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OPERATIONAL EFFICIENCY OF GRAPHENE-BASED CARBON COMPOSITE MATERIALS FOR AIRCRAFT STRUCTURAL ELEMENTS

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Abstract. This thesis analyzes the operational efficiency of graphene-based carbon composite materials used in structural elements of aircraft. In modern aviation and space technology, not only the mechanical strength of materials is important, but also their reliability during long-term operation, service life, maintenance costs, and impact on fuel efficiency. From this perspective, graphene-based composites are considered promising structural materials.

Graphene is distinguished by its high elastic modulus (approximately 1 TPa), high tensile strength, and excellent thermal and electrical conductivity. By incorporating it as a nano-additive into carbon fiber reinforced polymer composites, it is possible to enhance fatigue resistance, impact resistance, and interlaminar strength. This helps slow down crack initiation and propagation during operation, increases structural reliability, and extends maintenance intervals.

Research results indicate that the addition of graphene can improve the fatigue resistance of existing composites by 25–40%, reduce microcrack development, and enhance thermal stability. However, the uniform dispersion of graphene and its cost-effective large-scale industrial production remain significant challenges.

In conclusion, graphene-based carbon composite materials represent an important factor in improving the operational efficiency of aircraft and can provide long-term economic and technical advantages.

Keywords: Graphene, carbon composites, operational efficiency, aviation materials, fatigue resistance, lightweight structures, fuel efficiency, nanocomposites, fuselage, reliability.

Annotatsiya. Mazkur tezisdagi uchish apparatlari konstruksiya elementlarida qo'llaniladigan grafen asosidagi uglerodli kompozitsion materiallarning ekspluatatsion samaradorligi tahlil qilinadi. Zamonaviy aviatsiya va kosmik texnika sohasida materiallarning nafaqat mexanik mustahkamligi, balki uzoq muddatli ishlash jarayonidagi ishonchliligi, xizmat muddati, texnik xizmat ko'rsatish xarajatlari va yoqilg'i samaradorligiga ta'siri ham muhim ahamiyat kasb etadi. Shu nuqtai nazardan grafen asosidagi kompozitlar istiqbolli konstruksion material sifatida qaralmoqda. Grafen o'zining yuqori elastiklik moduli (taxminan 1 TPa), yuqori cho'zilish mustahkamligi va mukammal issiqlik hamda elektr o'tkazuvchanligi bilan ajralib turadi. Uni uglerod tolali polimer kompozitlar tarkibiga nanoqo'shimcha sifatida kiritish orqali materialning charchashga

chidamliligi, zarbaga bardoshliligi va qatlamlararo mustahkamligini oshirish mumkin. Bu esa ekspluatatsiya jarayonida yoriqlar paydo bo'lishi va tarqalishini sekinlashtiradi, konstruksiyaning ishonchliligini oshiradi hamda texnik xizmat ko'rsatish oralig'ini uzaytiradi.

Tadqiqot natijalari shuni ko'rsatadiki, grafen qo'shimchasi mavjud kompozitlarning charchashga chidamliligini 25–40 % gacha oshirishi, mikro yoriqlar rivojlanishini kamaytirishi va issiqlik barqarorligini yaxshilashi mumkin. Biroq grafenning bir tekis taqsimlanishi va sanoat miqyosida iqtisodiy jihatdan samarali ishlab chiqarilishi dolzarb masala bo'lib qolmoqda.

Xulosa qilib aytganda, grafen asosidagi uglerodli kompozitsion materiallar uchish apparatlarining ekspluatatsion samaradorligini oshirishda muhim omil bo'lib, uzoq muddatli iqtisodiy va texnik ustunliklarni ta'minlashi mumkin.

Kalit so'zlar: Grafen, uglerodli kompozitlar, ekspluatatsion samaradorlik, aviatsiya materiallari, charchashga chidamlilik, yengil vazn, yoqilg'i tejamkorligi, nanokompozitlar, fyuzelyaj, ishonchlilik.

Introduction. The rapid development of the aviation and space industries has significantly increased the requirements for structural materials. Modern aircraft operate at high speeds, high altitudes, and under complex climatic conditions. Therefore, their structural elements must withstand high mechanical loads, aerodynamic pressure, vibration, sharp temperature fluctuations, and corrosive environments [1].

Traditionally, aluminum and titanium alloys have been widely used in aviation. However, over the past decades, carbon fiber reinforced polymer composites have become increasingly common. The concept of operational efficiency is defined not only by material strength, but also by its long-term performance capability, resistance to fatigue processes, ease of repair, and influence on maintenance costs. One of the main problems of composite materials is interlaminar delamination and brittleness under impact loading [2]. For this reason, improving the microstructural strength of composites through nano-additives has become an urgent task [3].

Since its discovery in 2004, graphene has attracted great interest in materials science. Its high elastic modulus and mechanical strength make it an ideal reinforcing additive for composite materials. Studies show that graphene nanoparticles can limit the propagation of microcracks within the matrix and effectively distribute stress energy [4].

In addition, the high electrical conductivity of graphene can play a significant role in protecting aircraft structures against lightning strikes. This may reduce the need for additional metallic layers and further decrease structural weight.

Thus, graphene-based composite materials may offer advantages not only in mechanical properties but also in operational performance indicators.

Literature Review and Methodology. A review of scientific literature shows that research on the operational properties of graphene-based composites mainly focuses on fatigue resistance, thermal stability, and impact resistance [5].

Experimental studies on graphene-reinforced composites have demonstrated improved resistance to cyclic fatigue loading [6]. The research methodology typically includes tensile, bending, and cyclic loading tests.

Microstructural analysis has been conducted using scanning electron microscopy and X-ray diffraction techniques. In addition, load distribution has been modeled using the finite element method [7].

Life Cycle Assessment (LCA) and economic efficiency indicators have also been considered in evaluating operational performance.

Discussion. The obtained results indicate that graphene-based composites exhibit significantly higher operational efficiency. In particular, improved fatigue resistance contributes to extending the service life of structural components.

For example, in modern aircraft such as the Airbus A350, even a 1% reduction in weight leads to a noticeable decrease in annual fuel consumption. The use of graphene-based composites could further enhance this performance.

However, production costs and technological complexity may limit large-scale industrial application. Therefore, optimizing dispersion techniques and reducing production costs remain priority tasks [8].

Conclusion. Graphene-based carbon composite materials are promising structural materials with high operational efficiency for aircraft applications. They combine lightweight characteristics, high strength, and extended service life.

In the future, through the improvement of production technologies and economic optimization, these materials may be widely implemented in the aviation and space industries, contributing to higher efficiency and sustainability.

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