CONCEPTS OF STRESS AND STRAIN WITH MECHANICAL PROPERTIES OF ENGINEERING MATERIALS

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ABSTRACT

In this paper we are presenting concepts of stress and strain with mechanical properties of engineering materials. Often materials are subject to forces (loads) when they are used. Mechanical engineers compute those forces and material scientists how materials buckle (elongate, compress, and twist) or rupture as a function of functional load, time, temperature, and other conditions. Materials scientists learn about these mechanical properties by testing materials. Results from the tests depend on the size and shape of material. Stress can be defined by ratio of the perpindicular force applied to a specimen divided by its original cross sectional area, formally called engineering stress.

Keyword : - *Stress, Strain, materials, Mechanical Properties, Area etc.*

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1. INTRODUCTION

The engineering tension test is widely used to provide basic design information on the strength of materials and as an acceptance test for the specification of materials. In the tension test a specimen is subjected to a continually increasing uniaxial tensile force while simultaneous observations are made of the elongation of the specimen. The parameters, which are used to describe the stress-strain curve of a metal, are the tensile strength, yield strength or yield point, percent elongation, and reduction of area. The first two are strength parameters; the last two indicate ductility. The tensile test is probably the simplest and most widely used test to characterize the mechanical properties of a material. The test is performed using a loading apparatus such as the Tinius Olsen machine. The capacity of this machine is 10,000 pounds (tension and compression). The specimen of a given material (i.e. steel, aluminum, cast iron) takes a cylindrical shape that is 2.0 in. long and 0.5 in. in diameter in its undeformed (with no permanent strain or residual stress), or original shape. The results from the tensile test have direct design implications. Many common engineering structural components are designed to perform under tension. The truss is probably the most common example of a structure whose members are designed to be in tension (and compression).

The stress-strain curve characterizes the behavior of the material tested. It is most often plotted using engineering stress and strain measures, because the reference length and cross-sectional area are easily measured. Stress-strain curves generated from tensile test results help engineers gain insight into the constitutive relationship between stress and strain for a particular material. The constitutive relationship can be thought of as providing an answer to the following question: Given a strain history for a specimen, what is the state of stress? As we shall see, even for the simplest of materials, this relationship can be very complicated.

In addition to providing quantitative information that is useful for the constitutive relationship, the stress-strain curve can also be used to qualitatively describe and classify the material. Typical regions that can be observed in a stress-strain curve are:

1. Elastic region
2. Yielding
3. Strain Hardening
4. Necking and Failure

2. SRESS-STRAIN

A stress-strain curve with each region identified is shown below. The curve has been sketched using the assumption that the strain in the specimen is monotonically increasing - no unloading occurs. It should also be emphasized that a lot of variation from what's shown is possible with real materials, and each of the above regions will not always be so clearly delineated. It should be emphasized that the extent of each region in stress-strain space is material dependent, and that not all materials exhibit all of the above regions. A stress-strain curve is a graph derived from measuring load (stress - σ) versus extension (strain - ε) for a sample of a material. The nature of the curve varies from material to material. The following diagrams illustrate the stress-strain behavior of typical materials in terms of the engineering stress and engineering strain where the stress and strain are calculated based on the original dimensions of the sample and not the instantaneous values. In each case the samples are loaded in tension although in many cases similar behaviour is observed in compression.

3. HOOKE'S LAW

for materials stressed in tension, at relatively low levels, stress and strain are proportional through:
constant E is known as the modulus of elasticity, or Young's modulus.

$$\sigma = \mathbf{E}\varepsilon$$

Measured in MPa and can range in values from ~4.5x104 - 40x107 MPa

The engineering stress strain graph shows that the relationship between stress and strain is linear over some range of stress. If the stress is kept within the linear region, the material is essentially *elastic* in that if the stress is removed, the deformation is also gone. But if the elastic limit is exceeded, permanent deformation results. The material may begin to "neck" at some location and finally break. Within the linear region, a specific type of material will always follow the same curves despite different physical dimensions. Thus, it can say that the linearity and slope are a constant of the type of material only. In tensile and compressional stress, this constant is called the *modulus of elasticity* or *Young's modulus (E).*

E= *(F/A)/* (D*l*/*l*)
where stress = *F/A* in N/m2
strain = D*l*/*l* unitless
E = Modulus of elasticity in N/m2

4. CONCEPTS OF STRESS AND STRAIN

Stress can be defined by ratio of the perpindicular force applied to a specimen divided by its original cross sectional area, formally called engineering stress To compare specimens of different sizes, the load is calculated per unit area, also called normalization to the area. Force divided by area is called stress. In tension and compression tests, the relevant area is that perpendicular to the force. In shear or torsion tests, the area is perpendicular to the axis of rotation. The stress is obtained by dividing the load (F) by the original area of the cross section of the specimen (A_O).

$$\sigma= F/ A_O$$

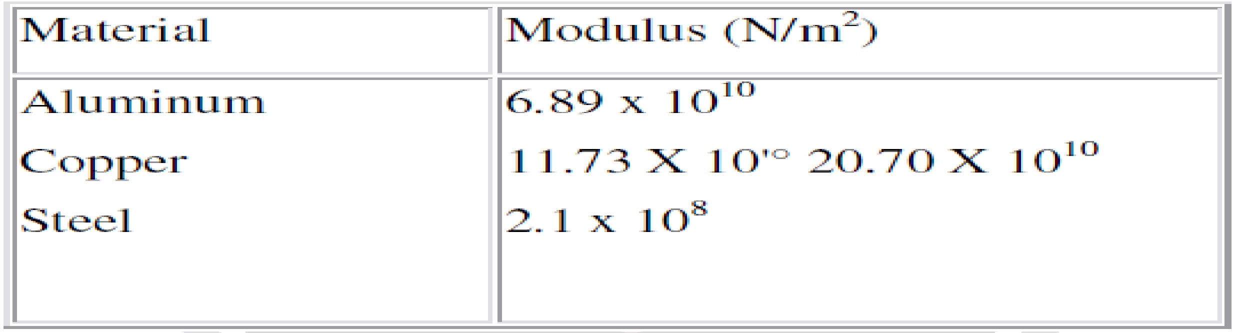
The unit is the Megapascal = 106 Newtons/m2. There is a change in dimensions, or deformation elongation, D*L* as a result of a tensile or compressive stress. To enable comparison with specimens of different length, the elongation is also normalized, this time to the length *lo*. This is called strain. So, Strain is the ratio of change in length due to deformation to the original length of the specimen, formally called engineering strain. strain is unitless, but often units of m/m (or mm/mm) are used

The strain used for the engineering stress-strain curve is the average linear strain, which is obtained by dividing the elongation of the gage length of the specimen, by its original length.

$$\varepsilon = \frac{l_i - l_o}{l_o} = \frac{\Delta l}{l_o}$$

Since both the stress and the strain are obtained by dividing the load and elongation by constant factors, the load elongation curve will have the same shape as the engineering stress-strain curve. The two curves are frequently used interchangeably. The shape and magnitude of the stress-strain curve of a metal will depend on its composition, heat treatment, prior history of plastic deformation, and the strain rate, temperature, and state of stress imposed during the testing. The parameters used to to describe stress-strain curve are tensile strength, yield strength or yield point, percent elongation, and reduction of area**.** The **f**irst two are strength parameters; the last two indicate ductility. The general shape of the engineering stress-strain curve requires further explanation. In the elastic region stress is linearly proportional to strain. When the load exceeds a value corresponding to the yield strength, the specimen undergoes gross plastic deformation. It is permanently deformed if the load is released to zero. The stress to produce continued plastic deformation increases with increasing plastic strain, i.e., the metal strain-hardens. The volume of the specimen remains constant during plastic deformation, A·L = A0·L0 and as the specimen elongates, it decreases uniformly along the gage length in cross-sectional area. Initially the strain hardening more than compensates for this decrease in area and the engineering stress (proportional to load P) continues to rise with increasing strain. Eventually a point is reached where the decrease in specimen crosssectional area is greater than the increase in deformation load arising from strain hardening. This condition will be reached first at some point in the specimen that is slightly weaker than the rest. All further plastic deformation is concentrated in this region, and the specimen begins to neck or thin down locally. Because the crosssectional area now is decreasing far more rapidly than strain hardening increases the deformation load, the actual *load* required to deform the specimen falls off and the engineering stress likewise continues to decrease until fracture occurs.

The modulus of elasticity has units of stress, that is, N/m2. The following table gives the modulus of elasticity for several materials. In an exactly similar fashion, the shear modulus is defined for shear stress-strain as modulus of elasticity.



Material	Modulus (N/m^2)
Aluminum Copper Steel	6.89 x 10^{10} 11.73 X 10'° 20.70 X 10^{10} 2.1 x 10^8

5. YIELD STRENGTH

The yield point, is defined in engineering and materials science as the stress at which a material begins to plastically deform. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed. Once the yield point is passed some fraction of the deformation will be permanent and non-reversible. Knowledge of the yield point is vital when designing a component since it generally represents an upper limit to the load that can be applied. It is also important for the control of many materials production techniques such as forging, rolling, or pressing. In structural engineering, **yield** is the permanent plastic deformation of a structural member under stress. This is a soft failure mode which does not normally cause catastrophic failure unless it accelerates buckling. It is often difficult to precisely define yield due to the wide variety of stress-strain behaviours exhibited by real materials. In addition there are several possible ways to define the yield point in a given material. Yeild occurs when dislocations first begin to move. Given that dislocations begin to move at very low stresses, and the difficulty in detecting such movement, this definition is rarely used.

- Elastic Limit
- Proportional Limit
- Offset Yield Point
- Yield point.
- Yield stress.

6. PROPERTIES OF MATERIALS

When the stress is removed, the material returns to the dimension it had before the load was applied.Valid for small strains (except the case of rubbers). Deformation is *reversible, non permanent* Materials subject to tension shrink laterally. Those subject to compression, bulge. The ratio of lateral and axial strains is called the *Poisson's ratio.* When a material is placed under a tensile stress, an accompanying strain is created in the same direction. When the stress is removed, the material does not return to its previous dimension but there is a *permanent*, irreversible deformation. For metallic materials, elastic deformation only occurs to strains of about 0.005. After this point, plastic (non-recoverable) deformation occurs, and Hooke’s Law is no longer valid. On an atomic level, plastic deformation is caused by *slip*, where atomic bonds are broken by dislocation motion, and new bonds are formed. Here the behavior is elastic but not the stress-strain curve is not immediately reversible. It takes a while for the strain to return to zero. The effect is normally small for metals but can be significant for polymers. When stress continues in the plastic regime, the stress-strain passes through a maximum, called the *tensile strength* (sTS) , and then falls as the material starts to develop a *neck* and it finally breaks at the *fracture point*. Note that it is called strength, not stress, but the units are the same, MPa. For structural applications, the yield stress is usually a more important property than the tensile strength, since once the it is passed, the structure has deformed beyond acceptable limits. For many years it was customary to base the strength of members on the tensile strength, suitably reduced by a factor of safety. The current trend is to the more rational approach of basing the static design of ductile metals on the yield strength. However, because of the long practice of using the tensile strength to determine the strength of materials, it has become a very familiar property, and as such it is a very useful identification of a material in the same sense that the chemical composition serves to identify a metal or alloy. Further, because the tensile strength is easy to determine and is a quite reproducible property, it is useful for the purposes of specifications and for quality control of a product. Extensive empirical correlations between tensile strength and properties such as hardness and fatigue strength are often quite useful. For brittle materials, the tensile strength is a valid criterion for design.

The area underneath the stress-strain curve is the toughness of the material- i.e. the energy the material can absorb prior to rupture.. It also can be defined as the resistance of a material to crack propogation. In materials science and metallurgy, **toughness** is the resistance to fracture of a material when stressed. It is defined as the amount of energy that a material can absorb before rupturing, and can be found by finding the area (i.e., by taking the integral) underneath the stress-strain curve.

The ability of a metal to deform plastically and to absorb energy in the process before fracture is termed toughness. The emphasis of this definition should be placed on the ability to absorb energy before fracture. Recall that ductility is a measure of how much something deforms plastically before fracture, but just because a material is ductile does not make it tough. The key to toughness is a good combination of strength and ductility. A material with high strength and high ductility will have more toughness than a material with low strength and high ductility. Therefore, one way to measure toughness is by calculating the area under the stress strain curve from a tensile test. This value is simply called “material toughness” and it has units of energy per volume. Material toughness equates to a slow absorption of energy by the material. The toughness of a material is its ability to absorb energy in the plastic range. The ability to withstand occasional, stresses above the yield stress without fracturing is particularly desirable in parts such as freight-car couplings, gears, chains, and crane hooks. Toughness is a commonly used concept, which is difficult to pin down and define. One way of looking at toughness is to consider that it is the total area under the stress-strain curve. This area is an indication of the amount of work per unit volume, which can be done, on the material without causing it to rupture. The high-carbon spring steel has a higher yield strength and tensile strength than the medium-carbon structural steel. However, the structural steel is more ductile and has a greater total elongation. The total area under the stresstrain curve is greater for the structural steel, and therefore it is a tougher material. This illustrates that toughness is a parameter that comprises **both** strength and ductility.

7. CONCLUSIONS

The ratio of lateral and axial strains is called the *Poisson's ratio.* When a material is placed under a tensile stress, an accompanying strain is created in the same direction. When the stress is removed, the material does not return to its previous dimension but there is a *permanent*, irreversible deformation. Once the yield point is passed some fraction of the deformation will be permanent and non-reversible. Knowledge of the yield point is vital when designing a component since it generally represents an upper limit to the load that can be applied. It is also important for the control of many materials production techniques such as forging, rolling, or pressing. In structural engineering, **yield** is the permanent plastic deformation of a structural member under stress. This is a soft failure mode which does not normally cause catastrophic failure unless it accelerates buckling. The engineering tension test is widely used to provide basic design information on the strength of materials and as an acceptance test for the specification of materials. In the tension test a specimen is subjected to a continually increasing uniaxial tensile force while simultaneous observations are made of the elongation of the specimen. The parameters, which are used to describe the stress-strain curve of a metal, are the tensile strength, yield strength or yield point, percent elongation, and reduction of area**.** The first two are strength parameters; the last two indicate ductility. . It should also be emphasized that a lot of variation from what's shown is possible with real materials, and each of the above regions will not always be so clearly delineated. It should be emphasized that the extent of each region in stress-strain space is material dependent, and that not all materials exhibit all of the above regions.

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