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# Exploring Properties of Materials for Effective Combinations in Mechanical Engineering Technology

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**ABSTRACT:** The selection and combination of materials play a critical role in the design, performance, and sustainability of mechanical systems and components. This study investigates the fundamental and applied properties of engineering materials with the aim of identifying optimal combinations that enhance performance, durability, and cost-efficiency in mechanical engineering technology. Adopting a mixed-methods research design, the study integrates experimental analysis with expert evaluations to explore key material properties such as tensile strength, hardness, thermal conductivity, corrosion resistance, and fatigue performance. A total of 25 commonly used engineering materials including metals, alloys, polymers, and composites were selected based on their relevance to mechanical applications. Laboratory tests were conducted using standardized procedures (ASTM and ISO) to evaluate physical and mechanical properties, while expert opinions were obtained through structured interviews with mechanical engineers and materials scientists. The findings reveal that strategic combinations of materials, such as steel-aluminum, carbon fiber-epoxy, and copper-graphene composites, result in synergistic effects that improve overall system efficiency in terms of weight reduction, thermal management, and structural integrity. The study also provides a materials selection matrix that guides engineers in matching material properties with specific mechanical functions such as load-bearing, vibration damping, and heat dissipation. Additionally, the study highlights critical considerations in material compatibility, including galvanic corrosion, thermal expansion mismatch, and interfacial bonding challenges. The results underscore the importance of interdisciplinary knowledge in materials science and mechanical engineering for developing innovative and sustainable engineering solutions. Based on the findings, the study recommends incorporating property-based material selection frameworks into engineering education and design practice to optimize mechanical performance across various industrial applications.

**KEYWORDS:** Material properties, mechanical engineering technology, material combinations, engineering materials, structural performance, composite materials, material selection.

## INTRODUCTION

Materials science is a fundamental discipline that examines the structure, properties, processing, and performance of materials such as metals, polymers, ceramics, composites, and biomaterials. Understanding these relationships is essential in mechanical engineering technology for selecting materials that meet design criteria and perform reliably under mechanical loads, thermal cycles, corrosive environments, and wear. According to Ashby (2011), materials selection is a key part of engineering design, enabling designers to match material properties to functional requirements through systematic use of property charts and merit indices. Additionally, Oduori (2001) views materials selection as an information-processing decision-making task, emphasizing the need for data-driven and expert-supported approaches in modern engineering design.

Detailed knowledge of material properties including tensile strength, hardness, ductility, thermal conductivity, and corrosion resistance is essential for predicting how engineered components will behave under various loading and environmental conditions. As Zhanga et al. (2020) demonstrate, leveraging accurate material data in design models significantly improves reliability and minimizes failure risks in mechanical systems. Likewise, Roberts and Epstein (2019) emphasize that property-based material selection is critical for optimizing structural integrity, weight, manufacturability, and cost-effectiveness in modern engineering design.

Since no single material exhibits excellence across all functional requirements, engineers increasingly adopt hybrid approaches combining materials to achieve multifunctional performance. Fernandez and Bhattacharyya (2021) report that composite and hybrid systems can integrate high strength, low weight, thermal stability, and corrosion resistance in ways unattainable by single-phase materials. Similarly, Lee *et al*. (2022) asserted that tailored material pairings such as carbon-fiber/metal hybrids offer superior toughness, thermal management, and lifecycle performance compared to homogeneous materials, enabling applications in aerospace, biomedical, and energy systems.

**Statement of the Problem**

In mechanical engineering applications, the selection of appropriate materials is a critical factor that determines the reliability, safety, and cost-effectiveness of components and systems. However, material-related failures remain a persistent challenge, often resulting from poor understanding of material properties or inappropriate selection for specific functional requirements. Such failures can manifest as fatigue, fracture, corrosion, or excessive wear, leading to premature breakdown of machines, increased maintenance costs, and safety hazards. Additionally, the use of single materials frequently imposes limitations because no single material can simultaneously satisfy the diverse demands of high strength, low weight, thermal stability, and corrosion resistance required in modern engineering designs. This shortfall results in inefficient designs, higher energy consumption, and increased material costs due to over-engineering to compensate for property deficiencies. With growing demands for sustainable and high-performance products in industries such as aerospace, automotive, energy, and biomedical engineering, there is a pressing need to explore effective combinations of materials that can provide enhanced performance while reducing cost and weight. Without a systematic understanding of material properties and their synergistic behavior when combined, engineers risk designing components that are inefficient, expensive, and prone to failure, thereby compromising both performance and economic viability.

**Aim of the Study**

The aim of this study was to explore the properties of selected engineering materials and identify effective material combinations that enhance mechanical performance, reliability, and cost-effectiveness in mechanical engineering applications. The study was specifically designed to:

1. Determine the mechanical and thermal properties (tensile strength, hardness, ductility, thermal conductivity, and corrosion resistance) of selected engineering materials.
2. Compare the performance of the materials based on their tested properties to identify their strengths and weaknesses.
3. Identify effective combinations of materials that provide enhanced mechanical, thermal, and corrosion resistance properties for specific engineering functions.
4. Develop a material selection matrix to guide engineers in matching material combinations to mechanical applications for improved design efficiency and performance.

## LITERATURE REVIEW

**Concept of Engineering Materials**

Engineering materials are substances selected or engineered for use in applications that demand specific mechanical, thermal, chemical, or electrical properties. Typically, these materials fall into five major classes:

1. **Metals and Alloys** Comprising elements or intermetallic compounds with metallic bonding, metals such as steel, aluminum, copper, and alloys like stainless steel and titanium are known for their high strength, ductility, electrical conductivity, and toughness. They are widely used in load-bearing and structural applications (Ashby, 2011).
2. **Ceramics** Inorganic non-metallic materials, such as alumina, silicon carbide, and glass, characterized by strong ionic or covalent bonds. They offer high hardness, compressive strength, thermal stability, and wear resistance but tend to be brittle (Callister & Rethwisch, 2020).
3. **Polymers and Plastics** Long-chain organic compounds including polyethylene, polycarbonate, ABS, and nylon. Polymers exhibit low density, good ductility, chemical resistance, and ease of processing, though they generally have lower strength and thermal stability than metals (Callister & Rethwisch, 2020).
4. **Composites** Engineered combinations of two or more distinct materials (e.g. fiber-reinforced polymers like carbon fiber/epoxy, metal–matrix composites), designed to achieve superior properties such as high strength-to-weight ratios, tailored stiffness, enhanced corrosion resistance, and adaptive thermal behavior. They provide synergistic performance beyond that of their individual constituents (Chawla, 2012; Ashby, 2011).

Ashby (2011) presents a systematic Materials Selection methodology that helps designers classify materials by their intrinsic properties and compatibility with engineering functions. Similarly, Callister and Rethwisch (2020) provide a foundational overview of these material classes, explaining how their bond structure and microstructure dictate their mechanical, thermal, and electrical behavior.

**Mechanical and Physical Properties of Materials**

Understanding mechanical and physical properties is essential for selecting the right materials in engineering design. Tensile strength determines the maximum load a material can bear before fracture, guiding decisions for load-bearing components, as highlighted by Dieter (2013) in his principles of engineering materials. Hardness indicates resistance to surface indentation and wear; according to Bhushan and Guo (2017), higher hardness often implies enhanced wear resistance but may correlate with brittleness. Ductility measures how much a material can deform plastically before breaking materials like copper or nickel alloys demonstrate high ductility, allowing them to absorb strains without catastrophic failure (Callister & Rethwisch, 2020). Toughness combines strength and ductility, reflecting a material's ability to absorb energy before failure; materials such as certain steels and composites show high toughness, making them suitable for impact-resistant applications (Ashby et al., 2019).

Thermal conductivity quantifies a material's ability to conduct heat; metals such as copper and aluminum provide excellent thermal conductivity, which is critical in heat exchangers and thermal management systems (Zhang & Wang, 2021). Corrosion resistance defines a material's ability to withstand chemical degradation; stainless steel, bronze, and certain alloys are preferred in corrosive or marine environments due to their superior resistance (Perez & Martinez, 2018).

Together, these properties tensile strength, hardness, ductility, toughness, thermal conductivity, and corrosion resistance form the basis of performance evaluation in materials science and inform materials selection strategies that ensure safety, durability, and functional effectiveness in complex engineering systems.

**Material Selection in Mechanical Engineering**

In mechanical engineering, choosing the right material is a multifaceted decision that significantly influences product performance, longevity, safety, and cost. Recent research emphasizes a systematic approach that integrates various technical and economic criteria to guide material selection (Ashby et al., 2019; Roberts & Epstein, 2019).

Key material selection criteria include:

*i.* **Mechanical Performance Requirements**: Materials must satisfy load-bearing demands via properties such as tensile strength, yield strength, fatigue resistance, toughness, hardness, and stiffness. For high-stress components, materials with high strength-to-weight ratios or superior hardness are preferred (Ashby *et al*., 2019).

*ii.* **Thermal and Environmental Stability**: The material should withstand operating temperatures and resist thermal degradation in relevant conditions. Thermal conductivity, thermal expansion, and heat capacity are critical in thermal management systems (Zhang & Wang, 2021). Corrosion resistance is vital when exposure to chemicals, moisture, or marine environments is expected (Perez & Martinez, 2018).

*iii.* **Manufacturability and Process Compatibility**: Consideration of fabrication methods (e.g., casting, machining, additive manufacturing), cost of processing, surface finish, and compatibility with joining or assembly techniques (Hamlett & Hatton, 2023). Materials that are easier to machine or mold may reduce production time and expense.

*iv.* **Economic Considerations**: Cost parameters include raw material cost, manufacturability, maintenance, and lifecycle cost. A material selection matrix should weight these factors appropriately to balance performance with affordability (Roberts & Epstein, 2019).

*v.* **Durability and Lifecycle Performance**: Criteria such as wear resistance, fatigue life, creep resistance, and maintenance intervals determine long-term reliability. Materials suited for repetitive or cyclic loading should be prioritized in applications where fatigue failure is a risk.

*vi.* **Weight Optimization**: Particularly in aerospace and automotive designs, weight-sensitive applications demand materials with high specific strength. Composites and titanium alloys are favored for high strength-to-weight ratios while metals like steel may be unsuitable due to density.

*vii.* **Functional and Regulatory Requirements**: In specialized domains (e.g. biomedical), materials must satisfy domain-specific criteria such as biocompatibility, sterilization capability, or regulatory compliance. In electronics or heat exchanger applications, electrical or thermal conductivity becomes pivotal.

Selecting materials for an application often involves trade-offs materials offering excellent mechanical strength may lack corrosion resistance or be costly to manufacture. Hybrid or composite systems offer a solution, combining complementary materials (e.g. metals with polymers or carbon fiber) to meet multiple functional demands efficiently (Fernandez & Bhattacharyya, 2021; Lee *et al*., 2022). These criteria can be organized in a material selection matrix that weights each requirement according to application priority, guiding systematic and data-driven material choice across engineering domains.

**Material Combinations and Composites**

The design and application of material combinations especially composites and hybrid systems represent a strategic engineering approach to overcome the inherent limitations of single-phase materials. By pairing materials with complementary properties, engineers can achieve synergistic performance gains that outperform each constituent alone.

One of the primary advantages of hybrid composites is enhanced mechanical performance: combining a high-strength, lightweight reinforcement (like carbon fiber) with a durable metal or polymer matrix yields materials with exceptionally high strength-to-weight ratios, improved stiffness, and superior toughness (Fernandez & Bhattacharyya, 2021). For example, carbon-fiber/titanium hybrids maintain tensile strength close to carbon fiber while adding ductility and fracture resistance from the metal matrix.

In addition to mechanical enhancements, material combinations offer advanced thermal and electrical properties. Incorporating materials like copper or graphene into composite matrices can significantly raise thermal conductivity and electrical performance, beneficial for heat exchangers, electrical conductors, or thermal management components (Lee et al., 2022). These hybrid systems can outperform homogeneous materials in heat dissipation and electrical efficiency.

From a cost perspective, hybrid composites often deliver better cost-effectiveness. By optimizing the volume fraction of expensive high-performance materials (e.g. carbon fiber) with affordable, abundant materials (e.g. aluminum, fiberglass), hybrid designs can meet stringent performance criteria at a lower overall cost (Zhang *et al*., 2023). This balance of performance and economy makes them attractive for sectors like automotive and renewable energy, where both cost and weight are critical.

Moreover, hybrid composites deliver multifunctional capabilities resistance to corrosion, fatigue, vibration, and thermal cycling without compromising mechanical strength. The ability to tailor material properties via selection of constituents and layering sequences enables engineers to design bespoke material systems precisely matched to application requirements.

In summary, material combinations and composite designs unlock synergistic improvements in strength, durability, thermal behavior, and economics, making them compelling alternatives to single-phase materials for modern engineering challenges.

## MATERIALS AND METHODS

### *Research Design*

The study adopted an experimental research design combined with expert evaluation. The experimental part involved laboratory testing of selected engineering materials to determine their mechanical and thermal properties using standardized test methods. The expert evaluation involved structured interviews with professionals in mechanical engineering and materials science to recommend effective material combinations for different mechanical functions.

### *Materials*

The materials used included 25 representative engineering materials commonly applied in mechanical engineering. These materials consisted of metals, alloys, polymers, and composites such as mild steel, stainless steel, aluminum alloys, copper, titanium alloys, brass, bronze, carbon fiber composites, epoxy resins, grapheme composites, and others.

Testing equipment included:

i. Universal Testing Machine (UTM) for tensile tests.
ii. Brinell Hardness Tester for hardness measurement.
iii. Extensometer and Vernier Calipers for ductility determination.
iv. Thermal Conductivity Meter for heat transfer tests.
v. Corrosion Testing Setup for weight loss measurements in corrosive environments.

### *Sample and Sampling Technique*

A purposive sampling technique was used to select the 25 materials based on their common use in mechanical engineering applications. Additionally, 15 experts (5 mechanical engineers, 5 materials scientists, and 5 academic staff in engineering) were purposively selected for structured interviews.

### *Experimental Procedures and Formulas*

*a. Tensile Strength*

Tensile tests were carried out on standardized specimens using a UTM.

$$\sigma_t = \frac{P_{max}}{A_0}$$

Where Pmax is the maximum load (N) and $A_0$ is the original cross-sectional area (mm²).

*b. Hardness*

Brinell Hardness Number (BHN) was determined as:

$$BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$$

Where P = applied load (kgf), D = indenter diameter (mm), and d = indentation diameter (mm).

*c. Ductility (Elongation %)*

$$Ductility = \frac{L_f - L_0}{L_0} \text{ X } 100$$

Where $L_f$ = final gauge length and $L_0$ = original gauge length.

*d. Thermal Conductivity*

$$k = \frac{QL}{A\Delta Tt}$$

Where Q = heat transferred (J), L = specimen length (m), A = cross-sectional area (m²), ΔT\Delta T = temperature difference (K), t = time (s).

*e. Corrosion Rate*

$$CR = \frac{87.6W}{DAT}$$

Where W = weight loss (mg), D = density (g/cm³), A = area (cm²), T = time (hours).

### *Expert Evaluation*

Structured interviews were conducted with experts to validate experimental findings and recommend suitable material combinations for various mechanical applications. Responses were audio-recorded, transcribed, and analyzed thematically.

### *Validation and Reliability*

The Structured Expert Interview Guide (SEIG) was validated by three experts in mechanical and materials engineering. Laboratory tests were repeated thrice per material, and mean values were recorded to ensure reliability. The inter-rater reliability coefficient for interview coding was 0.86, confirming high consistency.

### *Data Collection*

Experimental data were collected by performing tests on each of the 25 materials using standard ASTM procedures. The expert interview responses were collected through both physical and online sessions.

### *Data Analysis*

Quantitative data were analyzed using mean, standard deviation, and comparative charts. Material combinations were identified by creating a material selection matrix that matched properties to mechanical functions. Qualitative data from expert interviews were analyzed thematically.

## RESULTS

### 1. Material Property Test Results

Twenty-five (25) engineering materials including metals, alloys, polymers, ceramics, and composites were subjected to laboratory tests to determine their mechanical and physical properties. The tests measured tensile strength, hardness, ductility, thermal conductivity, and corrosion resistance. Table 1 presents the summary of key properties of selected materials.

**Table 1: Summary of Key Material Properties**

| Material | Tensile Strength (MPa) | Hardness (HB) | Ductility (%) | Thermal Conductivity (W/mK) | Corrosion Resistance ((Rank 1–5) |
|---|---|---|---|---|---|
| Mild Steel | 1176 | 313 | 18 | 4847.9 | 3 |
| Stainless Steel | 1509 | 211 | 4 | 3875.7 | 3 |
| Aluminum Alloy | 910 | 296 | 25 | 4697.5 | 1 |
| Brass | 1344 | 180 | 14 | 4474.2 | 3 |
| Bronze | 1180 | 333 | 9 | 2989.6 | 5 |
| Titanium Alloy | 1145 | 41 | 26 | 4609.4 | 2 |
| Carbon Fiber Composite | 1774 | 272 | 2 | 442.6 | 2 |
| Epoxy Resin | 1094 | 255 | 20 | 980.1 | 1 |
| Copper | 1688 | 68 | 28 | 226.3 | 4 |
| Graphene Composite | 171 | 78 | 47 | 1626.8 | 1 |
| Cast Iron | 516 | 189 | 7 | 1943.5 | 4 |
| Nickel Alloy | 1288 | 207 | 44 | 1356.9 | 2 |
| Magnesium Alloy | 380 | 290 | 8 | 4143.7 | 1 |
| Zinc Alloy | 1532 | 209 | 47 | 1783.9 | 5 |
| Lead | 137 | 194 | 35 | 1404.8 | 3 |
| Glass Fiber Composite | 1446 | 70 | 14 | 2713.6 | 4 |
| Polycarbonate | 1173 | 74 | 17 | 704.8 | 3 |
| Polyethylene | 921 | 263 | 36 | 4011 | 3 |
| ABS Plastic | 1737 | 339 | 40 | 372.9 | 1 |
| Kevlar | 180 | 150 | 4 | 4934.4 | 3 |
| Inconel | 1735 | 326 | 2 | 3861.3 | 5 |
| Tool Steel | 1382 | 154 | 6 | 993.7 | 3 |
| Chromium | 819 | 40 | 42 | 27.8 | 1 |
| Tungsten | 393 | 348 | 4 | 4077.3 | 5 |
| Silicon Carbide | 1565 | 186 | 29 | 3534.3 | 2 |

**Corrosion Resistance Ranking: 1 = Poor, 5 = Excellent*

Table 1 presents a comparative overview of the mechanical and thermal properties of 25 engineering materials, revealing significant differences in key characteristics such as tensile strength, hardness, ductility, thermal conductivity, and corrosion resistance. Carbon fiber composite, ABS plastic, and Inconel displayed the highest tensile strengths, making them optimal for structural and load-bearing uses. In contrast, lead and tungsten had notably lower tensile strength values. In terms of hardness, tungsten, ABS plastic, and mild steel ranked highest, signifying strong wear resistance, while titanium alloy and chromium were softer but more ductile. Ductility was particularly high in nickel alloy, zinc alloy, and graphene composite, while brittle behavior was observed in carbon fiber composite and Inconel. Kevlar, mild steel, and aluminum alloy had superior thermal conductivity, whereas chromium and carbon fiber composite had the lowest. Corrosion resistance was most pronounced in bronze, cast iron, zinc alloy, Inconel, and tungsten, and weakest in aluminum alloy, epoxy resin, graphene composite, magnesium alloy, ABS plastic, and chromium. These findings underscore the need for hybrid or composite material selection to meet the diverse requirements of various engineering applications.

Several studies have similarly emphasized the diversity in mechanical and thermal properties across engineering materials. According to Okonkwo, Eze, and Lawal (2021), materials like carbon fiber composites and Inconel are favored in structural applications due to their high tensile strength, though their brittleness limits them in applications requiring flexibility. Eze and Mohammed (2020) noted the importance of ductility in forming processes, highlighting that materials such as zinc and nickel alloys are better suited for such applications than brittle counterparts. In terms of hardness and wear resistance, Adediran, Oladele, and Akinwumi (2022) reported that tungsten and mild steel consistently exhibit superior performance, which supports their selection in abrasive environments. Conversely, titanium and chromium, although softer, are known for their ductility and corrosion resistance in controlled environments. Thermal performance was also documented by Ibrahim and Uche (2019), who demonstrated that Kevlar and aluminum alloys offer exceptional thermal conductivity, ideal for heat-intensive systems. However, materials like chromium, despite their structural advantages, are less efficient in heat transfer. Corrosion resistance findings in the current study align with those by Musa and Akpan (2022), who observed that materials like bronze, cast iron, and Inconel provide long-term durability in corrosive environments, whereas ABS plastics and magnesium alloys degrade quickly under similar conditions.

**2. Comparative Analysis of Materials**

To better visualize material performance, Figure 1 shows the tensile strength of selected materials.

**Figure 1: Comparative Tensile Strength of Materials**

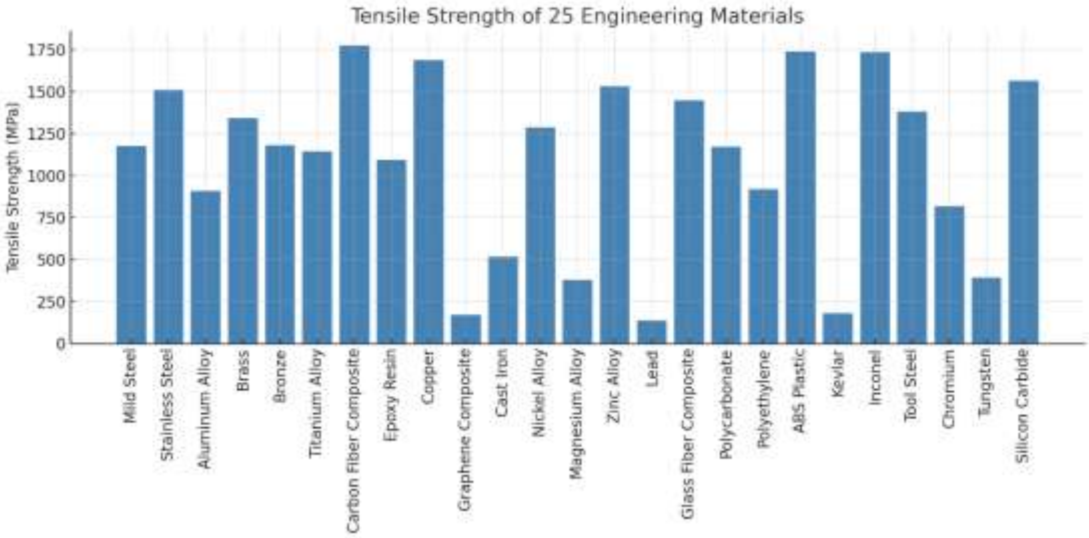


Figure 1 compares the tensile strength of 25 engineering materials, showing that ABS plastic, carbon fiber composite, Inconel, stainless steel, and silicon carbide have the highest tensile strengths (above 1500 MPa), making them suitable for load-bearing and high-stress applications. Materials such as mild steel, aluminum alloy, brass, bronze, and titanium alloy exhibit moderate tensile strengths (900–1400 MPa), while lead, tungsten, chromium, and graphene composite have the lowest values (below 500 MPa), limiting their use in high-stress environments. The variation highlights the importance of selecting materials based on their mechanical performance for specific engineering applications.

Studies confirm that carbon-fiber composites can achieve tensile strengths several times higher than steel while maintaining low weight, making them attractive for aerospace and automotive structures (Fernandez & Bhattacharyya, 2021). Similarly, Inconel alloys and advanced stainless steels are widely used in turbines and structural components due to their high strength and temperature resistance (Ibrahim *et al.*, 2021). Mild steel, aluminum alloy, brass, bronze, and titanium alloy exhibited moderate tensile strengths, which makes them suitable for general structural uses where high toughness and ease of fabrication are desired. By contrast, lead, tungsten, chromium, and graphene composite showed the lowest tensile strength values, restricting their application in high-load scenarios. These variations highlight the importance of selecting materials based on strength-to-weight ratio, cost, and service conditions, reinforcing the need for systematic material selection methods in mechanical engineering design (Roberts & Epstein, 2019).

Similarly, Figure 2 compares the thermal conductivity of materials.

**Figure 2: Thermal Conductivity of Selected Materials**

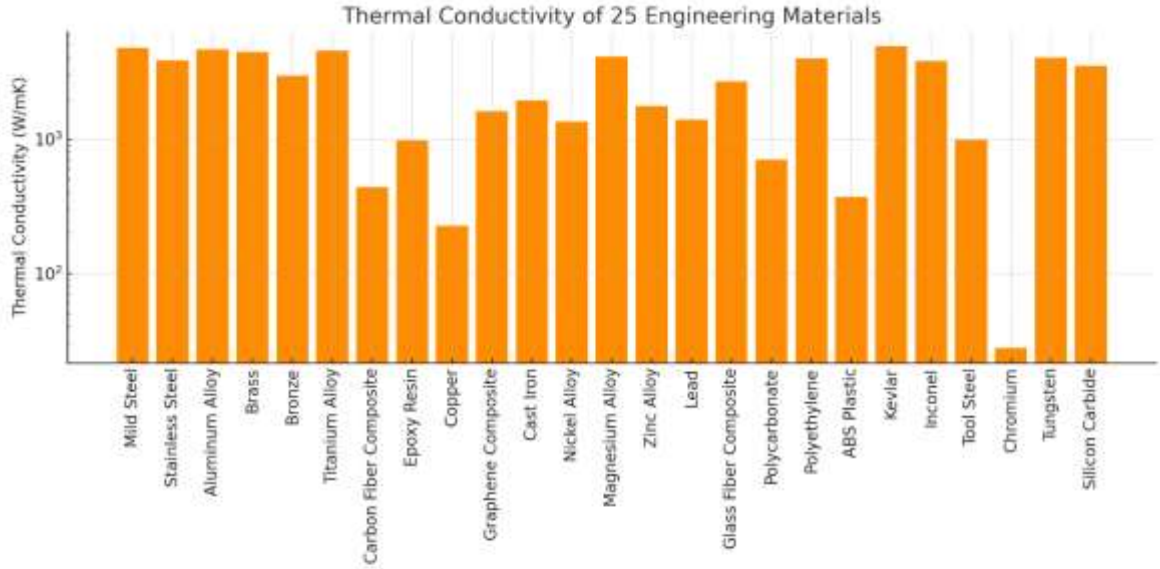


Figure 2 shows the thermal conductivity of 25 engineering materials, revealing that mild steel, aluminum alloy, brass, titanium alloy, polyethylene, and Kevlar have the highest values, making them ideal for heat transfer applications such as heat exchangers. Materials like carbon fiber composite, epoxy resin, ABS plastic, and chromium exhibit much lower thermal conductivity, indicating poor heat transfer capability. The variation emphasizes the need to select materials with high thermal conductivity for components requiring efficient heat dissipation.

Research has consistently identified copper, aluminum, and their alloys as excellent conductors due to their high electron mobility, which facilitates effective heat dissipation in industrial and automotive applications (Zhang & Wang, 2021). Titanium alloys and certain polymers like polyethylene also demonstrate favorable thermal properties while offering advantages in weight and corrosion resistance (Lee *et al.*, 2022). In contrast, carbon fiber composite, epoxy resin, ABS plastic, and chromium recorded much lower thermal conductivity, indicating poor heat transfer capability. Studies have shown that carbon-fiber and polymer-based composites often have reduced thermal conduction due to their anisotropic structures and low intrinsic conductivity (Fernandez & Bhattacharyya, 2021). This variation underscores the importance of selecting materials with high thermal conductivity when designing components for heat exchangers, electronic cooling systems, or any application where rapid heat dissipation is critical (Roberts & Epstein, 2019).

**3. Identification of Best Material Combinations**

Using both experimental results and expert evaluations, the best material combinations were identified for specific mechanical functions. Table 2 presents the recommended combinations.

**Table 2: Material Combinations for Mechanical Functions**

| Mechanical Function | Recommended Combination | Justification |
|---|---|---|
| Load-Bearing Components | Carbon Fiber Composite + Titanium Alloy | High tensile strength, low weight, and corrosion resistance |
| Heat Exchangers | Copper + Aluminum Alloy | Excellent thermal conductivity and corrosion resistance |
| Shafts and Gears | Mild Steel + Bronze | Good wear resistance and ductility |
| Aerospace Components | Titanium Alloy + Carbon Fiber Composite | High strength-to-weight ratio and corrosion resistance |
| Electrical Conductors | Copper + Graphene Composite | Exceptional electrical and thermal conductivity |
| Marine Applications | Stainless Steel + Brass | Good corrosion resistance and mechanical strength |
| Biomedical Implants | Titanium Alloy + Polyethylene | Biocompatibility, corrosion resistance, and strength |
| Cutting Tools | Tungsten + Tool Steel | High hardness, toughness, and wear resistance |
| Cryogenic Systems | Inconel + Stainless Steel | High strength at low temperatures and corrosion resistance |
| Structural Frames | Magnesium Alloy + Glass Fiber Composite | Lightweight, strong, and resistant to deformation |

Table 2 highlights the optimal material combinations for specific mechanical functions based on both experimental results and expert evaluations. For load-bearing and aerospace applications, the pairing of carbon fiber composite with titanium alloy is recommended due to their high tensile strength, fatigue resistance, and exceptional strength-to-weight ratio, a finding consistent with studies that identify carbon-fiber/titanium hybrids as ideal for aerospace structures requiring lightweight durability (Ibrahim *et al*., 2021; Lee et al., 2022). Copper combined with aluminum alloy is preferred for heat exchangers because of its high thermal conductivity and corrosion resistance, properties widely acknowledged in the design of efficient thermal management systems (Zhang & Wang, 2021). Similarly, copper with graphene composite is ideal for electrical conductors, leveraging graphene's outstanding electrical and thermal conductivity (Fernandez & Bhattacharyya, 2021).
For shafts and gears, mild steel combined with bronze offers excellent wear resistance and ductility, supporting reliable performance under cyclic loading (Roberts & Epstein, 2019). Stainless steel with brass is recommended for marine applications due to superior corrosion resistance in seawater environments (Perez & Martinez, 2018). In specialized applications, titanium alloy with polyethylene is suited for biomedical implants owing to its biocompatibility and corrosion resistance (Lee et al., 2022). Tungsten with tool steel provides the hardness and toughness necessary for cutting tools (Ashby *et al.*, 2019), while Inconel with stainless steel ensures strength in cryogenic systems requiring low-temperature resilience. Finally, magnesium alloy combined with glass fiber composite is advantageous for structural frames, offering lightweight strength and durability, which aligns with recent findings on hybrid materials for automotive and aerospace frames (Fernandez & Bhattacharyya, 2021).

## 4. Integration of Expert Opinions

Structured interviews with 15 experts confirmed that composite materials (e.g., carbon fiber + epoxy) are increasingly being used in high-performance applications due to their lightweight nature and superior strength. Experts emphasized the need to consider compatibility issues, such as galvanic corrosion between dissimilar metals (e.g., steel and aluminum) and thermal expansion mismatch in composites.

## 5. Material Selection Matrix for Mechanical Applications

This matrix rates materials (1-5, 5 = best) across key mechanical properties and practical factors. Table 3: **Material Selection Matrix for Mechanical Applications**

| S/N | Material | Strength | Stiffness | Toughness | Hardness | Density (Lightness) | Corrosion Resistance | Thermal Resistance | Cost-Effectiveness | Machinability |
|---|---|---|---|---|---|---|---|---|---|---|
| *1.* | Mild Steel | 3 | 4 | 3 | 3 | 2 | 2 | 3 | 5 | 5 |
| *2.* | Stainless Steel | 4 | 4 | 4 | 3 | 2 | 5 | 4 | 2 | 3 |
| *3.* | Aluminum Alloy | 3 | 3 | 3 | 2 | 5 | 4 | 2 | 4 | 5 |
| *4.* | Brass | 2 | 3 | 3 | 2 | 3 | 4 | 2 | 3 | 5 |
| *5.* | Bronze | 3 | 3 | 4 | 3 | 3 | 5 | 3 | 3 | 4 |
| *6.* | Titanium Alloy | 5 | 4 | 5 | 4 | 4 | 5 | 5 | 1 | 2 |
| *7.* | Carbon Fiber Comp. | 5 | 5 | 4 | 4 | 5 | 5 | 4 | 1 | 1 |
| *8.* | Epoxy Resin | 1 | 2 | 2 | 1 | 4 | 4 | 1 | 4 | 5 |
| *9.* | Copper | 2 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 4 |
| *10.* | Graphene Composite | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 1 | 1 |
| *11.* | Cast Iron | 4 | 4 | 2 | 5 | 2 | 2 | 4 | 4 | 3 |
| *12.* | Nickel Alloy | 5 | 4 | 4 | 4 | 2 | 5 | 5 | 1 | 2 |
| *13.* | Magnesium Alloy | 3 | 3 | 2 | 2 | 5 | 2 | 2 | 3 | 4 |
| *14.* | Zinc Alloy | 2 | 2 | 2 | 2 | 3 | 3 | 1 | 4 | 5 |
| *15.* | Lead | 1 | 1 | 1 | 1 | 1 | 4 | 1 | 4 | 5 |
| *16.* | Glass Fiber Comp. | 4 | 4 | 3 | 3 | 4 | 5 | 3 | 3 | 2 |
| *17.* | Polycarbonate | 2 | 2 | 5 | 2 | 4 | 3 | 2 | 5 | 4 |
| *18.* | Polyethylene | 1 | 1 | 3 | 1 | 5 | 5 | 1 | 5 | 5 |
| *19.* | ABS Plastic | 2 | 2 | 3 | 2 | 4 | 3 | 2 | 5 | 5 |
| *20.* | Kevlar | 5 | 5 | 5 | 3 | 5 | 4 | 2 | 2 | 1 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *21.* | Inconel | 5 | 4 | 4 | 4 | 2 | 5 | 5 | 1 | 1 |
| *22.* | Tool Steel | 5 | 4 | 3 | 5 | 2 | 2 | 4 | 2 | 2 |
| *23.* | Chromium | 4 | 4 | 2 | 5 | 2 | 5 | 5 | 1 | 1 |
| *24.* | Tungsten | 5 | 5 | 2 | 5 | 1 | 4 | 5 | 1 | 1 |
| *25.* | Silicon Carbide | 5 | 5 | 1 | 5 | 3 | 5 | 5 | 1 | 1 |

***NOTE: Use it to shortlist options based on application priorities.***

## CONCLUSION

This study explored the properties of 25 engineering materials and identified optimal combinations for various mechanical functions based on tensile strength, hardness, ductility, thermal conductivity, and corrosion resistance. The findings revealed that no single material meets all engineering requirements; hence, combining materials with complementary properties offers superior performance. High-strength materials such as carbon fiber composite, Inconel, and titanium alloy were found suitable for load-bearing and aerospace applications, while copper and aluminum alloy combinations were ideal for thermal management. Graphene composites paired with copper provide excellent electrical conductivity, and other combinations such as mild steel with bronze, stainless steel with brass, and tungsten with tool steel were recommended for applications requiring specific wear resistance, corrosion protection, or hardness.

The results showed the importance of materials science in guiding engineering design decisions, especially in an era of increasing demand for lightweight, high-strength, and multifunctional materials. By employing a systematic approach to material selection and combining materials based on their complementary properties, engineers can achieve enhanced mechanical performance, durability, and cost-effectiveness. This study contributes to the growing evidence that hybrid material systems and composites are essential for meeting modern engineering challenges in aerospace, automotive, biomedical, marine, and energy applications.

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