UNIT-V

PART A

1. What are the characteristics features of ductile fracture surface?

- Cup and cone formation.
- Very high roughness on fractured surfaces.
- Micro cones when observed through microscope.

2. Under what condition, twinning is preferred mechanism of plastic deformation.

In BCC metals deform by slip, as do FCC metals with medium to high values of *stacking fault energy (SFE)* such as copper (~80 mJ/m^2) and aluminum (~170 mJ/m^2). In metals with low values of *SFE* such as silver or in alloys like 70:30 brass and austenitic stainless steels with *SFE* ~20 mJ/m^2, the dislocations dissociate to form stacking faults, and twinning is the preferred mode of deformation. The tendency to deform by twinning is increased if the deformation temperature is lowered or the strain rate increased. Iron has a high stacking fault energy, as do all the BCC metals, but it too exhibits mechanical twinning at low temperatures and high strain rates.

3. Differentiate between brittle and ductile fracture.

Ductile fracture	Brittle fracture
• Material fractures after plastic deformation and slow propagation of crack	• Material fractures with very little or no plastic deformation.
• Surface obtained at the fracture is dull or fibrous in appearance	• Surface obtained at the fracture is shining and crystalling appearance
• It occurs when the material is in plastic condition.	• It occurs when the material is in elastic condition.
• It is characterized by the formation of cup and cone	• It is characterized by separation of normal to tensile stress.
• The tendency of ductile fracture is increased by dislocations and other defects in metals.	• The tendency brittle fracture is increased by decreasing temperature, and increasing strain rate.
• There is reduction in cross – sectional area of the specimen	• There is no change in the cross – sectional area.

4. What are the factors affecting fatigue.

Fatigue life is affected by cyclic stresses, residual stresses, material properties, internal defects, grain size, temperature, design geometry, surface quality, oxidation, corrosion, etc. The fatigue life of a component under the following different fatigue mechanisms can be ranked from low to high as: thermal shock, high temperature LCF, low temperature LCF, and HCF. In the assessment of the risk

5. How will the creep rupture surface look like.
   Creep rupture surface has the features of a ductile fracture.

6. Rockwell hardness test involves pressing either a diamond shaped penetrator or a hard ball penetrator into the surface of the metal and measuring the penetration depth. A number of different sized indenters and loads are used. This method can give variable results depending on the preparation of the test material and equipment.
7. **Differentiate between ductile and brittle fracture?(Apr/May 2017)**

Ductile failure	Brittle failure
1) It involves large plastic deformation.	1) It is associated with minimum plastic deformation.
2) It is always preceded by the localized deformation called "necking"	2) It does not involve "necking".
3) Ductile fracture normally occurs in F.C.C metals.	3) Brittle fracture is normally observed in B.C.C and H.C.P metal not in F.C.C metal.
4) Ductile fracture normally occurs through the grains.	4) Brittle fracture normally follows the gain boundaries.
5) A complete ductile fracture present a rough dirty surface. It has rough dirty contour	5) A complete brittle fracture shows sharp facets which reflect light.
6) It occurs by slow tearing of the metal with expenditure of considerable energy.	6) It occurs suddenly without any warning.

8. **What is the difference between HRB and HRC? (Apr/May 2017)**

Rock well Scale	Hardness symbol	Indenter	Load (kg)	Typical Material Tested
A	HRA	Cone	60	Carbides, ceramic
B	HRB	1.6 mm ball	100	Nonferrous metals
C	HRC	Cone	150	Ferrous metals, tool steels

9. **What are the characteristic features of brittle fracture?**

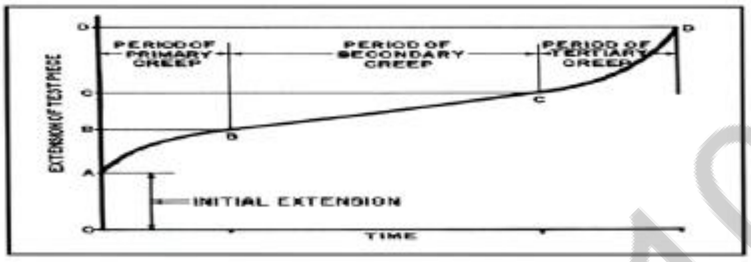
There is no gross, permanent deformation of the material. The surface of the brittle fracture tends to be perpendicular to the principal tensile stress although other components of stress can be factors.

10. **State hardness whether corresponds to ultimate tensile strength or yield strength. (Nov/Dec 2017)**

    Hardness corresponds to ultimate tensile strength

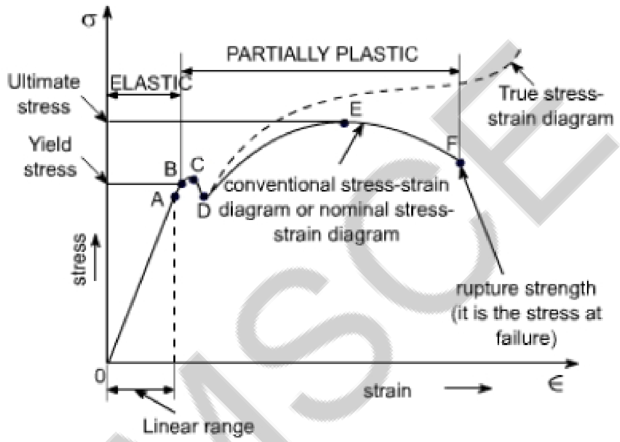
    11.

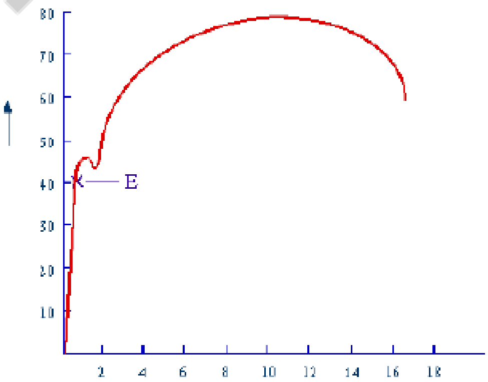
    Draw typical creep curve for ductile metal and explain the regions. (April/May 2015)



12.

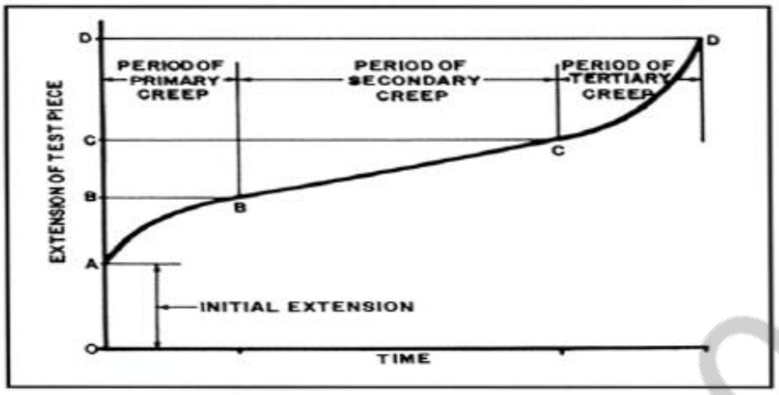
. **Draw a typical load versus percentage elongation curve for ductile material and explain the tensile properties (April/May 2015)**





13.

What are the characteristic features of fracture surface of creep rupture component (Nov/Dec 2015)



14.

State the advantages of Rockwell hardness testing over other techniques. (Nov/Dec 2015)

Among the commonly used hardness methods, Rockwell is the only one that allows direct reading of the hardness value without need of optical reading as per Vickers and Brinell methods. Therefore, it is the most rapid method and the only one that can be fully automated. The instruments working according to the Rockwell principle are the most popular, because they are less subject to operators influence. Even if, according to the standards, the test surface must be carefully smooth, among the different methods for hardness testing, the Rockwell test is the least influenced by surface roughness. The main limitations are due to the fact that between maximum and minimum load there is only a 10:1 ratio. In hardness testing, the most required loads by foundries and workshops are included in the range between 1 and 3000 kgf. For example, a Rockwell scale suitable for testing of cast iron or of steel sheets having a thickness lower than 0.15 mm does not exist. To overcome the limitation on light loads, instruments working according to the Rockwell principle are produced to work also with non-standardized light loads. Although the Rockwell method employs a wide range of hardness scales, for a range of materials of high importance, such as untreated steel, there is not a specific scale. In this case, it is advisable to employ an instrument working according to the Rockwell principle with Brinell loads and penetrators.

15.

What is the effect of the grain size on the mechanical properties of the material?

Size of the grain has the inversely proportional relation with ductility and fracture toughness.

16. **What is S-N diagram. what is the significance of it?**

S-N diagram shows the variation in strength of the material with respect to the various cycle of repeated loading and unloading cycles. Its significance is to find the fatigue strength of material and predict the robustness.

17. What is twinning?

Crystal twinning occurs when two separate crystals share some of the same crystal lattice points in a symmetrical manner. The result is an intergrowth of two separate crystals in a variety of specific configurations. A twin boundary or composition surface separates the two crystals. Crystallographers classify twinned crystals by a number of twin laws. These twin laws are specific to the crystal system. The type of twinning can be a diagnostic tool in mineral identification.

18. What is charpy?

It is the impact test method to measure the impact strength and fracture toughness.

19. What are the two components of the process of fracture?

Crack initiation

Crack propagation

20. What are the different types of fracture? Brittle

a. Ductile
b. Fatigue
c. Creep

PART B

1. Compare charpy and izod impact test.

Refer question no 7

2. Draw a typical creep curve and brief on the mechanism.

Refer question no 13.

3. Compare rockwell and Brinell hardness test.

Refer question no 10.

4. Draw a typical SN curve of fatigue testing and brief on the mechanism.

Refer question no 13.

5. Explain testing procedure for rockwell hardness test.
   Refer question no 10.

6. Explain the testing procedure of Tensile test of material.

Refer question no 18.

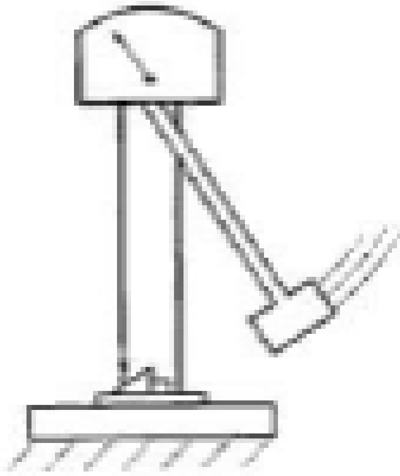
7. **With geometry and arrangement of impact test specimens explain Charpy and Izod test with relative advantages and disadvantages. (May/June 2015)**

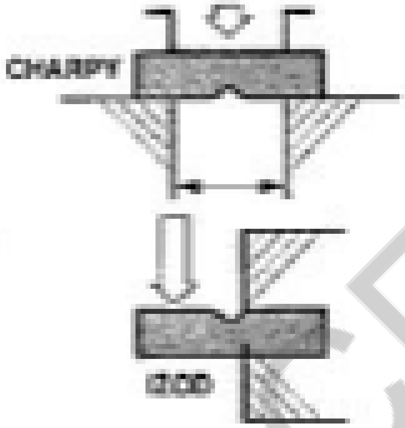
During the first part of the 20th century, a metallurgist named Izod invented an impact test for determining the suitability of various metals to be used as cutting tools. The test involved a pendulum with a known weight at the end of its arm swinging down and striking the specimen as it stood clamped in a vertical position. Some years later another metallurgist named Charpy modified the test slightly by orienting the specimen in a horizontal fashion. These pendulum impact test methods proved to be very useful, providing reliable, qualitative impact data throughout WWII up until the early 70’s. It then became apparent that higher velocities and impact energies could be achieved with vertical style drop towers and thus the trend began to shift. Pendulum machines remained popular with those testing to Izod and Charpy while more high speed, product oriented impact applications became the dominion of the drop tower.

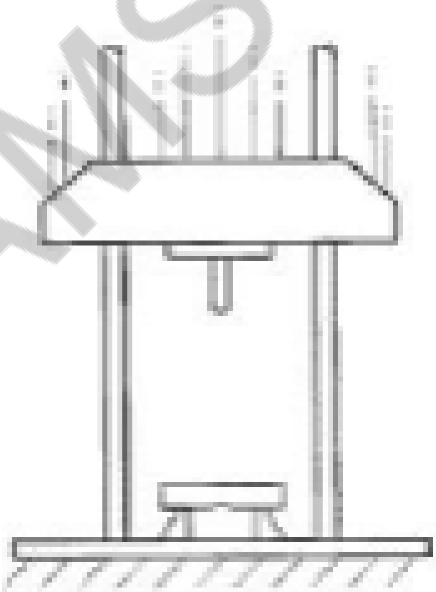
Specimens for Charpy and Izod Testing

While still used, pendulum impact testing has inherent weaknesses. In notched Izod testing, samples are mounted in a vise fixture with the notch facing a pendulum. A weighted pendulum, fixed at a point directly above the sample vise, is swung up and held stationary. This height and thus the speedof the pendulum at impact is a constant for this test. When released, the pendulum swings through the path where the sample is fixed. As the sample breaks, energy is absorbed by the sample. The height the pendulum attains after impact is measured by an indicator on a fixed scale which reads in joules (ft-lb). The impact strength is the loss of momentum in the pendulum while breaking the sample off at the notch. The Izod pendulum test configuration served as the standard in impact testing in the plastics and metals industry for many years. The problems with the Izod pendulum test involve several parameters which can drastically alter the results if not strictly controlled. First the radius of the notch is critical. It is meant to simulate conditions which might exist in applications where the features such as internal corner on an enclosure will act as a stress concentrator upon impact. In a pendulum test, the radius cannot be varied. The notch radius has a significant effect on the ability of a sample to absorb impact. Most polymers, especially polycarbonate and nylon have critical notch radii below which their impact strength falls off dramatically. In a fixedradius test, the data can give a false impression about the relative impact resistance of different polymers. In addition, the creation of the notch in the sample has been a problem. Notch consistency has been difficult so comparison between testing labs is difficult. Notching blades can overheat polymers and degrade the material around the notch thus resulting in inaccurate test results. Industry round robin studies have shown that test results among participants were impossible to correlate because of the tremendous variations in notches.

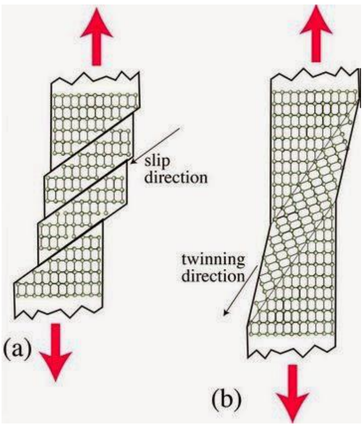
1. A Charpy pendulum impact test is a variation of Izod. In a Charpy test, a sample is laid horizontally on two supports against an anvil. The sample is notched in the center and the notch side is positioned away from the pendulum. When the pendulum swings through the gap in the anvil, it impacts the center of the sample with a radius hammer. The energy to break is measured and reported in the same way as with an Izod test.




CHARPY
IZOD



8. **Discuss the role of slip and twinning in plastic deformation of materials. (Nov/Dec 2015)**



When a metal is stressed below its elastic limit, the resulting deformation or strain produced in the metal is temporary. This strain or deformation vanishes after the removal of stress and the metal goes back to the original dimensions. When it is stressed above the elastic limit, permanent deformation takes place and the metal does not returns to its original shape after the removal of stress. The ability of a metal to undergo plastic deformation is one of the important property which is utilized for shaping of metals by various fabrication process such as rolling, forging, drawing, extrusion etc.,

Mechanism Of Plastic Deformation

Plastic deformation take place by slip, twinning, some times by both Slip:

Slip is a permanent displacement of one part of crystal relative to the other part. slip involves sliding of one plane of atoms over the other. The plane on which the slip occurs are called slip planes and the direction in which this occurs are called slip direction. Slip occurs when shear stress applied exceeds a critical value. During slip each atom usually moves same integral number of atomic distances along the slip plane producing a step, but the orientation of the crystal remains the same. Slip planes are usually the closest packed planes i.e., the planes of maximum atomic density. Such planes obviously will be widely spaced i.e., the inter planar distance between such planes is more. Slip results from the motion of dislocations from one place to the other place. There are two basic types of dislocations movements called as glide and climb. In glide, the dislocation moves in a surface defined by its line and Burger's vector (glide is conservative motion of dislocations). In climb, the dislocation moves out of the glide surface and therefore, climb becomes a non conservation motion of dislocation. Slip is the most common manifestation of glide.

Twinning:

Twinning is a process in which the atoms in a part of the crystal subjected to stress rearrange themselves so that the orientation of the part changes in such a way that the distorted part becomes a mirror image of the other part. The plane across which the two parts are mirror images is called twinning plane or composition plane. Like slip, twinning also occurs along the certain crystallographic planes and directions. These planes and directions are called as twin planes and twin directions. The important role of twinning in plastic deformation is that it causes changes in plane orientation so that further slip can occur.

9. **Discuss the mechanisms of slip and twinning in detail. (Apr/May 2017)**

Refer, Question No.**8**.

10. **Name and explain the different types of hardness tests with respect to procedure, relative advantages and disadvantages. (May/June 2015)**

Rockwell Hardness Test

The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load F0 (Fig. 1A) usually 10 kgf. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter is set to a datum position. While thepreliminary minor load is still applied an additional major load is applied with resulting increase in penetration (Fig. 1B). When equilibrium has again been reach, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration. The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number.

HR = E - e

F0 = preliminary minor load in kgf

F1 = additional major load in kgf

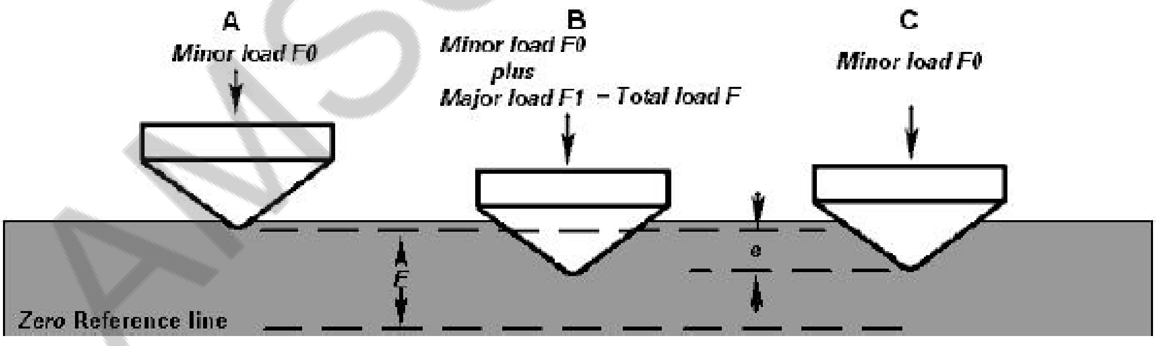
F = total load in kgf

e = permanent increase in depth of penetration due to major load F1 measured in units of 0.002 mm

E = a constant depending on form of indenter: 100 units for diamond indenter, 130 units for steel ball indenter

HR = Rockwell hardness number

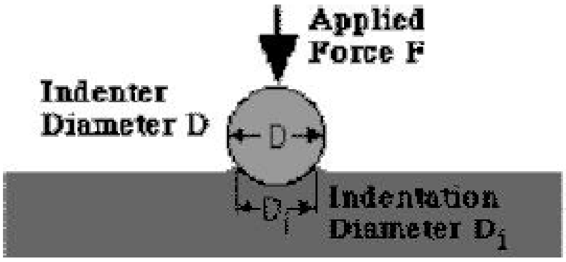
D = diameter of steel ball



Rockwell Principle

The Brinell Hardness Test

The Brinell hardness test method consists of indenting the test material with a 10 mm diameter hardened steel or carbide ball subjected to a load of 3000 kg. For softer materials the load can be reduced to 1500 kg or 500 kg to avoid excessive indentation. The full load is normally applied for 10 to 15 seconds in the case of iron and steel and for at least 30 seconds in the case of other metals. The diameter of the indentation left in the testmaterial is measured with a low powered microscope. The Brinell harness number is calculated by dividing the load applied by the surface area of the indentation. The diameter of the impression is the average of two readings at right angles and the use of a Brinell hardness number table can simplify the determination of the Brinell hardness. A well structured Brinell hardness number reveals the test conditions, and looks like this, “75 HB 10/500/30” which means that a Brinell Hardness of 75 was obtained using a 10mm diameter hardened steel with a 500 kilogram load applied for a period of 30 seconds. On tests of extremely hard metals a tungsten carbide ball is substituted for the steel ball. Compared to the other hardness test methods, the Brinell ball makes the deepest and widest indentation, so the test averages the hardness over a wider amount of material, which will more accurately account for multiple grain structures and any irregularities in the uniformity of the material. This method is the best for achieving the bulk or macro-hardness of a material, particularly those materials with heterogeneous structures.

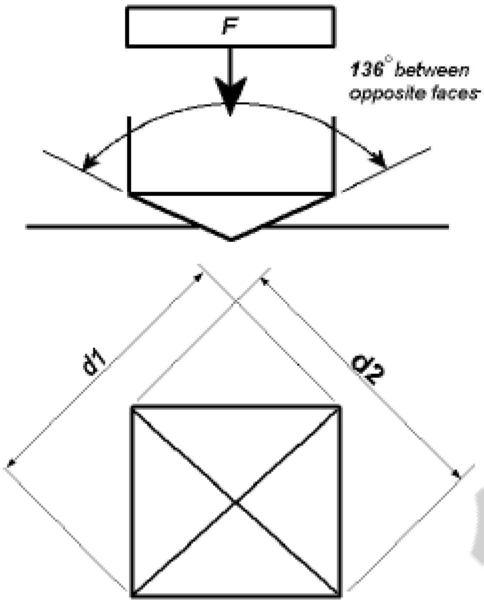


$$BHN = \frac{F}{\frac{\pi}{2} D \cdot \left(D - \sqrt{D^2 - D_i^2}\right)}$$

Vickers Hardness Test

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation. When the mean diagonal of the indentation has been determined the Vickers hardness may be calculated from the formula, but is more convenient to use conversion tables. The Vickers hardness should be reported like 800 HV/10, which means a Vickers hardness of 800, was obtained using a 10 kgf force. Several different loading settings give practically identical hardness numbers on uniform material, which is much better than the arbitrary changing of scale with the other hardness testing methods. The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments. Although thoroughly adaptable and very precise for testing the softest and hardest of materials, under varying loads, the Vickers machine is a floor standing unit that is more expensive than the Brinell or Rockwell machines.

There is now a trend towards reporting Vickers hardness in SI units (MPa or GPa) particularly in academic papers. Unfortunately, this can cause confusion. Vickers hardness (e.g. HV/30) value should normally be expressed as a number only (without the units kgf/mm2). Rigorous application of SI is a problem. Most Vickers hardness testing machines use forces of 1, 2, 5, 10, 30, 50 and 100 kgf and tables for calculating HV. SI would involve reporting force in newtons (compare 700 HV/30 to HV/294 N = 6.87 GPa) which is practically meaningless and messy to engineers and technicians. To convert a Vickers hardness number the force applied needs converting from kgf to newtons and the area needs converting form mm2 to m2 to give results in pascals using the formula above.



F= Load in kgf
d = Arithmetic mean of the two diagonals, d1 and d2 in mm

HV = Vickers hardness

$$HV = \frac{2F\sin\frac{136^\circ}{2}}{d^2} \qquad HV = 1.854\frac{F}{d^2} \text{ approximately}$$

11. Sketch and describe the following hardness test.

1. Brinell
2. Vickers.

Refer question no. 10.

12. **Compare slip and twinning (Nov/Dec 2017)**

When a metal is stressed below its elastic limit, the resulting deformation or strain produced in the metal is temporary. This strain or deformation vanishes after the removal of stress and the metal goes back to the original dimensions. When it is stressed above the elastic limit, permanent deformation takes place and the metal does not returns to its original shape after the removal of stress. The ability of a metal to undergo plastic deformation is one of the important property which is utilized for shaping of metals by various fabrication process such as rolling, forging, drawing, extrusion etc.,

Mechanism of Plastic Deformation
Plastic deformation take place by slip and twinning:

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During slip each atom usually moves same integral number of atomic distances along the slip plane producing a step, but the orientation of the crystal remains the same. Slip planes are usually the closest packed planes i.e., the planes of maximum atomic density. Such planes obviously will be widely spaced i.e., the inter planar distance between such planes is more.

Slip results from the motion of dislocations from one place to the other place. There are two basic types of dislocations movements called as glide and climb. In glide, the dislocation moves in a surface defined byits line and Burger's vector (glide is conservative motion of dislocations). In climb, the dislocation moves out of the glide surface and therefore, climb becomes a non conservation motion of dislocation. Slip is the most common manifestation of glide.

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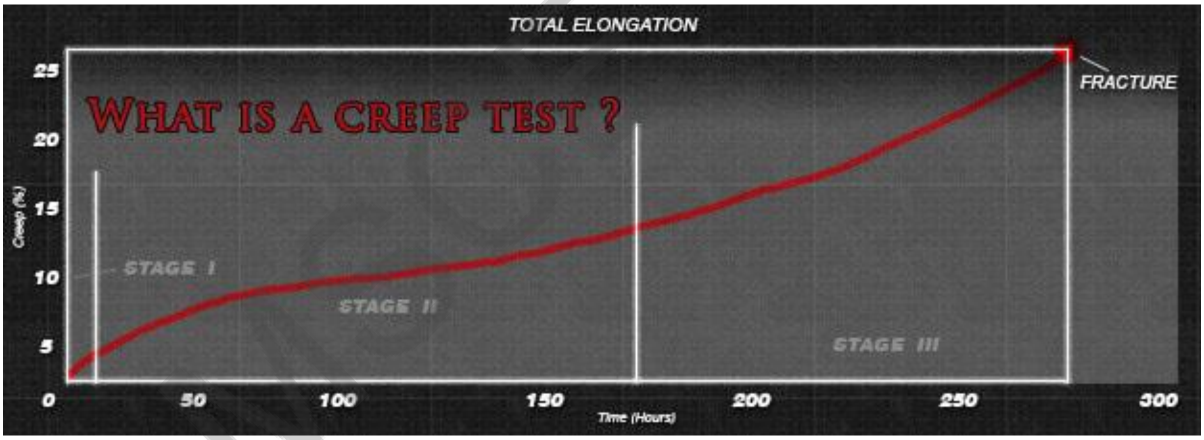
Twinning is a process in which the atoms in a part of the crystal subjected to stress rearrange themselves so that the orientation of the part changes in such a way that the distorted part becomes a mirror image of the other part. The plane across which the two parts are mirror images is called twinning plane or composition plane. Like slip, twinning also occurs along the certain crystallographic planes and directions. These planes and directions are called as twin planes and twin directions. The important role of twinning in plastic deformation is that it causes changes in plane orientation so that further slip can occur.

13. Draw a typical creep curve and brief on the mechanism. **(Nov/Dec 2017)**



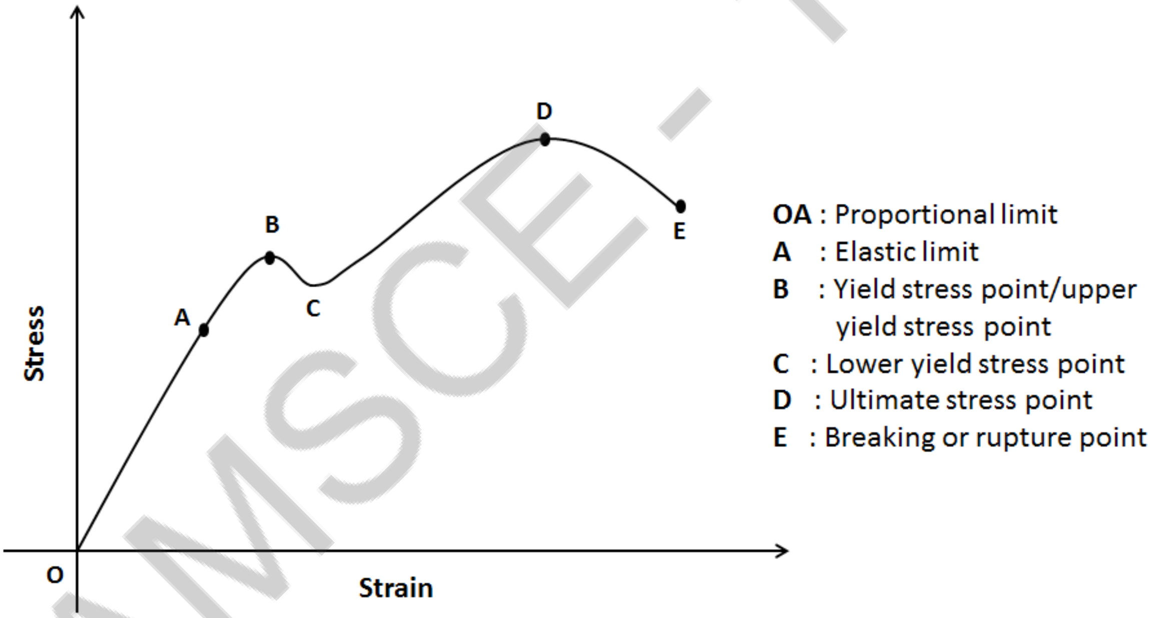
Creep Curve
Creep is high temperature progressive deformation at constant stress. "High temperature" is a relative term dependent upon the materials involved. Creep rates are used in evaluating materials for boilers, gas turbines, jet engines, ovens, or any application that involves high temperatures under load. Understanding high temperature behavior of metals is useful in designing failure resistant systems.

A creep test involves a tensile specimen under a constant load maintained at a constant temperature. Measurements of strain are then recorded over a period of time. Creep occurs in three stages: Primary, or Stage I; Secondary, or Stage II: and Tertiary, or Stage III. Stage I, or Primary creep occurs at the beginning of the tests, and creep is mostly transiently, not at a steady rate. Resistance to creep increases until Stage II is reached. In Stage II, or Secondary creep, The rate of creep becomes roughly steady. This stage is often referred to as steady state creep. In Stage III, or tertiary creep, the creep rate begins to accelerate as the cross sectional area of the specimen decreases due to necking or internal voiding decreases the effective area of the specimen. If stage III is allowed to proceed, fracture will occur.

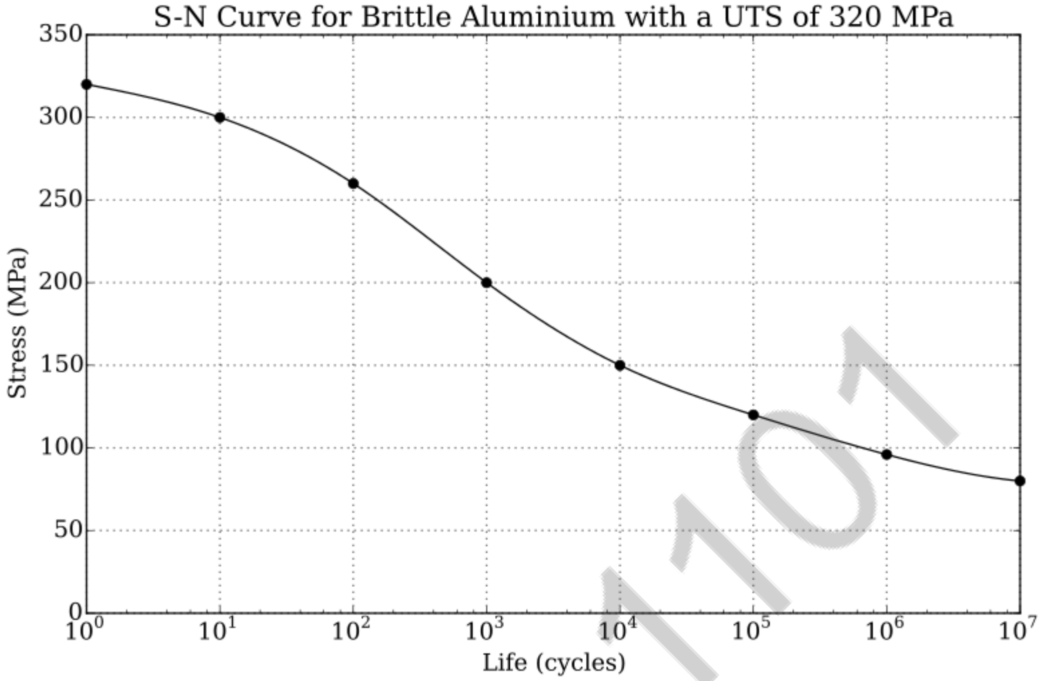
The creep test is usually employed to determine the minimum creep rate in Stage II. Engineers need to account for this expected deformation when designing systems.

Like the Creep Test, Stress Rupture Testing involves a tensile specimen under a constant load at a constant temperature. Stress rupture testing is like creep testing aside from the stresses is being higher than those utilized within a creep testing. Stress rupture tests are utilized to find out the time it takes for failure so stress rupture testing is always continued until failure of the material occurs. Data is plotted similar to the graph above. A straight line or best fit bend is normally obtained at every temperature of interest. The Stress Rupture test is used to determine the time to failure and elongation.

14. Draw a typical tensile test curve for a metallic sample, mark **the different points/ regions that represent different mechanical properties.**



15. Draw a typical S-N Curve of fatigue testing and brief on the **mechanism.**



Fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values that cause such damage may be much less than the strength of the material typically quoted as the ultimate tensile stress limit, or the yield stress limit.

Fatigue occurs when a material is subjected to repeated loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the stress concentrators such as the surface, persistent slip bands (PSBs), and grain interfaces. Eventually a crack will reach a critical size, the crack will propagate suddenly, and the structure will fracture. The shape of the structure will significantly affect the fatigue life; square holes or sharp corners will lead to elevated local stresses where fatigue cracks can initiate. Round holes and smooth transitions or fillets will therefore increase the fatigue strength of the structure.

Fatigue life

ASTM defines fatigue life, Nf, as the number of stress cycles of a specified character that a specimen sustains before failure of a specified nature occurs. For some materials, notably steel and titanium, there is a theoretical value for stress amplitude below which the material will not fail for any number of cycles, called a fatigue limit, endurance limit, or fatigue strength. Engineers have used any of three methods to determine the fatigue life of a material: the stress-life method, the strain-life method, and the linear-elastic fracture mechanics method. One method to predict fatigue life of materials is the Uniform Material Law (UML). UML was developed for fatigue life prediction of aluminium and titanium alloys by the end of 20th century and extended to high-strength steels, and cast iron.

Characteristics of fatigue

Fracture of an aluminium crank arm. Dark area of striations: slow crack growth. Bright granular area: sudden fracture. In metal alloys, and for the simplifying case when there are no macroscopic or microscopic discontinuities, the process starts with dislocation movements at the microscopic level, which eventually form persistent slip bands that become the nucleus of short cracks. Macroscopic and microscopic discontinuities (at the crystalline grain scale) as well as component design features which cause stress concentrations (holes, keyways, sharp changes of load direction etc.) are common locations at which the fatigue process begins. Fatigue is a process that has a degree of randomness (stochastic), often showing considerable scatter even in seemingly identical sample in well controlled environments. Fatigue is usually associated with tensile stresses but fatigue cracks have been reported due to compressive loads.

The greater the applied stress range, the shorter the life. Fatigue life scatter tends to increase for longer fatigue lives. Damage is cumulative. Materials do not recover when rested. Fatigue life is influenced by a variety of factors, such as temperature, surface finish, metallurgical microstructure, presence of oxidizing or inert chemicals, residual stresses, scuffing contact (fretting), etc. Some materials (e.g., some steel and titanium alloys) exhibit a theoretical fatigue limit below which continued loading does not lead to fatigue failure. High cycle fatigue strength (about 104 to 108 cycles) can be described by stress-based parameters. A load-controlled servo-hydraulic test rig is commonly used in these tests, with frequencies of around 20–50 Hz. Other sorts of machine like resonant magnetic machine can also be used, to achieve frequencies up to 250 Hz. Low cycle fatigue (loading that typically causes failure in less than 104 cycles) is associated with localized plastic behavior in metals; thus, a strain-based parameter should be used for fatigue life prediction in metals. Testing is conducted with constant strain amplitudes typically at 0.01–5 Hz.

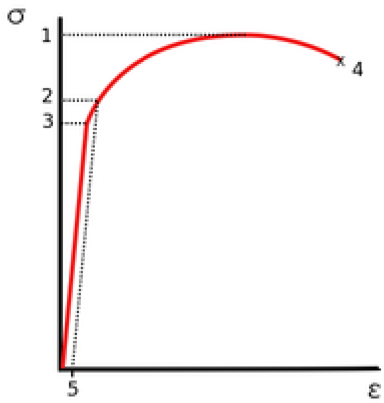
16. **Explain the different types of fracture?**

A fracture is the separation of an object or material into two or more pieces under the action of stress. The fracture of a solid usually occurs due to the development of certain displacement discontinuity surfaces within the solid. If a displacement develops perpendicular to the surface of displacement, it is called a normal tensile crack or simply a crack; if a displacement develops tangentially to the surface of displacement, it is called a shear crack, slip band, or dislocation. Fracture strength or breaking strength is the stress when a specimen fails or fractures.

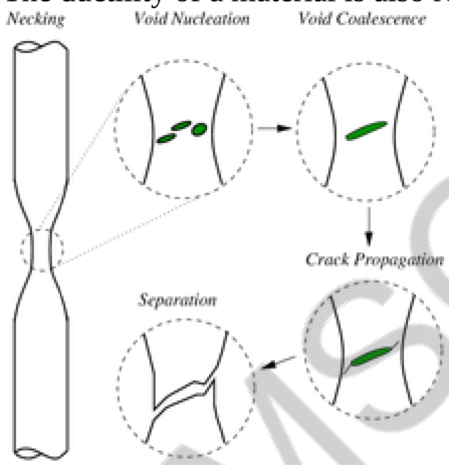
The word fracture is often applied to bones of living creatures (i.e. a bone fracture), or to crystalline materials, such as gemstones or metal. Sometimes, individual crystals fracture without the structure actually separating into two or more pieces. Depending on the substance, a fracture reduces strength (most substances) or inhibits transmission of waves, such as light (optical crystals). A detailed understanding of how fracture occurs in materials may be assisted by the study of fracture mechanics.

Fracture strength, also known as breaking strength, is the stress at which a specimen fails via fracture. This is usually determined for a given specimen by a tensile test, which charts the stress-strain curve (see image). The final recorded point is the fracture strength.

Ductile materials have a fracture strength lower than the ultimate tensile strength (UTS), whereas in brittle materials the fracture strength is equivalent to the UTS. If a ductile material reaches its ultimate tensile strength in a load-controlled situation, it will continue to deform, with no additional load application, until it ruptures. However, if the loading is displacement-controlled, the deformation of the material may relieve the load, preventing rupture.



In ductile fracture, extensive plastic deformation (necking) takes place before fracture. The terms rupture or ductile rupture describe the ultimate failure of ductile materials loaded in tension. Rather than cracking, the material "pulls apart," generally leaving a rough surface. In this case there is slow propagation and absorption of large amount energy before fracture. The ductility of a material is also referred to as toughness.



Many ductile metals, especially materials with high purity, can sustain very large deformation of 50–100% or more strain before fracture under favorable loading condition and environmental condition. The strain at which the fracture happens is controlled by the purity of the materials. At room temperature, pure iron can undergo deformation up to 100% strain before breaking, while cast iron or high-carbon steels can barely sustain 3% of strain.

Because ductile rupture involves a high degree of plastic deformation, the fracture behavior of a propagating crack as modeled above changes fundamentally. Some of the energy from stress concentrations at the crack tips is dissipated by plastic deformation ahead of the crack as it propagates.

The basic steps in ductile fracture are: void formation, void coalescence (also known as crack formation), crack propagation, and failure, often resulting in a cup-and-cone shaped failure surface.

Brittle fracture is the fracture of a metal or other material without appreciable prior plastic deformation. It is a break in a brittle piece of metal which failed because stress exceeded cohesion.

Brittle fracture is a breakage or cracking of a material into discernible parts, from which no deformation can be identified (a clean break). It is characterized by rapid crack propagation with low energy release and without significant plastic deformation. The fracture may have a bright granular appearance. The fractures are generally of the flat type and chevron patterns may be present.

In brittle crystalline materials, fracture can occur by cleavage as the result of tensile stress acting normal to crystallographic planes with low bonding (cleavage planes). In amorphous solids, by contrast, the lack of a crystalline structure results in a conchoidal fracture, with cracks proceeding normal to the applied tension.

In brittle fracture, cracks run close to perpendicular to the applied stress. This perpendicular fracture leaves a relatively flat surface at the break. Besides having a nearly flat fracture surface, brittle materials usually contain a pattern on their fracture surfaces. Some brittle materials have lines and ridges beginning at the origin of the crack and spreading out across the crack surface. Since there is very little plastic deformation before failure occurs, in most cases this is the worst type of fracture because the visible damage cannot be repaired in a part or structure before it breaks. Brittle fractures display either transgranular or intergranular fracture. This depends upon whether the grain boundaries are stronger or weaker than the grains:

Transgranular fracture - The fracture travels through the grain of the material. Cracks choose the path of least resistance.

Intergranular fracture - The crack travels along the grain boundaries, and not through the actual grains. This usually occurs when the phase in the grain boundary is weak and brittle.

17. **Explain Compression and Shear testing:**

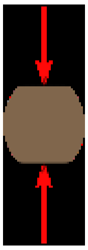
When a specimen of material is loaded in such a way that it extends it is said to be in tension. On the other hand, if the material compresses and shortens it is said to be in compression.

On an atomic level, the molecules or atoms are forced apart when in tension whereas in compression they are forced together. Since atoms in solids always try to find an equilibrium position, and distance between other atoms, forces arise throughout the entire material which oppose both tension and compression. The phenomena prevailing on an atomic level are therefore similar.

The "strain" is the relative change in length under applied stress; positive strain characterizes an object under tension load which tends to lengthen it, and a compressive stress that shortens an object gives negative strain. Tension tends to pull small sideways deflections back into alignment, while compression tends to amplify such deflection into buckling.

Compressive strength is measured on materials, components and structures.

By definition, the ultimate compressive strength of a material is that value of uniaxial compressive stress reached when the material fails completely. The compressive strength is usually obtained experimentally by means of a compressive test. The apparatus used for this experiment is the same as that used in a tensile test. However, rather than applying a uniaxial tensile load, a uniaxial compressive load is applied. As can be imagined, the specimen (usually cylindrical) is shortened as well as spread laterally. A stress–strain curve is plotted by the instrument and would look similar to the following:



The compressive strength of the material would correspond to the stress at the red point shown on the curve. In a compression test, there is a linear region where the material follows Hooke's Law. This linear region terminates at what is known as the yield point. Above this point the material behaves plastically and will not return to its original length once the load is removed

In engineering design practice, professionals mostly rely on the engineering stress. In reality, the true stress is different from the engineering stress. Hence calculating the compressive strength of a material from the given equations will not yield an accurate result. This is because the cross sectional area A0 changes and is some function of load $A = \varphi(F)$.

The difference in values may therefore be summarized as follows:

On compression, the specimen will shorten. The material will tend to spread in the lateral direction and hence increase the cross sectional area.

In a compression test the specimen is clamped at the edges. For this reason, a frictional force arises which will oppose the lateral spread. This means that work has to be done to oppose this frictional force hence increasing the energy consumed during the process. This results in a slightly inaccurate value of stress obtained from the experiment.

As a final note, it should be mentioned that the frictional force mentioned in the second point is not constant for the entire cross section of the specimen. It varies from a minimum at the centre, away from the clamps, to a maximum at the edges where it is clamped. Due to this, a phenomenon known as barreling occurs where the specimen attains a barrel shape.

Shear test:

A shear test is a common method to measure the mechanical properties of many deformable solids, especially soil (e.g., sand, clay) rock, and other granular materials or powders. There are several variations on the test.

In shear test, stress is applied to a sample of the material being tested in a way which results in stresses along one axis being different from the stresses in perpendicular directions. This is typically achieved by placing the sample between two parallel platens which apply stress in one (usually vertical) direction, and applying fluid pressure to the specimen to apply stress in the perpendicular directions.

The application of different compressive stresses in the test apparatus causes shear stress to develop in the sample; the loads can be increased and deflections monitored until failure of the sample. During the test, the surrounding fluid is pressurized, and the stress on the platens is increased until the material in the cylinder fails and forms sliding regions within itself, known as shear bands. The geometry of the shearing in a triaxial test typically causes the sample to become shorter while bulging out along the sides. The stress on the platen is then reduced and the water pressure pushes the sides back in, causing the sample to grow taller again. This cycle is usually repeated several times while collecting stress and strain data about the sample. During the test the pore pressures of fluids (e.g., water, oil) or gasses in the sample may be measured using Bishop's pore pressure apparatus.

From the triaxial test data, it is possible to extract fundamental material parameters about the sample, including its angle of shearing resistance, apparent cohesion, and dilatancy angle. These parameters are then used in computer models to predict how the material will behave in a larger-scale engineering application. An example would be to predict the stability of the soil on a slope, whether the slope will collapse or whether the soil will support the shear stresses of the slope and remain in place. Triaxial tests are used along with other tests to make such engineering predictions.

During the shearing, a granular material will typically have a net gain or loss of volume. If it had originally been in a dense state, then it typically gains volume, a characteristic known as Reynolds' dilatancy. If it had originally been in a very loose state, then contraction may occur before the shearing begins or in conjunction with the shearing.

Sometimes, testing of cohesive samples is done with no confining pressure, in an unconfined compression test. This requires much simpler and less expensive apparatus and sample preparation, though the applicability is limited to samples that the sides won't crumble when exposed, and the confining stress being lower than the in-situ stress gives results which may be overly conservative. The compression test performed for concrete strength testing is essentially the same test, on apparatus designed for the larger samples and higher loads typical of concrete testing.

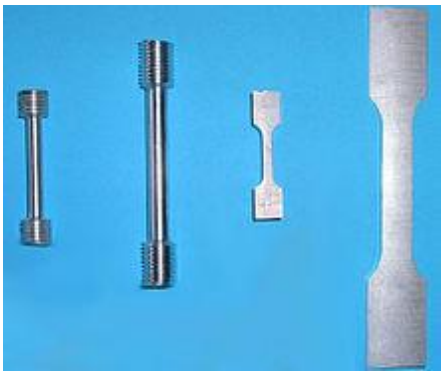
18. **With neat sketch explain in detail about Tensile testing:**

Tensile testing, is also known as tension testing, is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area.From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics. Uniaxial tensile testing is the most commonly used for obtaining the mechanical characteristics of isotropic materials. For anisotropic materials, such as composite materials and textiles, biaxial tensile testing is required.

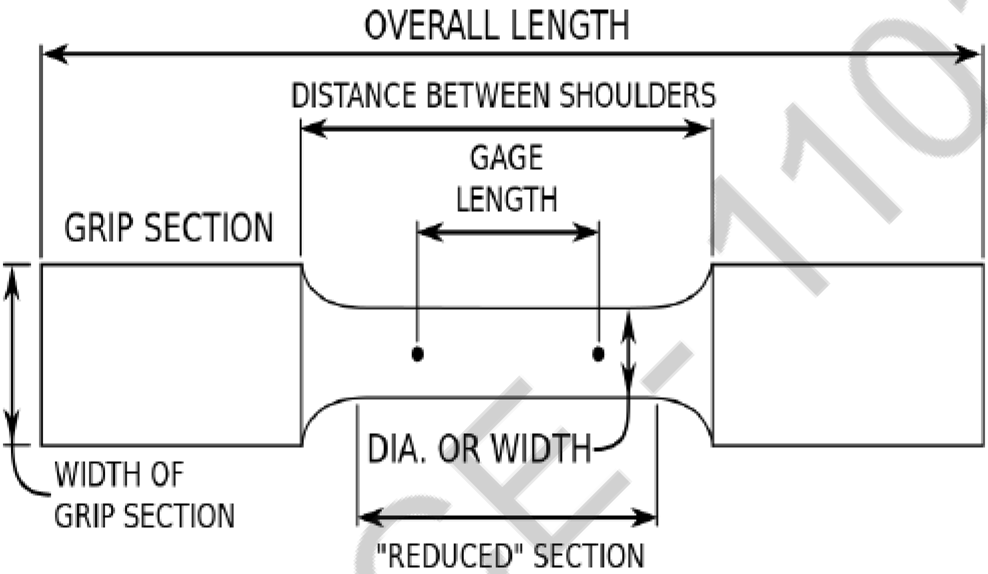
Tensile specimen:

A tensile specimen is a standardized sample cross-section. It has two shoulders and a gage (section) in between. The shoulders are large so they can be readily gripped, whereas the gauge section has a smaller cross-section so that the deformation and failure can occur in this area. The shoulders of the test specimen can be manufactured in various ways to mate to various grips in the testing machine (see the image below). Each system has advantages and disadvantages; for example, shoulders designed for serrated grips are easy and cheap to manufacture, but the alignment of the specimen is dependent on the skill of the technician. On the other hand, a pinned grip assures good alignment. Threaded shoulders and grips also assure good alignment, but the technician must know to thread each shoulder into the grip at least one diameter's length, otherwise the threads can strip before the specimen fractures.

In large castings and forgings it is common to add extra material, which is designed to be removed from the casting so that test specimens can be made from it. These specimens may not be exact representation of the whole work piece because the grain structure may be different throughout. In smaller work pieces or when critical parts of the casting must be tested, a work piece may be sacrificed to make the test specimens. For work pieces that are machined from bar stock, the test specimen can be made from the same piece as the bar stock



The left two specimens have a round cross-section and threaded shoulders.
The right two is flat specimens designed to be used with separate grips.



Test specimen nomenculature

The most common testing machine used in tensile testing is the universal testing machine. This type of machine has two crossheads; one is adjusted for the length of the specimen and the other is driven to apply tension to the test specimen. There are two types: hydraulic powered and electromagnetically powered machines.

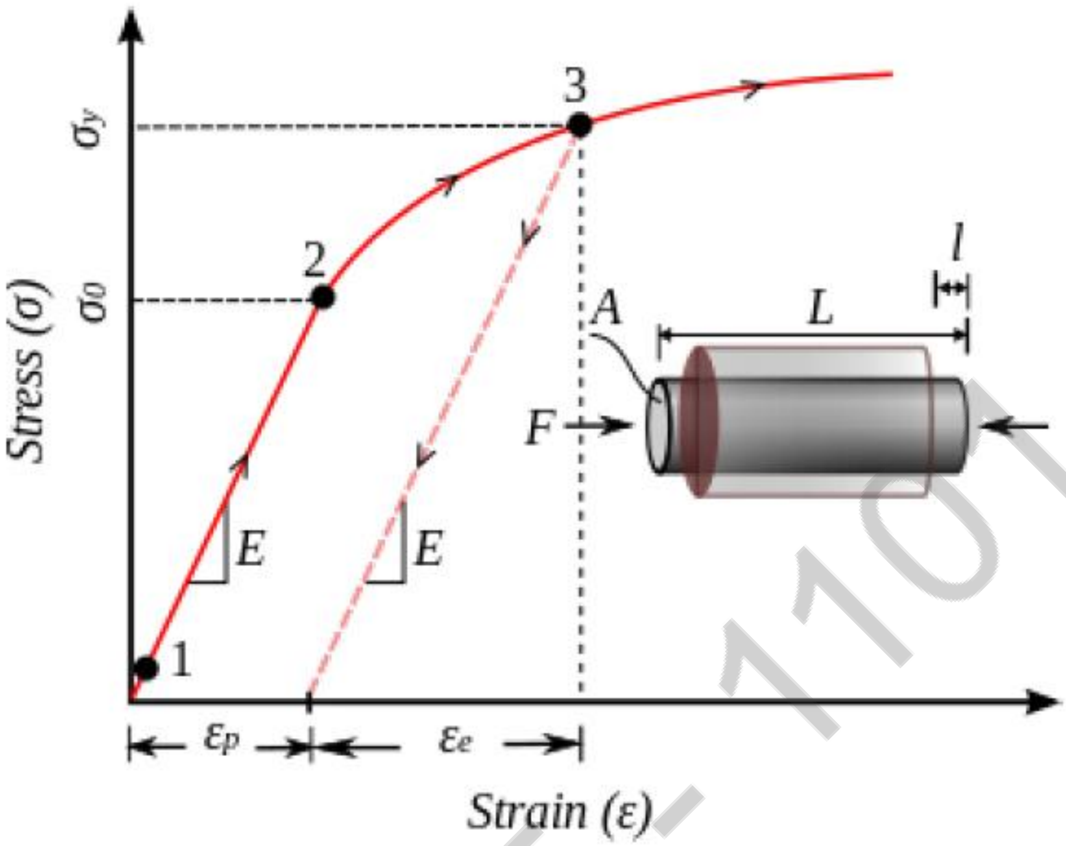
The machine must have the proper capabilities for the test specimen being tested. There are four main parameters: force capacity, speed, precision and accuracy. Force capacity refers to the fact that the machine must be able to generate enough force to fracture the specimen. The machine must be able to apply the force quickly or slowly enough to properly mimic the actual application. Finally, the machine must be able to accurately and precisely measure the gauge length and forces applied; for instance, a large machine that is designed to measure long elongations may not work with a brittle material that experiences short elongations prior to fracturing.

Alignment of the test specimen in the testing machine is critical, because if the specimen is misaligned, either at an angle or offset to one side, the machine will exert a bending force on the specimen. This is especially bad for brittle materials, because it will dramatically skew the results. This situation can be minimized by using spherical seats or U-joints between the grips and the test machine. If the initial portion of the stress–strain curve is curved and not linear, it indicates the specimen is misaligned in the testing machine.

The strain measurements are most commonly measured with an extensometer, but strain gauges are also frequently used on small test specimen or when Poisson’s ratio is being measured. Newer test machines have digital time, force, and elongation measurement systems consisting of electronic sensors connected to a data collection device (often a computer) and software to manipulate and output the data. However, analog machines continue to meet and exceed ASTM, NIST, and ASM metal tensile testing accuracy requirements, continuing to be used today.

Work hardening, also known as strain hardening or cold working, is the strengthening of a metal by plastic deformation. This strengthening occurs because of dislocation movements and dislocation generation within the crystal structure of the material. Many non-brittle metals with a reasonably high melting point as well as several polymers can be strengthened in this fashion. Alloys not amenable to heat treatment, including low-carbon steel, are often work-hardened. Some materials cannot be work-hardened at lowtemperatures, such as indium, however others can only be strengthened via work hardening, such pure copper and aluminum.

Work hardening may be desirable or undesirable depending on the context. An example of undesirable work hardening is during machining when early passes of a cutter inadvertently work-harden the work piece surface, causing damage to the cutter during the later passes. Certain alloys are more prone to this than others; super alloys such as Inconel require machining strategies that take it into account. An example of desirable work hardening is that which occurs in metalworking processes that intentionally induce plastic deformation to exact a shape change. These processes are known as cold working or cold forming processes. They are characterized by shaping the work piece at a temperature below its recrystallization temperature, usually at ambient temperature.Cold forming techniques are usually classified into four major groups: squeezing, bending, drawing, and shearing. Applications include the heading of bolts and cap screws and the finishing of cold rolled steel. In cold forming, metal is formed at high speed and high pressure using tool steel or carbide dies. The cold working of the metal increasing the hardness, yield strength, and tensile strength.



A phenomenological uniaxial stress-strain curve showing typical work hardening plastic behavior of materials in uniaxial compressionBefore work hardening, the lattice of the material exhibits a regular, nearly defect-free pattern (almost no dislocations). The defect-free lattice can be created or restored at any time by annealing. As the material is work hardened it becomes increasingly saturated with new dislocations, and more dislocations are prevented from nucleating (a resistance to dislocation-formation develops). This resistance to dislocation-formation manifests itself as a resistance to plastic deformation; hence, the observed strengthening.

In metallic crystals, irreversible deformation is usually carried out on a microscopic scale by defects called dislocations, which are created by fluctuations in local stress fields within the material culminating in a lattice rearrangement as the dislocations propagate through the lattice. At normal temperatures the dislocations are not annihilated by annealing. Instead, the dislocations accumulate, interact with one another, and serve as pinning points or obstacles that significantly impede their motion. This leads to an increase in the yield strength of the material and a subsequent decrease in ductility.

Such deformation increases the concentration of dislocations which may subsequently form low-angle grain boundaries surrounding sub-grains. Cold working generally results in higher yield strength as a result of the increased number of dislocations and the Hall-Petch effect of the sub-grains, and a decrease in ductility. The effects of cold working may be reversed by annealing the material at high temperatures where recovery and recrystallization reduce the dislocation density.

A material's work hardenability can be predicted by analyzing a stress-strain curve, or studied in context by performing hardness tests before and after a process.

Elastic and Plastic deformation:

Work hardening is a consequence of plastic deformation, a permanent change in shape. This is distinct from elastic deformation, which is reversible. Most materials do not exhibit only one or the other, but rather a combination of the two. The following discussion mostly applies to metals, especially steels, which are well studied. Work hardening occurs most notably for ductile materials such as metals. Ductility is the ability of a material to undergo plastic deformations before fracture (for example, bending a steel rod until it finally breaks). The tensile test is widely used to study deformation mechanisms. This is because under compression, most materials will experience trivial (lattice mismatch) and non-trivial (buckling) events before plastic deformation or fracture occur. Hence the intermediate processes that occur to the material under uniaxial compression before the incidence of plastic deformation make the compressive test fraught with difficulties.

A material generally deforms elastically under the influence of small forces; the material returns quickly to its original shape when the deforming force is removed. This phenomenon is called elastic deformation. This behavior in materials is described by Hooke's Law. Materials behave elastically until the deforming force increases beyond the elastic limit, which is also known as the yield stress. At that point, the material is permanently deformed and fails to return to its original shape when the force is removed. This phenomenon is called plastic deformation. For example, if one stretches a coil spring up to a certain point, it will return to its original shape, but once it is stretched beyond the elastic limit, it will remain deformed and won't return to its original state.

Elastic deformation stretches the bonds between atoms away from their equilibrium radius of separation, without applying enough energy to break the inter-atomic bonds. Plastic deformation, on the other hand, breaks inter-atomic bonds, and therefore involves the rearrangement of atoms in a solid material.

Increase of dislocations and work hardening:

Increase in the number of dislocations is a quantification of work hardening. Plastic deformation occurs as a consequence of work being done on a material; energy is added to the material. In addition, the energy is almost always applied fast enough and in large enough magnitude to not only move existing dislocations, but also to produce a great number of new dislocations by jarring or working the material sufficiently enough. New dislocations are generated in proximity to a Frank–Read source.

Yield strength is increased in a cold-worked material. Using lattice strain fields, it can be shown that an environment filled with dislocations will hinder the movement of any one dislocation. Because dislocation motion is hindered, plastic deformation cannot occur at normal stresses. Upon application of stresses just beyond the yield strength of the non-cold-worked material, a cold-worked material will continue to deform usingthe only mechanism available: elastic deformation, the regular scheme of stretching or compressing of electrical bonds (without dislocation motion) continues to occur, and the modulus of elasticity is unchanged. Eventually the stress is great enough to overcome the strain-field interactions and plastic deformation resumes.

However, ductility of a work-hardened material is decreased. Ductility is the extent to which a material can undergo plastic deformation, that is, it is how far a material can be plastically deformed before fracture. A cold-worked material is, in effect, a normal (brittle) material that has already been extended through part of its allowed plastic deformation. If dislocation motion and plastic deformation have been hindered enough by dislocation accumulation, and stretching of electronic bonds and elastic deformation has reached their limit, a third mode of deformation occurs: fracture.

19. **Explain in detail about the hot working process and also compare hot working and cold working process?**

Hot working refers to processes where metals are plastically deformed above their recryst-allization temperature. Being above the recrystallization temperature allows the material to recrystallize during deformation. This is important because recrystallization keeps the materials from strain hardening, which ultimately keeps the yield strength and hardness low and ductility high. This contrasts with cold working.

The lower limit of the hot working temperature is determined by its recrystallization temperature. As a guideline, the lower limit of the hot working temperature of a material is 60% its melting temperature (on an absolute temperature scale). The upper limit for hot working is determined by various factors, such as: excessive oxidation, grain growth, or an undesirable phase transformation. In practice materials are usually heated to the upper limit first to keep forming forces as low as possible and to maximize the amount of time available to hot work the work piece.

The most important aspect of any hot working process is controlling the temperature of the work piece. 90% of the energy imparted into the work piece is converted into heat. Therefore, if the deformation process is quick enough the temperature of the work piece should rise, however, this does not usually happen in practice. Most of the heat is lost through the surface of the workpiece into the cooler tooling. This causes temperaturegradients in the work piece, usually due to non-uniform cross-sections where the thinner sections are cooler than the thicker sections. Ultimately, this can lead to cracking in the cooler, less ductile surfaces. One way to minimize the problem is to heat the tooling. The hotter the tooling the less heat lost to it, but as the tooling temperature rises, the tool life decreases. Therefore the tooling temperature must be compromised; commonly, hot working tooling is heated to 500–850 °F (325–450 °C).

The advantages are:

Decrease in yield strength, therefore it is easier to work and uses less energy or force

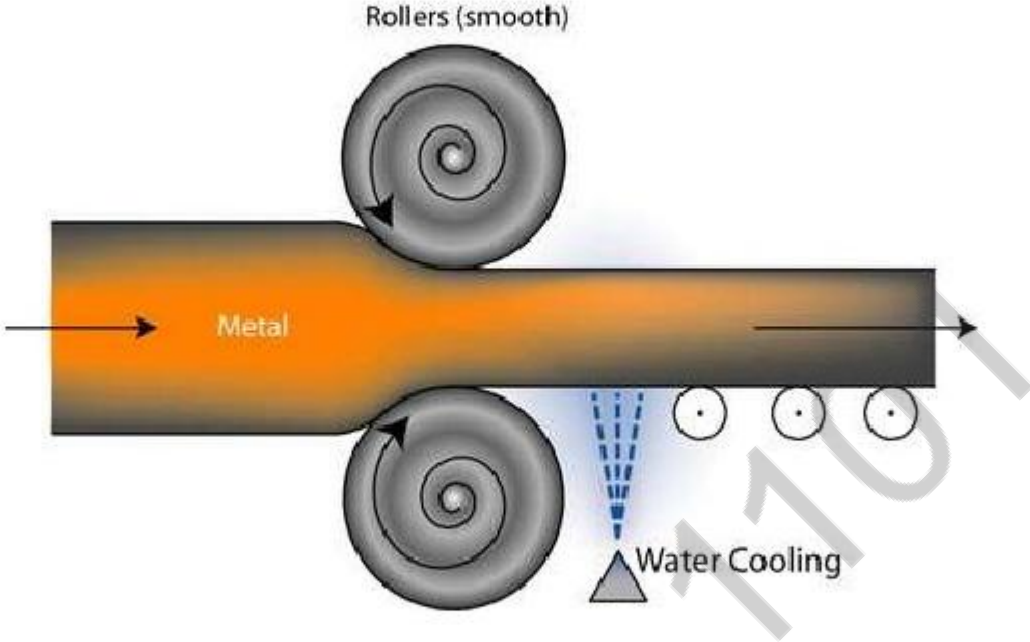
Increase in ductility

Elevated temperatures increase diffusion which can remove or reduce chemical in homogeneities

Pores may reduce in size or close completely during deformation

In steel, the weak, ductile, face-centered-cubic austenite microstructure is deformed instead of the strong body-centered-cubic ferrite microstructure found at lower temperatures

Usually the initial work piece that is hot worked was originally cast. The microstructure of cast items does not optimize the engineering properties, from a microstructure standpoint. Hot working improves the engineering properties of the work piece because it replaces the microstructure with one that has fine spherical shaped grains. These grains increase the strength, ductility, and toughness of the material.



The engineering properties can also be improved by reorienting the inclusions (impurities). In the cast state the inclusions are randomly oriented, which, when intersecting the surface, can be a propagation point for cracks. When the material is hot worked the inclusions tend to flow with the contour of the surface, creating stringers. As a whole the strings create a flow structure, where the properties are anisotropic (different based on direction). With the stringers oriented parallel to the surface it strengthens the work piece, especially with respect to fracturing. The stringers act as “crack-arrestors” because the crack will want to propagate through the stringer and not along it.

The disadvantages are:

Undesirable reactions between the metal and the surrounding atmosphere (scaling or rapid oxidation of the work piece)

Less precise tolerances due to thermal contraction and warping from uneven cooling

Grain structure may vary throughout the metal for various reasons

Requires a heating unit of some kind such as a gas or diesel furnace or an induction heater, which can be very expensive.

Comparison between Hot working and Cold working

S.No	Hot Working	Cold Working
1	Hot working is carried out above the recrystallization temperature and below the melting point. Hence the deformation of metal and recovery take place simultaneously.	Cold working is carried out below the recrystallization temperature. As such, there is no appreciable recovery.
2	No internal or residual stresses are set-up in the metal in hot working process.	In cold working process internal or residual stresses are set-up in the metal.
3	If cracks and blow boles are present in the metal, they can be finished through hot working.	In cold working the existing cracks propagate and new cracks may develop.
4	Close tolerance cannot be maintained.	Better tolerance can be easily maintained.
5	Surface finish of hot working process is comparatively not good.	Surface finish of cold working process is better.
6	It results in improvements of properties like impact strength and elongation.	It also results in improvements of properties like impact strength and elongation.
7	If hot working process is performed properly, it does not affect ultimate tensile strength, hardness, corrosion resistance yield strength and fatigue strength of the metal.	It improves ultimate tensile strength, hardness, yield strength but reduces the corrosion resistance of strength of the metal.
8	Due to recrystallisation very negligible hardening of metal takes place.	Since cold working is done below recrystallisation temperature the metal gets work hardened.
9	Hot working refines metal grains resulting in in improved mechanical properties.	Most of the cold working processes lead to distortion of grains.
10	Due to higher deformation temperatures, the stress required for deformation is much less.	The stress required to cause deformation is much higher.

20. **Explain about the various factors affecting fatigue life?**

Fatigue is failure under a repeated or varying load, never reaching a high enough level to cause failure in a single application. The fatigue process embraces two basic domains of cyclic stressing or straining, differing distinctly in character. In each domain, failure occurs by different physical mechanisms:

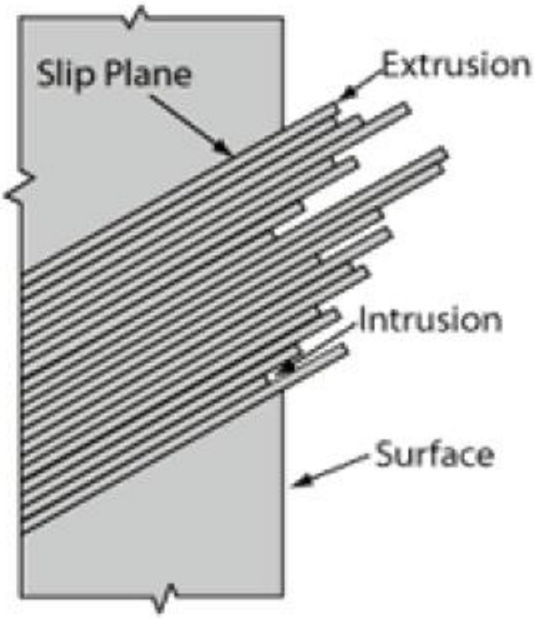
1. Low-cycle fatigue—where significant plastic straining occurs. Low-cycle fatigue involves large cycles with significant amounts of plastic deformation and relatively short life. The analytical procedure used to address strain-controlled fatigue is commonly referred to as the Strain-Life, Crack-Initiation, or Critical Location approach.
2. High-cycle fatigue—where stresses and strains are largely confined to the elastic region. High-cycle fatigue is associated with low loads and long life. The Stress-Life (S-N) or Total Life method is widely used for high-cycle fatigue applications—here the applied stress is within the elastic range of the material and the number of cycles to failure is large. While low-cycle fatigue is typically associated with fatigue life between 10 to 100,000 cycles, high-cycle fatigue is associated with life greater than 100,000 cycles.

Fatigue Properties:

Fatigue cracking is one of the primary damage mechanisms of structural components. Fatigue cracking results from cyclic stresses that are below the static yield strength of a material. The name “fatigue” is based on the concept that a material becomes “tired” and fails at a stress level below the nominal strength of the material. The facts that the original bulk design strengths are not exceeded and the only warning sign of an impending fracture is an often hard to see crack, makes fatigue damage especially dangerous.

The fatigue life of a component can be expressed as the number of loading cycles required to initiate a fatigue crack and to propagate the crack to critical size. Therefore, it can be said that fatigue failure occurs in three stages – crack initiation; slow, stable crack growth; and rapid fracture.

As discussed previously, dislocations play a major role in the fatigue crack initiation phase. In the first stage, dislocations accumulate near surface stress concentrations and form structures called persistent slip bands (PSB) after a large number of loading cycles.PSBs are areas that rise above (extrusion) or fall below (intrusion) the surface of the component due to movement of material along slip planes. This leaves tiny steps in the surface that serve as stress risers where tiny cracks can initiate. These tiny cracks (called micro cracks) nucleate along planes of high shear stress which is often 45o to the loading direction.

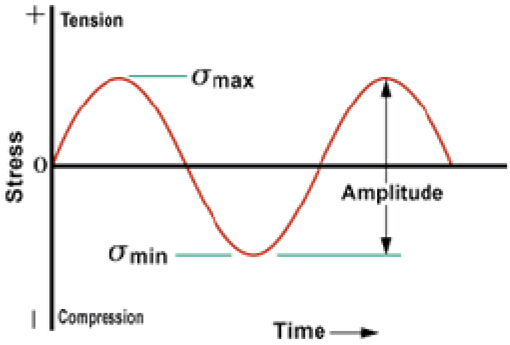


In the second stage of fatigue, some of the tiny micro cracks join together and begin to propagate through the material in a direction that is perpendicular to the maximum tensile stress. Eventually, the growth of one or a few crack of the larger cracks will loading, the growth of the dominate crack or cracks will continue until the remaining un-cracked section of the component can no longer support the load. At this point, the fracture toughness is exceeded and the remaining cross-section of the material experiences rapid fracture. This rapid overload fracture is the third stage of fatigue failure. Dominate over the rest of the cracks.

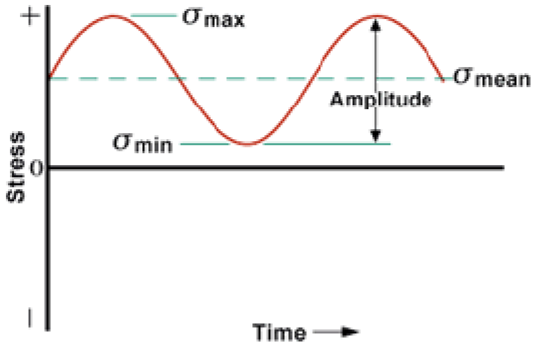
Factors affecting fatigue life:

In order for fatigue cracks to initiate, three basic factors are necessary. First, the loading pattern must contain minimum and maximum peak values with large enough variation or fluctuation. The peak values may be in tension or compression and may change over time but the reverse loading cycle must be sufficiently great for fatigue crack initiation. Secondly, the peak stress levels must be of sufficiently high value. If the peak stresses are too low, no crack initiation will occur. Thirdly, the material must experience a sufficiently large number of cycles of the applied stress. The number of cycles required to initiate and grow a crack is largely dependant on the first to factors.

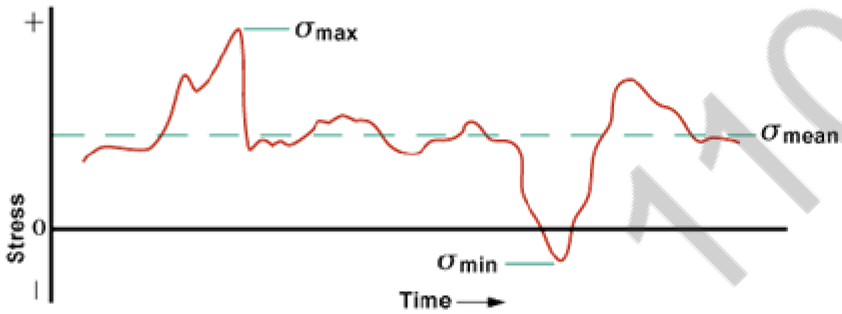
In addition to these three basic factors, there are a host of other variables, such as stress concentration, corrosion, temperature, overload, metallurgical structure, and residual stresses which can affect the propensity for fatigue. Since fatigue cracks generally initiate at a surface, the surface condition of the component being loaded will have an effect on its fatigue life. Surface roughness is important because it is directly related to the level and number of stress concentrations on the surface. The higher the stress concentration the more likely a crack is to nucleate. Smooth surfaces increase the time to nucleation. Notches, scratches, and other stress risers decrease fatigue life. Surface residual stress will also have a significant effect on fatigue life. Compressive residual stresses from machining, cold working, heat treating will oppose a tensile load and thus lower the amplitude of cyclic loading.



Tension/Compression Loading



Tension/Tension Loading



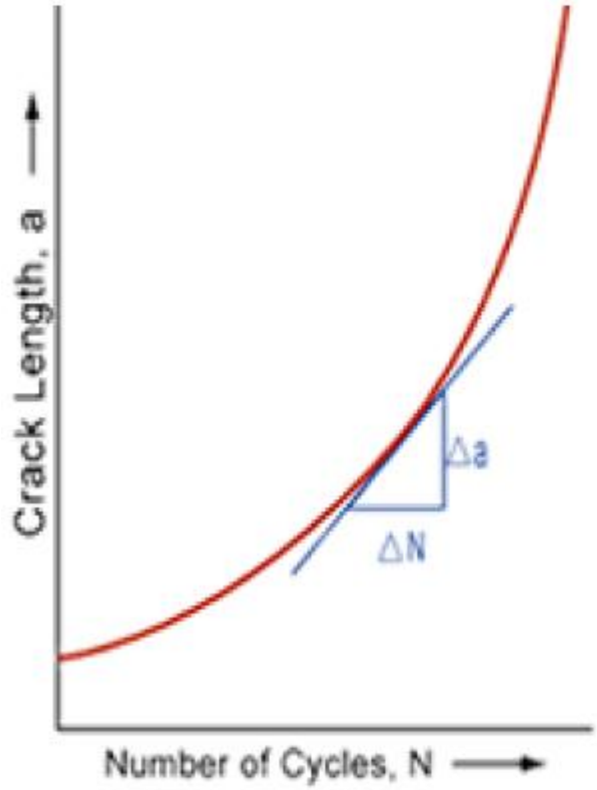
Spectrum Loading

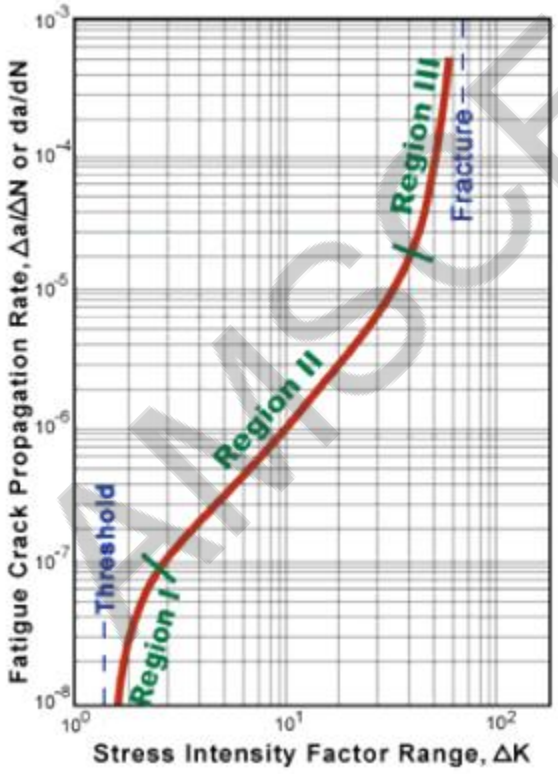
The above figure shows several types of loading that could initiate a fatigue crack. The upper left figure shows sinusoidal loading going from a tensile stress to a compressive stress. For this type of stress cycle the maximum and minimum stresses are equal. Tensile stress is considered positive, and compressive stress is negative. The figure in the upper right shows sinusoidal loading with the minimum and maximum stresses both in the tensile realm. Cyclic compression loading can also cause fatigue. The lower figure shows variable-amplitude loading, which might be experienced by a bridge or airplane wing or any other component that experiences changing loading patterns. In variable-amplitude loading, only those cycles exceeding some peak threshold will contribute to fatigue cracking.

Fatigue Crack Growth Rate Properties:

For some components the crack propagation life is neglected in design because stress levels are high, and/or the critical flaw size small. For other components the crack growth life might be a substantial portion of the total life of the assembly. Moreover, preexisting flaws or sharp design features may significantly reduce or nearly eliminate the crack initiation portion of the fatigue life of a component. The useful life of these components may be governed by the rate of sub critical crack propagation.

Aircraft fuselage structure is a good example of structure that is based largely on a slow crack growth rate design. Many years ago, the USAF reviewed a great number of malfunction reports from a variety of aircraft. The reports showed that the preponderance of structural failures occurred from 1) built-in preload stresses, 2) material flaws and 3) flaw caused by in-service usage. These facts led to a design approach that required the damage tolerance analysis to assume a material flaw exists in the worst orientation and at the most undesirable location. The analysis helps to ensure that structures are designed that will support slow stable crack growth until the crack reaches a length where it can reliable be detected using NDT methods.





The data can be reduced to a single curve by presenting the data in terms of crack growth rate per cycle of loading (Da/ DN or da/dN) versus the fluctuation of the stress-intensity factor at the tip of the crack (DKI). DKI is representative of the mechanical driving force, and it incorporates the effect of changing crack length and the magnitude of the cyclic loading. (See the page on fracture toughness for more information on the stress-intensity factor.) The most common form of presenting fatigue crack growth data is a log-log plot of da/dN versus DKI.

The fatigue crack propagation behavior of many materials can be divided into three regions as shown in the image. Region I is the fatigue threshold region where the Dk is too low to propagate a crack. Region II encompasses data where the rate of crack growth changes roughly linearly with a change in stress intensity fluctuation. In region III, small increases in the stress intensity amplitude, produce relatively large increases in crack growth rate since the material is nearing the point of unstable fracture.