

FUNDAMENTALS OF EVALUATING THE MECHANICAL PROPERTIES OF POLYMER MATERIALS BASED ON INTERNATIONAL STANDARDS

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Abstract: This article presents an analytical review of the principal testing methods used to evaluate the mechanical properties of polymer materials. The viscoelastic nature of polymers, along with their sensitivity to strain rate, temperature, and time, plays a critical role in the selection of appropriate mechanical testing methods and in the interpretation of test results. In this study, tensile, flexural, compressive, impact, fatigue, and dynamic mechanical analysis (DMA) tests are systematized in accordance with international ASTM and ISO standards, and their methodological characteristics, advantages, and limitations are examined. An analysis of the scientific literature indicates that evaluating mechanical properties through individual tests often fails to fully reflect the actual in-service behavior of materials. Therefore, the article discusses a comprehensive interpretation of mechanical test results, the influence of testing parameters, and their relationship with structural factors. The generalized conclusions obtained provide a methodological basis for making scientifically grounded decisions in the selection, design, and optimization of polymer materials.

Keywords: polymer materials; mechanical properties; mechanical testing; ASTM and ISO standards; viscoelasticity; dynamic mechanical analysis; materials evaluation.

1. Introduction

Polymer materials are among the most widely used classes of materials in modern materials science and engineering due to their low density, high technological adaptability, broad possibilities for modification, and the controllability of their structural–functional properties. The growing demand for polymers in aerospace engineering, automotive manufacturing, electronics, biomedical engineering, as well as in flexible and wearable devices and energy systems necessitates a deep and systematic investigation of their mechanical behavior under various loading conditions. Unlike metallic and ceramic materials, polymers exhibit a viscoelastic nature, and their mechanical response is strongly dependent on molecular chain mobility, intermolecular entanglement, degree of crystallinity, and external environmental factors [1,2].

In recent years, the rapidly increasing need for lightweight yet mechanically robust materials has elevated polymers from conventional structural materials to high-performance engineering materials with enhanced functionality. In particular, in wearable electronic devices, high-performance composites, and energy storage systems, tensile strength, flexural and compressive moduli, impact resistance, fatigue strength, and elastic

behavior of polymers are considered key design parameters. For instance, polyether ether ketone (PEEK), a thermoplastic with high thermal and mechanical stability, is widely used for structural components in the aerospace industry, whereas ultra-high-molecular-weight polyethylene (UHMWPE) is extensively employed in ballistic protection systems due to its high tensile and impact strength [3,4].

The scientific literature extensively addresses factors influencing the mechanical properties of polymers. Studies by Winter [5] and by Nelson and Cox [6] have substantiated the effects of molecular weight, degree of crystallinity, and chain orientation on mechanical strength. Bard and Faulkner [7] demonstrated that plasticizers and intermolecular interactions can enhance elasticity, although in certain cases they may lead to a reduction in mechanical strength. Moreover, the effects of temperature, humidity, and strain rate on the long-term performance of polymers have been reported in numerous studies [8]. However, most existing works are limited to specific polymer classes or individual mechanical properties, and issues related to the interdependence of mechanical parameters and their comprehensive evaluation have not been sufficiently systematized.

Furthermore, the systematic relationships between molecular structural parameters—such as crosslink density, tacticity, and chain mobility—and macroscopic mechanical behavior, including fracture resistance and fatigue life, have not yet been fully elucidated. Although tensile properties can be reliably evaluated using international standards such as ASTM D638 and ISO 527, methodologies aimed at assessing long-term mechanical behavior under fatigue, impact, and multiaxial loading conditions remain limited [9,10]. This limitation is particularly pronounced in modern polymer composites containing nanofillers and multiphase structures, where multiscale effects significantly restrict the applicability of existing models.

From a practical perspective, optimizing the mechanical properties of polymer materials not only ensures structural stability but also expands their multifunctional performance capabilities. For example, polymer electrolytes used in flexible energy systems are required to withstand mechanical loads, impact, and compressive forces while maintaining high ionic conductivity. In medical implants and biomaterials, resistance to cyclic loading and the stability of mechanical properties in biological environments are of critical importance. Therefore, a thorough understanding of the mechanisms by which structural, thermal, and environmental factors influence mechanical properties is essential for modern materials design.

The objective of this article is to provide a systematic and integrated scientific review of the principal mechanical properties of polymer materials, including tensile, compressive, flexural, impact, fatigue, and elastic behavior. The effects of composition, degree of crystallinity, chain orientation, plasticizers, fillers, temperature, and humidity on mechanical performance are examined using an analytical approach. In addition, testing methodologies based on ASTM and ISO standards, as well as the advantages and limitations of modern polymer and nanocomposite systems, are discussed. This review serves as a theoretical and practical platform for engineers and researchers to make scientifically grounded decisions in the selection and modification of polymer materials.

2. Methods for Evaluating the Mechanical Properties of Polymers

Determining the mechanical properties of polymer materials is one of the fundamental research directions required for their effective integration into structural, functional, and hybrid systems in fields such as engineering, medicine, and energy. The performance, reliability, and service life of polymer-based components largely depend on their mechanical stability under various loading conditions, including static, dynamic, cyclic, and impact loads. Unlike metallic and ceramic materials, polymers exhibit characteristics

such as viscoelasticity, nonlinearity, anisotropy, and environmental sensitivity, which complicate their mechanical behavior and necessitate advanced and rigorous testing methodologies.

Mechanical characterization is particularly critical for polymers used in advanced technological domains, including wearable electronics, aerospace composites, flexible energy storage devices, biomaterials, and micro-electromechanical systems (MEMS). In such applications, reliance on general material data is insufficient; instead, an accurate assessment of the mechanical response of polymers under realistic service conditions—considering temperature, humidity, strain rate, and loading mode—is essential.

To comprehensively measure the mechanical properties of polymers, a wide range of standardized testing methods developed by ASTM and ISO are employed. These methods enable the determination of key parameters such as tensile strength, flexural modulus, compressive resistance, impact toughness, fatigue resistance, and elastic modulus. Each parameter reflects a specific mechanical aspect of the material. Factors such as specimen geometry, loading rate, deformation measurement techniques, and boundary conditions can significantly influence test results. Therefore, adherence to international standards plays a crucial role in ensuring the comparability of results and their practical applicability.

This section provides an in-depth analysis of the principal mechanical testing methods. For each method, the underlying physical principles, governing equations, testing equipment configurations, and data analysis approaches are described. In addition, the advantages and roles of modern techniques—such as digital image correlation (DIC), dynamic mechanical analysis (DMA), and nanoindentation—in overcoming experimental limitations are discussed. These methods are particularly important for characterizing the complex behavior of time-dependent, scale-sensitive, and multicomponent polymer systems.

In summary, the systematic evaluation of the mechanical properties of polymers serves not only as a diagnostic tool but also as a critical design instrument for advanced modeling, performance prediction, and material selection. The following sections provide a detailed discussion of the information yielded by each testing method, their practical significance, and the extent to which they meet contemporary technological requirements.

The tensile test is one of the primary mechanical testing methods used to determine the resistance of polymer materials to uniaxial tensile loading. This method allows for the evaluation of essential mechanical parameters such as tensile strength, ultimate tensile force, Young's modulus (elastic modulus), and elongation at break. The test is conducted in accordance with international standards ASTM D638 and ISO 527 and plays a vital role in material selection for load-bearing, structural, and flexible applications [11,12].

During the test, a standard dumbbell-shaped specimen is mounted in a universal testing machine (UTM) and subjected to tensile loading at a constant crosshead speed from both ends. As the material elongates, a stress–strain curve is generated until fracture occurs. This curve clearly delineates the elastic, plastic, and fracture stages of deformation. The initial linear slope of the curve represents Young's modulus (E), which characterizes the stiffness of the material, while the peak of the curve corresponds to the maximum tensile strength of the polymer [13].

The tensile stress is determined using the following formula:

$$\sigma_t = \frac{F}{A} \quad \text{1-equation}$$

where: σ_t is the tensile stress (MPa), F is the applied force (N), and A is the initial cross-sectional area (mm^2).

The relative elongation is calculated as follows:

$$\varepsilon = \frac{\Delta L}{L_0} \text{ 2-equation}$$

where: ε is the strain (dimensionless), ΔL is the change in length, and L_0 is the initial gauge length [14].

The results of this test make it possible to analyze not only the strength of the material but also its elastic response to deformation. Compared with highly extensible elastomers, polymers with a crystalline structure (such as PEEK or UHMWPE) exhibit significantly higher tensile strength, which makes them particularly suitable for structural elements subjected to high loads and impact conditions [15].

In practice, tensile testing is widely used to evaluate the performance of films, fibers, automotive components, electrical insulation coatings, and composite structures. In addition, it is employed to assess the influence of plasticizers, fillers, or stabilizers on the mechanical properties of polymer compositions [16].

Flexural Test

The flexural test is one of the key mechanical testing methods used to evaluate the bending response of polymer materials. This method allows for the determination of flexural strength, flexural modulus, and resistance to deformation. Flexural testing is particularly important in applications involving layered composites, rigid plastics, profiles, and structural elements. The test is typically conducted in accordance with international standards ASTM D790 and ISO 178 [17,18].

The test can be performed using either three-point or four-point bending configurations. The most commonly used method is the three-point bending test, in which the specimen is supported at two points and a force is applied at the midpoint. The resulting load–deflection curve enables the determination of the elastic deformation limit and the maximum flexural stress. The flexural stress is calculated using the following formula:

$$\sigma_f = \frac{3FL}{2bd^2} \text{ 3-equation}$$

where:

σ_f – flexural stress (MPa),

F – maximum applied force (N),

L – span length between supports (mm),

b – specimen width (mm),

d – specimen thickness (mm) [19].

The flexural modulus is determined from the initial slope of the load–deflection curve, representing the material's stiffness under bending. Polymers with a high degree of crystallinity (e.g., PEEK, PC) typically exhibit higher flexural strength due to their ordered and dense molecular structure. In contrast, amorphous polymers (e.g., PS, PMMA) are more brittle under bending and show lower flexural strength [20].

From a practical perspective, flexural testing enables modeling of the performance of polymer plates, profiles, coatings, and structural components under load. Composite materials, such as polymers reinforced with glass or carbon fibers, are often comparatively evaluated through flexural tests. Additionally, this method can assess the effect of plasticizers, stabilizers, nanofillers, or other additives on the bending resistance of polymers [21].

Flexural testing can also be used to evaluate mechanical stability under varying conditions of temperature, moisture absorption, and aging, providing critical data for polymer selection in construction, electrical engineering, transportation, and biomedical industries.

Compressive Test

The compressive test is a fundamental mechanical analysis method used to evaluate the response of polymer materials under applied pressure. Unlike tensile or flexural tests, it measures the deformation that occurs when a uniaxial compressive (pushing) force is applied to the material. Compressive testing is particularly important for structural elements, foamed polymers, packaging materials, resin-based composites, and load-bearing components. This test is typically conducted according to international standards ASTM D695 and ISO 604 [22,23].

During the test, a cylindrical or rectangular specimen is placed between the two flat platens of a universal testing machine and compressed at a specified rate. As the compressive force increases, the resulting load–displacement data are used to construct a stress–strain curve. The compressive stress is determined using the following formula:

$$\sigma_c = \frac{F}{A} \quad \text{4- equation}$$

where:

σ_c – compressive stress (MPa),

F – applied force (N),

A – cross-sectional area of the specimen (mm²) [24].

Unlike metals, many polymers exhibit nonlinear behavior under compression. Viscoelastic or amorphous polymers (e.g., polyurethane, polystyrene) can undergo large deformations due to the high mobility of their molecular chains. In contrast, semi-crystalline or thermosetting polymers (e.g., PEEK or epoxy-based composites) demonstrate high compressive strength due to their rigid network structures [25].

The compressive test also allows the determination of the **compressive modulus**, which is analogous to the tensile modulus and reflects elasticity under compressive loading. This parameter is particularly important for energy-absorbing foams, medical prostheses, automotive bumpers, and thermal insulation systems. The test enables the identification and modeling of deformation modes such as buckling, plasticity, and brittle fracture.

From a practical perspective, compressive testing is widely used for quality control and validation of high-performance polymers in aerospace, automotive, construction, and biomedical engineering. For example, strong thermoplastics and fiber-reinforced composites used in orthopedic implants or aircraft panels must demonstrate adequate compressive strength. Additionally, low-density foamed materials are assessed to determine their energy absorption under static or dynamic pressure conditions.

Environmental factors such as temperature, humidity, and aging also significantly affect the compressive properties of polymers. In particular, hygroscopic polymers (e.g., polyamides) may weaken more rapidly under compressive loads in moist environments. Therefore, compressive testing serves as an essential tool for evaluating long-term mechanical stability.

The elastic modulus (or Young's modulus) is a key mechanical parameter that quantifies the stiffness of a polymer material under elastic deformation. It measures the extent to which a material deforms when subjected to a force and describes the linear relationship

between stress and strain. This relationship is expressed by Hooke's law, which is written as follows:

$$\sigma = E \cdot \varepsilon \quad \text{5-equation}$$

where:

σ – stress (MPa),

ε – strain (dimensionless),

E – elastic modulus (MPa or GPa) [27].

The elastic modulus indicates the extent to which a material will deform under applied load, whether in tension or compression. Materials with a high E value—such as PEEK, PC, and epoxy resins—are rigid and exhibit low deformation, whereas materials with a low E value—such as elastomers and silicone rubber—are soft and flexible [28].

The elastic modulus is most commonly determined through tensile testing (ASTM D638 or ISO 527), where the initial linear slope of the stress–strain curve is calculated. For higher precision, modern techniques such as dynamic mechanical analysis (DMA) or nanoindentation may be used. DMA enables the determination of the storage modulus (E') and loss modulus (E''), which are particularly important for viscoelastic materials [29].

The elastic modulus of polymers depends on molecular structure, degree of crystallinity, crosslink density, and environmental factors. Crystalline polymers typically exhibit high E values due to the ordered arrangement of their molecular chains. In contrast, amorphous polymers have disordered chains and tend to be more flexible. Elastomers represent very low-modulus materials and undergo large deformations under load [30].

From a practical perspective, the elastic modulus is a critical parameter in polymer selection. High E values are required for load-bearing structural components, whereas low E values are preferred for flexible packaging, cushioning components, or soft robotics. The elastic modulus is also significantly temperature-dependent: as temperature increases, molecular mobility rises and E decreases. Consequently, high-modulus, thermally stable polymers are required for applications demanding thermal stability [31].

Fatigue Testing

Fatigue testing is a key mechanical evaluation method designed to determine the durability of polymer materials under repeated or cyclic loading. Unlike one-time tensile or compressive tests, fatigue testing assesses the material's susceptibility to failure over time due to the accumulation of fatigue damage. This is especially critical in applications such as automotive suspensions, medical implants, structural joints, and flexible electronics, where components are regularly subjected to cyclic loads. Fatigue tests are conducted according to international standards ASTM D7791 and ISO 13003 [32,33].

During fatigue testing, a specimen is repeatedly loaded with sinusoidal, triangular, or square wave impulses at a specified frequency and amplitude. The test continues until the specimen fractures or reaches a predetermined number of cycles. The resulting **S–N curve** (stress–life curve) shows the relationship between the stress amplitude (σ_a) and the number of cycles to failure (N_f). This relationship is often expressed using Basquin's equation:

$$\sigma_a = \sigma'_f \cdot (N_f)^b \quad \text{6-equation}$$

where:

σ_a – stress amplitude (MPa),

σ'_f – fatigue strength coefficient,
 N_f – number of cycles to failure,
 b – fatigue exponent [34].

Polymers respond differently to fatigue compared with metals due to their viscoelastic and time-dependent behavior. For example, thermoplastics (PP, PE) tend to soften or accumulate residual deformation under load, whereas crosslinked or reinforced polymers (epoxies, fiber-reinforced composites) exhibit greater fatigue resistance due to their stable network structures. Environmental factors—particularly temperature, humidity, and oxidation—can significantly accelerate fatigue in hygroscopic polymers, such as polyamides [35].

Modern fatigue analysis often incorporates dynamic mechanical analysis (DMA), which evaluates the time- and frequency-dependent viscoelastic parameters of a material, providing insight into damping (energy dissipation) and internal heat absorption mechanisms [36]. In addition, post-test examination using scanning electron microscopy (SEM) allows detailed microscopic analysis of crack initiation, fracture surfaces, and fatigue marks.

From a practical perspective, fatigue testing is a crucial tool for predicting the service life and ensuring the reliability of polymer components subjected to cyclic loading. For instance, polymers used in medical joints or prostheses must withstand millions of cycles and are therefore rigorously fatigue-tested. In aerospace and automotive industries, composites reinforced with carbon or glass fibers undergo fatigue testing to ensure structural safety [37].

A thorough understanding of fatigue behavior is not only critical for selecting existing materials but also guides the design of new polymers. Incorporating crosslinking, nanofillers, or reinforcing phases can produce materials with enhanced fatigue resistance. Therefore, fatigue testing is a fundamental evaluation method for any advanced material intended for dynamic loading applications.

Impact Testing

Impact testing is an important evaluation method used to determine how polymer materials respond to sudden, high-velocity mechanical loads, how they absorb energy, and how resistant they are to fracture. Unlike static tests, impact testing simulates real-life scenarios such as collisions, drops, shocks, or explosions. This makes it particularly relevant for automotive safety, aerospace structures, electronic housings, sports equipment, and protective gear. Through impact testing, the material's brittleness, plasticity, fracture resistance, and energy absorption capacity are assessed. Standard test methods include ASTM D256 (Izod) and ASTM D6110 (Charpy) [38,39].

In this test, a notched specimen is struck by a swinging pendulum at high speed. The energy required by the pendulum to fracture the specimen is recorded, and the impact strength is calculated using the following formula:

$$\sigma_i = \frac{E}{A} \quad \text{7-equation}$$

where:

σ_i – impact strength (J/m²),

E – absorbed energy (J),

A – cross-sectional area (m²) [40].

Notched specimens simulate real-life stress concentrators (weak points) and accelerate crack initiation. Test outcomes are strongly influenced by notch geometry, temperature, and loading rate. Polymers with high impact resistance undergo significant plastic deformation prior to failure, thereby absorbing more energy.

Polymers exhibit diverse responses to impact. For instance, polycarbonate (PC) and ABS (acrylonitrile–butadiene–styrene) are well-known for high impact resistance due to their dense molecular structure and efficient energy distribution. In contrast, brittle and amorphous polymers such as PMMA (acrylic) or PS (polystyrene) are prone to fracture even under relatively low-impact loads. Semi-crystalline polymers (e.g., HDPE, PP) exhibit intermediate behavior depending on temperature and degree of crystallinity [41].

Impact testing not only assesses strength but also reveals the failure mechanisms of the material, such as ductile tearing, smooth cracks, microcracking, or brittle fracture. Post-test examination using scanning electron microscopy (SEM) or high-speed video enables analysis of fracture surfaces, crack propagation, and deformed zones [42].

From a practical standpoint, impact testing is essential for the design of collision-resistant components, drop-resistant electronics, and blast-proof enclosures. Many technical regulations—ASTM, ISO, or UL—consider impact resistance a primary selection criterion for products operating under hazardous conditions. Advanced methods, such as instrumented drop-weight testing, allow real-time measurement of force–displacement data, enabling a detailed evaluation of energy absorption, contact mechanics, and damage processes [43].

Environmental conditions—such as low temperature, humidity, or UV exposure—can significantly reduce a material’s impact resistance. Therefore, impact tests are often conducted under various environmental conditions, including cold, wet, or UV-exposed settings.

In summary, impact testing provides a comprehensive understanding of how polymers respond to rapid, dynamic loads. It establishes a direct link between mechanical design and safety performance, supplying engineers and materials scientists with critical data to develop durable, reliable, and protective products.

Dynamic Mechanical Analysis (DMA)

Dynamic Mechanical Analysis (DMA) is a high-precision technique used to evaluate the viscoelastic properties of polymer materials as functions of temperature, frequency, and time. Unlike static mechanical tests, DMA applies oscillatory deformation (e.g., sinusoidal stress or strain) to a specimen and measures the resulting phase shift between stress and strain. This allows simultaneous evaluation of the material’s elastic (storage) and viscous (loss) components. DMA is particularly effective for studying time-dependent behavior, molecular mobility, damping, energy dissipation, phase transitions, and internal structural changes [44].

During a DMA test, the specimen is subjected to oscillatory loading at a specified frequency, and the resulting deformation or force is measured. Due to viscoelasticity, a phase lag occurs between stress and strain, from which the following three parameters are determined:

$$\tan \delta = \frac{E''}{E'} \quad \text{8-equation}$$

- **E' (Storage Modulus):** Represents the elastic energy stored by the material, corresponding to the recoverable deformation component.

- **E'' (Loss Modulus):** Denotes the magnitude of energy dissipation, representing the component absorbed as heat.
- **$\tan \delta$ (Damping Factor):** Expressed as the ratio of the loss modulus to the storage modulus:

These parameters exhibit significant dependence on temperature and frequency. For instance, as temperature increases, the mobility of polymer chains rises, leading to a reduction in E' and causing $\tan \delta$ to reach a local maximum. This peak is typically associated with the glass transition temperature (T_g) and serves as a critical design criterion for temperature-sensitive applications. The position and magnitude of the $\tan \delta$ peak provide essential data regarding molecular relaxation, interfacial mobility, and interphase interactions within composite systems [45,46].

Operational Modes and Applications MA can be implemented across various deformation regimes, including tension, compression, bending (dual cantilever, 3-point bending), shear, and torsion. The selection of the specific mode depends on the specimen geometry and the objective of simulating actual loading conditions. This methodology is utilized to analyze films, fibers, cellular materials, and high-density solid polymers.

For thermoplastic elastomers, DMA identifies multi-stage transitions and long-range characteristics of segmental motion. In the case of thermosetting resins and composites, this analysis is employed to determine cross-link density, filler–matrix interactions, and the impact of thermal aging on mechanical stability. For nanocomposites, a shift in T_g and an increase in E' indicate the efficiency of the dispersion and the quality of interfacial load transfer [47].

Engineering and Quality Control Perspectives From an engineering standpoint, DMA is an indispensable tool for predictive modeling, material design, process parameter optimization, and failure analysis. DMA results are utilized for numerical modeling (e.g., Finite Element Analysis), the selection of vibration and noise-damping materials, and the performance assessment of components operating under thermo-mechanical cycling.

Furthermore, DMA is widely applied in quality control (QC), particularly in industries where batch-to-batch variability, aging, or moisture sensitivity are critical factors (e.g., automotive seals, medical tubing, and insulation coatings). In contrast to static testing, DMA is capable of detecting the most subtle structural transitions.

Mechanical Characterization Results and Discussion In conclusion, DMA allows for a profound and precise investigation of the viscoelastic and thermo-mechanical behavior of polymer materials. It bridges the gap between molecular dynamics and macroscopic performance, ensuring stable mechanical behavior under complex real-world conditions.

Experimental analyses indicate that the mechanical response of polymers is governed by their internal molecular structure, degree of crystallinity, interchain interactions, the presence of additives (fillers, plasticizers), and environmental factors.

Tensile, Bending, and Compression Tests:

Materials with high crystallinity (e.g., PEEK, UHMWPE) demonstrated superior mechanical stability. Conversely, amorphous polymers (e.g., PMMA, PS) exhibited a propensity for failure at lower stress levels. Elastomers (e.g., TPU), while possessing lower stiffness, were characterized by significant elongation and energy absorption properties.

Fatigue Analysis:

Polymers reinforced with fibers or cross-linking elements (epoxy composites) showed significant superiority over conventional thermoplastics, withstanding millions of cycles

without failure. Moisture and temperature were found to accelerate fatigue cracking, particularly in hygroscopic polymers (e.g., PA).

Impact Testing:

Polycarbonate (PC) and ABS exhibited high impact energy absorption, confirming their capacity for plastic deformation and impact toughness. In contrast, brittle polymers like PMMA and PS failed at low energy levels. The shift in T_g and the increase in the storage modulus in nano-filled polymer systems further demonstrate the structural efficiency of the composites. The comprehensive results are summarized in the following table:

1-table. Mechanical Test Results of Polymers

Polymer Type	Tensile Strength (MPa)	Flexural Modulus (GPa)	Impact Resistance (J/m ²)	Fatigue Life (Nf)	Tg (°C)	References
PEEK	90–100	3.6–4.1	400–600	>10 ⁶ cycles	143	[12–15]
Polycarbonate (PC)	55–70	2.0–2.4	600–900	10 ⁵ –10 ⁶ cycles	150	[16–18]
PMMA (Acrylic)	50–65	1.8–3.1	20–50	<10 ⁵ cycles	105	[19–21]
UHMWPE	20–30	0.6–1.2	300–500	≈10 ⁶ cycles	—	[22–24]
TPU (Elastomer)	5–10	0.01–0.10	100–300	Very high (no failure observed)	–40...–60	[25–27]
Epoxy Composite (fiber-reinforced)	100–150	>10	300–400	>10 ⁷ cycles	>160	[28–31]

Note: The values presented in the table are generalized based on ranges reported in various sources and may vary depending on testing conditions such as temperature, loading rate, and specimen geometry.

As observed from the table, no single polymer meets all mechanical requirements perfectly. Therefore, material selection must be application-specific: PEEK or epoxy composites are preferred for high-load and structurally demanding applications, TPU or PC for impact and elongation resistance, and PMMA or amorphous polymers for optical clarity, transparency, and ease of processing.

Conclusion

This analytical review systematically and critically summarized the primary testing methods used to evaluate the mechanical properties of polymer materials. The findings indicate that the mechanical response of polymers is intrinsically linked to their molecular structure, degree of crystallinity, intermolecular interactions, and environmental factors, and that individual mechanical tests cannot fully capture these complex behaviors.

While tensile, flexural, and compressive tests provide insight into the fundamental strength parameters of materials under static loading, fatigue and impact tests are crucial for assessing long-term and dynamic performance. Dynamic Mechanical Analysis (DMA) is the most sensitive method for revealing the viscoelastic nature of polymers, complementing static test results by determining the glass transition temperature, damping behavior, and segmental mobility.

In summary, evaluating polymer materials for real operational conditions requires an integrated and comprehensive testing approach. The insights from this review support engineering design, the development of advanced polymer composites, and informed material selection for energy, biomedical, and flexible electronics applications.

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