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8. Mechanical Properties of Materials

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Abstract:

A material's mechanical properties are those that concern how it responds to an applied load. The range of a material's applicability and the anticipated service life are established by the mechanical characteristics of metals. Material classification and identification techniques also make use of mechanical qualities. Strength, ductility, hardness, impact resistance, and fracture toughness are the most often used characteristics.

The list of mechanical qualities is quite lengthy, so we should probably start by acknowledging that. When describing a substance, some terms are more crucial and prevalent than others. As a result, we are approaching the subject from an engineer's viewpoint. When designing something, he needs to understand the basics of how different metal types compare to one another. For their design applications, every design engineer must be able to choose the best materials, and in order to do so, they must be aware of the materials' mechanical properties. The mechanical properties of materials will be covered in this essay.

Keywords:

Mechanical, Properties, Material, Strength Ductility, Hardness, Impact Resistance, Fracture, Engineering, Raw Materials, Metal's Spectrum, Mechanical Strength.

8.1 Introduction:

The mechanical qualities of a material are those that influence its ability to be molded into a suitable shape and mechanical strength. Some common mechanical qualities have extensive uses in the automotive and space sectors.

These characteristics are related to the materials' ability to withstand loads and mechanical forces, and they are measured in terms of how the material responds to a force. Mechanical qualities can be identified to give the engineer design data or to verify the quality of the raw materials.

The behavior of materials under the influence of loads, or external forces, is determined by their mechanical properties. The predicted service is determined by the mechanical properties of metals, which are defined by the metal's utility spectrum.

Before selecting a material for a specific technical product or application, it is essential to understand its mechanical qualities. According to Wikipedia, "the mechanical properties of engineering materials are those that influence their mechanical strength and capacity for shaping into a desired shape." alternatively, "Mechanical properties are physical properties that a material exhibits upon the application of forces." [1]

It's crucial to comprehend the material's mechanical characteristics. The mechanical qualities of a substance are those that influence its mechanical strength and capacity for shaping into a desired shape.

A material's typical mechanical properties include some of the following:

- Strength
- Stiffness
- Toughness
- Hardness
- Ductility
- Brittleness
- Elasticity
- Fatigue
- Plasticity
- Creep
- Malleability

8.1.1 Strength:

Strength is the capacity of a material to withstand breakdown or deformation in the presence of loads or outside forces. Materials that we choose for our engineering goods need to be sufficiently strong mechanically to function under a variety of mechanical forces or loads.

Strength can be divided into six main subcategories:

Compressive Strength: The capacity of a material to endure a force that causes it to shrink. Consider the material as being squeezed.

Shear Strength: A material's capacity to withstand forces that would otherwise cause its internal structure to slide against itself.

Tensile (or ultimate) Strength. The capacity of a substance to bear a load that stretches or pulls it apart without breaking.

Yield Strength. The capacity of a substance to resist being stretched or torn apart under stress without deforming.

Elastic Strength. The capacity of a substance to regain its former shape after being under stress.

Fatigue Strength. The capacity of a material to endure recurrent and/or varying pressures (such loading and unloading). [2]

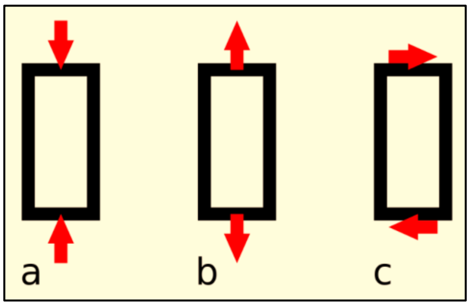

Figure 8.1: Material Being Loaded in A) Compression, B) Tension, C) Shear.

8.1.2 Stiffness:

It is described as a material's capacity to withstand deformation under stress. Stiffness or rigidity refers to a material's resistance to elastic deformation or bending. The indicator of stiffness is the modulus of elasticity. A material has a high degree of stiffness or rigidity if it deforms under load only slightly or hardly at all.

Aluminum suspended beams, for example, will "sag" or deflect more even if both materials may be strong enough to support the requisite weight. This indicates that a steel beam is more rigid or stiff than an aluminum beam. It gauges a material's capacity to resist deflection under an applied load. For instance, even though cast iron is significantly more rigid and less likely to deflect than steel, which is much stronger overall, cast iron is still recommended for machine beds and frames to prevent alignment and precision loss. [3]

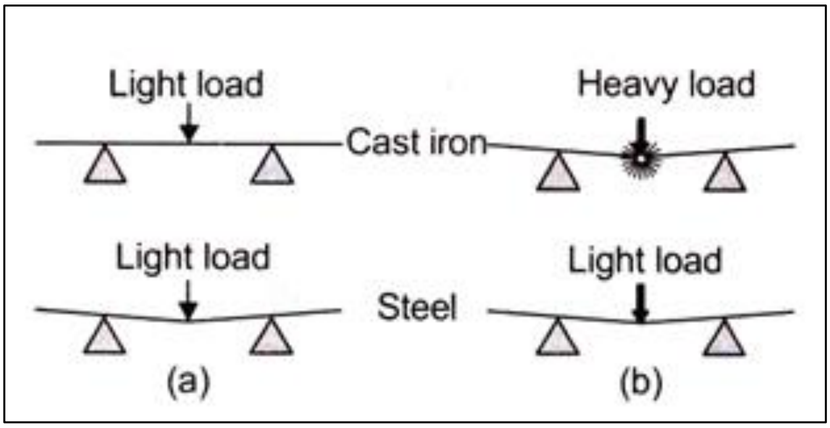

Figure 8.2: Stiffness (Rigidity) (a)The tested materials deflect under a light load (b) The tested materials deflect under a heavy load.

8.1.3 Toughness:

It refers to a material's capacity to take in energy and undergo plastic deformation without breaking. The quantity of energy per unit volume determines its numerical value. The measure is Joule/m3. The toughness value of a material can be determined using its stress-strain characteristics. To be tough, materials must be strong and ductile. A metal's toughness is assessed using impact testing equipment.

8.1.4 Hardness:

One of the key mechanical characteristics of engineering materials is hardness, which enables the material to withstand localized permanent deformation and scratching.

Figure 8.3: Hardness

There are several ways to assess hardness, including scratch resistance, indentation resistance, and rebound resistance.

a. **Scratch Hardness:** The ability of a material to resist scratches to the outer surface layer caused by external force is known as scratch hardness.
b. **Indentation Hardness:** It is the capacity of a material to resist a punch from an outside item that is both hard and sharp.
c. **Rebound Hardness:** Dynamic hardness is another name for rebound hardness. The material is tested by measuring the height of "bounce" of a diamond-tipped hammer dropped from a fixed height. Table 8.1 provides the Moh's scale of hardness measurement. The element and acting load can be used to calculate the measurement, as stated in table 8.1. The hardest material is diamond, which can be cut or punctured by another diamond. [4]

Table 8.1: Moh's scale of Hardness (Scale value in number)

Scale	Element	Applying load for penetration
1	Talc	Can be crushed by a finger nail
2	Gypsum	Scratched by a finger nail
3	Calcite	By a bronze coin
4	Fluorite	By glass
5	Apatite	By penknife
6	Orthoclase	By Quartz
7	Quartz	By Hard steel file
8	Topaz	By Corundum
9	Corundum	By Diamond
10	Diamond	Only by diamond

8.1.5 Ductility:

The ability of a solid substance to deform when put under tensile stress is known as its ductility. One method to describe ductility is the ability of a substance to be dragged or pulled into a wire. This mechanical quality, which is temperature-dependent, is also a component of a material's plasticity. The ductility of a substance increases with temperature.

8.1.6 Brittleness:

A material's brittleness refers to how easily it fractures under the influence of a force or load. When brittle material is stressed, it experiences very little energy and cracks without experiencing a lot of strain. Brittleness is the antithesis of a material's ductility. Brittleness of a material is temperature-dependent. At low temperatures, some metals that are ductile at normal temperature become brittle. [5]

Figure 8.4: Brittleness

8.1.7 Elasticity:

A material's ability to return to its original shape after deformation when the stress or load is relieved is referred to as elasticity. Elastic materials include rubber, heat-treated springs, and others.

Figure 8.5: Elasticity

8.1.8 Fatigue:

The weakening of a material brought on by repeated loading is known as fatigue. Microscopic cracks start to form at grain boundaries and interfaces when a material is subjected to cyclic loading and loading that exceeds a threshold value but is far below the material's strength (ultimate tensile strength limit or yield stress limit). [6]

The crack eventually grows to a dangerous extent. The wear and tear of a material over time due to repeated straining action is known as fatigue. The term "fatigue" is used to characterize a material's wear and tear as a result of repeated applied stresses.

8.1.9 Plasticity:

Plasticity is the property of a material under which the material is permanently deformed and is unable to return to its original shape even after the removal of the load. Only once the material has passed its elastic limit does plastic deformation occur.

Materials like clay, lead, and other plastic materials are plastic at room temperature, and steel is plastic at forging temperature, therefore this feature is useful in forming, shaping, extruding, and many other hot or cold working processes. In general, this property increases with an increase in temperature of materials.

8.1.10 Creep:

A metal item will experience a slow, irreversible deformation known as creep when it is subjected to high continuous tension at a high temperature over an extended length of time. Continuously applying high loads at higher temperatures can cause a fracture to form, which can then spread toward what is known as creep failure.

A part will experience creep, which is a slow and irreversible deformation, if it is exposed to a steady tension at a high temperature over a protracted length of time. When designing IC engines, boilers, and turbines, property is taken into account. Viscous flow is the most basic type of creep deformation. Creep is particularly sensitive to temperature in materials like plastics, rubber, and amorphous ones.

Creep strength is the stress for a given rate of strain at a fixed temperature. When a material is subjected to constant loads for a long time, it may deform further until it eventually tends to fracture under the same load. We call this creep. The sample will gradually grow if a load is applied and left on it for several months or perhaps several years. At higher temperatures, creep in metals with high melting points becomes an issue.

Testing for creep and stress rupture is used to determine how much stress a material can tolerate before failing and elongating.

For items in the oil & gas, aerospace, automotive, power generation, medical, and many other industries, they are crucial indicators.

The image depicts the three phases of a conventional creep curve. The initial creep begins quickly and then slows down.

However, the rate of the secondary creep is quite constant. Tertiary Creep, which began in the third stage but was speeded up, ends when the material ruptures or fractures. It is related to both grain boundary void generation and necking. [7]

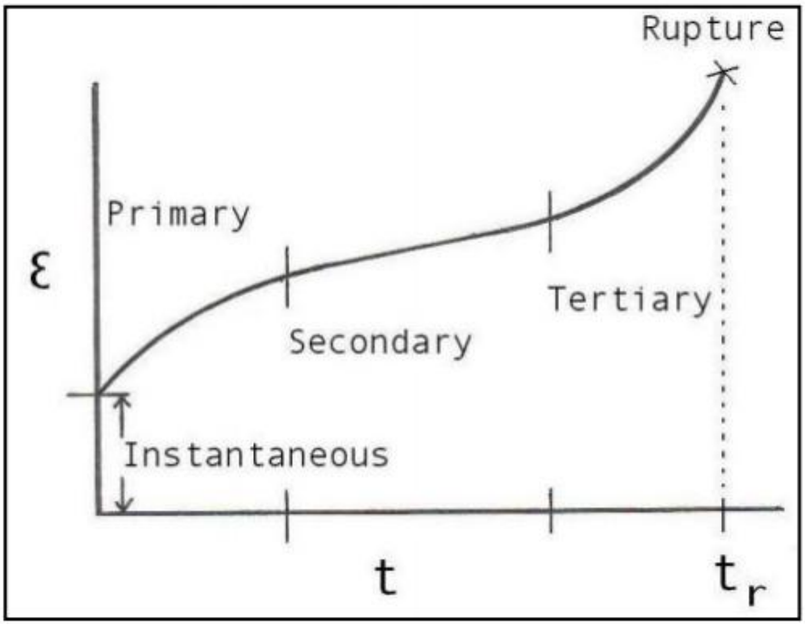

Figure 8.6: Classical Creep Curve

8.1.11 Malleability:

It is due to specific features that metals may be pounded into thin sheets. The ability of metals to be beaten or formed into thin sheets is known as malleability, which is the subject of this article.

8.2 Properties of Materials:

Materials have the following three qualities:

- Material's mechanical characteristics
- Materials' electrical characteristics
- The material's physical and chemical characteristics.

The way a material responds to being loaded depends on its mechanical qualities.

The mechanical qualities of a material are those that have an impact on its mechanical strength and capacity for shaping into a desired shape. Elasticity, plasticity, malleability, ductility, toughness, brittleness, tenacity, fatigue, fatigue resistance, impact resistance property, machineability, strength, strain energy, resilience, proof resilience, modulus of resilience, creep, rupture, and modulus of toughness are just a few of the mechanical properties. [8]

8.2.1 Applications of Mechanical Properties:

In terms of materials science, a material's mechanical properties are critically significant. Each mechanical feature has a particular use in the design of components for the manufacturing industries, such as the automotive, forging, power generation, and aerospace sectors.

Table 8.2: lists a few applications and their characteristics.

Sr. No.	Properties	Applications
1	Proportional limit	Precision instruments, springs
2	Plasticity	forming, forging, shaping, extruding, hot & cold working, ornamental work, stamping, rolling, drawing, pressing
3	Elasticity	Desirable for materials used in tools and machines.
4	Malleability	rolling, hammering
5	Toughness	Desirable for shock & impact loads.

Sr. No.	Properties	Applications
6	Resilience	springs
7	Creep	In designing IC engines, boilers, turbines
8	Hardness	resistance to wear, scratching, deformation
9	Fatigue	High speed aero and turbine engine

8.2.3 Material Stress and Strain:

We must first clarify some of the underlying physical ideas that underlie the mechanical features. Stress is the primary one. Stress reveals the magnitude of the force acting on a certain location. It is commonly stated in MPa or N/mm2 in mechanical engineering. Both of those are interchangeable. The following is the equation for stress:

σ=F/A, where F is force (N) and A is area (mm2).

The second crucial idea is strain. Since strain is a ratio of lengths, it lacks a unit. The formula is as follows:

ε=(l-l0)/l0, where l0 is starting or initial length (mm) and l is stretched length (mm). [9]

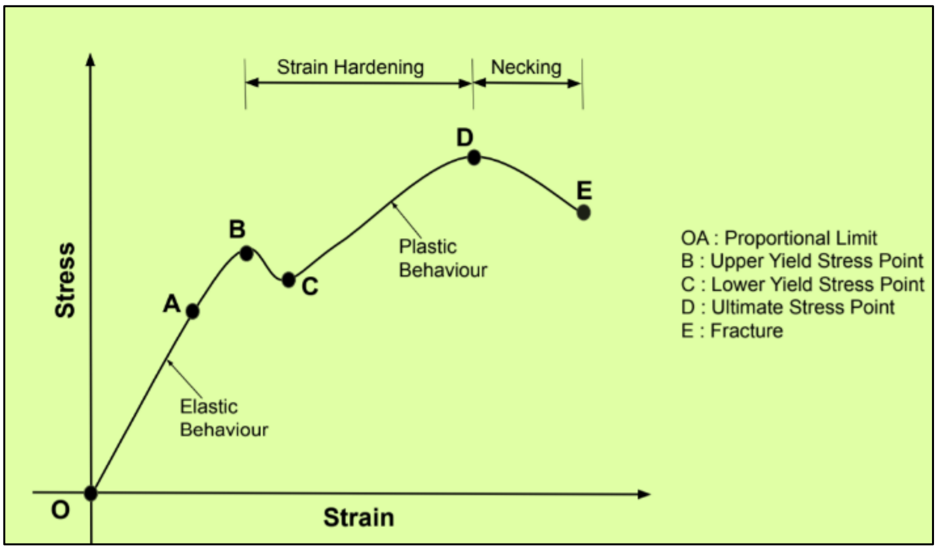

Figure 8.7: Material Stress and Strain

It is necessary to provide more context for the engineering stress-strain curve's general shape. Stress and strain are linearly correlated in the elastic area. The specimen experiences gross plastic deformation when the load surpasses a threshold value that corresponds to the yield strength. If the load is released to zero, it will become permanently distorted.

With rising plastic strain, or strain-hardening of the metal, the stress required to produce ongoing plastic deformation rises. A L = A0 L0 states that the specimen's volume is constant during plastic deformation, and as it lengthens, its cross-sectional area falls equally along the gage length. [10]

8.2.4 Mechanical Properties of Carbon Fiber:

A lengthy chain of carbon atoms that are chemically bound together is referred to as carbon fiber. Carbon fiber's physical characteristics include:

- High tensile strength
- High strength to weight ratio
- Low thermal expansion

These characteristics make carbon steel ideal for application in sectors including aerospace engineering, the military, and motorsports where materials need to be strong but lightweight.

8.2.5 Mechanical Properties of Steel:

Steel is an iron and carbon-based alloy. Each type of steel, which comes in a variety of iron, carbon, and other metal compositions, has slightly unique qualities. But generally speaking, the following characteristics apply to the majority of steel types:

- High tensile strength
- High hardness
- High yield strength
- High weight to strength ratio
- High ductility

Steel is the best material for use in building construction because of these characteristics. In fact, when compared to other building materials, steel has the best strength-to-weight ratio.

8.2.6 Mechanical Properties of Polycarbonate:

One particular kind of plastic that is naturally translucent is polycarbonate (PC). It is a strong, high-performing, amorphous thermoplastic polymer. It is easy to shape, thermoform, and work with. PC is renowned for maintaining its strength and color over time.

The following are some properties of polycarbonate:

- High impact resistance
- High tensile strength
- High dimensional durability
- Excellent electrical & thermal insulator
- Easy to fabricate and machine.

It is utilized in a variety of items, such as compact disc players, safety helmets, auto headlight lenses, roof and glazing applications, as well as a wide range of other products.

8.2.7 Mechanical Properties of Titanium:

Since titanium metal is corrosion-resistant, lightweight, and strong, it is a very durable metal for industrial purposes. Although it is twice as strong as high-strength steel, it is 40% lighter than steel. [11]

8.2.8 Mechanical Properties of Polylactic Acid (PLA):

PLA (polylactic acid) is a reusable and biodegradable polyester made from sustainable feedstock. Due to its inexpensive cost of production from renewable resources, PLA has gained popularity.

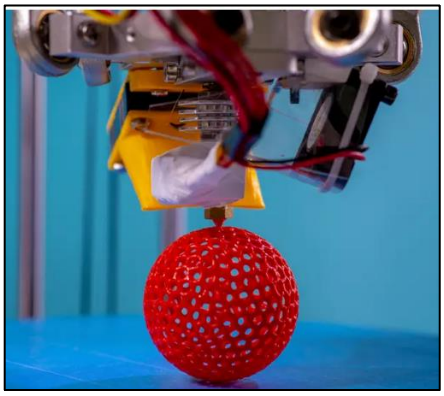

Figure 8.8: Material Stress and Strain

8.2.9 Mechanical Properties of Copper:

A very ductile metal with remarkable electrical and thermal conductivity is copper (Cu). Nature contains copper in its free metallic form. It is employed by the jewelry, electrical, marine, defense, building, and construction industries.

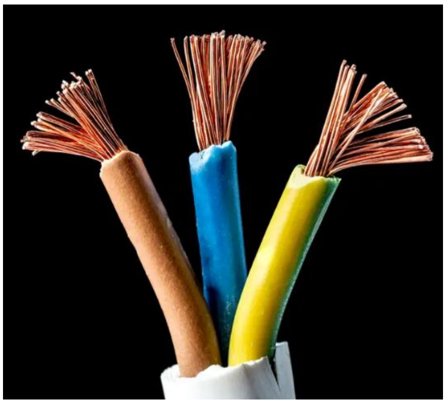

Figure 8.9: Mechanical Properties of Copper [12]

8.3 Conclusion:

the many mechanical property classifications, their applications, and testing methods. Since the success of the material selection depends entirely on how an engineer chooses a material for their developing products, knowing them is necessary to turn the idea design into a product in an industry.

Also mentioned below is innovative technology created in India for home improvement. We really hope that we have allayed your questions regarding the properties of metals. You can get in touch with us or post a question in the comments if you still have any questions about "Mechanical Properties of Materials."

8.4 References:

1. Fa-Hwa Cheng, Initials. (1997). Strength of material. Ohio: McGraw-Hill Mechanics of Materials, E.J. Hearn Alfirević, Ivo. Strength of Materials I. Tehnička knjiga, 1995. ISBN 953-172-010-X.
2. Alfirević, Ivo. Strength of Materials II. Tehnička knjiga, 1999. ISBN 953-6168-85-5.
3. E. Mark, Burak Erman and Mike Roland, Editor(s), The Science and Technology of Rubber (Fourth Edition), Academic Press, Boston, 2013, Pages 473–516, ISBN 9780123945846, 10.1016/B978-0-12-394584-6.00010-8
4. Mott, Robert L. Applied Strength of Materials, 4th edition. Prentice-Hall, 2002.
5. Senthil Murugan S, Jegan V, Development of Hybrid Composite for Automobile Application and its Structural Stability Analysis Using ANSYS‖, ―International Journal of Modern Studies in Mechanical Engineering (IJMSME) Volume 3, Issue 1, 2017, PP 23-34 ISSN 2454-9711 (Online) DOI: http://dx.doi.org/10.20431/2454-9711.0301004.
6. Jong Hun Kim, Jae Hwan Jeong, et al., Mechanical properties of two-dimensional materials and their applications, Journal of Physics D: Applied Physics, Volume 52, Number 8. [7] Astakhov V.P. (2018) Mechanical Properties of Engineering Materials: Relevance in Design and Manufacturing. In: Davim J. (eds) Introduction to Mechanical Engineering. Materials Forming, Machining and Tribology. Springer, Cham.
7. S. P. Timoshenko: History of Strength of Materials (Dover, New York 1983).
8. T. Young: A Course of Lectures on Natural Philosophy and the Mechanical Arts, Vol. 1 (Johnson, London 1807).
9. J. S. Smith, M. D. Wyrick, J. M. Poole: An evaluation of three techniques for determining the Young's modulus of mechanically alloyed materials. In: Dynamic Elastic Modulus Measurements in Materials, ASTM STP, Vol. 1045, ed. by A. Wolfenden (American Society Testing and Materials, Philadelphia 1990) pp. 195–206.

10. Hertzberg, R.W., Deformation and Fracture Mechanics of Engineering Materials, Wiley, New York, 1976.
11. Anderson, T.L., Fracture Mechanics: Fundamentals and Applications, CRC Press, Boca Ra-ton, 1991.
12. Budynas, Richard G., and Ali M. Sadegh. 2020. “TABLES: MECHANICAL PROPERTIES OF MATERIALS.” Chap. 3.14 in Roark's Formulas for Stress and Strain. 9th ed. New York: McGraw-Hill Education.