Lecture Notes (Part.)

On

Material Testing

Subject code – Th1

Prepared By : Goutam Kumar Majhi

Lecturer

Metallurgical Engineering Department

UGIE Rourkela

Email id : majhi.goutam5@gmail.com

Contact No: +91-7899050056

Fatigue Test

Definition: Fatigue is the type of failure that occur due to fluctuating stress or vibration.

Ex: Automotive, aircraft, compressor pump, turbine blade etc.

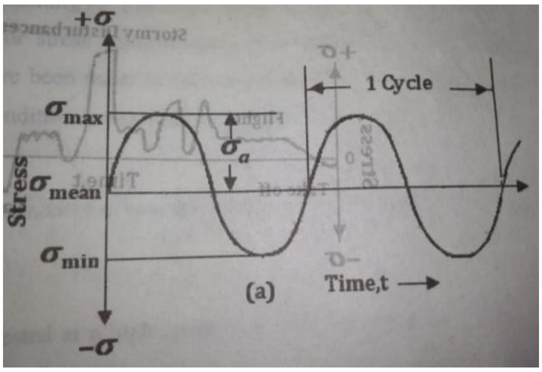
- The maximum load during fluctuation is well below the ultimate tensile strength or even yield strength. Failure occurring under fluctuating load is called fatigue.

Different Stress Cycles:

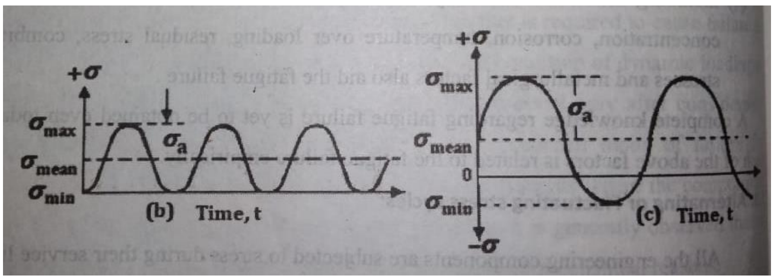
There are various types of load that is being experienced by an engineering material during its service period. In case of fatigue the load could fluctuate in regular or irregular manner. If the load varies in regular manner, then it is called as stress cycle.

Various type of load that could cause fatigue are:

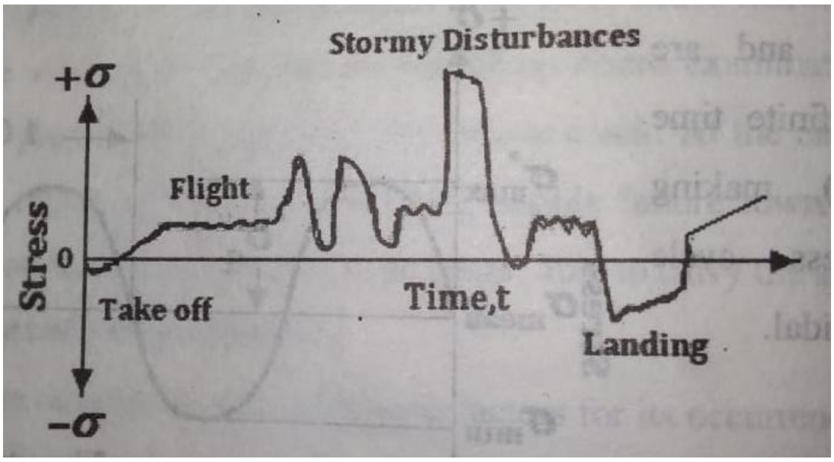
I. *Completely reversed cycle of stress (sinusoidal form)*
In this type of stress cycle the maximum and minimum stresses are equal and are repeated with definite time interval (as shown in Fig.), making the stress cycle completely sinusoidal.



II. In this type of stress cycle, the cycle is repeated in regular time interval. But the maximum and minimum levels of the stress are different.



III. This type of stress cycle is the most complex one as there is no particular trend that is being followed. That means the maximum and minimum stress is not constant with respect to time. This type of stress cycles are observed in the aircraft wing and automobile parts where the components are subjected to unpredictable overloads due to various reason during their service life.



The representative cyclic loading curves are characterized by following parameters:

1. σ_{min}: Minimum stress
2. σ_{max}: Maximum stress
3. σ_m: Mean stress; $\sigma_m = (\sigma_{min} + \sigma_{max})/2$
4. σ_a: Stress amplitude; $\sigma_a = (\sigma_{max} - \sigma_{min})/2$
5. R: Stress ratio; $R = \sigma_{min}/\sigma_{max}$
6. $\Delta\sigma$: Stress range; $\Delta\sigma = \sigma_{max} - \sigma_{min}$
7. A: A-ratio; $A = \sigma_a / \sigma_m$

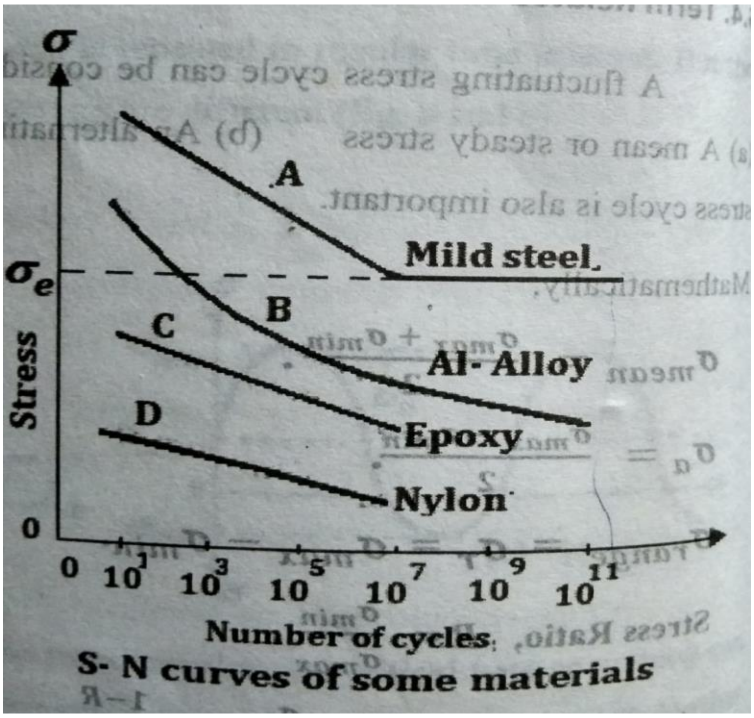
S-N curve

Presentation of Fatigue Data:

In general fatigue test results are presented by means of S-N curve (i.e. Stress-number of cycles to failure).

Procedure to plot S-N curve:

- To plot S-N curve for a material, several samples are prepared from the same material.
- The first sample is tested at relatively higher stress, as expected the sample fails at less number of stress cycle.
- The next sample is tested at a stress lower than the stress value of the previous test. This is continued till one or two sample doesn't fail with in the specified no. of cycle.
- Then stress(σ) is plotted against the number of cycles to failure (N) of the test specimen. The general shape of the plot for different materials is shown below.



Endurance limit

- The concept of an endurance limit is used for safe stress designs.
- From the above plot it can be observed that, the number of cycle a material can sustain is increasing with decrease in the applied stress.
- Out the above four curve the curve A (Mild steel) shows a distinct feature. The curve is getting parallel to X-axis. That means below certain stress level mild steel can with stand infinite number of stress cycle without fracturing.
- A stress level below which the material does not fail and can be cycled infinitely is called ***endurance limit***. If the applied stress level is below the

endurance limit of the material or the structure is said to have an infinite life.

- Many non-ferrous metals and alloys, such as aluminium, magnesium, and copper alloys, do not exhibit well-defined endurance limits. These materials instead display a continuously decreasing S-N response, similar to Curve B in Figure.
- In such cases a fatigue strength for a given number of cycles must be specified. An effective endurance limit for these materials is sometimes defined as the stress that causes failure at $1x10^8$ or $5x10^8$ loading cycles.

Fatigue testing

Fatigue test can be classified into two types:

(i) High Cycle Fatigue (HCF)
(ii) Low Cycle Fatigue (LCF)

(i) High Cycle Fatigue (HCF):

- If the test is conducted for 10^5 cycles or more then it is termed as High Cycle Fatigue test.
- The stress on the test sample is within the elastic limit.
- It is said to be load/stress controlled test. That is the test is conducted for specified load/stress.

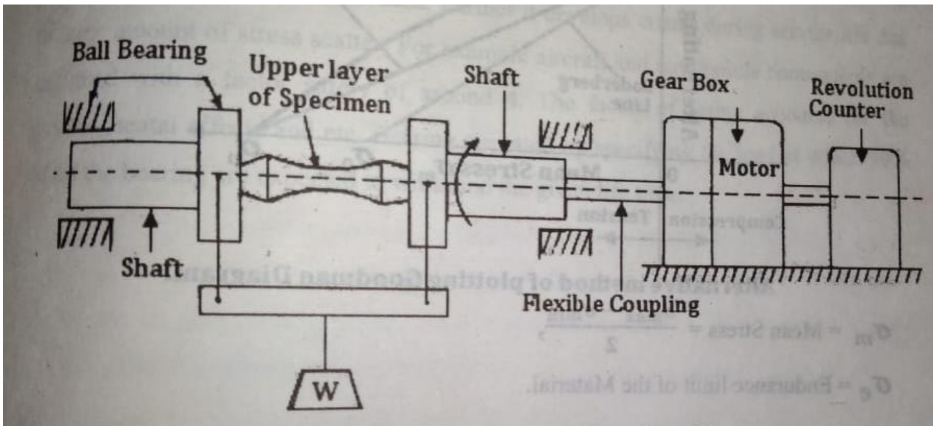
(ii) Low Cycle Fatigue (LCF):

- If the test is conducted for less than10^5 cycle, it is termed as Low Cycle Fatigue test.
- The stress on the test sample is beyond yield stress.
- It is said to be strain controlled test. That is the test is conducted for specified strain or deformation.

Fatigue testing machine

- Fatigue testing mostly done on rotating beam fatigue testing machine developed by Moore.
- In this machine, a polished specimen(beam) is placed as simply supported beam & loaded in pure bonding by a dead weight (W). This beam rotates in a ball bearing at a speed ranging from 3000 to 10,000 rpm. A variable speed motor/constant speed motor with a gear box is used for this purpose.

The top mast layer of the rotating specimen remains in compression while bottom most in tension. Thus, sinusoidal alternating stress is produced on the surface of the specimen during each revolution. A mechanical revolution(counter)recorded the number of cycles of stress reversal the machine automatically went off after the specimen broken.



Moore Rotating Beam Fatigue Testing Machine.

Factors affecting fatigue behaviour

Experimentally it has been observed that fatigue crack usually nucleates/initiate at the surface of the material under cyclic loading. So, in general the factors which helps in formation of surface crack will decrease the fatigue strength and vice versa. Following factors greatly affect fatigue property of metal and alloys:

(a) composition
(b) stress concentration
(c) size effect
(d) surface condition
(e) residual stress
(f) Metallurgical factors
(g) Temperature

(a) Composition : The alloying elements which increase the tensile strength of a material are observed to increase the fatigue strength as well.
(b) Stress concentration : Presence of stress raisers like notch, holes decrease the fatigue strength. This stress raisers are the location from which a fatigue crack starts.
(c) size effect: As the size of the component increases the fatigue strength decreases. It has been evident that as the size increases the number of crack and the size of pre-existing crack increases.

(d) surface condition: Fatigue strength of a material strongly depend upon surface condition. As the fatigue crack always start from the surface. Therefore, for better fatigue strength the surface of the material should be smooth.

(e) residual stress: Presence of compressive residual stress on the surface of the sample increases fatigue strength as it closes the initiating cracks and vice versa.

- Compressive stress on the surface of a component can be formed by: shot peening, surface rolling etc.

(f) Metallurgical factors :

- Solid solution alloying increases the fatigue strength.
- Finer/smaller the grain size higher the fatigue strength.
- Hardening increases the fatigue strength as the martensite percentage increases.
- Tempering after quenching increases the fatigue strength.
- Carburising, nitriding, case hardening or any surface hardening technique increases fatigue strength. While decarburising decreases the fatigue strength.

(g) Temperature: Fatigue strength increases with decrease in temperature unlike impact strength. However, there is no sudden increase in fatigue strength with fall of temperature.

Creep Test

Introduction

- The deformation behaviour of a material at room and at high temperature are not same.

- In general, a material becomes comparatively softer when deformed at elevated temperature.
- Now a days several metal components have found their use at high temperature application like: jet engine, power plants, automobiles, chemical plants etc.
- Hence it is therefore necessary to study the deformation behaviour of materials at high temperature.

Definition and importance

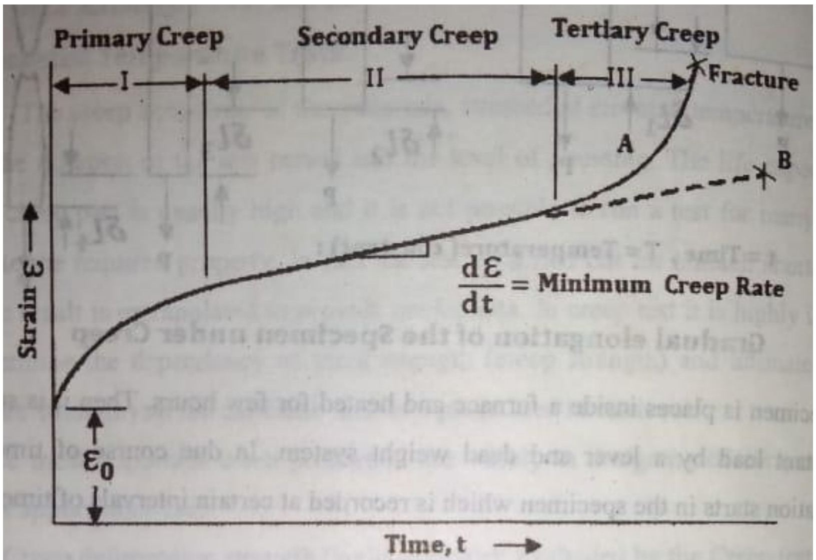
- *Creep is defined as, a time-dependent plastic deformation under a certain constant applied load or stress.*
- Generally, occurs at high temperature (thermal creep), but can also happen at room temperature in certain materials (e.g. lead or glass).
- As a result, the material undergoes a time dependent increase in length, which could be dangerous while in service in places like: Industrial belts, turbine blades, pistons, rockets etc. and may lead to failure. So, it is necessary to study the creep behaviour of materials which are being used at elevated temperature.
- The term high temperature cannot be defined universally because for material like lead room temperature is also high temperature.
- In order to take care of this anomaly temperature is often expressed as homologous temperature. *It is the ratio of working temperature of a material and it's melting temperature both in kelvin scale unit.*

  Homologous temperature = T/T_m

  Where, T = working temperature in kelvin
  T_m = Melting temperature in kelvin.
- Creep deformation generally occurs when Homologous temperature ≥ 0.5.

Creep Curve

- As Creep deformation is a time dependant process, so the total creep test may take few hours, few days, few months or even few years according to the importance and need.
- The total creep or elongation or strain (ε) is measured for the entire duration of the test. *The plot of strain (ε) versus time (t) as shown in figure below is known as creep curve*.
- The curve A in the figure below represents an idealized creep curve. The slope of the curve is termed as creep rate.
- After an instantaneous elongation, the creep rate decreases with time, then reaches a steady state during which there is very little change in creep rate with time.
- Finally, the creep rate increases rapidly with time till fracture occurs. This phenomenon is divided into three distinct stages such as:
  1. Stage I: Primary Creep.
  2. Stage II: Secondary Creep.
  3. Stage III: Tertiary Creep.



Typical creep curve showing three stages of creep.
Curve A: Constant load test ; Curve B :constant stress test

1. Stage I :
   The first stage of the creep is known as primary creep or this shows a region of decreasing transient creep rate. During this stage, the creep resistance of the material increases due to strain hardening. At low temperature and stress, Stage I creep is significant while this zone vanishes as temperature & stress increases.

2. Stage II:
   The Stage II creep is known as secondary creep. This is the period of nearly constant creep rate and is of great engineering importance. This constant creep rate results from the balance between the two competing processes that is strain hardening & recovery. For this reason secondary creep is known as Steady Creep.

3. Stage III:
   Third stage of the creep curve is known as Tertiary Creep. Tertiary creep occurs when there an effective reduction in cross-sectional area of the specimen either due to necking or due to formation of internal voids. This leads to ultimate failure of the material.

Andrade's analysis of creep Curve

Andrade was the first to examine the creep curve in detail and published his results in 1951.

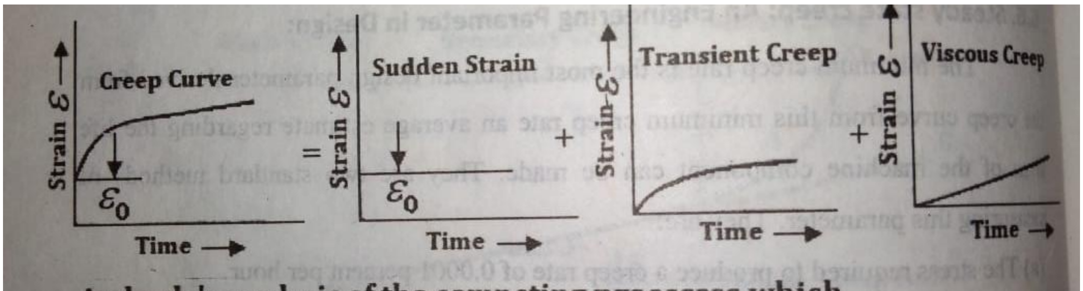
- According to him the constant stress steep curve represents the superimposition of two separate creep processes which occur immediate after sudden strain(ε_0) and results from applying the load.
- The first component of creep curve is 'transient creep' with a creep rate decreasing with time added to this is a constant rate 'viscous creep'.

  Stage I:
- The Stage I of the creep curve is known a transient creep or cold creep. This even occurs at low temperature hence known as primary or cold creep. Andrade's law for Transient Creep is:
  Parabolic law: Transient creep for metals and alloys, $\boldsymbol{\varepsilon_{cr}} = \mathbf{Ct^n}$.
  Where, C= constant, n Power index whose value is 1/3, t= Time.

  Stage II:
- This stage is known as secondary creep or steady state creep that result Creep from a balance between the competing processes of strain hardening and recovery.
- This stage of creep is also known as a viscous creep or hot creep.
  Secondary creep law:
  $\mathcal{E}cr = \mathcal{E}_1 + \nu_{cr}t$
  Where, $\mathcal{E}_1$=The strain intercept, ν_{cr} = The minimum or viscous creep rate.

Stage III.

Third stage of creep is known as /tertiary creep, during which the creep rate increase rapidly and finally results in failure of the material.



Andrade's analysis of the competing processes which determine the Creep curve

The total creep strain, $\varepsilon = \varepsilon_o + \varepsilon_p + \varepsilon_s$

ε_o = instantaneous strain at loading (elastic and plastic)

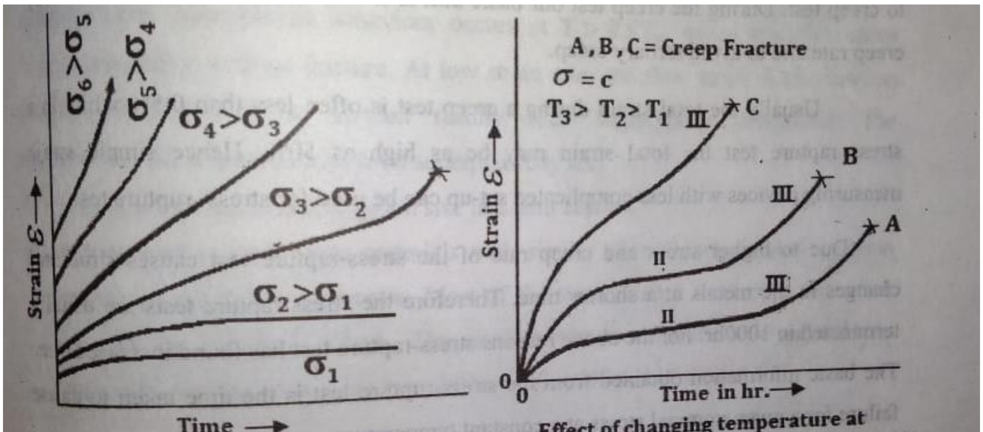
ε_s = steady-state creep strain

ε_p = primary or transient creep

Factors affecting Creep

There are mostly three parameters which affect creep: stress, temperature and microstructure.

- Both increase in temperature and stress will increase creep rate and the failure will be early as shown in figure.
- However, we can tune the microstructure to get good creep resistance.



Effect of stress on Creep curve at constant temperature (schematic).

Effect of changing temperature at constant stress, on Strain - Time profile

Creep testing machine

- Measures dimensional changes accurately at constant high temperature and constant load or stress.
- Useful for modelling long term applications which are strain limited.
- Provides prediction of life expectancy before service. This is important for example turbine blades.

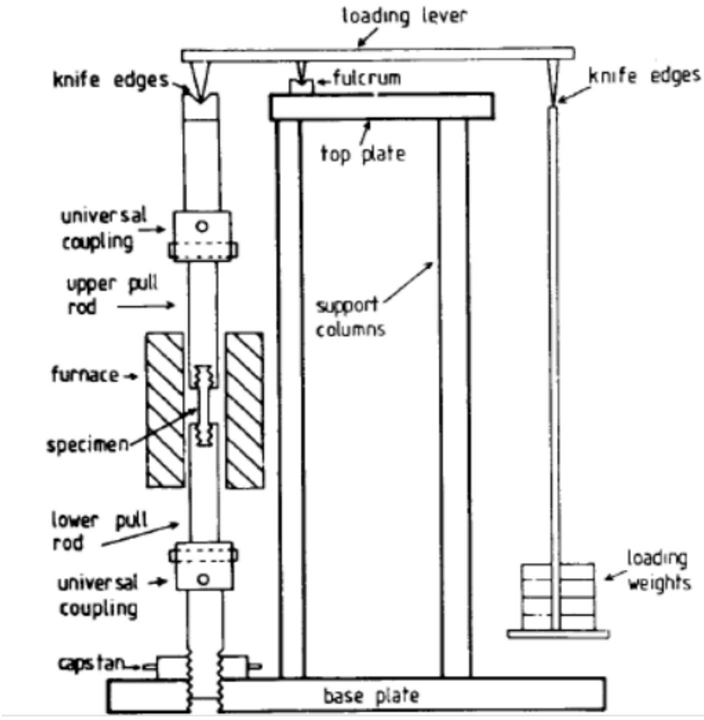


Fig: Creep test apparatus

- Measures strain vs. time at constant T and Load (Similar to graph seen previously).
- Relatively low loads and creep rate • Long duration 2000 to 10,000 hours.
- Not always fracture.
- Strain typically less than 0.5%.

Stress Rapture Test:

- The stress rapture test is basically similar to Creep test. However, this test is always conducted at much higher loads and always continued up to the failure unlike creep test.
- As load is higher, the creep rates in case of stress rupture test are also higher compared to creep test.

- Usually the total strain during a creep test is often less than 0.5% while in a stress rapture test the total strain may be as high as 50%.
- The basic information obtained from the stress rupture test is the time taken to cause failure for a given nominal stress at a constant temperature.

Equicohesive temperature

- It is the temperature at which there is transition of crack propagation from intergranular to transgranular occurs.
- In other word the temperature at which the cohesive force at grain boundary becomes equal to grain interior.

Model Questions

1. (2 marks question)

a) Define/ differentiate/explain elastic and plastic deformation.

b) Mention the type of indenter and load used for Rockwell C scale measurement.

c) Define strain and mention the formula for measurement of strain.

d) Draw the specimen with dimension for impact testing by Izod method/Charpy method.

e) Define Resilience/toughness. How it is calculated?

f) Define Impact strength and mention its unit.

g) Define ductility and how to measure it.

h) Define yield strength and UTS.

i) What is the difference between Engg. Stress/Engg strain and True stress/true strain. Give the mathematical expression.

j) Define modulus of elasticity and Proof stress.

k) Draw Engg Stress-Strain Curve/ true Stress-strain curve.

l) Draw stress strain curve for yield point elongation.

m) What is DBTT?

n) Write the empirical relation between hardness and strength.

o) Write the empirical formula for hardness by Vickers hardness test method

2. (5 marks)

a) Briefly explain the phenomenon of Yield point elongation.

b) Explain the hardness test in detail adopted by Geologist.

c) Discuss the significance of transition temperature.

d) Explain in detail about the various indentation hardness test (Rockwell, Brinell and Vickers).

(10 marks)

3. Draw the Engg Stress-Strain curve for Aluminium, low carbon steel, glass rod and rubber. Explain the significance of those curves.

4. Derive the expression for VHN. Compare Brinell hardness test with Vickers hardness test.

5. A cylindrical sample having diameter of 2cm,length 10cm subjected to tension test with load of 400N. If the final length of the sample is 10cm. Calculate (i) Engineering stress (ii) Engineering strain (iii) True stress and (iv) true strain.