Material: Characteristics, Properties, and Application

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ABSTRACT:
The appropriateness of materials for certain purposes and how they behave in different environments are fundamentally influenced by their characteristics. The main features of these qualities and their importance in the fields of engineering and manufacturing are covered in the chapter of material properties. Many different physical, mechanical, thermal, electrical, and chemical characteristics exist in materials. These characteristics may be divided into two groups: derived qualities and inherent features. The term inherent properties describe a material's qualities that are inherent and independent of the sample's size or form. These characteristics include chemical reactivity, density, melting and boiling points, specific heat capacity, thermal conductivity, and electrical conductivity. They offer crucial details on the material's activity and reaction to outside stimuli.

KEYWORDS:

Materials, Point, Strength, Stress, Strain, Tensile.

I. INTRODUCTION

Materials are the main components of manufacturing and the force behind technological advances. We use materials in a variety of ways, and they are all around us. If one is aware of the different sorts of manufacturing processes and materials, they can be better understood. various materials and their characteristics. Materials' behaviour and suitability for diverse applications are determined by their distinct characteristics. Physical, chemical, mechanical, or electrical characteristics can be present. Designing components, choosing the best material for a given application, and anticipating how a material will behave under various conditions all require an understanding of a material's properties. Physical qualities are traits that can be seen or quantified about a substance without affecting its chemical makeup, like density, colour, melting and boiling points, thermal conductivity, and electrical conductivity. Chemical properties, such as reactivity, corrosion resistance, and oxidation resistance, describe how materials behave as they go through chemical reactions [1], [2].

The behaviour of materials under applied forces, such as stress, strain, and deformation, is referred to as their mechanical characteristics. Elasticity, plasticity, strength, toughness, and ductility are some of these characteristics. The ability of a substance to conduct or resist the flow of electric current is referred to as its electrical characteristics. Understanding a material's behaviour and applicability for various uses requires knowledge of its attributes. We can assess a material's strengths and weaknesses and decide where to employ it in different fields and applications by looking at its physical, chemical, mechanical, and electrical qualities. varied materials have variously varied qualities, and as a result, they respond differently depending on the circumstances. Mechanical characteristics, electrical properties, thermal qualities, chemical properties, magnetic properties, and physical properties are among these attributes. When designing machines and buildings, design engineers are particularly interested in the mechanical behaviour of materials under load. Depending on how much of a load is applied, every material will either deform, give, or break.

The mechanical properties of a given material, or its behaviour under a load, are essentially what we are interested in learning about. The traits or attributes that define how a material acts under specific circumstances are referred to as a material's properties. These characteristics enable us to comprehend how diverse materials interact with their surroundings and how they might be applied to a variety of applications. Metals, ceramics, and polymers are the three basic groups into which materials can be divided. These materials are useful in different industries, such as manufacturing, aircraft, building, and medicine, because of their distinctive qualities. The physical characteristics of materials are among their most fundamental attributes. Mass, density, melting and boiling points, as well as specific heat capacity, are some of these characteristics. While density is the amount of mass per unit volume, mass refers to the amount of substance in a material. The temperatures at which a substance transforms from a solid to a liquid and from a liquid to a gas are known as the melting point and boiling point, respectively. The amount of energy needed to raise a material's temperature by one degree Celsius is known as its specific heat capacity. To predict how a material will perform in different applications, it is crucial to understand its physical properties [1], [3].

Mechanical properties are yet another crucial set of characteristics. These characteristics specify how a substance reacts to pressure, tension, bending, and shearing from outside sources. Strength, stiffness, toughness, hardness, ductility, and elasticity are some of them. Stiffness is a material's resistance to deformation, whereas strength is a term used to describe a material's capacity to bear external forces without breaking. Hardness is a material's resistance to being scratched or indented, whereas toughness is a material's capacity to absorb energy before breaking. A material's ductility refers to its capacity to deform under stress, whereas its elasticity refers to its capacity to recover its original shape after deformation. Designing buildings and machines that can endure a range of loads and stresses requires a thorough understanding of the mechanical characteristics of materials. Another set of significant material characteristics is their thermal qualities. Thermal conductivity, thermal expansion, and specific heat are some of these characteristics. A material's capacity to carry heat is referred to as thermal conductivity, but its propensity to expand when heated is referred to as thermal expansion. The quantity of energy needed to raise a material's temperature by one degree Celsius is known as specific heat. Designing materials for use in high-temperature applications, such as engines, furnaces, and power plants, requires an understanding of thermal characteristics [4], [5].

When creating materials for use in electrical and electronic applications, electrical characteristics are also crucial. Conductivity, resistivity, dielectric strength, and magnetic properties are some of these characteristics. A material's conductivity refers to its capacity to carry electricity, whereas its resistivity refers to how easily electricity flows through it. Magnetic characteristics characterise a material's capacity to either attract or repel magnetic fields, while dielectric strength measures a material's capacity to tolerate electrical stress without degrading. Another crucial collection of a material's attributes is its chemical composition. These characteristics define how a substance interacts with different compounds, such as acids, bases, and other chemicals. Reactivity, corrosion resistance, and flammability are examples of chemical qualities. Designing materials for use in diverse chemical processes, such as the creation of pharmaceuticals, fertilisers, and plastics, requires a thorough understanding of chemical characteristics [6]–[8].

II. DISCUSSION

Stress-Strain Diagram

Consider a rod with beginning dimensions of L0 and A0 that is being loaded with F. The strain is the length change δ divided by the original length, while the stress is the force per unit area. Thus,

$$\textbf{Stress } \sigma = F/A0$$

$$\textbf{Strain } \varepsilon = \delta/L0$$

Figure 1 depicts the σ-ε curve for a material, like mild steel. The fluctuation in strain and stress is linear up to the proportionality point A. Up until this time, Hooke's law is applicable.

$$\sigma \propto \varepsilon$$

$$\sigma = E\varepsilon$$

where E is Young's modulus, often known as the elasticity modulus. When the forces operating on it are eliminated, the material stays elastic beyond point A and up to point B, returning to its initial condition. If the specimen is stressed past point B, a permanent set occurs, and we enter the zone of plastic deformation. Even after the force that caused the strain in the plastic deformation zone is withdrawn, the strain is not eliminated. Point 'C' is when the test is completed if the force is increased further. Even when the stress is not increased, the specimen stretches. The yield point is where this occurs. There are two yield pointscalled upper and lower yield points, respectivelyat C and D. As the material is strained further, a phenomenon known as strain hardening or work hardening takes place. The material gets harder and stronger, and it can support more weight. As a result, the test specimen can withstand additional pressure. Point E is attained by gradually increasing the force pressing on the specimen. The stress-strain curve's highest peak, which denotes the point of maximum stress, is at this location. Therefore, it is known as the material's ultimate tensile strength UTS. It is equal to the greatest force applied divided by the test specimen's initial cross-sectional area A0.

Here, we must take into account how an increase in load will affect the test specimen's cross-sectional area. The specimen's cross-sectional area shrinks as plastic deformation progresses. The initial cross-sectional area is taken into consideration, though, when calculating the stress in the stress-strain graph. This explains why the UTS point E appears to shatter at a higher stress level than the point of breakage F. After UTS point E, the test specimen's cross-sectional area is drastically reduced, and a neck forms in the centre of the specimen. As the neck gets thinner and thinner, the test specimen eventually snaps in two. If the reduced cross-sectional area of the test specimen is taken into account, the actual breaking stress is significantly larger than the UTS. The ultimate tensile strength at point E is used to determine a material's strength. The yield point, however, is more significant from the perspective of a design engineer since the structure he created must endure forces without giving. The term yield strength of a material refers to the yield stress, which is typically two-thirds of the UTS at point D.

In real life, a tensile test on a universal testing machine or tensile testing machine is used to determine UTS. The test piece used for the tensile test has been standardised so that tests performed on the same material in various laboratories can yield the same test results. In Figure. 1, an ordinary test object is displayed.

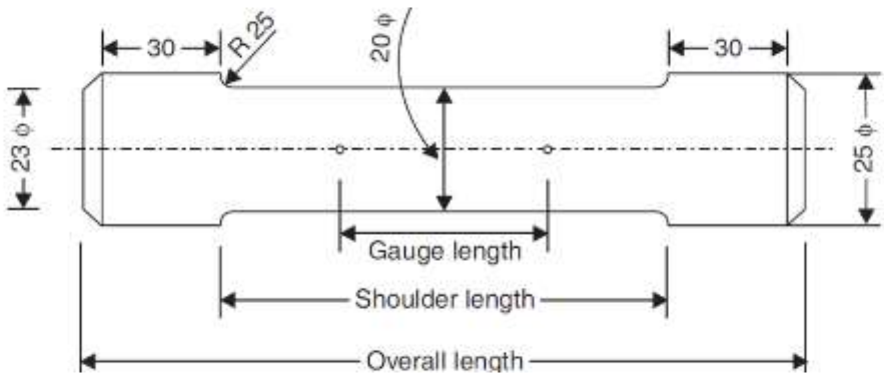

Figure 1: Dimensions of a standard tensile test piece [Research Gate].

A test bar made of fragile material is put through tensile testing equipment to produce a stress-strain curve. As the tensile load progressively rises, the test piece's extension is noted. A brittle material's stress-strain curve has certain distinct features when compared to the curve that was discovered for a ductile material. In Figure 2, a typical stress-strain curve for a brittle material is displayed.

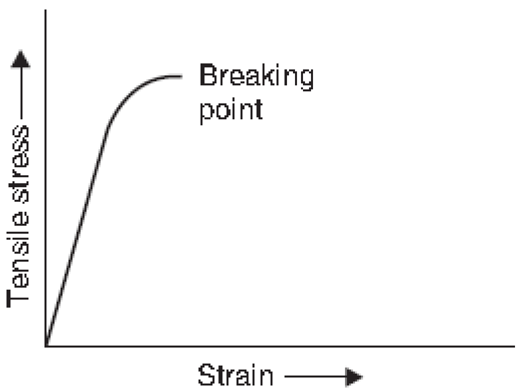

Figure 2: Stress-strain curve for brittle material

The test specimen breaks abruptly without any discernible necking or elongation along this curve, which lacks a yield point. In the lack of a yield point, the notion of proof stress has developed to measure the yield strength of brittle materials. For instance, 0.2% proof stress represents the stress at which the test specimen suffers a persistent elongation equal to 0.2% of the original gauge length and is indicated by 0.2. Because it can reveal a wealth of information about other material properties, the tensile test and stress-strain curve have been detailed in some depth above. It should be mentioned that the majority of tensile testing machines come equipped to do compressive strength tests as well.

Malleability and Ductility

These two characteristics have to do with the material's ductility. While ductility relates to plastic deformation under tensile pressures, malleability refers to the capacity of plastic to deform under compressive loads. A malleable substance can be hammered into thin foils and sheets. It is possible for a ductile substance to wires to be dragged. Percentage elongation is a metric for ductility. Two punch marks are made on the stem of the tensile test piece before the test starts. Gauge length, the distance between these markers, is indicated. The two fragments of the tensile test component are recovered and positioned as closely as possible after it breaks into two pieces. Now, the distance between the two punch marks is measured once more and documented. Let's say this distance is. The percentage of elongation is computed as High percentage elongation values signify a very ductile material. Low values show brittle and low ductility in the material. The percentage of elongation for mild steel is often 20% or more.

Brittleness

It is possible to think of brittleness as the reverse of ductility. It is a quality that glass and other ceramics prominently display. When glass is dropped on a hard surface, it shatters and breaks into several fragments. The incapacity of the material to absorb stress loads is the true cause of brittleness. Glass is, of course, a particularly brittle substance.

Stiffness and Resilience

A material is described as stiff or resilient depending on the value of its elastic modulus. Materials with a high elastic modulus are described as stiff. Take into account a material that is experiencing tensile stress in the elastic range. If the substance has a high Young's modulus value Young's modulus is the modulus of The material won't stretch much if it has low elasticity elasticity equivalent to tensile stress. It will act like a stiff substance. In this situation, the line OA will have a greater slope. The quality of resilience is completely opposed to that of stiffness. Under the same loading conditions, a beam constructed of stiff material will deflect less than one made of resilient material.

Toughness and Impact Strength

The qualities of toughness and impact strength are related or comparable, yet there are some distinctions as will be discussed later. They show how much energy the material can withstand before failing or breaking. If the y-axis scale is altered, force is plotted on it, and both of these conditions hold, instead of a stress-strain curve, we would get a force-elongation curve if actual elongation were shown on the x-axis rather than strain. Only the x and y axes' scales will change; the shape of the curve will stay the same. This curve's area under it will now reflect the energy needed to fracture the material. The toughness of a material increases with energy. Combining strength and percentage elongation results in toughness. This characteristic, which allows a material to resist both elastic and plastic strains, is particularly significant stronger toughness correlates with stronger impact strength. The loads employed in actual impact testing are dynamic, and they are directed towards the specimen through a sharp notch. To gauge a material's impact strength as well as its toughness, two tests have been developed that are standard. The first test is the IZOD test, while the second test is the Charpy test. The IZOD test is briefly explained below.

The IZOD testing device has this specimen placed in a vertical position. The test specimen is then struck 22 mm above the notch by a blow from a swinging pendulum falling from a predetermined height. The pendulum's mass is known. Considering the height from which We are aware of the energy accumulated in the pendulum m.g.h. before the pendulum strikes the blow. The pendulum swings and breaks the test piece at the notch before moving on, and the height to which it climbs on the opposite side of the test piece is documented and measured. Thus, it is possible to determine how much energy the pendulum still has. The energy used up in breaking the test specimen is calculated as the difference between the initial energy in the pendulum and the energy still there after it was broken. This is regarded as the specimen's material's impact strength. To obtain an accurate result, a correction factor for friction at the pendulum bearing is applied. A brittle substance has poor toughness and low impact strength.

Hardness

A highly significant characteristic of materials is hardness. Hardness is a measure of durability and resistance to scuffing or scratching. A hard substance also provides resistance to piercing by external bodies. A scale of hardness was developed in the past, and diamond, the hardest material known to man, was placed at the top positioned at the top of this scale. On this scale, glass and other elements were placed lower. The standard was a straightforward scratch exam. If a substance can scratch another substance, it is thought to be harder than the latter and is ranked higher on the hardness scale. Several hardness tests have been developed in the modern era. Brinell hardness test, Rockwell hardness test, and Vicker's hardness test are the three most common ones. All of these tests are based on the material's resistance to penetration by an indentor that has been specifically created and manufactured into the test specimen's surface while being subjected to a prescribed load. The indentor cannot penetrate the surface of a tougher substance to the same depth as it could if it were softer because the harder material provides more resistance. To quantify the hardness of a material, either the depth or the area of the impression created by the indentor into the test specimen is utilised.

Fracture of Material

A specimen will fail and eventually fracture into two or more pieces if it is subjected to excessive stress beyond its strength. We have already encountered ductile and brittle material fractures while describing the tensile test. The ductile fracture manifests a characteristic reduction in the cross-sectional area close to the fractured part and occurs after significant plastic deformation. There is a brittle fracture. abruptly happens when a tiny crack develops in the material's cross-section, leading to a total fracture. However, this type of fracture does not exhibit considerable plastic deformation. A skilled metallurgist can infer a wealth of intriguing information about the most likely reason for a failure by carefully examining the fractured surface and performing macro and micro metallurgical analyses on the fractured specimen. In addition to fractures that are ductile and brittle, we also have fractures brought on by material that is fatigue and creep.

Fatigue Failure

If the stress is either i of the alternating kind or ii varies periodically, materials frequently fail or fracture at a stress level much below their strength. What does the term alternate stress mean? This will be made obvious using an example. Consider an axle with two wheels. The axle supports the weight of the wheels of the vehicle while also rotating independently of them. Due to weight, the axle deflects somewhat, creating compressive stress in the top half of the crosssection and tensile stress in the bottom half.

However, because it rotates, the bottom half transforms into the upper half and vice versa with each 180° rotations. As a result, the rotation of the axle causes the type of stress at any point to alternate between compression and tension. When a stress cycle is variable, the stress keeps fluctuating in amplitude while being constant in sign. Even though the amplitude of such stresses may be significantly smaller than its strength, if the material is subjected to several million cycles of either alternating or changing stress, it becomes exhausted and fails. Fortunately, there is a certain amount of alternating and variable stress that a material can bear without breaking even after an endless number of cycles. The endurance limit is what's used to describe this. A designer makes sure that a component that is prone to fatigue in use is constructed in such a way that the actual stress level is kept below the endurance limit.

1. A fatigue fracture can be visually inspected and reveals three separate zones. Which are:
2. The point of crack initiation, also known as the genesis of the crack; could be a material flaw such as an impurity or even a surface imperfection.
3. The region where a crack spreads while in use. Typically, this region is distinguished by round scratch marks that resemble rings with the point of fracture initiation in the middle.
4. The remaining cross-sectional area exhibits symptoms of abrupt breaking. There comes a point where the remaining cross-sectional area is too small to withstand the stress and breaks unexpectedly as a result of the crack spreading over time.

Creep Failure

Within the limits of its strength, a material can fail even when subjected to constant loads. This occurs when components are subjected to sustained loads for an extended period, particularly when they are exposed to high temperatures. The stays in boilers, the blades of steam turbines, the components of furnaces, etc. are a few typical examples. Because of the way the material fails, these failures are known as creep failures. In such circumstances, however, at a very very slow rate, it nevertheless deforms plastically. However, the effect of creep might become noticeable over a lengthy period and eventually cause the component to fail.

III. CONCLUSION

The appropriateness of materials for certain applications and their overall performance are fundamentally influenced by their characteristics. For engineers, designers, and manufacturers to make educated judgments about material selection, design considerations, and production methods, they must have a thorough understanding of the characteristics of materials. Mechanical, thermal, electrical, optical, and chemical characteristics are only a few examples of how materials' qualities may be widely characterized. Each attribute has a unique relevance and effect on how the material behaves and functions. Here are some crucial ideas surrounding The Conclusion of Material Properties.

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