

**PHYSICAL AND MECHANICAL PROPERTIES OF PARTS MADE
FROM POLYMER COMPOSITE MATERIALS USED IN MECHANICAL
ENGINEERING**

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Annotation. Polymer composite materials have become increasingly important in mechanical engineering applications due to their unique physical and mechanical properties, which offer a combination of high strength, low weight, corrosion resistance, and flexibility. These materials typically consist of a polymer matrix reinforced with various fibers, such as glass, carbon, or aramid, and are engineered to achieve specific performance characteristics. This paper examines the key physical and mechanical properties of polymer composite materials, focusing on aspects such as density, tensile strength, modulus of elasticity, impact resistance, and fatigue behavior. Additionally, the influence of factors such as fiber orientation, matrix type, and manufacturing processes on the overall performance of polymer composite parts is discussed. The paper also highlights the practical applications of these materials in mechanical engineering, including their use in automotive, aerospace, and structural components, emphasizing the balance between material properties and design requirements for optimal performance. The ongoing advancements in composite material technology, as well as the challenges in recycling and environmental considerations, are also explored. This comprehensive overview aims to provide insights into the advantages and limitations of polymer composites in engineering design, contributing to the continued development and utilization of these materials in modern mechanical engineering [1,2].

Keywords. Polymer composites, mechanical engineering, physical properties, mechanical properties, tensile strength, modulus of elasticity, impact resistance, fatigue behavior, fiber reinforcement, matrix materials.

Introduction. Polymer composite materials have gained significant traction in mechanical engineering due to their exceptional balance of strength, lightweight, durability, and versatility. These materials typically consist of a polymer matrix, such as epoxy, polyester, or vinyl ester, reinforced with fibers like glass, carbon, or aramid. The combination of these components results in materials that offer a unique set of physical and mechanical properties, making them suitable for a wide range of engineering applications [3].

In mechanical engineering, the demand for high-performance materials is constant, particularly in industries such as automotive, aerospace, and manufacturing. Polymer composites have been increasingly favored for their ability to reduce weight without compromising strength, enhance fatigue resistance, and provide resistance to corrosion and wear. As these materials continue to evolve, understanding their physical and mechanical properties becomes critical in ensuring optimal performance and reliability in end-use applications [4].

The physical properties, including density, thermal conductivity, and dimensional stability, influence the selection of polymer composites for specific applications. Meanwhile, mechanical properties such as tensile strength, elasticity, impact resistance, and fatigue life are crucial in determining the material's behavior under stress and long-term use. The optimization of these properties is achieved through careful selection of reinforcing fibers, resin matrices, and manufacturing processes, which all play a pivotal role in shaping the material's final performance. This introduction aims to provide an overview of the importance of polymer composite materials in mechanical engineering, with a particular focus on their physical and mechanical properties. By understanding these properties, engineers

can make informed decisions regarding the design, application, and performance of polymer composite parts in various mechanical systems [5,6].

Methods. The analysis of the physical and mechanical properties of parts made from polymer composite materials involves several methods, including material characterization techniques, mechanical testing, and computational simulations. These methods are critical in understanding how the properties of polymer composites influence their performance in mechanical engineering applications. The following methods are commonly employed:

1. Material Selection and Preparation: Composite Fabrication: The first step involves selecting the appropriate polymer matrix and reinforcing fibers. The polymer matrix (e.g., epoxy, polyester, vinyl ester) is chosen based on its compatibility with the reinforcing fibers (such as glass, carbon, or aramid). Various fabrication techniques, such as hand lay-up, filament winding, resin transfer molding (RTM), and vacuum bagging, are used to manufacture the composite parts. **Fiber-Matrix Interface:** The interaction between the fibers and the polymer matrix is optimized to enhance the mechanical performance of the composite. Surface treatments, like fiber sizing or plasma treatment, are often employed to improve bonding and interfacial strength [7].

2. Physical Property Testing: Density Measurement: The density of polymer composites is determined using techniques like Archimedes' principle or by calculating the ratio of mass to volume. This property is critical for applications where weight reduction is a key factor. **Thermal Conductivity:** The thermal behavior of the composite is assessed using differential scanning calorimetry (DSC) or thermal conductivity testing to understand its performance under different temperature conditions. **Dimensional Stability:** To evaluate the dimensional stability of composites, tests such as thermal cycling or moisture absorption tests are performed, which indicate how the material reacts to environmental changes over time [8].

3. Mechanical Property Testing: Tensile Testing: Tensile strength and modulus of elasticity are measured by applying a uniaxial tensile force to a specimen using a universal testing machine (UTM). The stress-strain curve obtained from this test helps determine the material's ability to withstand tensile loads. **Flexural Testing:** This test measures the bending properties of polymer composites under a three-point or four-point loading system. Flexural strength and modulus are critical for components that are subject to bending stresses. **Impact Testing:** Charpy or Izod impact tests are conducted to evaluate the material's resistance to sudden forces or impacts. This is important in assessing the composite's ability to withstand sudden loading conditions and its overall toughness. **Compression Testing:** Compression tests are performed to determine the compressive strength and modulus of the composite. These tests are essential for applications where the material will experience compressive forces. **Fatigue Testing:** Fatigue resistance is evaluated through cyclic loading tests that simulate real-world mechanical conditions. The number of cycles to failure provides insight into the material's long-term durability. **Shear Testing:** Shear tests are used to measure the material's resistance to shear forces, which are important for composites in applications subject to torsional or shear stresses [9].

4. Microscopic Analysis: Scanning Electron Microscopy (SEM): SEM is used to examine the microstructure of the composite material. This helps in identifying fiber-matrix bonding, detecting voids or defects, and observing the failure mechanisms under stress. **Optical Microscopy:** To study the surface morphology and the distribution of reinforcement within the composite, optical microscopy is utilized.

Results: The results of testing the physical and mechanical properties of parts made from polymer composite materials indicate significant performance advantages in various mechanical engineering applications. Based on the evaluation of various polymer composite materials, including glass fiber, carbon fiber, and aramid fiber reinforced polymers, the following results were observed:

Physical Properties: Density: Polymer composites typically have lower densities than metals, with glass fiber reinforced composites having densities ranging from 1.6 to 2.0 g/cm³ and carbon fiber reinforced composites between 1.5 and 1.8 g/cm³. These low-density materials contribute to weight reduction, which is critical in industries such as aerospace and automotive. **Thermal Conductivity:** The thermal conductivity of polymer composites is relatively low compared to metals, typically ranging from 0.2 to 0.5 W/m·K. This property makes composites suitable for applications where insulation and temperature control are essential, such as in electronic housing or thermal management systems.

Dimensional Stability: Moisture absorption tests indicate that polymer composites show varying degrees of dimensional stability, with glass fiber composites generally exhibiting low moisture absorption (0.2–0.5%), while carbon fiber composites are even more resistant. However, care must be taken to ensure that moisture does not compromise long-term performance, particularly in marine or outdoor environments [10].

Conclusion. Polymer composite materials have proven to be highly advantageous in mechanical engineering due to their remarkable combination of physical and mechanical properties. These materials, which consist of a polymer matrix reinforced with fibers such as glass, carbon, or aramid, offer a unique balance of strength, light weight, and durability, making them ideal for demanding applications in industries such as aerospace, automotive, and construction. The physical properties of polymer composites, such as low density, good thermal stability, and dimensional stability, provide significant benefits in applications requiring weight reduction and resistance to environmental factors. Additionally, their ability to resist corrosion and offer low thermal conductivity enhances their usability in challenging conditions. Mechanically, polymer composites excel in tensile strength, flexural strength, impact resistance, and fatigue life. Carbon fiber composites, in particular, stand out for their superior strength-to-weight ratio, while glass fiber composites offer excellent value for applications requiring

moderate strength and cost-effectiveness. The ability of polymer composites to withstand cyclic loading and high-stress environments further adds to their versatility. While polymer composites offer numerous advantages, challenges remain in terms of cost, manufacturing complexity, and recyclability. The high production cost of carbon fiber composites, in particular, limits their widespread adoption, especially in cost-sensitive industries. Furthermore, improving the recyclability of these materials and developing sustainable alternatives are critical areas for future research and innovation. In conclusion, polymer composites are an essential material class in mechanical engineering, offering a broad spectrum of properties that make them indispensable in advanced engineering applications. As manufacturing techniques continue to improve and the development of more sustainable composite materials progresses, the use of polymer composites in mechanical engineering will likely expand, leading to the creation of lighter, stronger, and more efficient products.

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