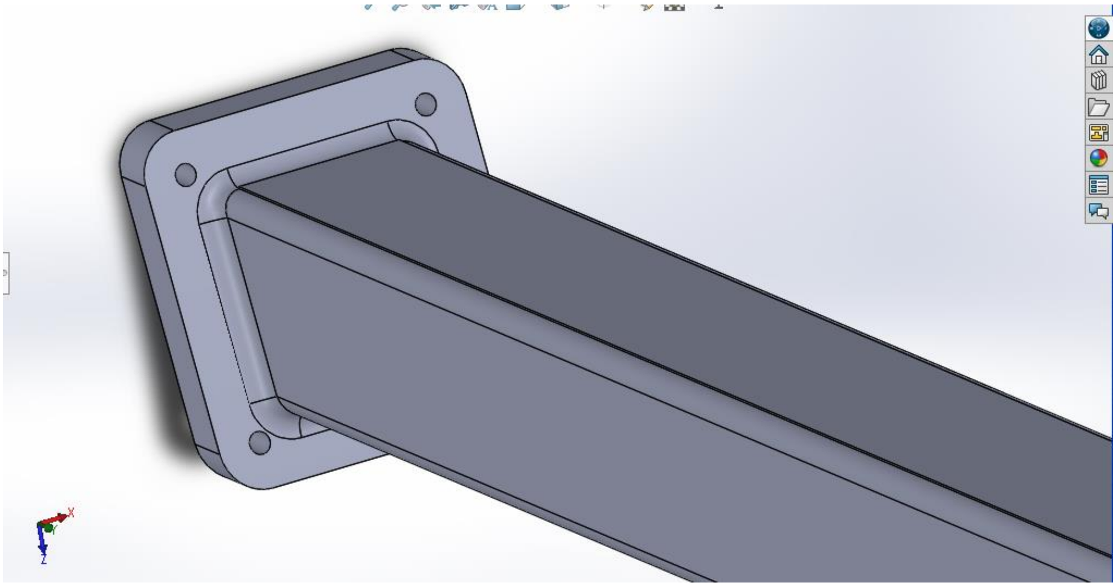

Fig. 3. Fastening the beam to the fuselage

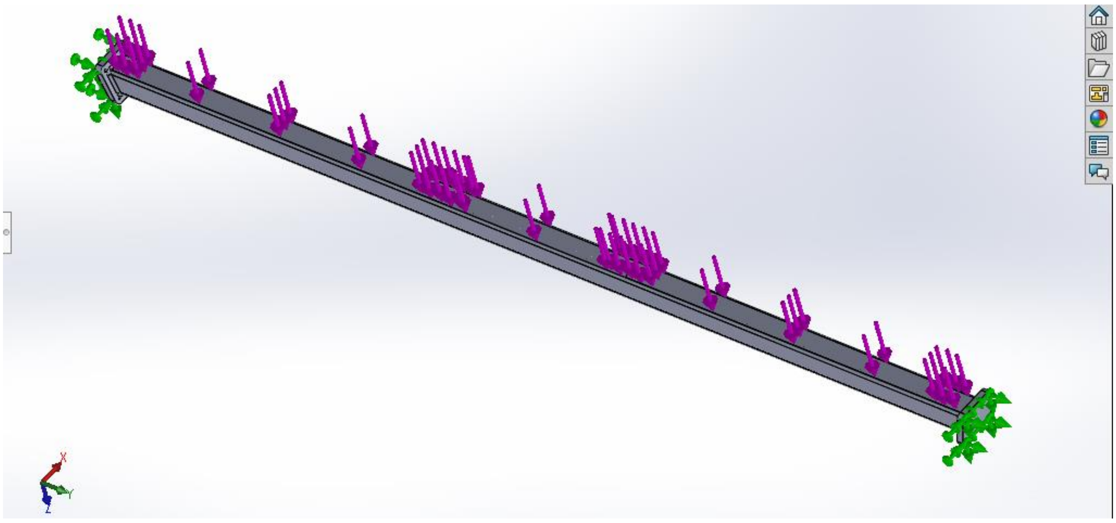

Fig. 4. Load distribution on the beam

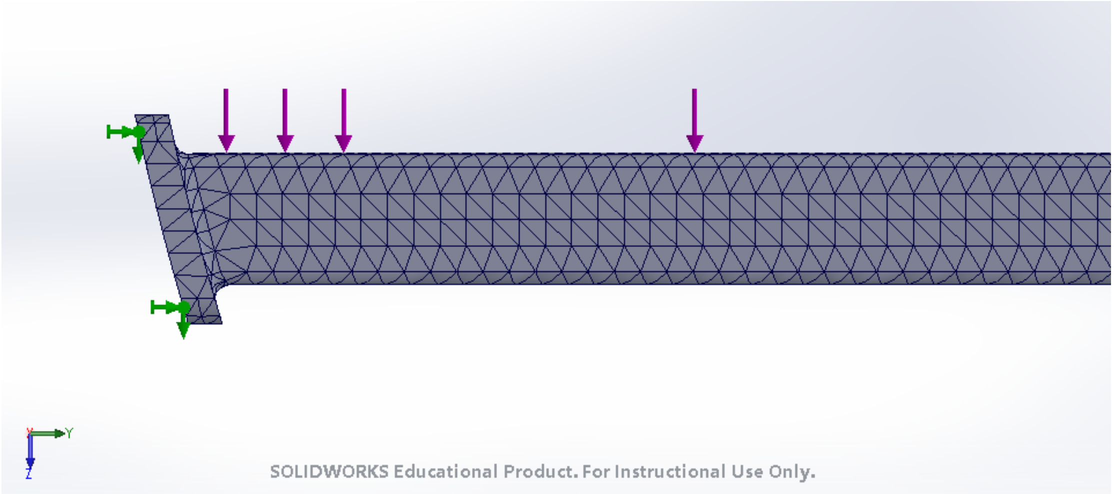

Fig. 5. Dividing a beam into a mesh for strength analysis

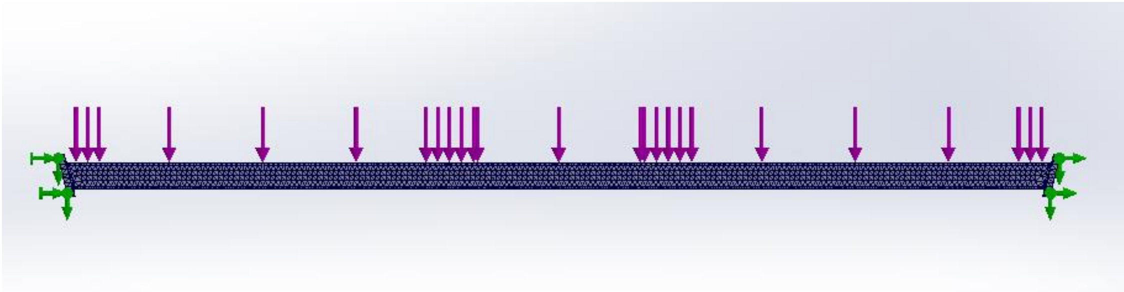

Fig. 6. Distribution of the load on the beam, which is divided into a grid for strength calculation

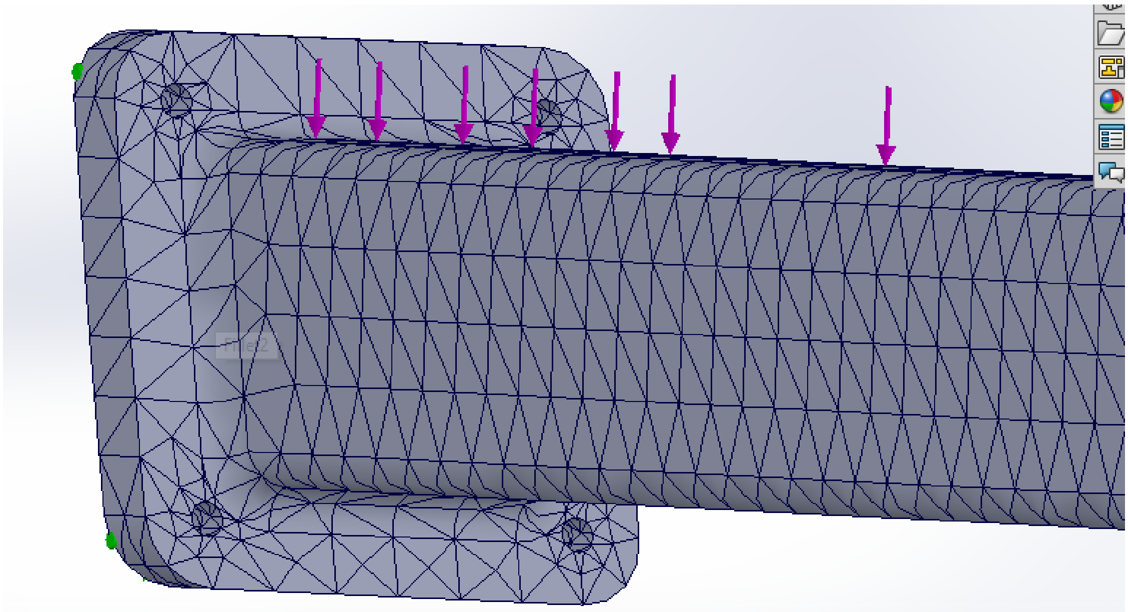

Fig. 7. Distribution of the load on the beam, which is divided into a grid for strength calculation

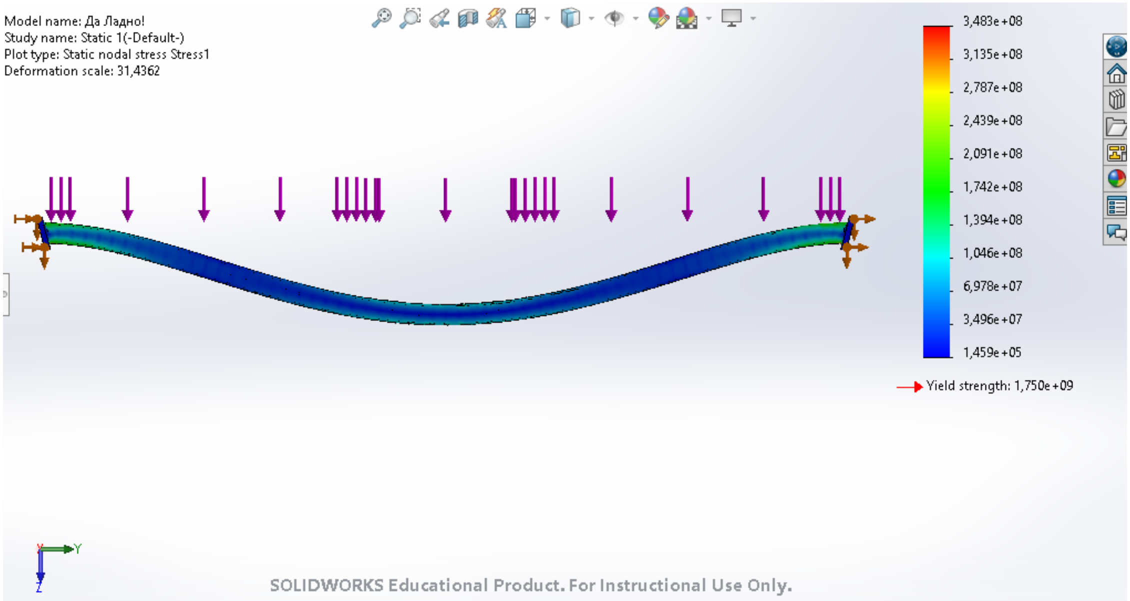

Fig. 8. Stress analysis

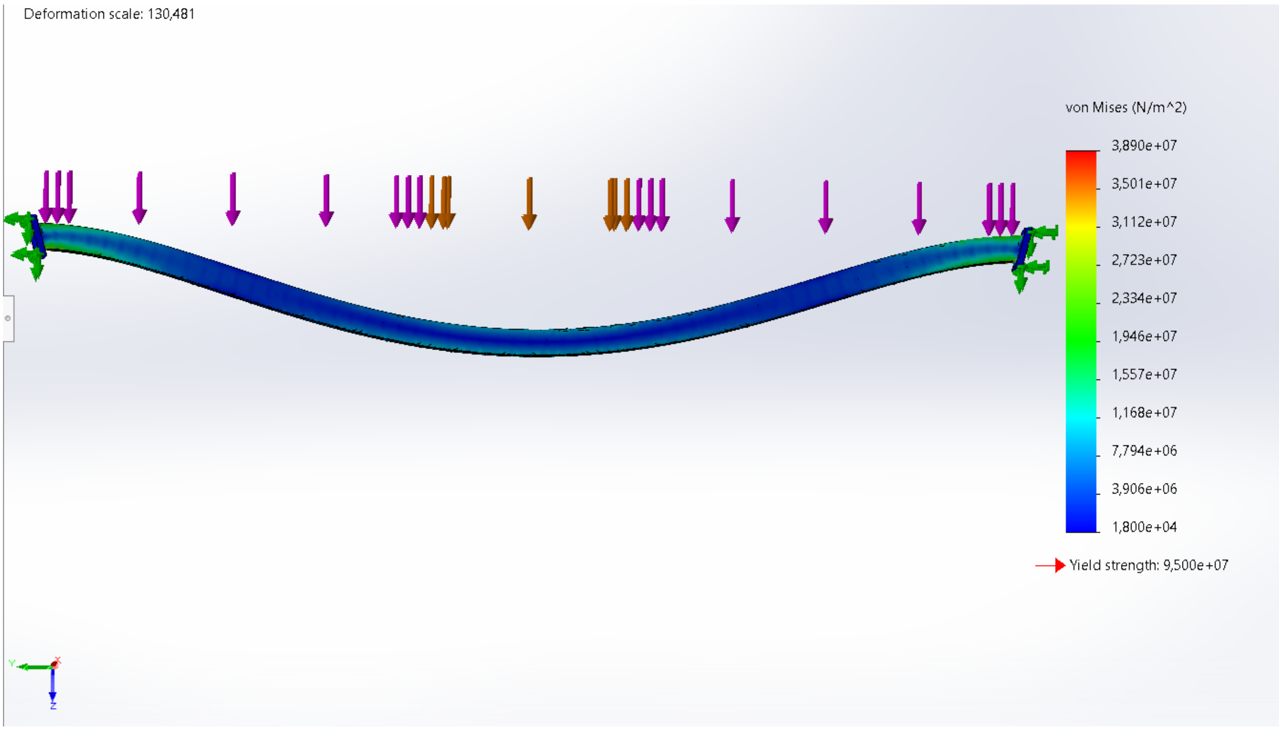

Fig. 9. Stress analysis aluminum metal 7075

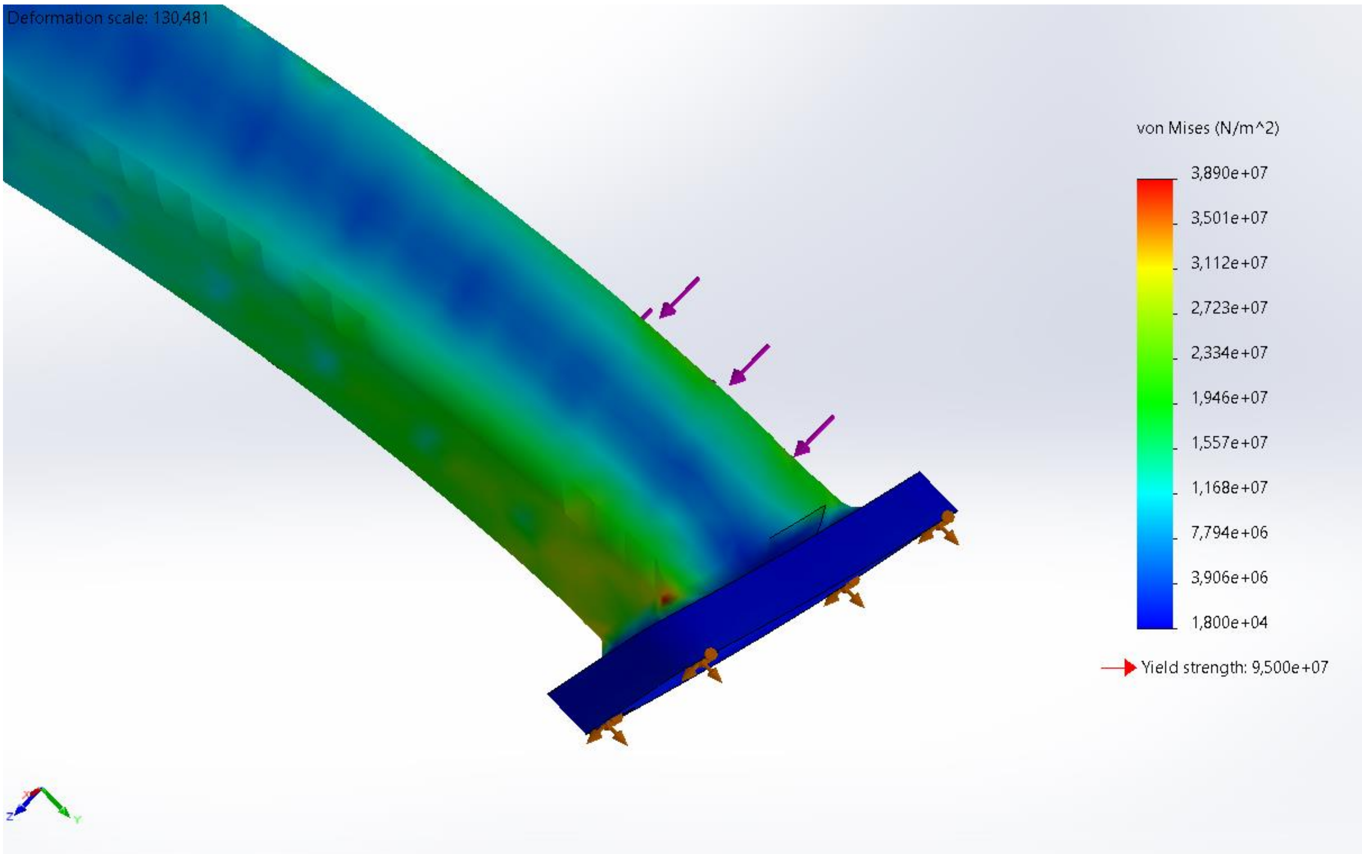

Fig. 10. Stress analysis, aluminum metal 7075

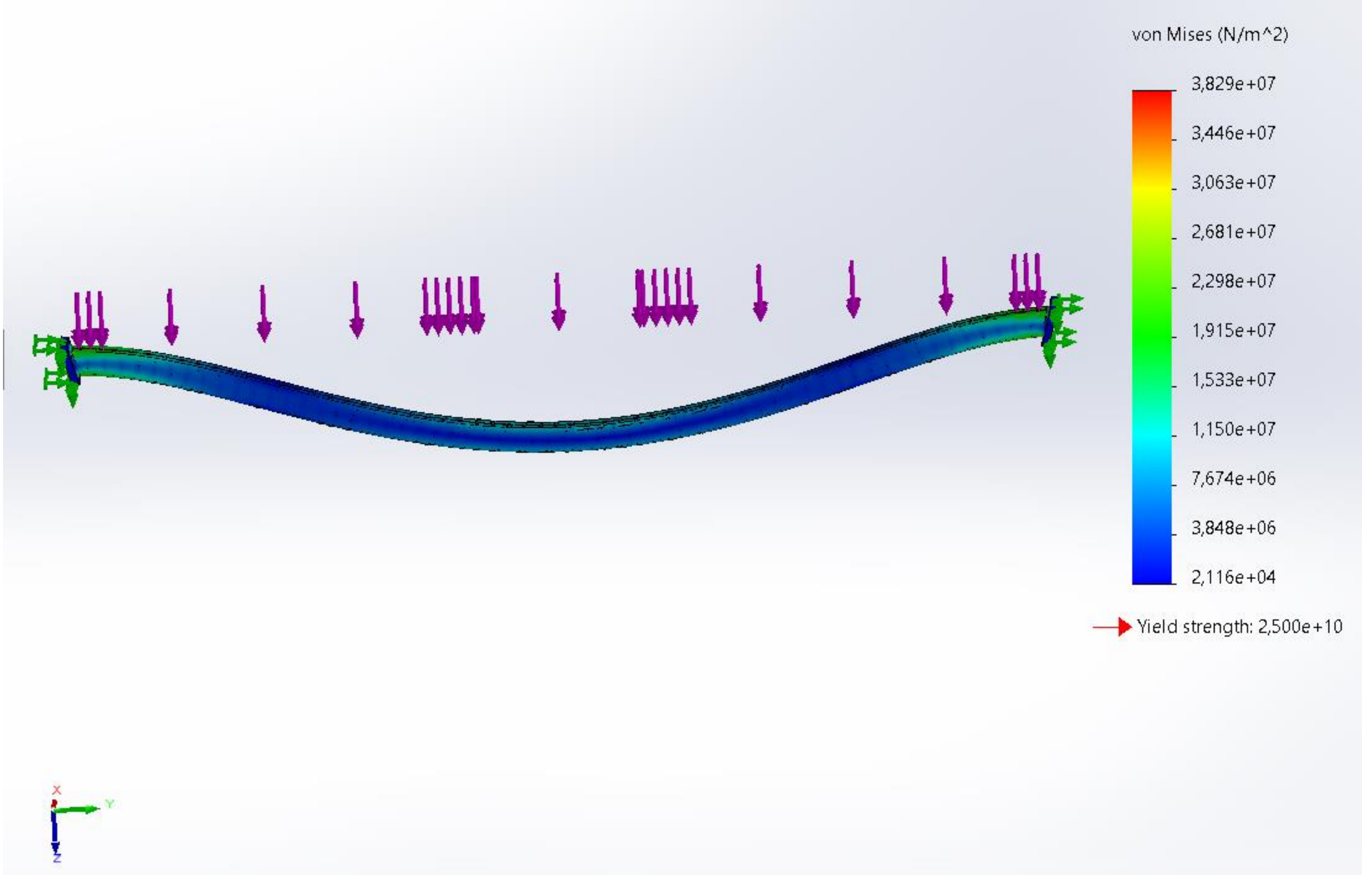

Fig. 11. Stress analysis, OMC

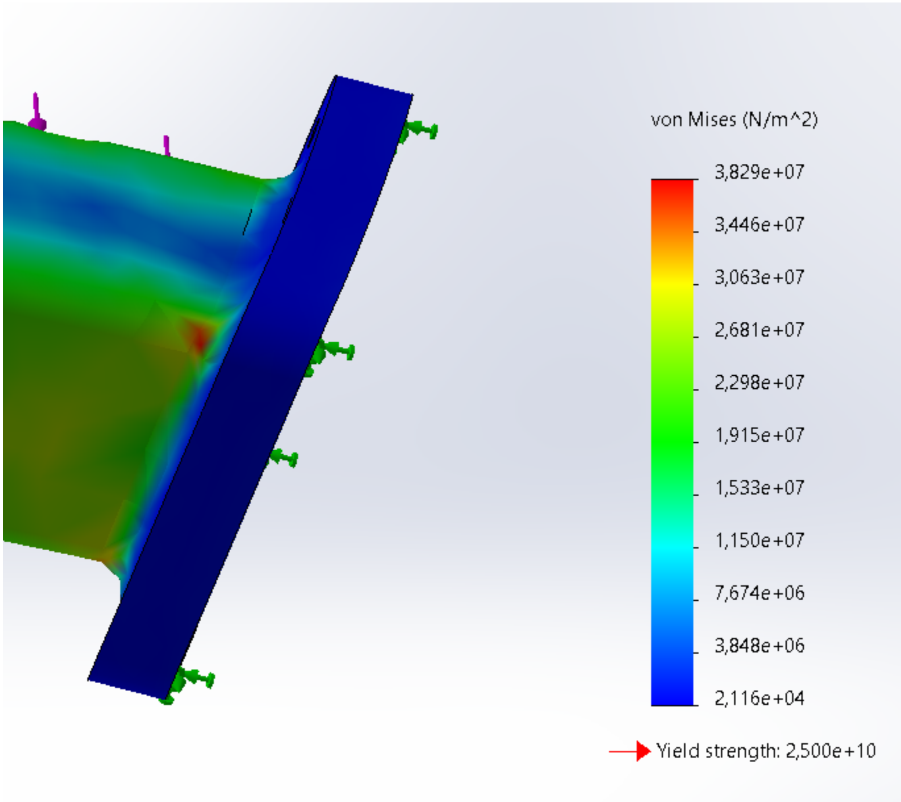

Fig. 12. Stress analysis, OMC

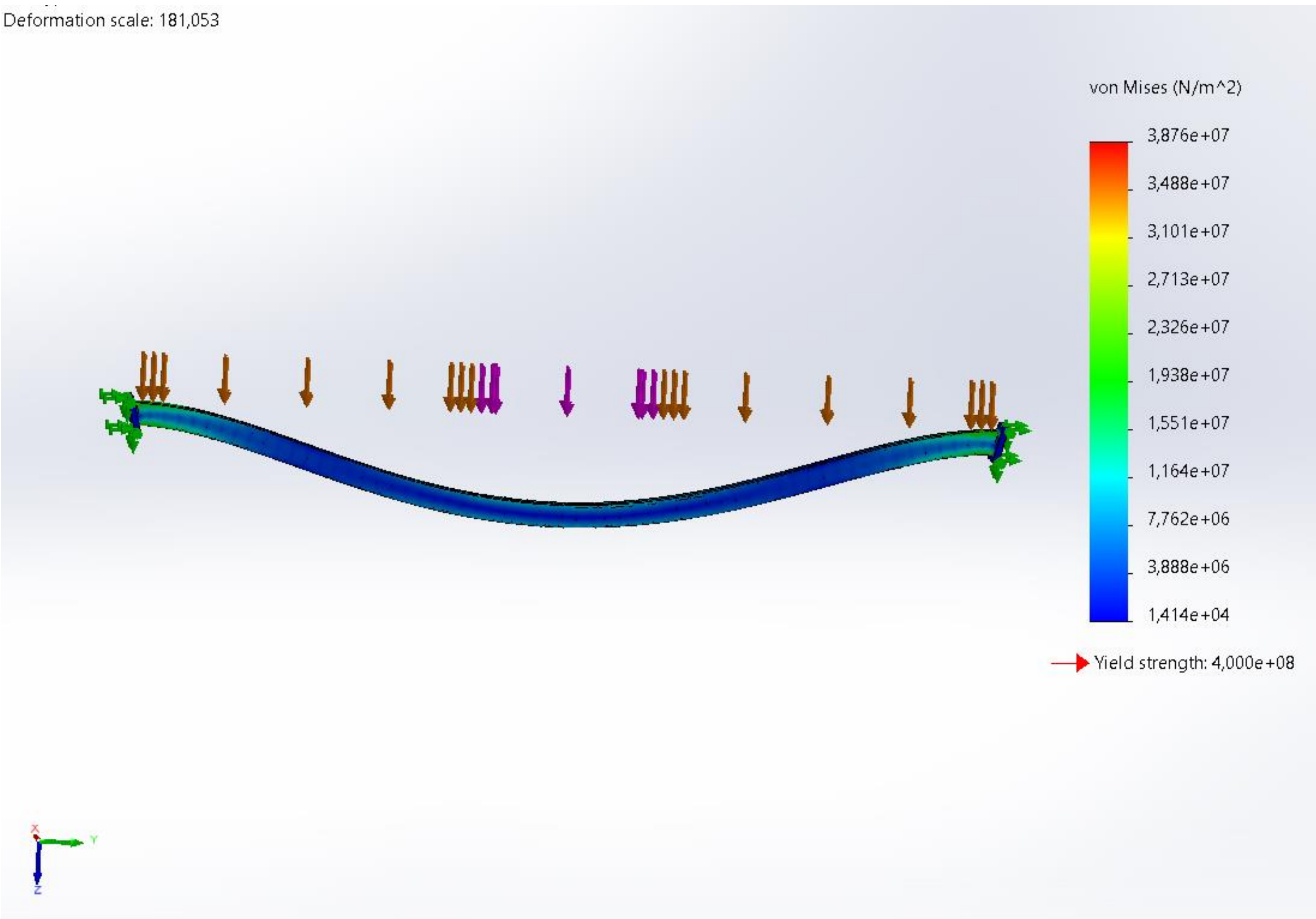

Fig. 13. Stress analysis, MMC

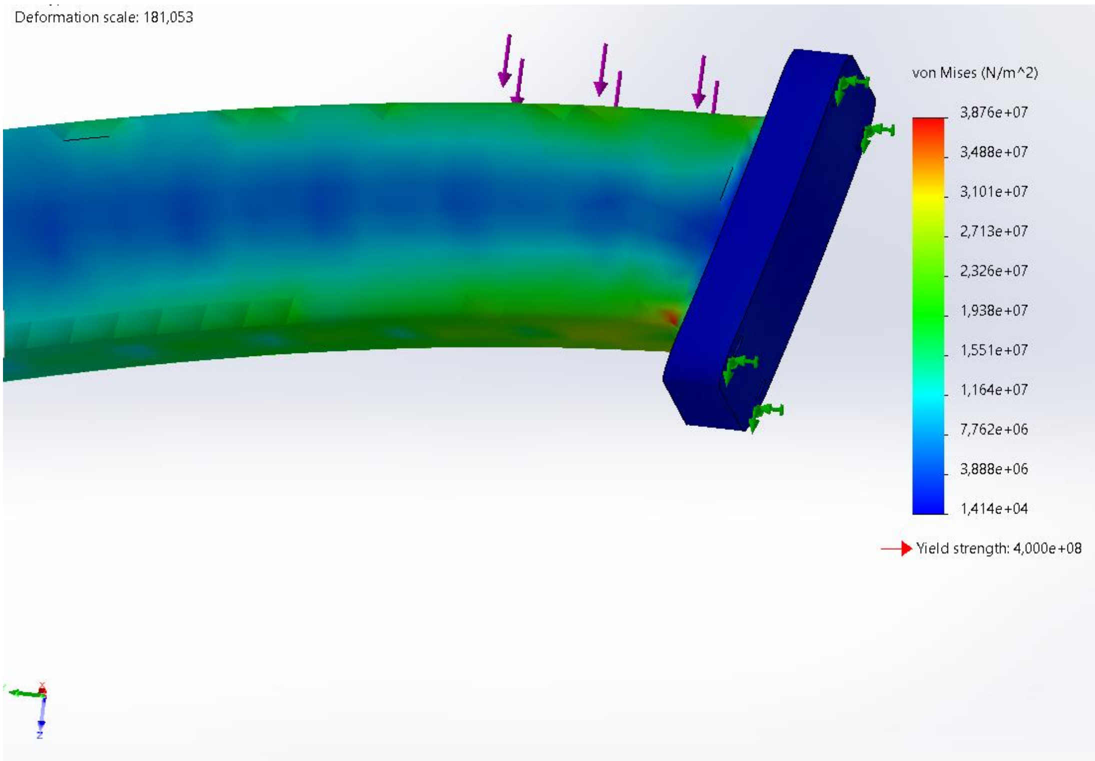

Fig. 14. Stress analysis, MMC

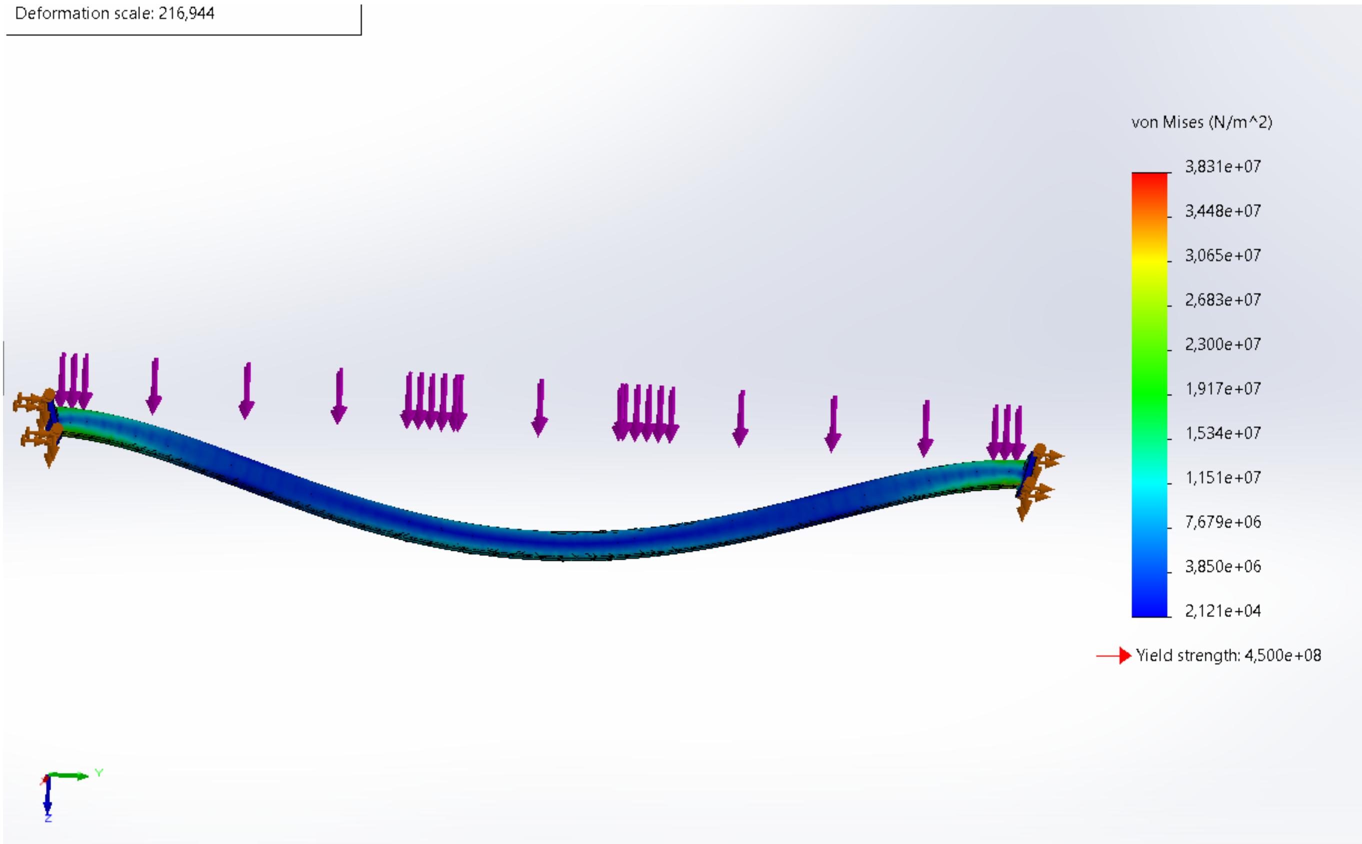

Fig. 15. Stress analysis, CMC

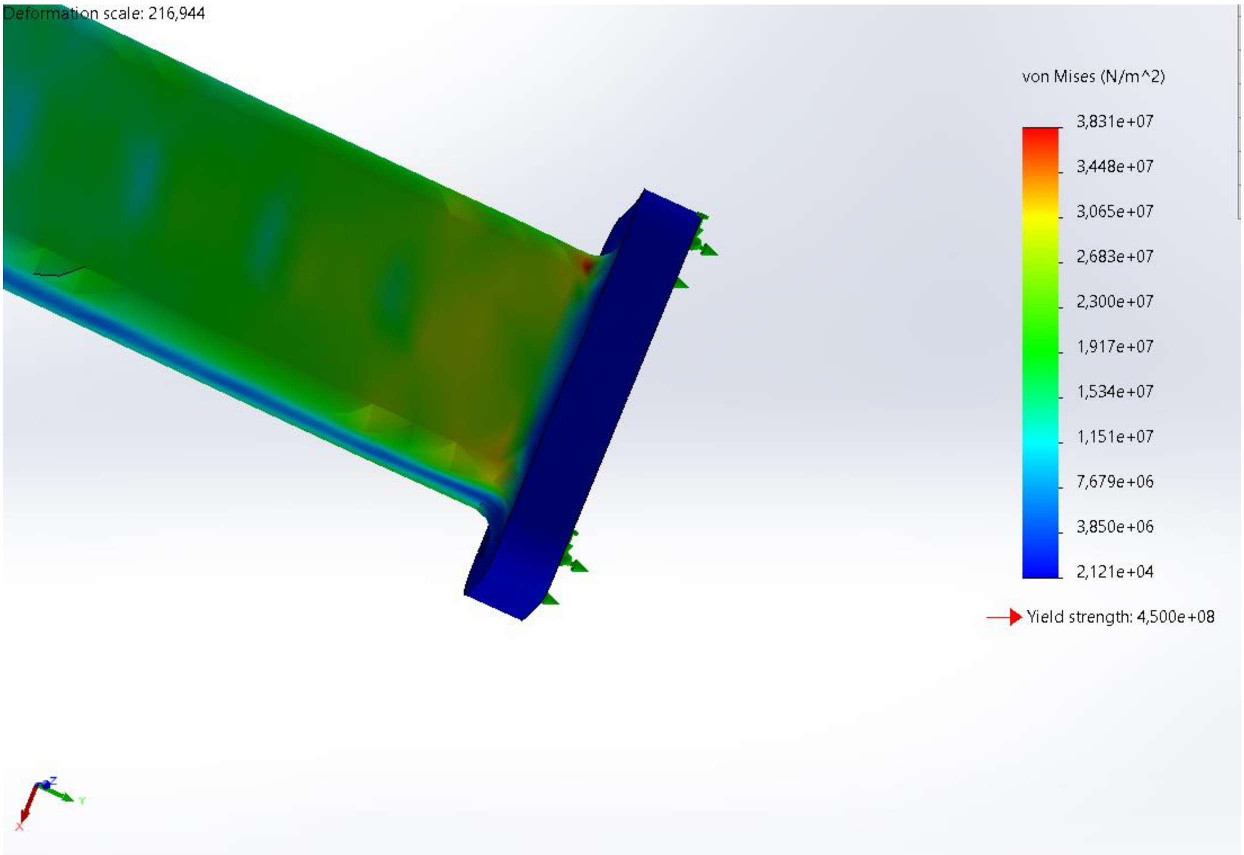

Fig. 16. Stress analysis, CMC

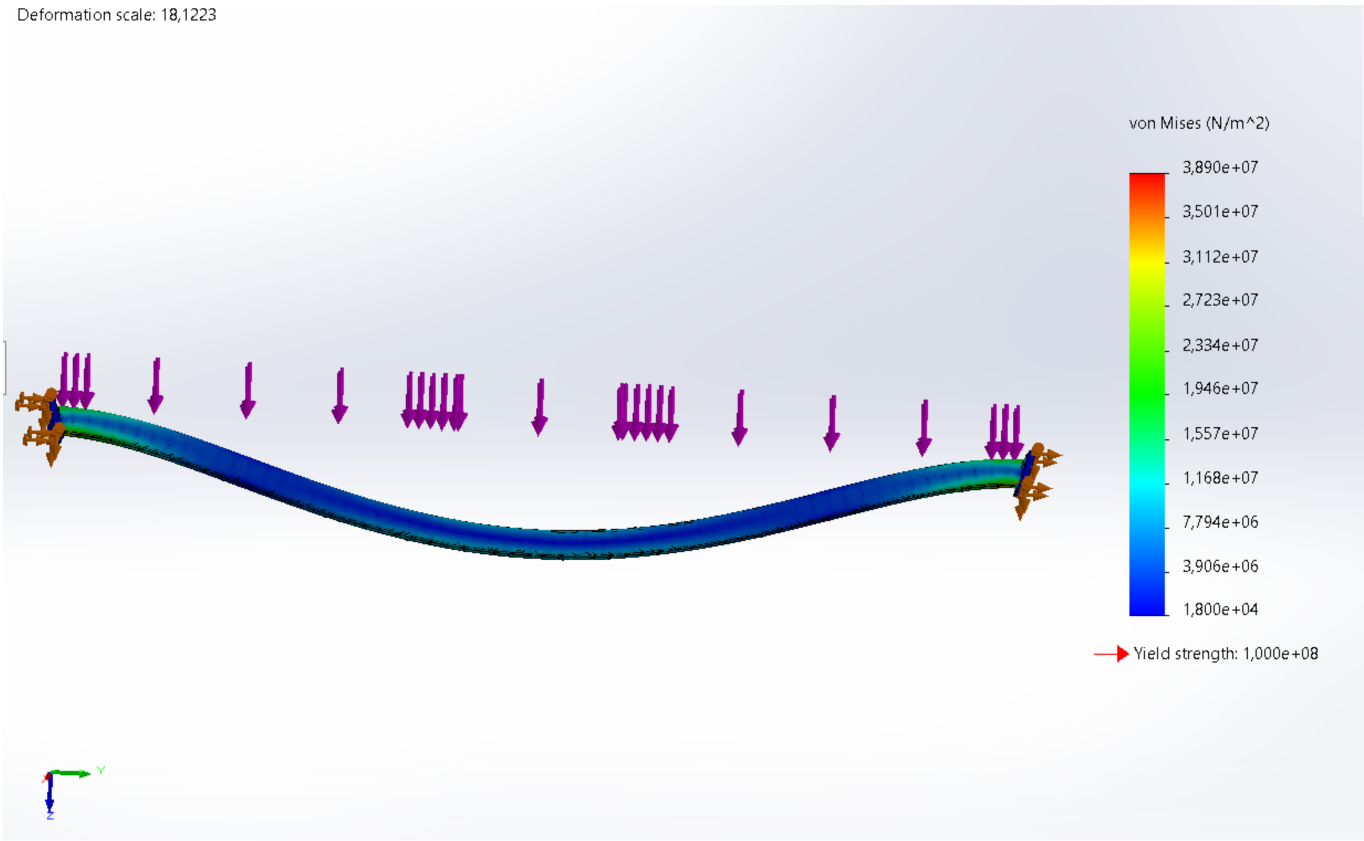

Fig. 17. Stress analysis, PMC

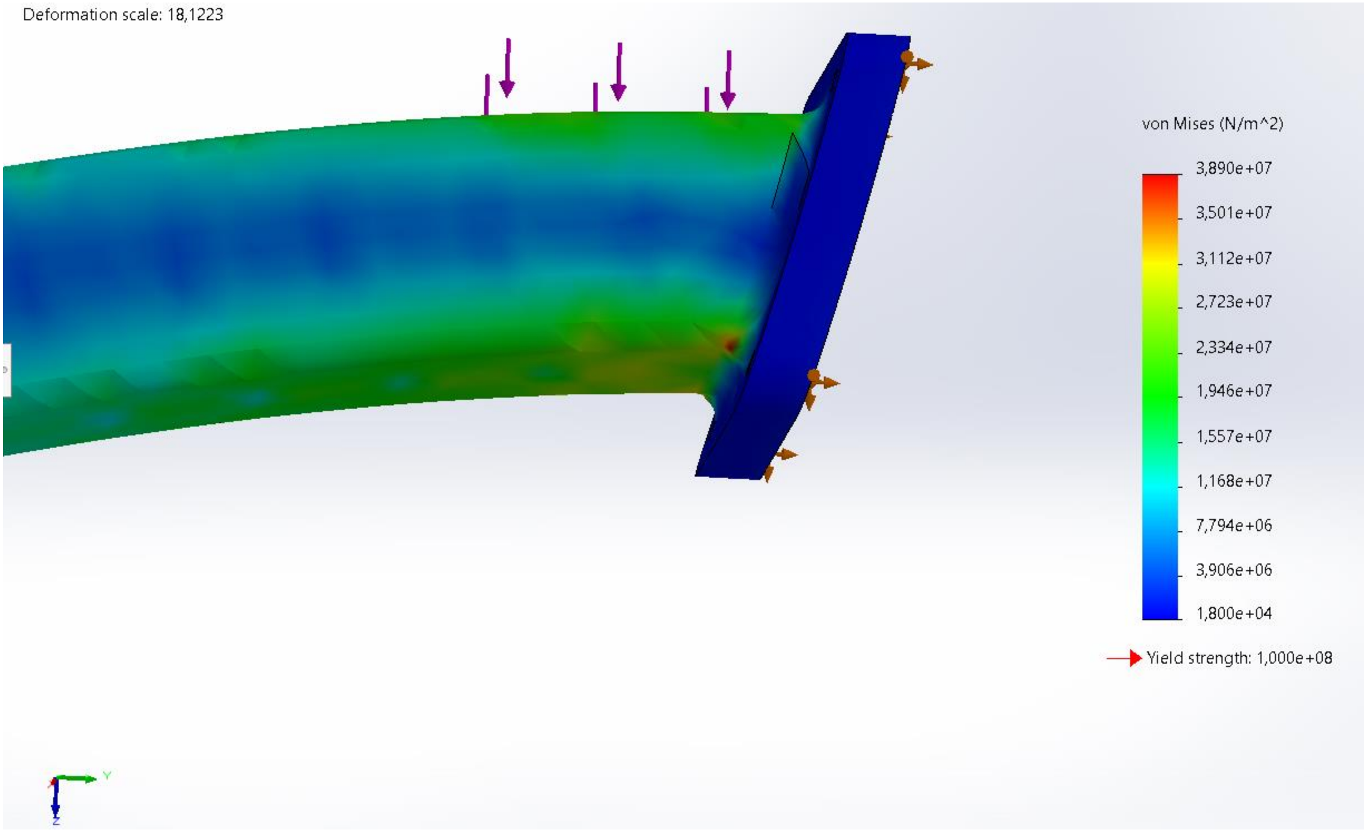

Fig. 18. Stress analysis, PMC

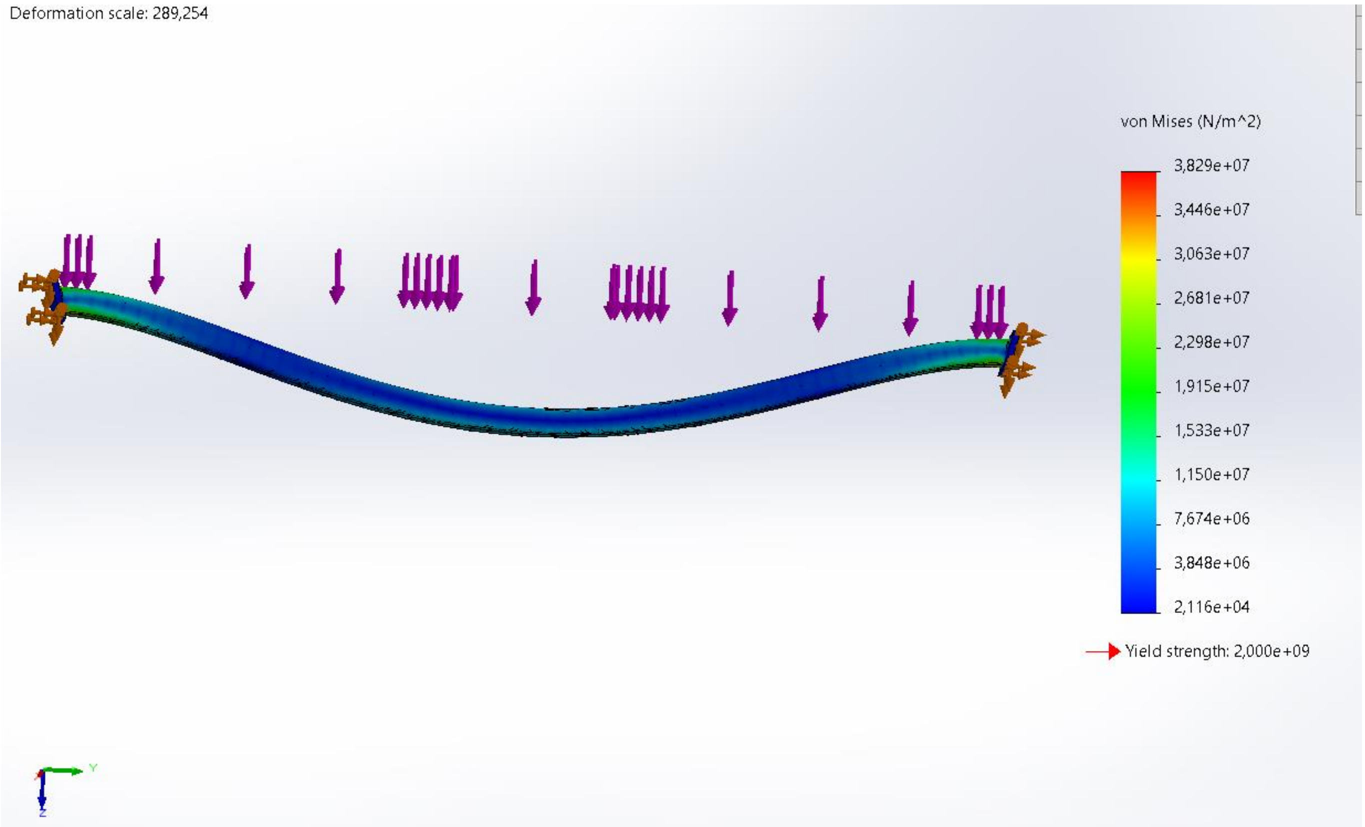

Fig. 19. Stress analysis, CFRPC