Subject: Materials Science and Engineering

2nd Class

Lecture two

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Mechanical Properties

Introduction:

In determining تحديد the fabrication التصنيع and possible practical applications التطبيقات العملية الممكنة, the mechanical properties of materials, their strength قوتها , rigidity صلابتها and ductility ليونة are of vital importance أهمية حيوية . The important mechanical properties of materials are: elasticity المرونة , plasticity اللدونة , strength المقاومة, ductility الليونة , hardness الصلاده , brittleness الهشاشة , toughness المتانه , stiffness, resilience المرونة , malleability المطيلية , fatigue الكلال, creep الزحف , etc. Materials exhibit تُظهر a wide range of mechanical properties ranging تتراوح , e.g., from the ductility of pure copper من ليونة النحاس ، to the hardness of diamond صلابة الماس and most surprising elastic الأكثر إثارة للدهشة behaviour of rubber المطاط . There are several materials behave quite differently تتصرف بشكل مختلف تمامًا when stressed in different ways بطرق مختلفة , e.g. على سبيل المثال steel and wood are stronger in tension whereas cast iron الحديد الزهر, cement and bricks الطوب are much stronger in compression. Obviously من الواضح , stresses can produce a shape change and may also cause a material to break or fracture الإجهاد يمكن أن ينتج عنه تغير في الشكل وقد يتسبب أيضًا في كسر المادة أو كسرها. For materials which have to withstand تتحمل high temperatures, the melting point نقطة الانصهار is also of importance.

The combination الجمع of high yield الخضوع strength مقاومه and good fracture toughness وصلابة الكسر الجيدة or ductility الليونة makes steel an excellent structural material. Modern high strength low alloy سبائك الفولاذ منخفضة القوة الحديثة (HSLA) steels have a very fine grain size بحجم حبيبات دقيق جدًا around 10 micro-meters which

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provides both high strength and good crack growth resistance ومقاومة جيدة لنمو التشقق or fracture toughness متانة الكسر .

In addition to mechanical properties of materials, the following properties are also important for an engineer, to enable him in selecting suitable metals for various jobs:

بالإضافة إلى الخصائص الميكانيكية للمواد ، فإن الخصائص التالية مهمة أيضًا للمهندس ، لتمكينه من اختيار المعادن المناسبة لمختلف الوظائف.

- **Physical Properties:** These properties of materials include shape, size, colour, lusters, specific gravity, porosity, structure, finish, etc.

تشتمل خواص المواد على الشكل ، الحجم ، اللون ، اللمعان ، الثقل النوعي ، المسامية ، الهيكل ، التشطيب ، إلخ.

- **Technological Properties:** We may note that all the technical properties of a metal are essentially its mechanical properties, which include properties like malleability, machinability , weldability, formability or workability, castability, etc.

قد نلاحظ أن جميع الخواص الفنية للمعدن هي في الأساس خواصه الميكانيكية ، والتي تشمل خواص مثل قابليتها للطرق ، واعاده تصنيع ، وقابليه اللحام ، وقابلية التشكيل أو قابلية التشغيل ، وقابيله الصب ، وما إلى ذلك.

- **Thermal Properties:** Specific heat, thermal conductivity, thermal expansion, latent heat, thermal stresses, thermal shock, etc. fall under thermal properties of materials.

الحرارة النوعية ، التوصيل الحراري ، التمدد الحراري ، الحرارة الكامنة ، الضغوط الحرارية ، الصدمة الحرارية ، إلخ. تقع تحت الخواص الحرارية للمواد.

- **Electrical Properties:** These include conductivity, resistivity, relative capacity, dielectric strength, etc.

وتشمل الموصلية ، المقاومة ، السعة النسبية ، قوة العزل ، إلخ.

- **Chemical Properties:** These properties include atomic weight, equivalent weight molecular weight, atomic number, acidity, alkalinity, chemical composition, corrosion, etc.

تشمل هذه الخواص الوزن الذري ، الوزن الجزيئي المكافئ ، العدد الذري ، الحموضة ، القلوية ، التركيب الكيميائي ، التآكل ، إلخ

Common Terms: المصطلحات الشائعة

(i) Isotropy: A body is said to be isotropic if its physical properties خواصه الفيزيائية are not dependent لا تعتمد upon the direction in the body along which they are measured.

(ii) Anisotropy: The quality of variation of a physical property with the direction in a body along which the property is measured.

Difference Between Isotropic and Anisotropic Materials The difference Between Isotropic and Anisotropic Materials is as follows.

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S. No	Isotropic Material	Anisotropic Material
1	Isotropic materials show the same properties in all directions.	Anisotropic materials show different properties in different directions.
2	Glass, crystals with cubic symmetry, diamonds, metals are examples of isotropic materials.	Wood, composite materials, all crystals (except cubic crystal) are examples of anisotropic materials.
3	These materials are direction-independent.	These materials are direction-dependent.
4	These materials have a single refractive index.	These materials have many refractive indices.
5	These materials have consistent chemical bonding.	These materials have inconsistent chemical bonding.
6	Isotropic minerals generally appear dark.	Anisotropic minerals generally appear light.
7	These materials don't show characteristics such as optical activity, dichroism, etc.	Optical activity, dichroism, dispersion in presence of different refractive indices are a few characteristics of anisotropic materials.

(iii) Elasticity: It is the property of a material which enables it to regain its original shape and size after deformation within the elastic limit. However, in nature no material is perfectly elastic, i.e., a certain limit exists for every material beyond which it will not be able to regain its original shape and size. This limit is termed as elastic limit. Materials with high elastic limit are called as more elastic than the others. This property is always desirable in metals used in machine tools and other structural constituents. Steel and rubber are amongst the common examples of materials having elasticity.

المرونة: هي خاصية مادة تمكنها من استعادة شكلها الأصلي وحجمها بعد التشوه ضمن الحد المرن. ومع ذلك ، في الطبيعة ، لا توجد مادة مرنة تمامًا ، أي يوجد حد معين لكل مادة لا تستطيع بعدها استعادة شكلها

الأصلي وحجمها. هذا الحد يسمى بالمرونة. تسمى المواد ذات المرونة العالية بأنها أكثر مرونة من غيرها. هذه الخاصية مرغوبة دائمًا في المعادن المستخدمة في أدوات الآلات والمكونات الهيكلية الأخرى. يعد الفولاذ والمطاط من بين الأمثلة الشائعة للمواد التي تتمتع بالمرونة.

(iv) Plasticity: It is the ability of material to be permanently deformed التشوه الدائم (with fracture) even after the load is removed. It is of importance in deciding manufacturing processes like forming, extruding operations etc. Metals possess more plasticity at high temperatures. Usually, plasticity of a material increases with increase in temperature.

اللدونة: إنها قدرة المادة على التشوه الدائم (بالكسر) حتى بعد إزالة الحمل. وهي ذات أهمية في تحديد عمليات التصنيع مثل التشكيل والتشكيل وعمليات البثق وما إلى ذلك. تمتلك المعادن المزيد من اللدونة في درجات الحرارة العالية. وعادةً ما تزداد لدونة المادة بزيادة درجة الحرارة.

(v) Ductility: It is defined as the property of a metal by virtue of which it can be drawn into wires or elongated before rupture takes place. It is measured by the percentage of elongation and the percentage of reduction in area before rupture of test piece.

الليونه: هي خاصية المعدن التي يمكن من خلالها سحبه إلى أسلاك أو إطالته قبل حدوث التمزق. ويتم قياسها من خلال نسبة الاستطالة ونسبة الانخفاض في المساحة قبل تمزق قطعة الاختبار.

$$Percentage\,elongation = \frac{Increase\,in\,length}{Original\,length} \times 100$$
$$= \left[\left(l_f - l_o \right) / l_o \right] \times 100$$

Similarly, the term percentage reduction of cross-sectional area is the maximum decrease in cross sectional area.

$$= \frac{Decrease\ in\ cross-sectional\ area}{Original\ cross-sectional\ area} \times 100$$

$$= \left[\left(A_o - A_f \right) / A_o \right] \times 100$$

Ductility is a measure of the amount of permanent deformation كمية التشوه الدائم that has occurred when the material reaches its breaking point نقطة الكسر.

Metals with more than 15% elongation are considered as **ductile**. Metals with 5 to 15% elongation are considered of **intermediate ductility**. However, the metals with less than 5% elongation are considered as **brittle** ones.

تعتبر المعادن ذات استطالة أكثر من 15٪ قابلة للسحب. تعتبر المعادن ذات استطالة 5 إلى 15 ٪ من الليونة المتوسطة. ومع ذلك ، تعتبر المعادن التي تحتوي على أقل من 5٪ استطالة هشّة.

(vi) Strength: It may be defined as the capacity of material by virtue بفضل ذلك of which it can withstands or support an external force or load with rupture. It is expressed as force per unit area of cross-section. This is most important property of a metal, which plays a decisive role in designing various structures and components.

المقاومة: يمكن تعريفها بأنها قدرة المادة على تحمل أو دعم قوة خارجية أو حمل مع التمزق. يتم التعبير عنها بالقوة لكل وحدة مساحة من المقطع العرضي. هذه هي الخاصية الأكثر أهمية للمعدن، والتي تلعب دورًا حاسمًا في تصميم الهياكل والمكونات المختلفة.

A material has to withstand different types of load, e.g. tensile, compressive and shear load. Accordingly, one may broadly classify strength into :

يجب أن تتحمل المادة أنواعًا مختلفة من الحمل ، على سبيل المثال حمل الشد والضغط والقص. وفقًا لذلك ، يمكن للمرء تصنيف القوة بشكل عام إلى:

1- Depending upon the value of stress, the strengths may be elastic or plastic.

2-Depending upon the nature of stress, the strengths of a metal may be tensile, compressive, shear, bending and torsional. Now, we study all these types of strengths.

- **Ultimate strength:** It is the load required to fracture a unit cross-section of material.
- **Elastic Strength:** It is the value of strength corresponding to transition from elastic to plastic range, i.e. when material changes its behaviour from elastic range to plastic range.
- **Plastic strength:** It is the value of strength of the material which corresponds to plastic range and rupture. It is also termed as ultimate strength.

القوة القصوى: هو الحمل المطلوب لكسر وحدة عرضية من المادة.

القوة المرنة: هي قيمة القوة المقابلة للانتقال من النطاق المرن إلى البلاستيك ، أي عندما تغير المواد سلوكها من النطاق المرن إلى النطاق البلاستيكي.

قوة البلاستيك: هي قيمة قوة المادة التي تتوافق مع المدى البلاستيكي والتمزق. كما يطلق عليه القوة النهائية.

In actual practice, a specimen is subjected to a stress which is always less than the working stress. The ratio of ultimate stress to the working stress of a metal is termed as factor of safety or factor of ignorance. This greatly depends upon the nature of loads or stresses.

في الممارسة الفعلية ، تخضع العينة لضغط يكون دائمًا أقل من ضغط العمل. نسبة الإجهاد النهائي إلى ضغط العمل من المعدن تسمى عامل الأمان أو عامل الجهل. هذا يعتمد بشكل كبير على طبيعة الأحمال أو الضغوط.

Tensile Strength: It is the maximum tensile stress which a material is capable of developing when subjected to loading up to rupture. Mathematically,

قوة الشد: هي أقصى إجهاد شد يمكن للمادة تطويره عند تعرضها للتحميل حتى تمزقها. رياضيا ،

$$Tensile\ Stress = \frac{Maximum\ tensile\ load}{Original\ cross-sectional\ area}$$

The tensile stress is expressed in N/mm^2 or MN/m^2.

Tensile strength is obtained from the following relation:

$$Tensile\ Strength = \frac{Maximum\ Force\ in\ kg}{Original\ \ area\ in\ squre\ cm}$$

It is measured by the highest point on the conventional stress-strain curve. This strength provides the basic design information on the material’s acceptance in engineering tests.

يتم قياسها من خلال أعلى نقطة على منحنى الإجهاد والانفعال التقليدي. توفر هذه القوة معلومات التصميم الأساسية حول قبول المادة في الاختبارات الهندسية.

(vii) Stress and Strain: Stress is defined as the force per unit area and strain as the fractional change in length, area or volume.

$$Stress = \frac{Force}{Area}$$

$$\sigma = \frac{P}{A_o}$$

The stress is said to be ***normal*** if load *P* is normal to the surface and ***tangential*** or **shearing**, if load is tangential to this surface. The normal or direct (tensile or compressive) stress is produced over a section when force is acting normal to the section. If the force is acting away from the section, the stress is tensile, if it is acting towards the section the section is compressive.

Strain is the deformation produced per unit length of a body due to the effect of stress on it. It is the ratio of the change in length of the specimen to its original length. If *L* is the original length of the sample and *l* is the change in length, then longitudinal strain,

$$\varepsilon = \frac{l}{L}$$

Strain is simply a ratio and has no unit and it is a dimensionless quantity. Depending upon the type of load, strain can be lateral strain or shear strain.

As there are different types of stresses, there are different types of strains, e.g. (i) tensile strain (ii) compressive strain, (iii) shear or transverse strain and (iv) volumetric strain.

The strain associated with the change in length is called the elongation strain (l/L). Similarly ($\Delta V/V$) is the volume strain where V is the volume. When there is a change in shape and no change in volume, corresponding strain is called shear

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strain. The shear strain is measured by the angle. The behaviour of a material within the elastic limit is the same under compression as under tension.

Corresponding to elastic and plastic properties of materials, we have two classes of strain:

- Elastic Strain: It is the change in dimension of a body when it is subjected to a load. This is reversible phenomenon هذه ظاهرة قابلة للعكس , i.e., elastic strain disappears يختفي after the applied load is removed. This is proportional to the stress applied.
- Plastic Strain: This is the permanent change التغيير الدائم in the body when subjected to a load. The change remains even after the applied load is removed.

The amount of elongation, expressed as a percentage of the original gauge length is called as the percentage elongation:

$$Percentage\ elonggation = \frac{Final\ length - Initial\ length}{Initial\ length} \times 100$$

(viii) Hooke's Law: In 1678, Robert Hooke, for the first time stated that *within elastic limits, stress is proportional to strain*, i.e.

Stress = a constant * Strain

The ratio of stress to strain is a constant characteristic of a material, and this proportionality constant is called **modulus of the material**. It differs from material to material and for different nature of stresses. When the stress applied is tensile or compressive, the constant is called Young's modulus of elasticity. The slope of stress-strain diagram up to the limit of proportionality is called Young's Modulus of elasticity (Y or E).

$$\therefore Y \ or \ E = \frac{Stress}{Strain} = \frac{\sigma}{\varepsilon} = cons\tan t$$

When the shear stress (τ) and strain (γ) are used, it is called ***modulus of rigidity* (*G*).** It is given by :

$$\therefore \tau = G\gamma$$

G is also called shear modulus. G and E are related as :

$$\therefore G = \frac{E}{2}(1+\nu)$$

Where υ is Poisson's ratio.

For volumetric stresses and strains, the constant is called bulk modulus (K). The relation between K and E is :

$$\therefore K = \frac{E}{3(1-2\nu)}$$

Poisson's ratio (υ):

Poisson's ratio is an important elastic constant and its value is different for different materials. For most engineering structural materials its value is usually between 0.3 and 0.6. The relation between E, G and υ is :

$$\therefore \nu = \frac{E}{2G} - 1$$

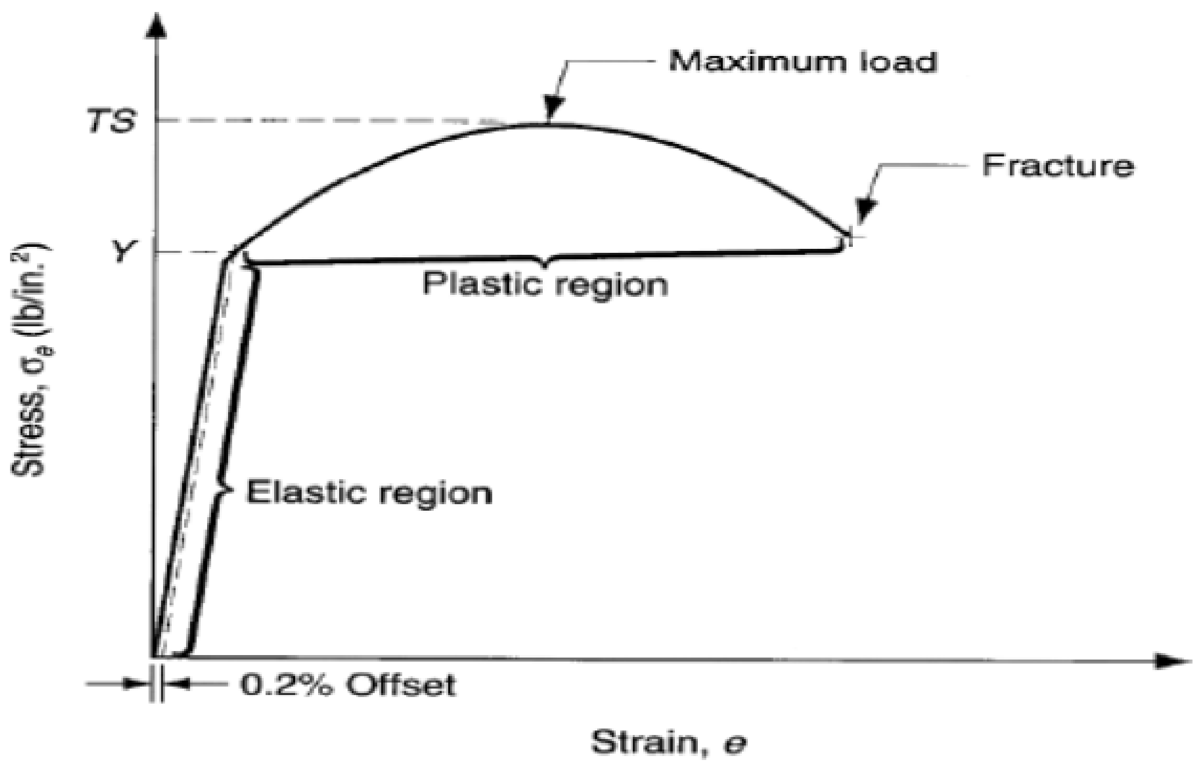

Fig .(2.1) : Typical engineering stress – strain plot in a tensile test in a malel

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