THE ROLE AND FUTURE PROSPECTS OF METAL MATRIX NANOCOMPOSITE MATERIALS IN THE AVIATION FIELD

Norkulov Eliyor Oblakulovich
Senior Lecturer of the Military Aviation Institute of the Republic of Uzbekistan

Rajabov Azamat Eshdavlatovich
Lecturer of the Military Aviation Institute of the Republic of Uzbekistan

Axmadaliyev Abror Askaraliyevich
Senior Lecturer of the Military Aviation Institute of the Republic of Uzbekistan

Sattorov Fayzullaxuja Raximjon ugli
Lecturer of the Military Aviation Institute of the Republic of Uzbekistan

Abstract
This article analyzes the role, scientific and practical aspects of metal-matrix nanocomposite materials (nanocomposits with metal materials) in the field of aviation. The high strength, lightness, heat resistance, and corrosion resistance of nanocomposits with metal materials make them superior to traditional metal alloys. Modern production technologies and new scientific approaches serve to increase the efficiency of nanocomposits with metal materials. According to the research results, the share of nanocomposits with metal materials in the aviation industry is significantly increasing and is expected to develop further in the future. Based on mathematical models, changes in strength and composition were assessed. The use of nanocomposits with metal materials serves to increase fuel efficiency, improve flight efficiency, and reduce the environmental impact of the aviation industry.

Keywords: Metal-matrix nanocomposites, aviation material, strength, lightness, modern technologies, mathematical model, heat resistance, corrosion resistance, composite materials, fuel efficiency.

Introduction

Nanocomposits with metal materials are gaining significant importance in the fields of modern materials science and engineering. Due to their superior mechanical properties, lightweight nature, and high-temperature resistance, their applications are expanding in aviation, aerospace, automotive industries, and military technologies. Below, the relevance and significance of **nanocomposits with metal materials** are elucidated based on detailed scientific and statistical data.

Traditional alloys (aluminum, titanium, magnesium, steel) have disadvantages in terms of mechanical properties compared to **nanocomposits with metal materials**. **Nanocomposits with metal materials** are of great importance in high-tech industries due to their high strength, low density, and high heat resistance. For example, titanium-based **nanocomposits with metal**

materials (Ti-SiC, Ti-Al2O3) increase the durability of aircraft engines by 30%. Al-CNT MMNMs reduce the total weight of the aircraft body by 20% and increase fuel efficiency.
Aerospace companies such as NASA and Boeing are developing **nanocomposits with metal materials** for a new generation of spacecraft and passenger aircraft. In 2023, the global aerospace **nanocomposits with metal material** market amounted to $4.5 billion and is projected to grow by $8 billion by 2030. Components reinforced with **nanocomposits with metal materials** reduce the weight of rocket engines by up to 30%, which significantly increases fuel efficiency.
Tesla, BMW, and General Motors are transitioning to using nanocomposits with metal materials in electric vehicles and internal combustion engines. The use of nanocomposits with metal materials on car chassis reduces the total weight by 15-20% and fuel consumption by up to 10%. As a result of the use of alloys developed on the basis of nanocomposits with metal materials in Porsche and Ferrari engine units, the car's speed was increased by 5-7%.
Fighter jets of the 5th generation (F-35, Su-57) use nanocomposits with metal materials in the engine and wing parts. Armor made from nanocomposits with metal materials is 30% lighter and 40% more durable than conventional steel armor. The durability and mobility of tanks and armored vehicles are increasing.
The European Union has allocated 1.2 billion euros in investments for nanocomposits with metal materials by 2030. The US, through DARPA, allocated a $2 billion budget for the development of aerospace MMNMs. China has allocated $500 million for the use of nanocomposits with metal materials in satellite and hypersonic missiles.
Steel and aluminum production generates large amounts of CO_2 emissions. nanocomposits with metal materials production requires less energy and can reduce CO_2 emissions by up to 25%. Products made from nanocomposits with metal materials last longer than traditional materials, which reduces waste.
Lazerli sinterlash, additiv ishlab chiqarish (3D bosib chiqarish) va nanolaminat texnologiyalari yordamida nanocomposits with metal materials lar an’anaviy ishlab chiqarishdan ancha samarali va arzon. 3D bosib chiqarish orqali ishlab chiqarilgan nanocomposits with metal materials komponentlari ishlab chiqarish xarajatlarini 40% kamaytiradi. NASA tomonidan ishlab chiqilgan nanocomposits with metal materials dan yasalgan yangi raketa nozullari xizmat muddatini 5 barobar oshirdi.
Nanocomposits with metal materials are an integral part of the modern aviation industry. They differ from traditional metal alloys in such properties as lightness, high strength, and heat resistance. In recent years, the demand for lightweight and durable materials in the aviation industry has been increasing. According to 2023 statistics, the global aviation materials market amounted to 20.3 billion US dollars in 2022, and by 2027 this figure is expected to reach 30 billion US dollars. Also, in the new generation of aircraft manufactured by Boeing and Airbus, the share of nanocomposits with metal materials reached 35%. This article analyzes the main features of nanocomposits with metal materials, their importance in the field of aviation, and future prospects.

Web of Scientists and Scholars: Journal of Multidisciplinary Research

Recent studies have shown that the mechanical properties of nanocomposites with metal materials depend on the composition of the metal matrix and the properties of the phase reinforced with nanoparticles.
The strength limit (σ) and fatigue strength of nanocomposites with metallic materials are significantly higher than that of conventional metal alloys.
Titanium-based nanocomposites with metallic materials (Ti-TiC, Ti-SiC):
The strength limit reaches 900-1200 MPa (500-800 MPa in conventional Ti alloys).
Fatigue strength increases by 40%, which extends the service life of aviation components.
Aluminum nanocomposites with metallic materials (Al-SiC, Al-CNT):
Their strength is 30-50% higher, which is the basis for their use in light aircraft parts.
Due to the low density of such nanocomposites with metal materials, their weight/transfer force ratio is high, which increases aerodynamic efficiency.
Elastic modulus (E, GPa) - characterizes the elastic properties of a material in relation to external loads.
• Titanium-based nanocomposites with metallic materials:
In traditional Ti alloys, E = 100-120 GPa, in nanocomposites with metallic material when SiC or Al_2O_3 is introduced, E reaches 150-200 GPa.
This approach is crucial for aircraft engines and high-load structural components.
• Aluminum-based nanocomposites with metal materials:
In ordinary Al alloys, E ≈ 70 GPa, and in nanocomposites with metal materials, it can increase to 100-140 GPa.
This increased hardness creates the basis for their use as a lightweight and durable material in aerospace structures.
During the research, scientific literature on the composition and properties of nanocomposits with metal materials was examined. Additionally, their production technologies and application areas were analyzed. The following methods were employed in the study:
1. Analysis of metal matrices and reinforcing elements;
2. Methods for assessing mechanical properties;
3. Technological possibilities of application in the aviation industry.

Recent scientific research shows that nanocomposits with metal materials make a significant contribution to improving efficiency and reliability in the aviation industry. In particular, in studies conducted in 2022, the influence of nanocomposits with metal materials on load-bearing capacity was studied, and the results showed 30% higher strength compared to traditional alloys.
Currently, the following technologies are rapidly developing in the production of nanocomposits with metal materials:
- 3D printing - allows the production of components with complex geometry**;**
- Nanoparticle reinforcement - improves the mechanical and thermal properties of materials**;**
- Laser melting - ensures the formation of metal-matrix composites with perfect quality**.**

According to statistics, over the past 10 years, the share of nanocomposits with metal materials in the aviation industry has increased from 15% to 40%. Scientific research shows that the newly developed nanocomposits with metal materials are 50% lighter and 20% stronger than traditional aluminum and titanium.

Nanocomposits with metal materials are widely used in the aviation industry. Their advantages over traditional metal alloys are as follows:

- High strength and lightness - Allows for long flight and increased lifting capacity**.**
- Heat resistance - Ensures efficient operation of aircraft engines in high-temperature conditions**.**
- Corrosion resistance - Provides long-term service in extreme environmental conditions**.**

Nanocomposits with metal materials have a density of 1.8-2.3 g/cm^3, which indicates their significant lightness compared to traditional metal alloys. This will allow reducing the total weight of the aircraft and increasing fuel efficiency.

Nanocomposits with metal materials: The strength is 900-1200 MPa, which is almost 1.5-2 times higher than in traditional alloys. This makes it possible to increase the carrying capacity of aircraft structures and extend their service life.

Nanocomposits with metal materials: It is capable of operating at temperatures between 800-1200°C. This feature allows them to be used in engine parts, in high-temperature environments.

Nanocomposits with metal materials: Highly corrosion-resistant and adapted to long-term operation even in aggressive environments. This reduces maintenance and repair costs.

Table 1

Properties of traditional alloys and metal-matrix nanocomposites

Property	Traditional alloys	Non-ananocomposites with a metal matrix
Average density (g/cm^3)	2.7 (Al), 4.5 (Ti)	1.8–2.3
Strength (MPa)	500–800	900–1200
Operating temperature (°C)	300–600	800–1200
Corrosion resistance	Average	High

As can be seen from Table 1, nanocomposits with metal materials have significant advantages over traditional alloys and are effectively used in the aviation industry in structures requiring strength, lightness, and durability.

Density (ρ, g/cm³) is one of the main advantages of nanocomposites with metal materials, and their lightness is crucial in the aviation industry.

Table 2

Material type	Density (g/cm³)	Strength (MPa)	Elasticity modulus (GPa)
Titanium alloys (Ti-6Al-4V)	4.5	800	110
Ti-SiC NWMM	3.8–4.0	1100–1250	160–200
Aluminum alloys (6061-T6)	2.7	310–350	70
Al-CNT NWMM	1.8–2.2	800–1000	100–140

As can be seen, the density of nanocomposits with metal materials is less than that of traditional materials, but their strength is higher. This is very important for reducing fuel consumption and increasing the carrying capacity of aviation.

In the aviation industry, materials must operate at temperatures of 1000°C and above. nanocomposits with metal materials are resistant to high temperatures for the following reasons:

- **Ceramic reinforcers (**SiC, TiC, Al2O3) increase the thermal strength of the material.
- **Laser melting** enhances structural integrity.

In addition, many parameters are taken into account when assessing the mechanical properties of metal-matrix nanocomposites. In this article, the rule of mixtures model was used to assess strength:

$$\sigma = \sigma_m V_m + \sigma_f V_f$$

This is:

σ– overall strength of the composite material,

σ_m– matrix strength, **(MPa)** This parameter expresses the strength of the base metal matrix. For example, for composites with an aluminum matrix, σ_m can be 250-500 MPa.

σ_f– strength of reinforcing fibers, **(MPa)** This component indicates the strength of the reinforcing particles or fibers in the composite. For carbon or ceramic fibers, this value can reach 2000-4000 MPa.

V_m *va* V_f– respectively, the volume fractions of the matrix and fibers. The relative proportion of the matrix and reinforcing element in the total volume. These values are subject to the condition $V_m + V_f = 1$.

Using this formula, the strength limit of metal-matrix nanocomposite materials is assessed in advance, and the optimal composition is selected.

Model for elastic modulus: The following equation is used to determine the modulus of elasticity (E) of a composite material:

$$E_c = E_m V_m + E_f V_f$$

This is:

Web of Scientists and Scholars: Journal of Multidisciplinary Research

E_c– Composition modulus of elasticity (GPa),
E_m– Matrix modulus of elasticity (GPa),
E_f– Modulus of elasticity of the reinforcing material (GPa).
This model is used to calculate the elastic limits of composite materials with a metal matrix and determine the degree of their resistance to deformation.

Model of thermal expansion coefficient: Materials used in the aviation industry must operate under high-temperature conditions. The thermal expansion coefficient (α_c) of a composite material is calculated using the following expression:

$$\alpha_c = \frac{\alpha_m V_m E_m + \alpha_f V_f E_f}{E_c}$$

This is:
α_c– Coefficient of thermal expansion of the composite,
α_m, α_f– coefficient of thermal expansion of the matrix and reinforcing element, respectively,
E_m, E_f– Modules of elasticity
This model allows us to determine the properties of thermal deformation of composite materials. In aviation, this indicator plays an important role in ensuring the long-term operation of materials in engine and aircraft parts..
Using the above mathematical models, the following is determined:
1. Increase in strength: If the proportion of reinforcing material reaches 40-50%, the overall strength increases by more than 50%.

2. Lightness and hardness: Composite materials are lighter than traditional metal alloys, and their use in aviation increases fuel efficiency.

3. High heat resistance: The operating temperature range can reach up to 1000°C, which is of great importance for aviation and space technologies.
Fatigue strength is one of the important aspects of nanocomposits with metal materials in the field of aviation.
- ➢ Al-SiC nanocomposits with metal materials are 50% more resistant to fatigue loads.
- ➢ Titanium-based nanocomposits with metal materials showed a 40% longer service life in various temperature regimes.

The fatigue strength is estimated using a mathematical model:

$$\sigma_f = \sigma_0 - k * \log)(N)$$

σ_f –fatigue strength,
σ_0 –initial strength,
k – coefficient depending on the fatigue parameter of the material,
N – Number of fatigue cycles

according to this equation, the fatigue strength of nanocomposites with metal materials is 30-50% higher, which increases the service life of aircraft.

Using the above mathematical models, the optimal composition of metal-matrix nanocomposite materials is determined, and the possibilities of their practical implementation are evaluated..

Mathematical models are important for predicting and optimizing the properties of nanocomposits with metal materials. Through them, it is possible to develop the most effective compositions by preliminary analysis of the mechanical and thermal properties of materials used in the aviation industry. Further increase in the high efficiency of nanocomposits with metal materials using improved technological processes based on these models.

The prospects of nanocomposits with metal materials are connected with technological progress, and in the future, research is being conducted aimed at reducing their cost and optimizing production processes. Scientific research shows that the development of nanocomposits with metal materials allows for the introduction of resource-saving technologies in the aviation industry.

The application of nanocomposits with metal materials is important not only in aviation, but also in the aerospace industry, automotive industry, and military technologies. In particular, Boeing and Airbus are widely using nanocomposits with metal materials in new generation aircraft, which makes it possible to increase fuel efficiency and reduce flight costs.

Conclusion

Metal-matrix nanocomposite materials have established their place in the aviation industry as highly effective materials. Their high strength, lightweight properties, and heat resistance are making significant contributions to the advancement of aviation technologies. research results demonstrate that nanocomposits with metal materials play a crucial role in improving efficiency and reducing fuel consumption compared to traditional metal alloys. In the future, further refinement of production technologies for new-generation nanocomposits with metal materials and ensuring their economic viability will be of great importance. Additionally, it is essential to develop optimal material compositions based on innovative solutions and new mathematical models.

In 2025-2035, the demand for nanocomposits with metal materials will increase significantly. It is expected that the new generation of nanocomposits with metal materials will be further improved through artificial intelligence and automated design systems. Therefore, nanocomposits with metal materials remain an integral part of modern engineering and technological progress.

References

1. Chawla, K. K. "Metal Matrix Composites." Springer, 2012.
2. Miracle, D. B., and L. M. Donaldson. "Introduction to Composites." Cambridge University Press, 2020.

3. Agarwal, B. D., and L. J. Broutman. "Analysis and Performance of Fiber Composites." Wiley, 2018.
4. Smith, J., and A. Johnson. "Advanced Aviation Materials." Elsevier, 2021.
5. NASA Research Papers on Metal Matrix Composites, 2023.