ERCİYES ÜNİVERSİTESİ
Uçak Mühendisliği Bölümü
HAVA UZAY YAPILARI
Malzeme Özellikleri ve Çevre Etkisi

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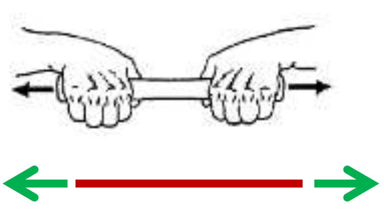
1

Tension (çekme)*;*



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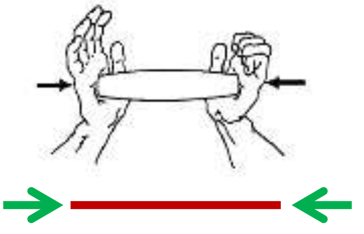
Compression (basma);



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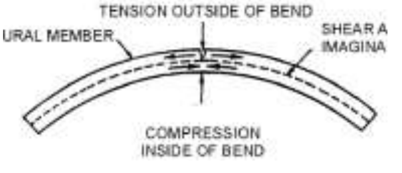
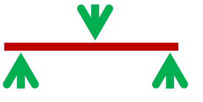
Torsion (burulma);

4

Bending (eğilme);





5

Shear (kesme);

6

- Stiffness : dayanıklılık
- Strength : mukavemet

7

- Bir yaya etkiyen kuvvet ile yayın uzaması arasında doğrusal ilişki vardır.

$$P = k\ x$$

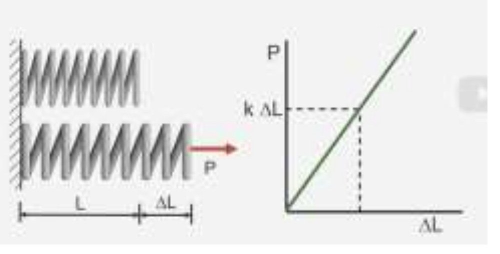
uzama

Yay katsayısı

Yük

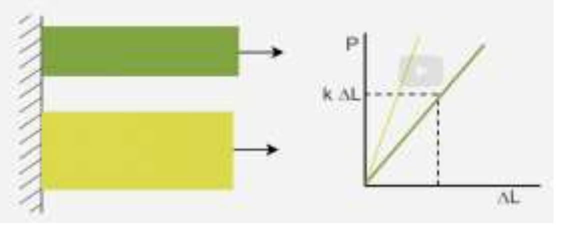
8

- Yayın dayanımı (k)
- Yüke karşı direnç
- Kirişler de yay gibi davranırlar



9

- Kirişin boyutu arttıkça deformasyona direnci (dayanımı) artar.
- Dayanıklılık kiriş kesiti silindirik olması halinde en yüksek olur.



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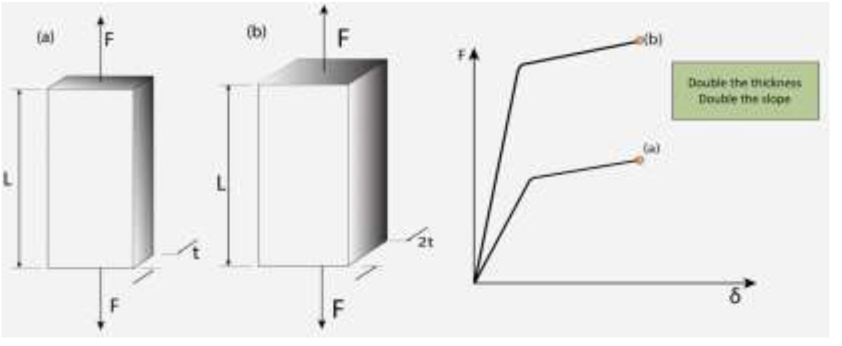
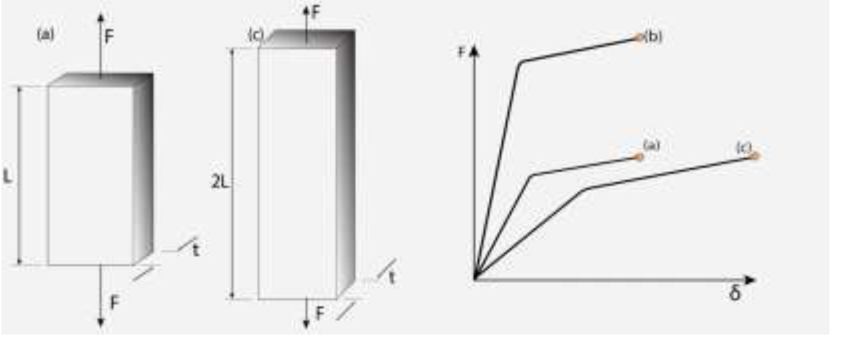
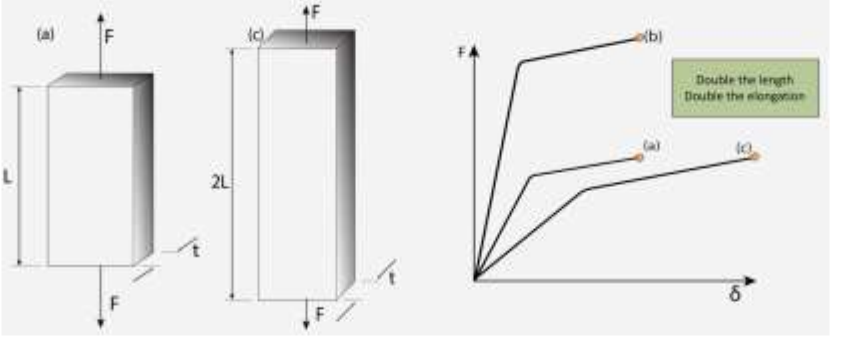

(a)
F
L
t
F
(b)
F
L
2t
F
F
(b)
Double the thickness
Double the slope
(a)
δ

11


(a)
F
L
t
F
F
(c)
2L
t
F
F
(b)
(a)
(c)
δ

12



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- Kiriş elemanları aynı malzemeden yapıldı ise farklılık geometriden kaynaklanacaktır.
- Tasarım sırasında geometri ve şeklin özelliklerinin etkisini ortadan kaldırmamız gereklidir.
- Bunun için gerilim (stress) ve uzama (strain) tanımlarını kullanacağız.
- Gerilim ve uzama, yük altındaki malzemenin boyutlarından bağımsız olarak tanımlanırlar.

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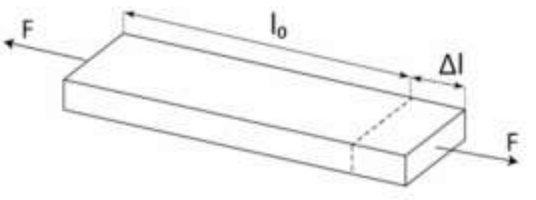
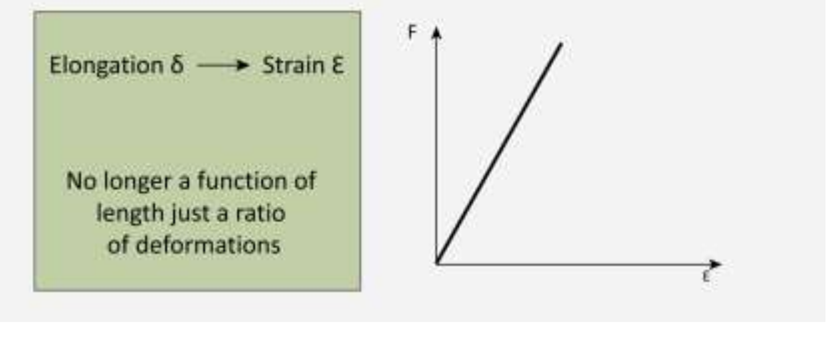


$$\varepsilon = \frac{\Delta L}{L}$$

15



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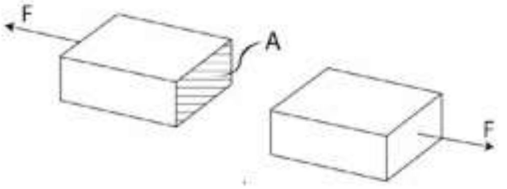
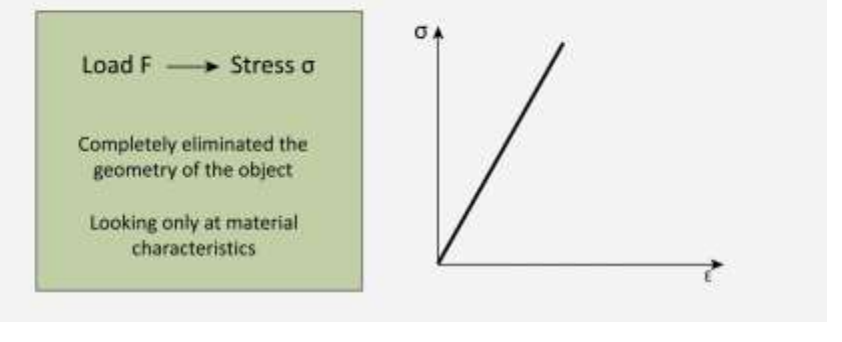


$$\sigma = \frac{F}{A}$$

17



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GERİLİM-UZAMA EĞRİLERİ
STRESS–STRAIN CURVES

- Farklı malzemelerin çekme ve basma testlerinden elde edilen sonuçlar detaylıca incelendiğinde izleyen slaytlardaki çıkarımlar ve genelleştirmeler elde edilir.

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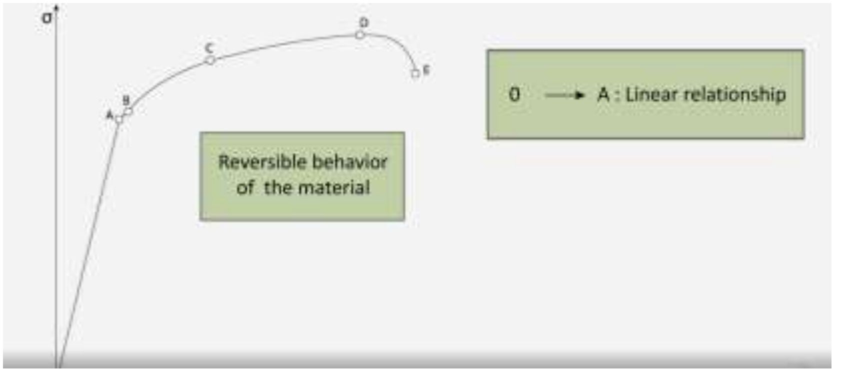
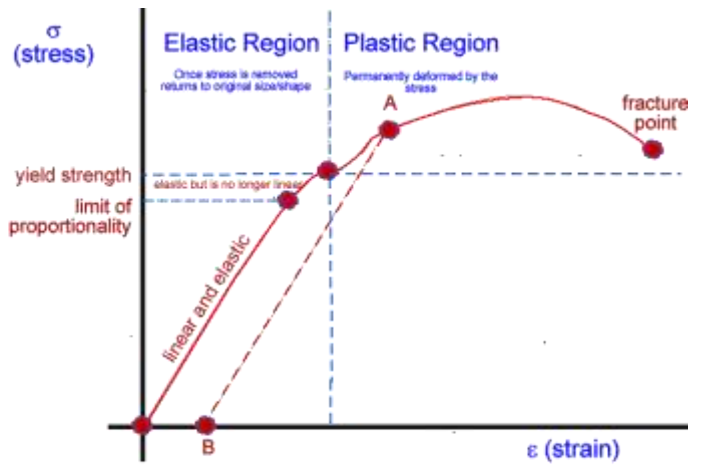


Lineer elastic davranış: boy değişimnden sonra malzeme eski şeklini alır

22

Malzemelerin deformasyonu



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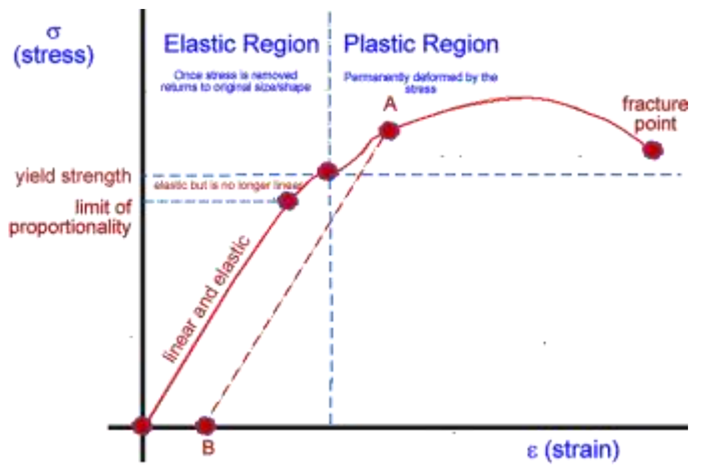
Malzemelerin deformasyonu



B noktası genelde yüzde 0.2 lik bir uzamayı işaret eder ve $\sigma_{0.2}$= sünme (yield) gerilimi olarak anılır. Bu noktadan sonraki gerilimler artık kalıcı (plastik) etki bırakacaktır.

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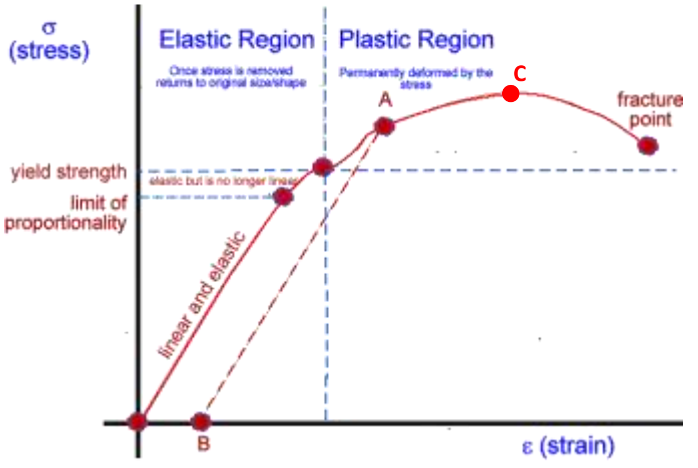
Malzemelerin deformasyonu



C noktası taşınabilecek en yüksek gerilimi işaret eder ve σ_{ult}= sınır (ultimate) gerilim olarak anılır. Bu noktadan sonra malzeme kırıma uğrar.

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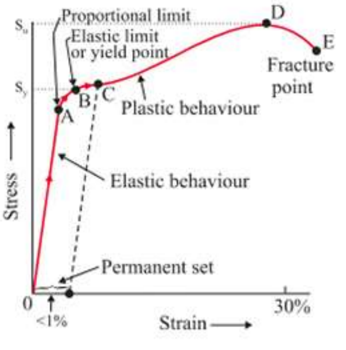

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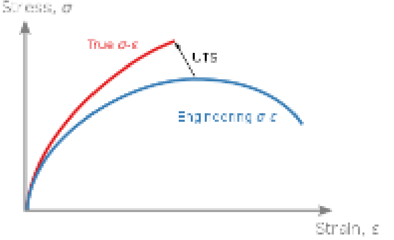
- Gerilim uygulandıkça kesitin azaldığını biliyorsak, gerilimin iki ayrı tanımı karşımıza çıkıyor.
- Mühendislik gerilimi nominal alan kullanılarak hesaplanan ve
- Gerçek gerilim gerçek kesit alanı kullanılarak hesaplanan gerilimdir.
- Mühendislik hesaplarında güvenli alanda kalacak şekilde nominal kesit kullanılır.



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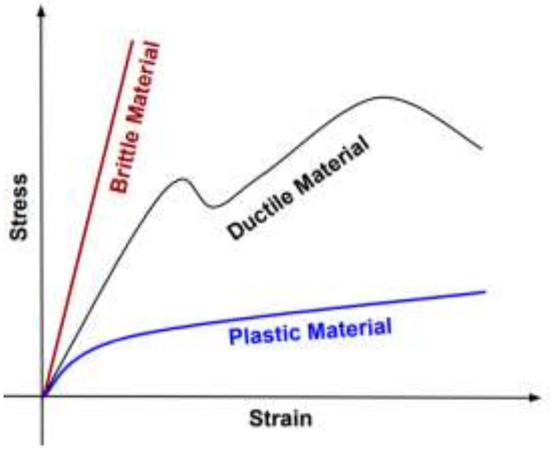

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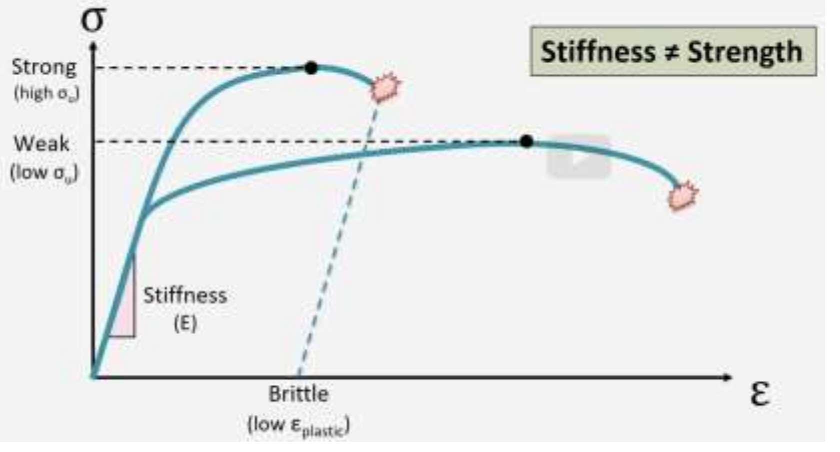
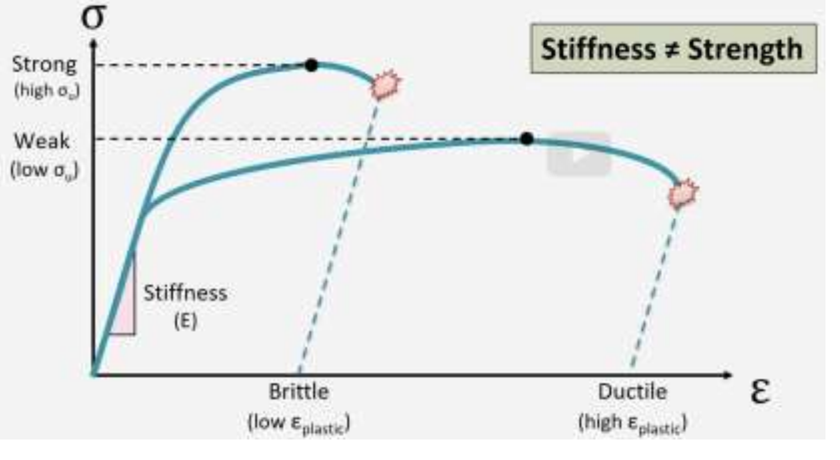

σ
Stiffness ≠ Strength
Strong
(high σ_u)
Weak
(low σ_u)
Stiffness
(E)
Brittle
(low $\varepsilon_{plastic}$)
ε

29


σ
Stiffness ≠ Strength
Strong
(high σ_u)
Weak
(low σ_u)
Stiffness
(E)
Brittle
(low $\varepsilon_{plastic}$)
Ductile
(high $\varepsilon_{plastic}$)
ε

30

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PROPERTIES OF MATERIALS

- **Ductility (süneklik):** A material is said to be ductile if it is capable of withstanding large strains under load before fracture occurs. These large strains are accompanied by a visible change in cross-sectional dimensions and therefore give warning of impending failure. Materials in this category include mild steel, aluminum and some of its alloys, copper, and polymers.
- **Brittleness (kırılganlık, gevreklik)**: A brittle material exhibits little deformation before fracture, the strain normally being below 5 percent. Brittle materials therefore may fail suddenly without visible warning. Included in this group are concrete, cast iron, high strength steel, timber, and ceramics.

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- **Elastic materials (elastik malzemeler)**: A material is said to be elastic if deformations disappear completely on removal of the load. All known engineering materials are, in addition, linearly elastic within certain limits of stress, so that strain, within these limits, is directly proportional to stress.
- **Plasticity (esneklik):** A material is perfectly *plastic* if no strain disappears after the removal of load. Ductile materials are elastoplastic and behave in an elastic manner until the elastic limit is reached, after which they behave plastically. When the stress is relieved the elastic component of the strain is recovered but the plastic strain remains as a *permanent set*.

- **Isotropic materials (izotropik malzemeler):** In many materials, the elastic properties are the same in all directions at each point in the material, although they may vary from point to point; such a material is known as isotropic. An isotropic material having the same properties at all points is known as homogeneous (e.g., mild steel).
- **Anisotropic materials**: Materials having varying elastic properties in different directions are known as anisotropic.
- **Orthotropic materials**: Although a structural material may possess different elastic properties in different directions, this variation may be limited, as in the case of timber, which has just two values of Young’s modulus, one in the direction of the grain and one perpendicular to the grain. A material whose elastic properties are limited to different values in *three mutually perpendicular directions* is known as orthotropic.

Düşük karbon çeliği (orta çelik - mild steel)

- Sünek bir malzeme (a ductile material) olan orta çelik için gerilim-uzama eğrisi, şekil 11.9. ile verilmiştir.

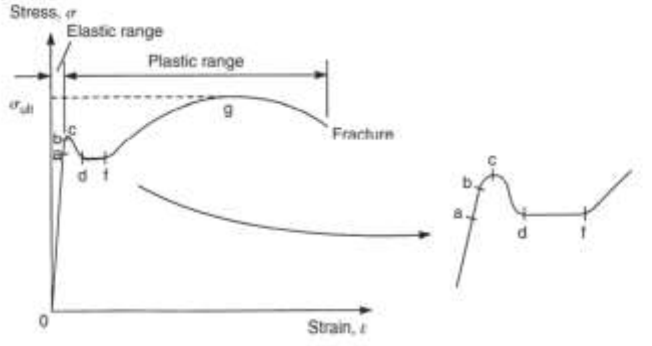

FIGURE 11.9 Stress–Strain Curve for Mild Steel

- From *0* to *a*, the stress–strain curve is linear, the material in this range obeying *Hooke's law*.
- Beyond *a*, the *limit of proportionality*, stress is no longer proportional to strain and the stress–strain curve continues to b, the *elastic limit*, which is defined as the maximum stress that can be applied to a material without producing a *permanent plastic deformation* or *permanent set* when the load is removed.
- In other words, if the material is stressed beyond *b* and the load then removed, a residual strain exists at zero load.
- For many materials, it is impossible to detect a difference between the limit of proportionality and the elastic limit.
- From *0* to *b*, the material is said to be in the **elastic range**, while from *b* to fracture, the material is in the **plastic range**.

- The transition from the elastic to the plastic range may be explained by considering the arrangement of crystals in the material.
- As the load is applied, slipping occurs between the crystals aligned most closely to the direction of load. As the load is increased, more and more crystals slip with each equal load increment, until appreciable strain increments are produced and the plastic range is reached.

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- A further increase in stress from b results in the mild steel reaching its upper yield point at *c*, followed by a rapid fall in stress to its lower yield point at *d*.
- The existence of a lower yield point for mild steel is a peculiarity of the tensile test, wherein the movement of the ends of the test piece produced by the testing machine does not proceed as rapidly as its plastic deformation; the load therefore decreases, as does the stress.

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- From *d* to *f*, the strain increases at a roughly constant value of stress until *strain hardening* again causes an increase in stress. This increase in stress continues, accompanied by a large increase in strain to *g*, the ultimate stress, σ_{ult}, of the material. At this point, the test piece begins, visibly, to "neck" as shown in Fig. 11.10.
- The material in the test piece in the region of the "neck" is almost perfectly plastic at this stage, and from this point onwards to fracture, there is a reduction in nominal stress.

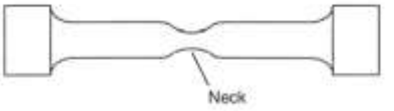

FIGURE 11.10 "Necking" of a Test Piece in the Plastic Range

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- For mild steel, yielding occurs at a stress of the order of 300 N/mm^2.
- At fracture, the strain (i.e., the elongation) is of the order of 30 percent. The gradient of the linear portion of the stress–strain curve gives a value for Young's modulus in the region of 200,000 N/mm^2.

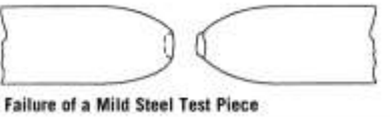

FIGURE 11.11 "Cup-and-Cone" Failure of a Mild Steel Test Piece

40

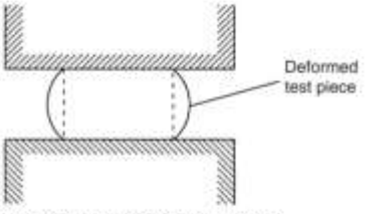

FIGURE 11.12 "Barrelling" of a Mild Steel Test Piece in Compression

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Aluminum

- Aluminum and some of its alloys are also ductile materials, although their stress–strain curves do not have the distinct yield stress of mild steel. A typical stress–strain curve is shown in Fig. 11.13.
- The points *a* and *b* again mark the limit of proportionality and elastic limit, respectively, but are difficult to determine experimentally. Instead, a proof stress is defined, which is the stress required to produce a given permanent strain on removal of the load.

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- In Fig. 11.13, a line drawn parallel to the linear portion of the stress–strain curve from a strain of 0.001 (i.e., a strain of 0.1 percent) intersects the stress–strain curve at the 0.1 percent proof stress. For elastic design this, or the 0.2 percent proof stress, is taken as the working stress.

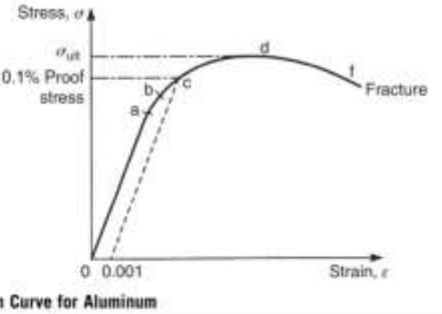

FIGURE 11.13 Stress–Strain Curve for Aluminum

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- A feature of the fracture of aluminum alloy test pieces is the formation of a "double cup," as shown in Fig. 11.14, implying that failure was initiated in the central portion of the test piece while the outer surfaces remained intact. Again, considerable "necking" occurs.

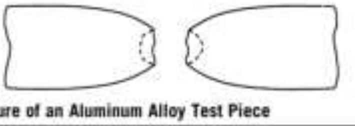

FIGURE 11.14 "Double-Cup" Failure of an Aluminum Alloy Test Piece

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Brittle materials

- These include cast iron, high-strength steel, concrete, timber, ceramics, and glass. The plastic range for brittle materials extends to only small values of strain. A typical stress–strain curve for a brittle material under tension is shown in Fig. 11.15. Little or no yielding occurs and fracture takes place very shortly after the elastic limit is reached. This is thought to be due to the presence of microscopic cracks in the material, giving rise to high stress concentrations, which are more likely to have a greater effect in reducing tensile strength than compressive strength.

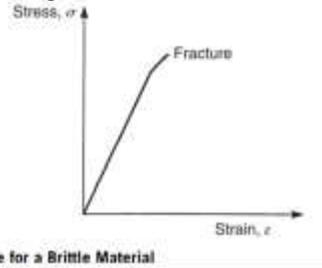

FIGURE 11.15 Stress–Strain Curve for a Brittle Material

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Composites

- Fiber composites have stress–strain characteristics indicating that they are brittle materials (Fig. 11.16).
- There is little or no plasticity, and the modulus of elasticity is less than that of steel and aluminum alloy.
- However, the fibers themselves can have much higher values of strength and modulus of elasticity than the composite. For example, carbon fibers have a tensile strength of the order 2,400 N/mm^2 and a modulus of elasticity of 400,000 N/mm^2.
- Fiber composites are highly durable, require no maintenance, and can be used in hostile chemical and atmospheric environments; vinyls and epoxy resins provide the best resistance.

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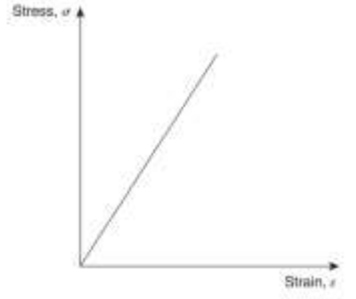

FIGURE 11.16 Stress–Strain Curve for a Fiber Composite

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Strain hardening

- The stress–strain curve for a material is influenced by the strain history, or the loading and unloading of the material, within the plastic range. For example, in Fig. 11.17, a test piece is initially stressed in tension beyond the yield stress at a to a value at b. The material is then unloaded to c and reloaded to f, producing an increase in yield stress from the value at a to the value at d. Subsequent unloading to g and loading to j increases the yield stress still further to the value at h.

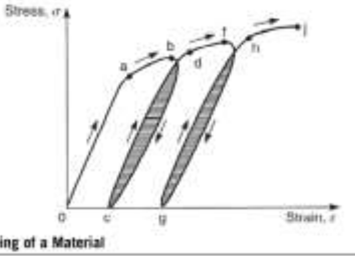

FIGURE 11.17 Strain Hardening of a Material

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- This increase in strength resulting from the loading and unloading is known as strain hardening.
- It can be seen, from Fig. 11.17, that the stress–strain curve during the unloading and loading cycles form loops (the shaded areas in Fig. 11.17).
- These indicate that strain energy is lost during the cycle, the energy being dissipated in the form of heat produced by internal friction.
- This energy loss is known as *mechanical hysteresis* and the loops as *hysteresis loops*.
- Although the ultimate stress is increased by strain hardening, it is not influenced to the same extent as yield stress. The increase in strength produced by strain hardening is accompanied by decreases in toughness and ductility.

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Creep and relaxation

- A given load produces a calculable value of stress in a structural member and hence a corresponding value of strain once the full value of the load is transferred to the member.
- However, after this initial or 'instantaneous' stress and its corresponding value of strain have been attained, a great number of structural materials continue to deform slowly and progressively under load over a period of time.
- This behavior is known as creep. A typical creep curve is shown in Fig. 11.18.

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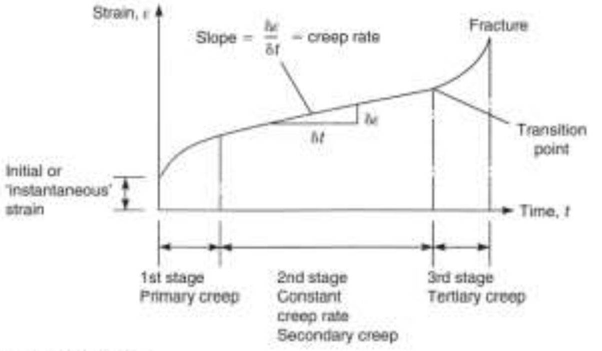

FIGURE 11.18 Typical Creep Curve

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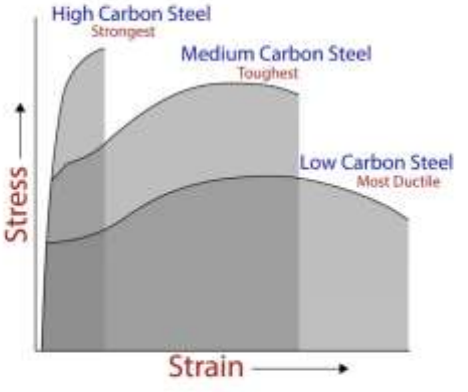

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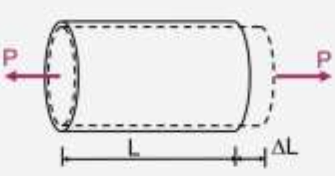
Stiffness - Dayanıklılık

53

Linear-elastic uni-axial stress-strain condition in structures



Shown for tension case

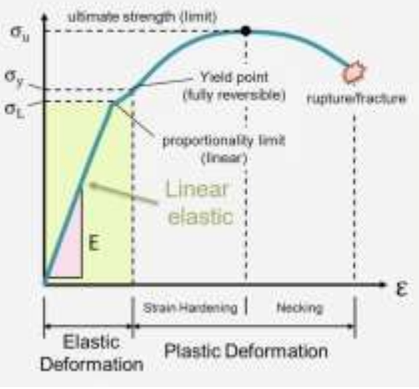
Normal Stress

$$\sigma_l = \frac{F}{A}$$

Normal Strain

$$\varepsilon_l = \frac{\Delta L}{L} = \frac{\sigma_l}{E}$$

54

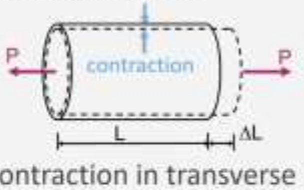


Modulus of Elasticity or Young's Modulus

Measure for material resistance against imposed **Elastic** deformation

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

Assuming volume constant and linear uni-axial stress-strain conditions:



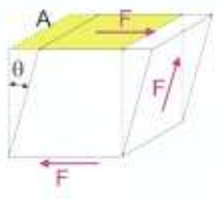
Contraction in transverse direction occurs

Transverse Strain

$$\varepsilon_t = -\nu\varepsilon_l = -\nu\frac{\sigma_l}{E}$$

with

ν = Poisson's ratio, a material property



$$\tau = \frac{F}{A}$$

$$\gamma = \frac{\tau}{G}$$

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For isotropic materials a relation exists between *E* and *G:*

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

Shear Modulus	**Isotropic Materials**
Measure for material resistance against shear	Material having identical mechanical properties in all directions

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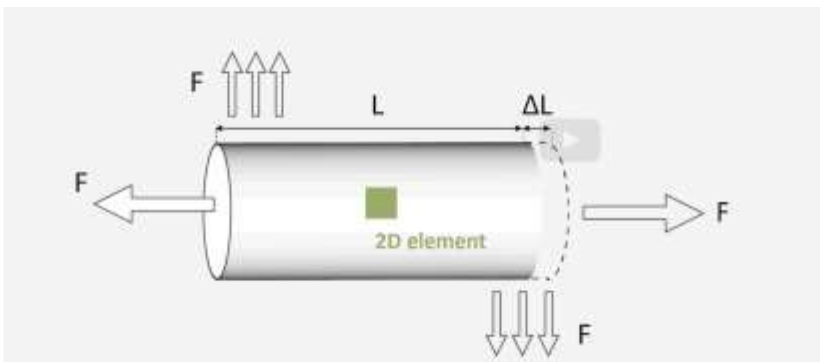
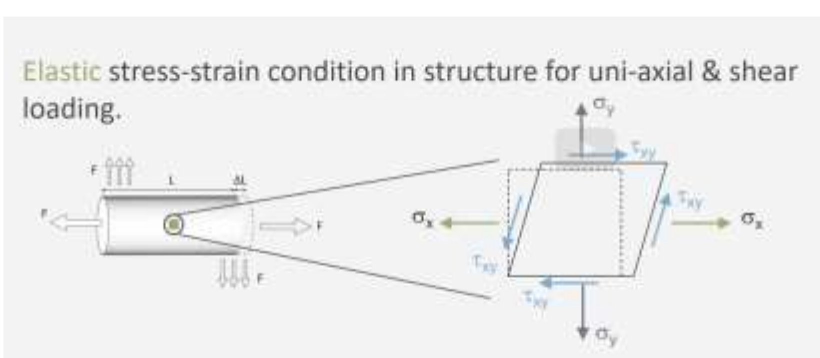

F
L
ΔL
F
2D element
F
F

59


Elastic stress-strain condition in structure for uni-axial & shear loading.
σy
τyy
τxy
σx
σx
τxy
τxy
σy

60

Testing of engineering materials

- The properties of engineering materials are determined mainly by the mechanical testing of specimens machined to prescribed sizes and shapes.
- The testing may be static or dynamic in nature, depending on the particular property being investigated. Possibly the most common mechanical static tests are tensile and compressive tests which are carried out on a wide range of materials.
- Ferrous and nonferrous metals are subjected to both forms of test, while compression tests are usually carried out on many nonmetallic materials.
- Other static tests include bending, shear, and hardness tests, while the toughness of a material, in other words, its ability to withstand shock loads, is determined by impact tests.

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Tensile tests

- Tensile tests are normally carried out on metallic materials and, in addition, timber. Test pieces are machined from a batch of material, their dimensions being specified by Codes of Practice. They are commonly circular in cross-section, although flat test pieces having rectangular cross-sections are used when the batch of material is in the form of a plate. A typical test piece has the dimensions specified in Fig. 11.2. Usually, the diameter of a central portion of the test piece is fractionally less than that of the remainder to ensure that the test piece fractures between the gauge points.

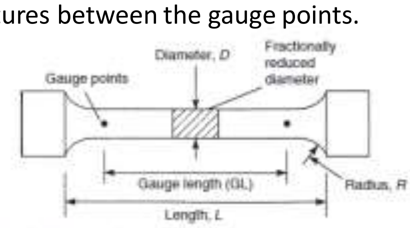

FIGURE 11.2 Standard Cylindrical Test Piece

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- A *stress–strain curve* is drawn (details to follow), the stress normally being calculated on the basis of the original cross-sectional area of the test piece, that is, a nominal stress as opposed to an actual stress (which is based on the actual area of cross-section).
- For ductile materials, there is a marked difference in the latter stages of the test, as a considerable reduction in cross-sectional area occurs between yield and fracture. From the stress–strain curve, the ultimate stress, the yield stress, and Young's modulus, E, are obtained.

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Compression tests

- A compression test is similar in operation to a tensile test, with the obvious difference that the load transmitted to the test piece is compressive rather than tensile. This is achieved by placing the test piece between the platens of the testing machine and reversing the direction of loading.
- Test pieces are normally cylindrical and are limited in length to eliminate the possibility of failure being caused by instability.
- Again, contractions are measured over a given gauge length by a suitable strain measuring device.

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Bending tests

- Many structural members are subjected primarily to bending moments. Bending tests are therefore carried out on simple beams constructed from the different materials to determine their behavior under this type of load.

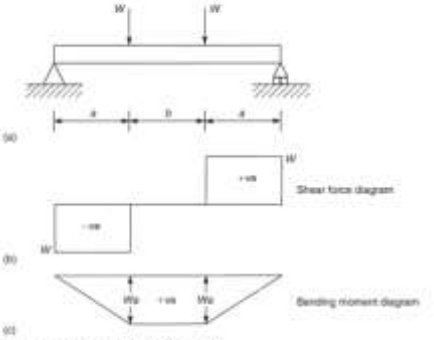

FIGURE 11.3 Bending Test on a Beam, "Two-Point" Load

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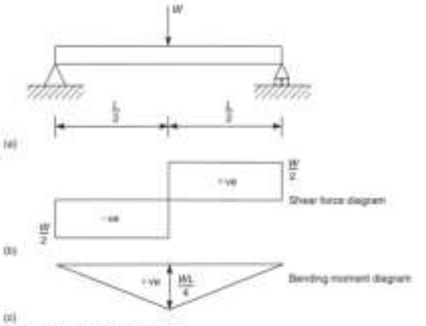

FIGURE 11.4 Bending Test on a Beam, Single Load

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Shear tests

- Two main types of shear test are used to determine the shear properties of materials. One type investigates the direct or transverse shear strength of a material and is used in connection with the shear strength of bolts, rivets, and beams.
- A typical arrangement is shown diagrammatically in Fig. 11.5, where the test piece is clamped to a block and the load is applied through the shear tool until failure occurs. In the arrangement shown the test piece is subjected to double shear, whereas if it is extended only partially across the gap in the block, it is subjected to single shear.

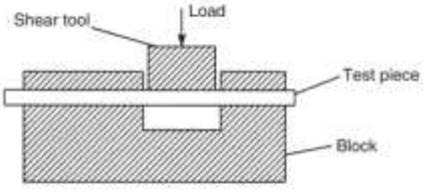

FIGURE 11.5 Shear Test

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Hardness tests

- The machinability of a material and its resistance to scratching or penetration are determined by its "hardness."
- There also appears to be a connection between the hardness of some materials and their tensile strength, so that hardness tests may be used to determine the properties of a finished structural member where tensile and other tests would be impracticable.
- Hardness tests are also used to investigate the effects of heat treatment, hardening and tempering, and cold forming. Two types of hardness test are in common use: *indentation tests* and *scratch and abrasion tests*.

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- Indentation tests may be subdivided into two classes: static and dynamic. Of the static tests, the *Brinell* is the most common. In this, a hardened steel ball is pressed into the material under test by a static load acting for a fixed period of time.
- The load in kilograms divided by the spherical area of the indentation in square millimeters is called the *Brinell hardness number* (BHN).
- In Fig. 11.6, if *D* is the diameter of the ball, *F* the load in kilograms, *h* the depth of the indentation, and *d* the diameter of the indentation, then

$$BHN = \frac{F}{\pi D h} = \frac{2F}{\pi D[D - \sqrt{D^2 - d^2}]}$$

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- In practice, the hardness number of a given material is found to vary with F and D, so that for uniformity the test is standardized. For steel and hard materials, F = 3000 kg and D = 10 mm, while for soft materials F = 500 kg and D = 10 mm; in addition, the load is usually applied for 15 s.
- In the Brinell test, the dimensions of the indentation are measured by means of a microscope. To avoid this rather tedious procedure, direct reading machines have been devised.

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- The indenting tool, a hardened sphere, is first applied under a definite light load. This indenting tool is then replaced by a diamond cone with a rounded point, which is then applied under a specified indentation load. The difference between the depth of the indentation under the two loads is taken as a measure of the hardness of the material and is read directly from the scale.

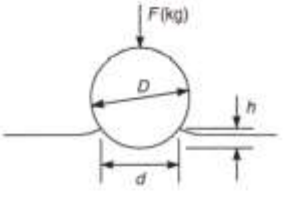

FIGURE 11.6 Brinell Hardness Test

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Impact tests

- It has been found that certain materials, particularly heat-treated steels, are susceptible to failure under shock loading, whereas an ordinary tensile test on the same material shows no abnormality.
- Impact tests measure the ability of materials to withstand shock loads and provide an indication of their toughness.
- Two main tests are in use, the *Izod* and the *Charpy*.
- Both tests rely on a striker or weight attached to a pendulum.
- The pendulum is released from a fixed height, the weight strikes a notched test piece, and the angle through which the pendulum then swings is a measure of the toughness of the material.

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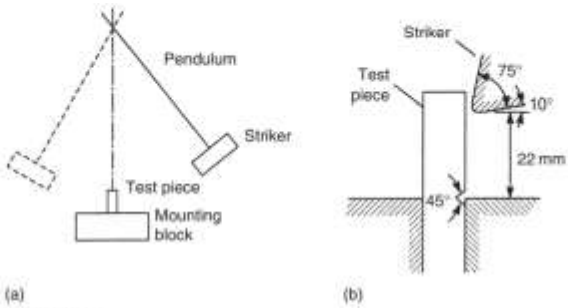

FIGURE 11.7 Izod Impact Test

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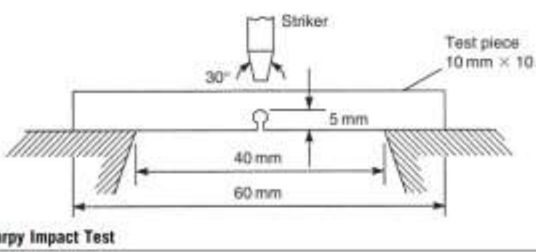

FIGURE 11.8 Charpy Impact Test

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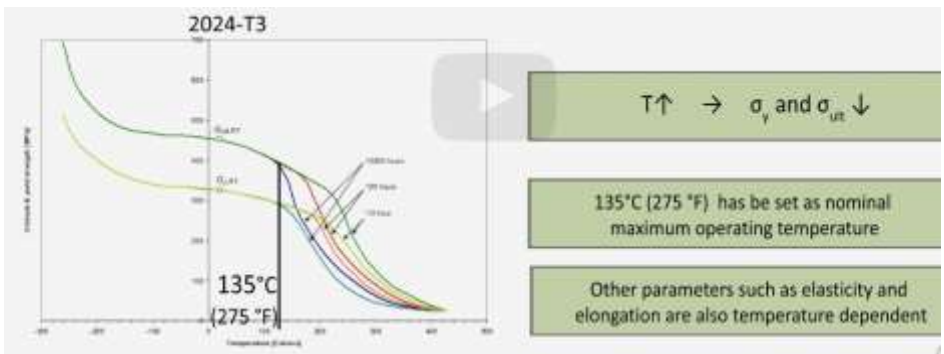
Çevrenin Malzeme Üzerindeki Etkisi



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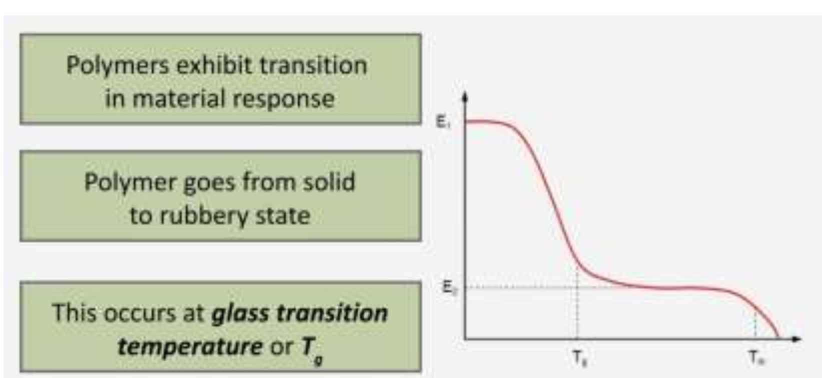

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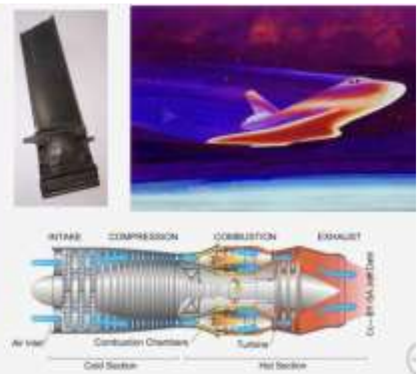
Phenomena:

Creep - Steady deformation when constant stress is applied

Yield strength decreases

Both are limiting factors when selecting components to work at high temperatures



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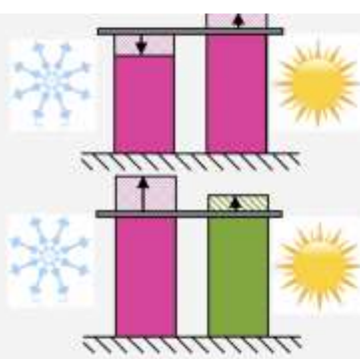

Coefficient of thermal expansion α

$$\alpha = \frac{1}{V}\frac{dV}{dT}$$

Thermal strain

$$\varepsilon_T = \alpha \Delta T$$

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- Sıcaklık yükseldikçe;
  - Mekanik özellikler düşer
  - Yorulma dayanımı düşer
  - Isıl gerilimler artar
- Sıcaklık düştükçe
  - Mekanik özellikler iyileşir
  - Yorulma dayanımı artar
  - Plastik deformasyona dayanım artar
  - Kimyasal reaksiyonlar ve girişim oranı düşer

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Deniz etkisi

Saline environment

Contributes to corrosion

Can lead to serious failure:
Aloha Flight 243

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Uzay etkisi

Typical aspects:
- Radiation/UV exposure
- Atomic Oxygen (O^+)
- Vacuum (degassing)

In the outer atmosphere free radicals have a large effect on degradation of materials

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UV etkisi

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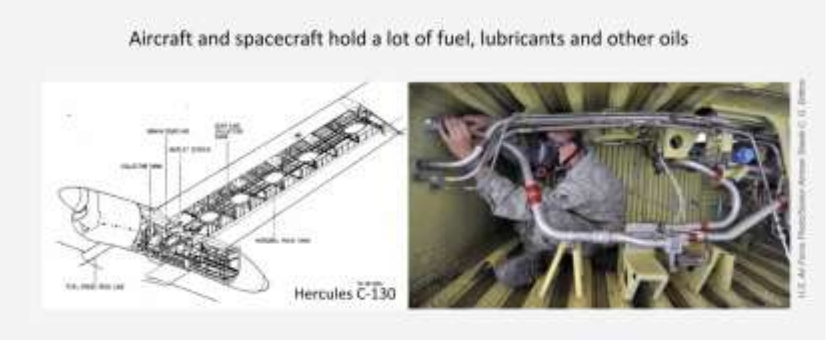
Yakıt ve yağların etkisi



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Kimyasalların etkisi

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Galvanic Korozyon

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Galvanic corrosion between chromium plated brass spoke nipple and aluminum rim

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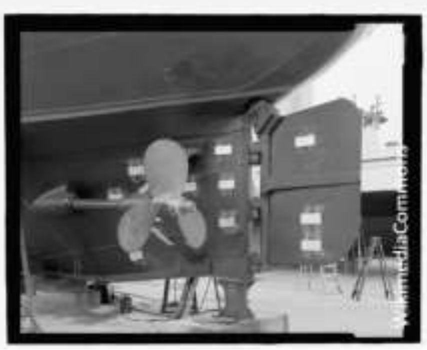
Feda edilen malzeme



Sacrificial Material

Material placed deliberately, to protect a primary metal from corrosion by acting as a sacrificial anode.

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Fatigue

- Structural members are frequently subjected to repetitive loading over a long period of time.
- For example, the members of a bridge structure suffer variations in loading possibly thousands of times a day as traffic moves over the bridge.
- In these circumstances, a structural member may fracture at a level of stress substantially below the ultimate stress for nonrepetitive static loads; this phenomenon is known as *fatigue.*

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- Fatigue cracks are most frequently initiated at sections in a structural member where changes in geometry, such as holes, notches, or sudden changes in section, cause *stress concentrations*. Designers seek to eliminate such areas by ensuring that rapid changes in section are as smooth as possible. At re-entrant corners for example, fillets are provided, as shown in Fig. 11.19.

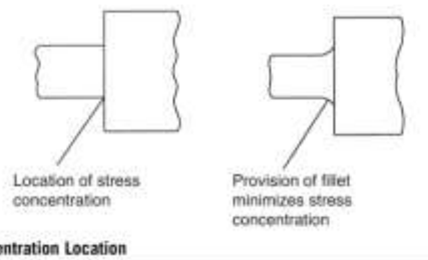

FIGURE 11.19 Stress Concentration Location

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- Other factors which affect the failure of a material under repetitive loading are the type of loading (fatigue is primarily a problem with repeated tensile stresses, probably because microscopic cracks can propagate more easily under tension), temperature, the material, surface finish (machine marks are potential crack propagators), corrosion, and residual stresses produced by welding.

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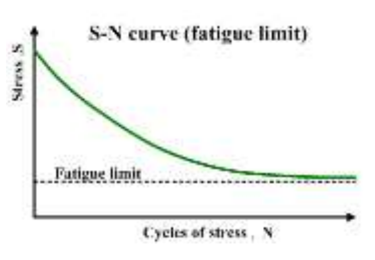
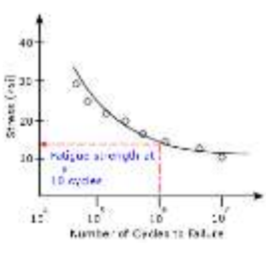
- The fatigue strength of a part is based on the magnitude of the alternating load and the total number of cycles that occur over time. This is best illustrated using a Stress/Number of cycles graph, commonly known as the S/N curve.





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- Frequently in structural members, an alternating stress, σ_{alt}, is superimposed on a static or mean stress, σ_{mean}, as illustrated in Fig. 11.20.
- The value of σ_{alt} is the most important factor in determining the number of cycles of load that produce failure. The stress σ_{alt} that can be withstood for a specified number of cycles is called the fatigue strength of the material.

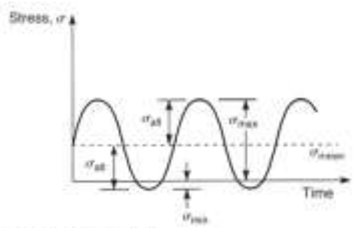

FIGURE 11.20 Alternating Stress in Fatigue Loading

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- Some materials, such as mild steel, possess a stress level that can be withstood for an indefinite number of cycles. This stress is known as the endurance limit of the material; no such limit has been found for aluminum and its alloys.
- Fatigue data are frequently presented in the form of an S–n curve or stress–endurance curve, as shown in Fig. 11.21.

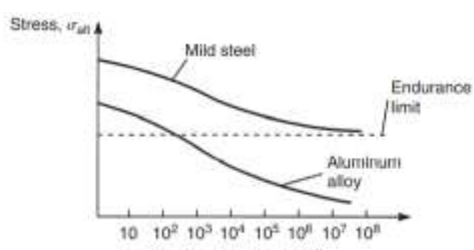

FIGURE 11.21 Stress–Endurance Curves

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- In many practical situations, the amplitude of the alternating stress varies and is frequently random in nature. The S–n curve does not, therefore, apply directly, and an alternative means of predicting failure is required. *Miner's cumulative damage theory* suggests that failure occurs when

$$\frac{n_1}{N_1} + \frac{n_2}{N_2} + \ldots + \frac{n_r}{N_r} = 1$$

- where $n_1, n_2, \ldots, n_r$ are the number of applications of stresses σ_{alt}, σ_{mean} and $N_1, N_2, \ldots, N_r$ are the number of cycles to failure of stresses σ_{alt}, σ_{mean}

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- **QUESTIONS**

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