ME 218: Solid Mechanics Lab – Spring 2021

Lab Meets: Online: All sections meet on Monday at 2 PM on MST.
Offline: In Solid Mechanics Lab (ground floor ME department). Subject to prevailing institute guidelines.

S1 – Monday 2-5 PM S2 – Tuesday 2-5 PM S3 – Thursday 2-5 PM
Students in batches will be allowed at different times to adhere to COVID19 protocols.

Instructors: Prof. Krishna Jonnalagadda
Lab Technical Staff: Mr. Shanideo Jadhav

Assessment Scheme:
Lab sessions + Reports + Quiz: 60% (online or offline does not matter)
Student design project (Report, Presentation, Viva): 40% (subject to prevailing Covid19 situation)

Instructions:ˆ

Following COVID-19 protocols set by the institute is compulsory. Lab staff may include additional requirements that you must follow in the interest everyone's safety, both real and perceived. Students violating protocols will be asked to leave the lab and marked absent for the session. If you repeat the violation twice, you will be banned from entering the lab further.

1. The lab experiment demonstration will start at exactly 2 PM on MS-Teams (if online will take place on Monday at 2 PM). If the lab is run offline then at 2 PM in SOM lab on the respective day of the week assigned to the section.
   a. Before coming to the lab (offline) you should read the manual, watch the demo video, other material corresponding to the experiment, and write a 1 page individual pre-lab report consisting of details of the experiment. This pre-lab report is compulsory and those who do not submit will be marked absent for that session (leading to zero in lab and report marks for that particular experiment).
   b. Wearing appropriate clothing for the lab is important for your own safety. Shoes with closed toes are compulsory according to department guidelines. If you are unsure, please ask the lab staff.
2. Attendance policy: Attending the online or offline session is compulsory. No make ups will be given. If you have a valid excuse, kindly inform well in advance, so we can compensate in "other" ways.
3. Report:
   a. Experimental data will be sent to all students on the day of demonstration through Moodle in case of online session. In all offline sessions, the students need to record data and/or get the data from the respective TA on the same day.
   b. The lab manual is just one reference in writing the report. You should choose books and other resources to complete the report. Some material will be shared with you on MST. However, do not forget to cite all sources of information you have used. It is a good practice to give credit to those who did it before you and for you.
   c. The report should contain, analysis of the experimental data, observations from the demonstration and your analysis, and possible conclusions, including comparison with theory, if any. A generic template will be provided for lab report, but it is up to you to present and discuss your results. Your ability to describe and interpret results will be evaluated.
   d. The report should be a concise document, consisting of only things mentioned under each experiment. You can cite the manual, standard textbooks and standards, wherever necessary.
   e. The report is due after you complete each set, within a week of conducting the last experiment. So, you have to submit only 3 reports in the semester. Two reports for the experiments conducted in the lab or online, and one for the student design experiment.
   f. Report should be hand written and plots/graphs, etc., should be generated using computer based tools, e.g., MS Excel, MATLAB, MAPLE, etc.
   g. Plots should have their axes labelled properly. As far as possible present your data on a square chart, with scale, labels and legend.
   h. Each student will write his own report and submit, for sets 1 and 2. Final student design experiment project reports will be group submissions. Copying of report will be reported to DDAC and all permissible penalties will be applied.

ME 218: EXPERIMENTS FOR SOLID MECHANICS LAB.

Sr. No.	Title of the experiment
Set 1	
1	Uniaxial tensile test
2	Uniaxial compression test
3	Torsion of a circular rod
Set 2	
4	Rockwell hardness measurement of metals
5	Charpy impact test
6	Strain in a proving ring under combined bending and extension

Student Design Project (SDE)

In this project, you will use one of the instruments available in the lab, plan and execute an experiment to find at least one of the following:
(a) material property,
(b) stress or strain distribution in a specimen geometry, e.g., of practical importance, and
(c) structural behavior validating a theoretical result, e.g., beam bending.

You will do this project as a group.

Some experiments and instruments available in the lab (not exhaustive):
1. UTMs of different load capacities.
2. Photoelasticity (circular polariscope) setup with a dial gauge load indicator and screw to load planar samples.
3. Rotating beam bending machine for fatigue (HCF) experiments.
4. Simply supported beam bending rig with dead weights and dial gauge displacement indicators.
5. Torsion instruments with displacement (twist angle) control.
6. Muffle furnace
7. …

Note: As things evolve on campus, these experiments and SDE may be conducted in an online mode. Appropriate modifications to instructions will be made and informed to you. Our primary goal is to conduct experiments in sets 1 and 2. SDE duration will be modified appropriately based on prevailing COVID19 situation.

Uniaxial Compression Test

Objective: To perform compression test and determine,
(a) The machine compliance
(b) The compressive flow strength at ~10% strain of an aluminum sample
(c) The Young's modulus in compression and the complete true stress vs. true strain curve

Equipment and Tools:-

The Universal Testing Machine with compression platens, grease, Vernier Caliper, Scale, aluminum and steel samples.

Theory:

Several machine and structural components such as columns and struts are subjected to compressive load in applications. Depending on the material the properties in compression could be different from those in tension, which is referred to as Bauschinger effect. For most isotropic materials, tension, compression and torsion comprise the most important experiments to extract the constitutive response, i.e., stress vs. strain relationship. Also, failure in compression is often different from that seen in tension. Failure in metals under compression usually comprises of buckling, shear banding and diametric cracking (in relative less ductile materials). Compression experiments are also preferred to understand the stress vs. strain response of isotropic materials due to small specimen size requirement and ease of preparation.

In this experiment, you will be measuring the stress vs. strain response of a ductile aluminum alloy in uniaxial compression. In the absence of a compression extensometer, you will be conducting two compression experiments to calculate the strain in aluminum sample. The first experiment will be on a steel sample with very high yield strength and of known elastic modulus, loaded below the proportional limit. From this experiment, you will extract the UTM compliance by plotting displacement over force for the machine assuming that the specimen is a linear elastic spring, whose deformation can be calculated form the elastic modulus and specimen geometry. The second experiment will be on an aluminum sample of unknown elastic modulus and constitutive behavior, for which you will extract the force vs. displacement curve. Then, construct the true stress vs. true strain curve for aluminum using the compliance data obtained from the experiment on steel specimen.

Procedure:

1. Dimensions of yhe test specimens (steel and aluminum) are measured at three different places along its height/length to determine the average cross-section area (A_0) and length (h).
2. The geometry of the specimen should be right circular cylinder.
3. The specimen is placed centrally between the two compressions plates, such that the centre of the moving head is vertically above the centre of specimen.
4. Load is applied on the specimen by moving the movable head at a constant velocity.

Observations:

1. Initial length or height of specimen (h) = ----------mm.
2. Initial diameter of specimen (d_o) = ----------mm.
3. Measure the deformed dimensions of the aluminum specimen to verify you strain calculation with compliance correction.

Report: In the report you should present the following along with discussion.

a) Plot the machine compliance curve for the machine, i.e., force vs. displacement.
b) Plot the stress-strain curve for steel and aluminium specimens and compare.
c) From the stress- strain curve, calculate the value of Young's modulus in GPa of aluminum
d) Find the percentage reduction in length and increase in cross-section area.
e) Compare the experimental value of modulus with the value given in data book for aluminum
f) Comment on your observations during the experiment, data analysis, errors, uncertainty in the measurement of Young's modulus of aluminum.

Uniaxial Tensile Test

Objective: To determine the following in uniaxially loaded mild steel and aluminum specimens. Also, calculate:

a) The maximum tensile stress
b) The modulus of elasticity.
c) The percentage reduction in cross section and hence strain to failure assuming plastic incompressibility.
d) Construction of the true-stress vs. true stain curve.

Equipment and Tools: The Universal Testing Machine, Vernier Calipers, ruler, extensometer.

Background and Theory: The uniaxial tensile test is a very important and useful experiment conducted in experimental solid mechanics. Besides provided elastic and inelastic material properties such as elastic modulus, yield/flow stress, strain hardening, etc., the failure of a material can best be studied from this experiment. The uniaxial tensile test is also often used to develop elasto-plastic constitutive equations for homogeneous and isotropic materials. Variations of this experiment (not done in this lab) including high temperatures and multiple strain rates reveal valuation information on the mechanisms of deformation sought after in the design of new materials (e.g., alloy systems).

In this experiment a dog-boned shaped specimen is loaded in displacement control while measuring load using a Universal Testing Machine (UTM). It is called universal because tension, compression, bending and shear test can be performed on the same machine. The machine has a capacity of 100 KN. The machine has two motor driven screws, which carries the upper beam. Load cell, which measures the force applied, is fixed on the upper beam. The crosshead displacement is measured using LVDT (linear variable differential transformer). The load deformation curve is plotted on the monitor screen. Extensometer is an instrument by which you will measure strain. The mechanical extensometer provided consists of two lever arms, which are bound to the specimen using a elastic band a distance 20 mm apart. The relative motion of the arms is recorded by the extensometer-amplifier circuit, which gives a voltage output. This voltage output is converted to displacement using a calibration sheet. The displacement divided by the original length of the gauge section chosen (20 mm) will give engineering strain. The engineering stress is computed from the force measured by the load cell and the initial cross-sectional area of specimen. From the respective engineering stress and strain, the true stress and strain data is calculated and properties of the material extracted.

Procedure:

The general requirement for tension tests are given in Indian standard “IS: 1608/1972 - Methods for tensile testing of steel products”. Measure the diameter “d” of the specimen at three to four places to the average diameter. For uniformity and proper interpretation of test results, gauge length L = 5d. Percentage elongation is maximum strain (percent) at failure. This is measured over the gauge length. Calculate L (in this case take L = 20 mm). Mark the center of the specimen approximately and two additional points on either side of this central mark at a distance equal to 10 mm with a marker pen. Mount the specimen on Universal Testing Machine. Select appropriate load range and cross-head velocity. Continue loading until the specimen breaks. Collect data from the UTM as well as the extensometer (which gives the strain vs. time data). Fit the broken parts together and measure the distance between the marks made earlier as well as the cross-section area. This enables you to calculate percentage elongation.

REPORT

a) Plot the engineering as well as true stress-strain curves
b) From the true stress-strain curve, calculate the value of Young’s modulus of elasticity in GPa
c) Calculate the yield stress.
d) Calculate the ultimate tensile stress.
e) Measure and calculate the percentage elongation.
f) Calculate the percentage reduction in cross-section area.
g) Compare the experimental values of elastic modulus with values given in data book.

Optical Strain Measurement Using Digital Image Correlation

Objective: - Non-contact full-field strain measurement in tensile metal samples using image correlation.

Equipment and tools: Digital camera, appropriate optical lens, computer, Al sheet specimen, pattern generating apparatus, Vernier calipers, tripod.

Introduction: - Experimental techniques in solid mechanics depend on surface displacement field measurements. Conventional strain measurement techniques involve either a bonded foil strain gage or an extensometer. These methods give local average strain measurement over an area or a given gauge length, respectively. To measure full-field stain over a large area on a surface with/without gradients several non-contact methods (direct and indirect) are used, such as, photoelasticity, Moire interferometry, speckle interferometry, etc. Digital image correlation is a relatively new method in solid mechanics for strain measurement with is easy to setup and conduct measurements using low cost hardware.

Digital Image Correlation (DIC) is an image based numerical measuring technique, which offers the possibility of determining complex displacement and deformation fields on the surface of objects under various loading conditions. It is a popular method, especially in micro- and nano-scale mechanical testing applications due to its relative ease of implementation and use. The main advantage is the technique is suited to any kind of image (optical, electron microscope, etc.) as long as the deformation causes on contrast change in the digital pixels of the image before and after deformation.

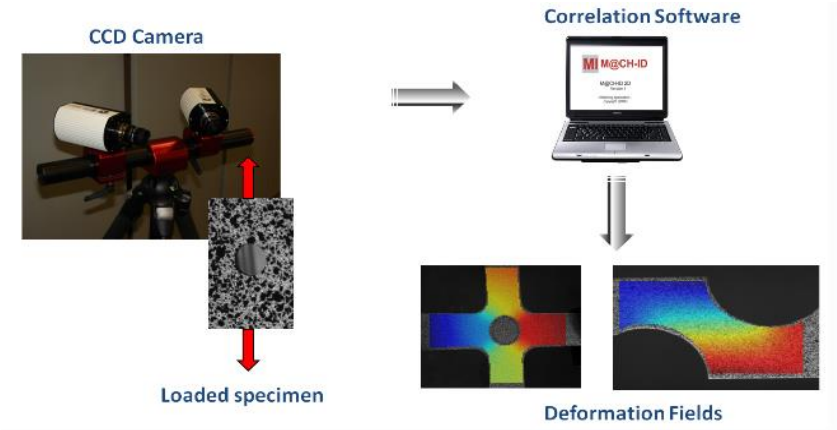


Fig.1- Block Diagram showing Set-up for experiment

Theory: - This technique starts with a picture before loading (reference image) and then a series of pictures are taken during the deformation process (deformed images).These images are then compared to detect displacements by searching a matched point form one image to another. Here, because it is almost impossible to find the matched point using a single pixel, hence an area with multiple pixel points is used to perform matching process. This area is naturally called as subset. The subset has a random gray level (light intensity for optical monochrome images) distribution of pixels, but it lends a unique identity to the subset. It is assumed that this light intensity does not change during deformation. However in practice, the light intensity may vary during experimentation. The numerical algorithm is usually equipped to handle any offsets or linear variations in the light intensity. The displacement of the subset is found out by searching the area of same light intensity distribution with the subset. Once the location of this subset in the deformed image is found, the displacement can be determined using simple Euclidean distance formula. In order to perform this process, the surface of the object must have a feature that allows matching the subset. If no feature is observed on surface of object, an artificial random pattern must be applied (as shown in fig 2).

To evaluate the similarity degree between the reference subset and the deformed subset, a cross-correlation (CC) criterion is used. The criterion quantifies the similarity of a particular region in the deformed image to that of the subset. The matching procedure is completed through searching the peak position of the distribution of correlation coefficient. Once the correlation coefficient extremum is detected, the position of the deformed subset is determined. The differences in the positions of the reference subset center and the target subset center yield the in-plane displacement vector at point *P*, as illustrated in figure 3. Note that in this calculation of displacement it is assumed that the field of view contains the pixel/point of interest before and after deformation.

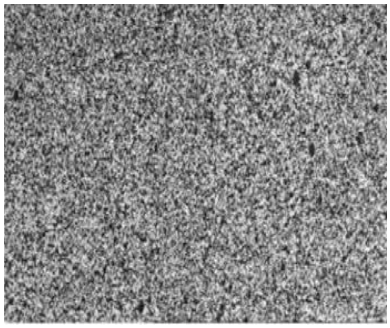


Fig-2 Speckle Pattern

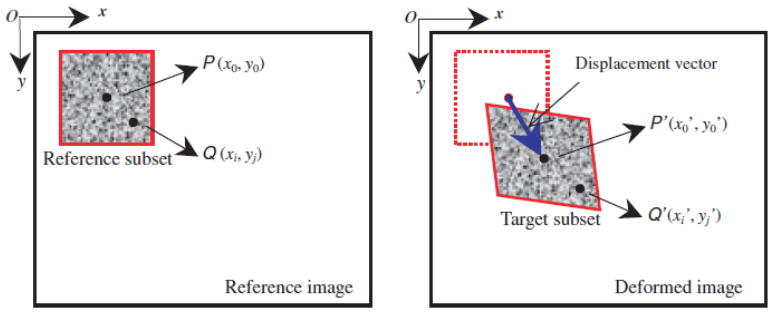
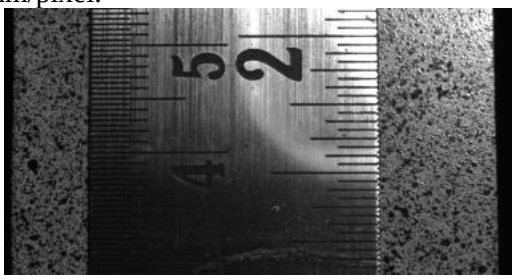


Fig-3 Schematic illustration of a reference square subset before deformation and a target (or deformed) subset after deformation

Procedure:-

1) Specimen Preparation: - For good results, it is essential to get a good speckle pattern. The speckle pattern can be naturally occurring or can be applied. It can be applied with white and black paint. First, paint the surface with a thin layer of white paint (it could be spray paint) and then apply a black mist of paint (spray paint) to create the black speckles.
2) Image Capture: - To take the pictures during the deformation period, the specimen needs to be prepared to be subject to the mechanical test. After the sample is prepared and the universal testing machine is configured, select an accessible position for the digital camera and adjust the focal length to fix and acquire a clear image. Set the aperture range of the camera lens with the lowest f-number as possible to let the entrance of the maximum amount of light. The illumination has to be appropriate. The sample must be illuminated by a standard white light source. If ambient illumination is not sufficient, additional lighting may be needed. Before starting the test, a picture is taken for reference (non-deformed image). While the specimen is subject to external loads, consecutive pictures are taken (deformed images).
3) These images are then given as input to the code or software from where displacement or strains can be obtained. Code will be explained to you by the TA during the lab.
4) Calibration:- The calibration is essential as the code gives the displacements in pixels and has to be converted into actual/true scale. Hold a measuring scale vertically and attached to the surface of the deforming body. Acquire an image in this position and observe the scale divisions spanning the image length. Assuming, x mm. of the measuring scale covers y pixels of the image, a simple linear calibration yields x/y mm/pixel.



Report:

(a) Speckle pattern generation and its histogram (computer using Matlab, etc.)
(b) Obtain experimental data, viz., images of the sample surface during deformation and load vs. time plot.
(c) Construct stress vs. strain curve using the load vs. time and strain (calculated using DIC) vs. time.
(d) Compare the Young's modulus from the experiment and the material data sheet.
(e) Plot and show that there is uniform strain on the surface of the sample at various load levels.

Notes:

1. It is important that the alignment of the specimen be as good as possible, i.e., the camera sensor should be parallel to the specimen surface being imaged.
2. The specimen should be well aligned at the beginning of the experiments in such as way that it does not rotate during the application of load.
3. The region of interest should be in the middle of the specimen
4. Neither the camera nor the UTM should be vibrating during the experiments as this causes blurred images.

Determination of Stress Concentration Factor Using Photoelasticity

Objective: To find the stress concentration factor using Photoelasticity technique

Equipment and Tools: Epoxy resin, photoelasticity setup

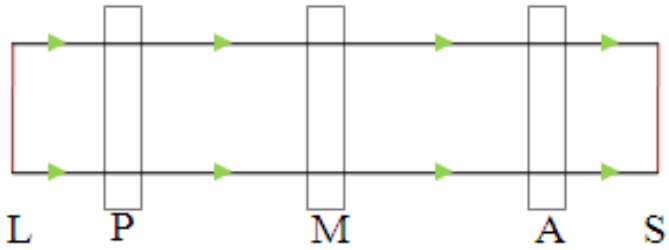


Fig. E3.1: Schematic of plane polariscope

Theory: Photoelasticity is an experimental technique for stress measurement and is particularly useful when the geometry is irregular or it has a discontinuity. This method is based on the discovery of David Brewster that when a piece of glass is stressed and viewed by a polarized light transmitted through it, a brilliant pattern due to stress is seen. These color patterns are used to infer measurement of stresses in engineering structures.

Birefringence is a property by virtue of which a ray of light passing through a birefringent material experiences two refractive indices. Many transparent materials like polycarbonates exhibit birefringence on application of stress and this effect is termed as "photoelastic effect". When monochromatic light (L) is incident on the polarizer (P), only the component of light with an electric vector parallel to the axis of the polariser will be allowed to pass through. When the plane polarised light arrives at the specimen (M) it is refracted and, if the material of the specimen is stressed, it is split into two separate waves, one vibrating parallel to one permitted vibration direction and the other wave parallel to the other (orthogonal) permitted vibration direction. The velocities of these waves will be determined by the relevant refractive indices, which will be different for the two directions and therefore the waves will become progressively out of phase as they pass through the material. The phase difference can alternatively be expressed in terms of the optical path difference, the distance that progressively separates points on the two waves that coincided initially. Upon emerging, the two waves recombine; however the exact way they recombine will depend on the phase difference between, which depends on the difference between the two refractive indices, the birefringence, Δn, and the distance travelled by the light through the specimen. In general the resultant wave will have a component of its electric vector parallel to the analyser (A) direction. Finally the light is passed on to the screen (S) on which a pattern of interference fringes is formed.

Plane polarised light has its electric vector vibrating along one direction, the polariser direction. When a material is orientated so that one of the permitted vibration direction lies parallel to the polariser direction, the light travels through the specimen without change in its polarisation state and therefore emerges from the specimen with its electric vector still parallel to the polariser direction and so perpendicular to the analyser direction. This light will not pass through the analyser. These settings are known as extinction positions and produce isoclinic fringes, which occur wherever either principal stress direction coincides with the polariser direction.

The transmitted intensity will also be zero when the optical path difference is an integral number of wavelengths (the phase difference is an integral multiple of 2π). In this case, the beams recombine to give a beam with the same polarisation state as the incident beam, i.e. with the electric vector parallel to the polariser direction, and hence the transmitted intensity is zero.

If a general system of stress is applied in the plane of a transparent material, the optical birefringence, Δn, produced will be proportional to the difference, Δσ between the two principal stresses in the plane. We can define the stress-optical coefficient C, such that,

$$|\Delta n| = C(\sigma_1 - \sigma_2),$$

whereσ_1 and σ_2 are the maximum and minimum principal stresses. The above stress-optic law can be rewritten as,

$$(\sigma_1 - \sigma_2) = NF/t,$$

Where, $N =$ fringe order (related to the color at the point under consideration), $F =$ stress fringe value of the material (to be found out from calibration specimen), and specimen thickness. Table E3.1 relates the fringe order N with the color observed in the interference fringe.

For a sample of uniform thickness, regions in which $(\sigma_1 - \sigma_2)$ is constant show the same interference color when viewed between crossed polars. Contours of constant principal stress difference are therefore observed as isochromatic lines. In order to determine the directions of the principal stress it is necessary to use isoclinic lines as these dark fringes occur whenever the direction of either principal stress aligns parallel to the analyser or polariser direction.

In a circular polariscope setup two quarter-wave plates are added to the experimental setup of the plane polariscope. The first quarter-wave plate is placed in between the polarizer (P) and the specimen (M) and the second quarter-wave plate is placed between the specimen (M) and the analyser (A). The effect of adding the quarter-wave plates is that we get circularly polarised light. The basic advantage of a circular polariscope over a plane polariscope is that in a circular polariscope setup we only get the isochromatics and not the isoclinics. This eliminates the problem of differentiating between the isoclinics and the isochromatics.

Color	Approximate Relative Retardation nm	Fringe Order N
Black	0	0
Gray	160	0.28
White	260	0.45
Pale Yellow	345	0.60
Orange	460	0.80
Dull Red	520	0.90
Purple (Tint-of-Passage)	575	1.00
Deep Blue	620	1.08
Blue-Green	700	1.22
Green-Yellow	800	1.39
Orange	935	1.63
Rose Red	1050	1.82
Purple (Tint-of-Passage)	1150	2.00
Green	1350	2.35
Green-Yellow	1440	2.50
Red	1520	2.65
Red/Green Transition	1730	3.00
Green	1800	3.10
Pink	2100	3.65
Pink/Green Transition	2300	4.00
Green	2400	4.15

Table E3.1: Color versus fringe order

Procedure:

1. **Calibrate Photoelastic Material:** Load specimenstepwise. At each load, Note colour at point A in figure1. Stress Fringe Value of Specimen=F = Δσ * t / N

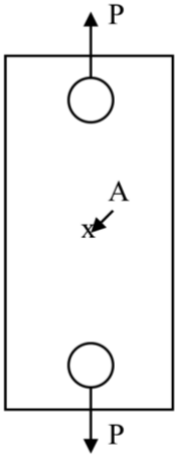


Figure 1: Calibration Specimen

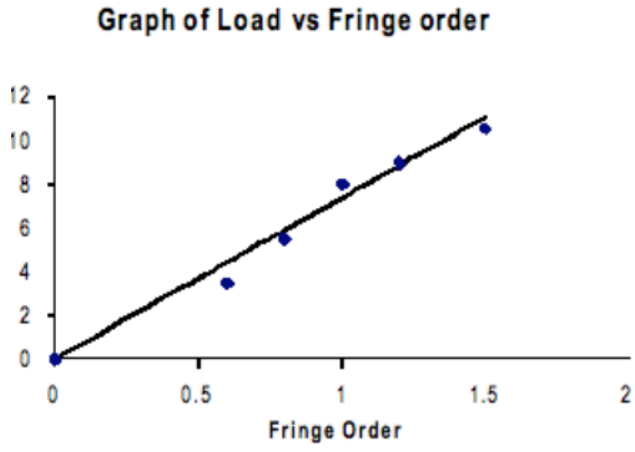


Figure 2: Fringe order vs. applied load (on vertical scale)

2. **Stress Concentration Factor of plate with single hole (Figure 2):**

Find maximum stress at point A, by noting fringe order. Also find maximum stress at point B.

Stress = $\sigma 1 - \sigma 2 = N * F / t$

At point A : $\sigma 2 = 0$, as inner surface of hole is free, so only maximum principle stress exists, tangent to hole.
At point B : We assume stress distribution is sufficiently uniform and we can assume $\sigma 2 = 0$.
Therefore, stress difference in our case nothing but maximum stress.

Stress concentration factor = stress at point A / Stress at point B.

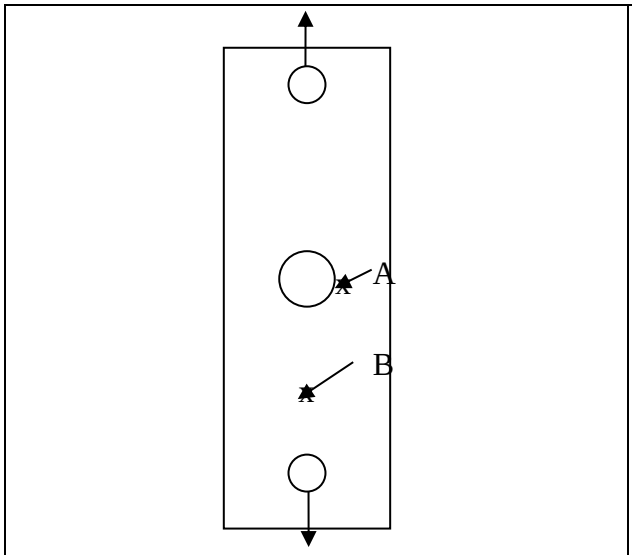


Figure 2

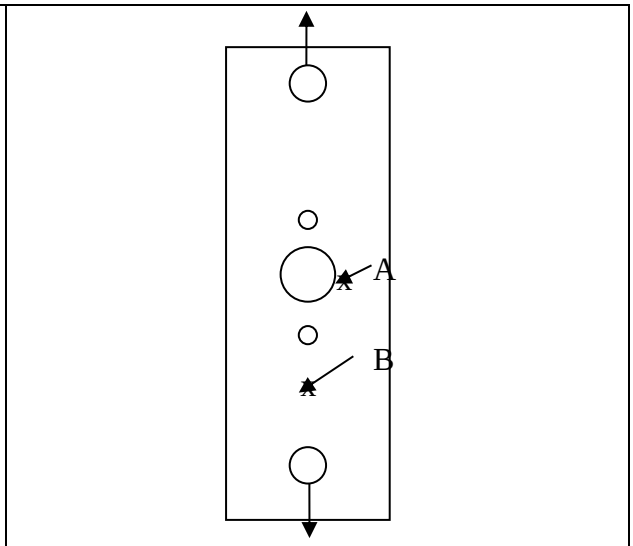


Figure 3

3. Stress Concentration Factor of plate with three holes (Figrue 3):
Find maximum stress at point A, by noting fringe order. Also find maximum stress at point B.
Stress = $\sigma_1 - \sigma_2 = N*F / t$
Stress concentration factor = stress at point A / Stress at point B.

4. Find stress concentration factor for above plates using stress concentration handbook. Assume that material is linear elastic **isotropic** and homogenous in experiment range. To model specimen, carefully note dimensions of specimen.

Report:
Tabulate the stress concentration factors found out by a) photoelasticity technique. Compare the results and comment on discrepancies in results, if any.

Refrences:
1. Experimental stress analysis, Dally, J. W., Riley, W. F.
2. Photoelasticity, Frocht, Max Mark.
3. Photoelasticity for designers, Heywood, R.B.
4. Polariscope Description, attached with this mail.
5. http://www.doitpoms.ac.uk/tlplib/photoelasticity/index.php

Photoelastic Setup

Any photoelastic setups consists of both plane and circular polariscopes and a loading devicel.

Principles of Fringe formation in Polariscope

The first setup shown below is a plane polariscope. It consists of a light source, a polariser, model, an analyser and the screen. Consider that the light source is a source of monochromatic light. Light from the source travels forward along a straight line with vibrations on all planes transverse to the straight path. As soon as the ray pass through the polariser, all the transverse vibrations are annihilated

except the one whose plane of vibration coincides with the axis of polarisation. Let us represent the polarised light as a cosine wave.

$$E_P = a\cos\omega t$$

After emerging from the polariser, the wave moves towards the model. As soon as it meets the front face of the model it gets resolved into two components along planes coinciding the two principal directions σ_1 and σ_2. That is, after entering into the polariser, there are two components,

$$E_{\sigma 1'} = a\cos\omega t\ \cos\beta \qquad E_{\sigma 2'} = a\cos\omega t\ \sin\beta$$

These two components travel with different velocities because the model shows birefringent properties under loading. Indeed, the component travelling along the σ_2 plane travels with a slower velocity, so it slows down. The extent of slowing down depends on model thickness and its material properties and the wavelength of light. Let us represent this phase difference between the two components as Δ. Therefore after the model we have two components, which can be represented as follows.

$$E_{\sigma 1} = a\cos\omega t\ \cos\beta \qquad E_{\sigma 2} = a\cos(\omega t - \Delta)\ \sin\beta$$

These two components gets recombined as one component along the plane of polarisation of the analyser, which is very similar like the polariser. The combined wave is

$$\begin{aligned} E_S &= E_{\sigma 2}\cos\beta - E_{\sigma 1}\sin\beta \\ &= a\cos(\omega t - \Delta)\sin\beta\cos\beta - a\cos\omega t\ \cos\beta\sin\beta \\ &= a\ \sin\tfrac{\Delta}{2}\ \sin 2\beta\ \sin(\omega t - \tfrac{\Delta}{2}) \end{aligned}$$

This light *Es* travels along the horizontal plane. The intensity of light/wave incident on the corresponding point on the screen is

$$I = C\ (a\ \sin\frac{\Delta}{2}\ \sin 2\beta)^2;\ C \text{ is a constatnt.}$$

The intensity I=0 under the following conditions.

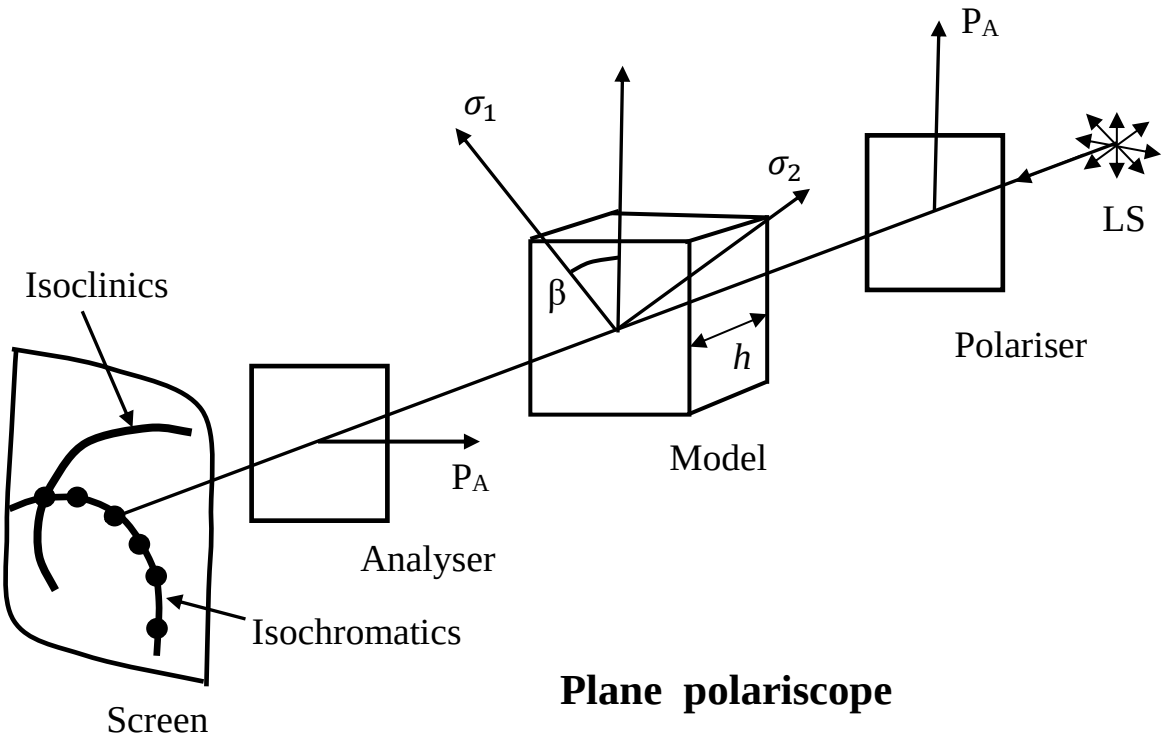
1) If β=0. That is the direction of ploarisation coincides with the maximum principal stress directions. The locus of such points gives a fringe pattern which is termed as 'isoclinics'.

2) If $\frac{\Delta}{2} = n\pi$, n=0, 1, 2, 3, ...∞ .
That is, $\frac{\Delta}{2\pi} = n$. In fact, $\Delta = (\sigma_1 - \sigma_2)\frac{2\pi ch}{\lambda}$, or, $(\sigma_1 - \sigma_2) = n\,f_\sigma$, where $f_\sigma = \frac{\lambda}{ch}$.
f_σ is the model fringe constant and *n* is known as the fringe order. The locus of such points gives a fringe on the screen, which is termed as isochromatic. All along such a fringe the difference between the two principal stresses is a constant. For *n*=0, the zeroeth fringe is obtained. For *n*=1, the first order fringe is obtained, ...

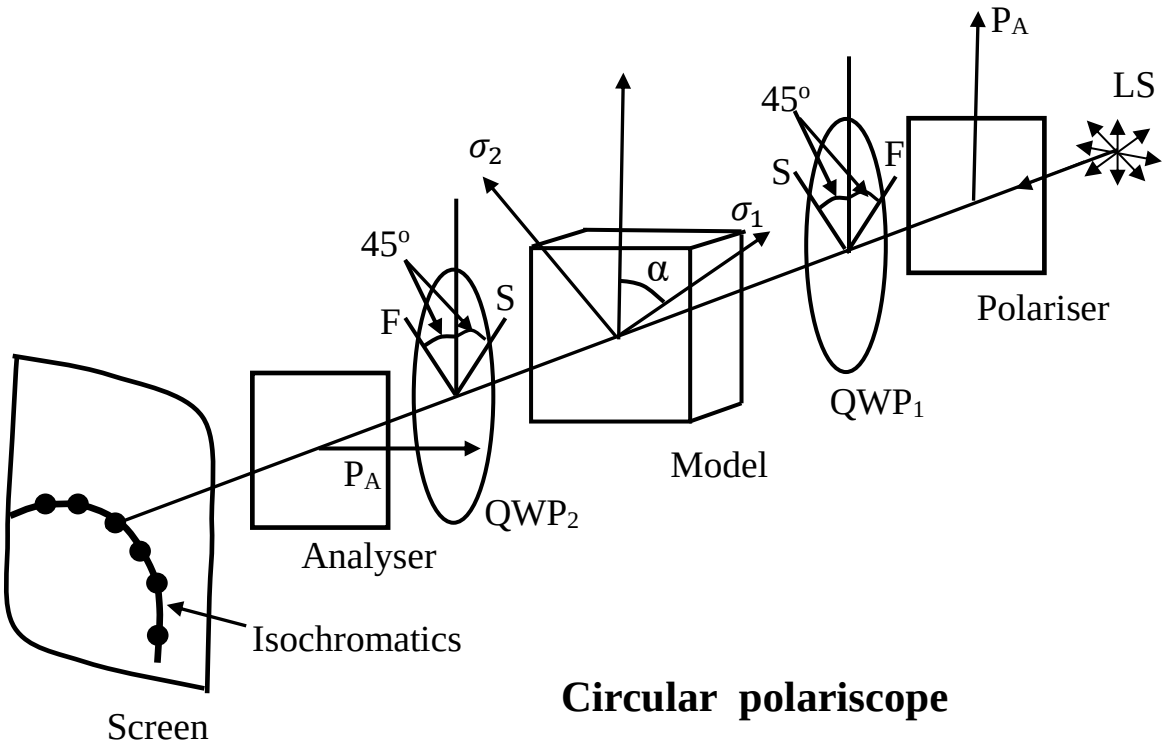
In the event of a white light source, the screen shows fringe patterns of different colours. The monochromatic light helps to get fringes of single colour and the fringes are very easily distinguishable.
In order to obtain only the isochromatics on the screen, the circular polrariscope is employed. It has extra two quarter wave plates. These are made of materials which show double refractive properties at no load, e.g., Calcite and NACl crystals.
In the case of a circular polariscope, the light wave falling on the screen is given by

$$E_S = a\ \sin\frac{\Delta}{2}\ \sin 2\beta\ \sin(\omega t + 2\alpha - \frac{\Delta}{2})$$

This indicates the *I* is 0 only when $\frac{\Delta}{2} = n\pi$, n=0, 1, 2, 3, ...∞. Thus the isoclinics are eliminated by this optical arrangement.
By knowing the fringe order at a point the difference between the two principal stresses is obtained. If one of the principal stress is zero, nf_σ gives the value of the non-zero principal stress directly.
The model fringe constant is obtained by doing either tensile test or simple bending test on the setup separately.



Plane polariscope



Circular polariscope

.

Rotating Beam Bending Fatigue Experiment

Objective: To study the effect of cantilever loading on standard rotating bending fatigue specimen and to find its endurance strength

Theory: In many machines, components are subjected to cyclic (repeated) loads of varying frequencies as well as amplitudes.The stresses induced due to such forces are called as fluctuating stresses. It is observed that about 80% of failures of mechanical components are due to fatigue loading resulting from fluctuating stresses. It has been observed that materials fail under fluctuating stresses at a stress magnitude, which is lower than ultimate tensile strength of the material. Sometimes the magnitude is even smaller than the yield strength. Further it has been found that the magnitude of the stress causing fatigue failure decreases as the number of stress cycles increases. This phenomenon of decreased resistance of the materials to fluctuating stresses is called fatigue.

Fatigue failure begins with the nucleation of a crack at some point in the material. This crack is more likely to nucleate in the following regions:

1] Regions of discontinuity, such as oil holes, keyways, screw threads, etc.
2] Regions of irregularities in machining operations such as scratches on surface, etc.
3] Internal cracks due to defects in materials, e.g., blow holes.

These regions are subjected to stress concentration due to the crack. The crack grows due to fluctuating stresses until a section of the component is so reduced that the remaining portion is subjected to sudden fracture.

There are two distinct areas of fatigue failure

1] Region indicating slow growth of crack with a fine fibrous appearance (sub-critical crack growth)
2] Region of sudden fracture with a coarse granular appearance (catastrophic crack propagation)

Fatigue cracks are not visible till they reach the surface and by that time the failure has already occurred. The fatigue failure is sudden and total. The fatigue failure, however, depends upon a number of factors, such as number of cycles, mean stress, stress amplitude, stress concentration, residual stresses, corrosion & creep. The fatigue or endurance limit for a material is defined as the maximum amplitude of completely reversing stress that the standard specimen can sustain for an unlimited number (asymptotically) of cycles without fatigue failure. In this experiment, the test specimen is of standard size & has a highly polished surface. It is rotated by an electric motor & the number of revolutions before the occurance of the first fatigue crack is recorded on a revolution counter. The test specimen is subjected to pure bending moment and the magnitude of bending stress is adjusted by means of dead-weights. The results of these tests are plotted by means of an S-N curve. The S-N curve is a graphical representation on a log-log scale of the maximum applied stress S_f versus the number of stress cycles N before fatigue failure. The endurance limit stress is always expressed as a function of the number of stress cycles. The endurance strength, is not exactly a property of the material like yield strength. It is affected by the size and shape of the component, surface finish, temperature, andnotch sensitivity.The endurance strength of standard specimen is calculated using the formula,$M = \pi Sd^3/32$ or $M = 0.0982\ Sd^3$, where, M is the setting for poise weight in kg cm, S is the desired bending stress level in specimen at minimum cross-section in kg/cm^2, d is the diameter of specimen at minimum cross-section in cm.

Procedure:

1. Measure the specimen dimensions most importantly the smallest diameter (d).
2. Initially adjust the load to zero position.
3. Load the specimen into the collet of machine spindle and check for runout at different locations.
4. Adjust the specimen until required alignment is achieved.
5. Adjust the poise weight to known value of bending moment and lock it.
6. With the spindle revolving, adjust the cutoff switch as instructed.
7. Note down the value of bending moment applied and also the number of stress cyclesreached by specimen to failure (in your experiment, the moment the end displacement is reached, which indicates the nucleation of a defect or loss of stength.

Report:

1. Calculate the value of endurance strength of the specimen using the formula mentioned above and also from the number of stress cycles obtained in experiment.
2. Compare the both giving suitable reasons.

Rockwell Hardness Measurement of Metals

Objective: The aim of this experiment is to determine the Rockwell hardness numbers of metals.

Equipment and Tools: Rockwell hardness testing machine, indenters, flat and polished specimens.

Theory: Of the many definitions of hardness, for metals the most appropriate one would be "resistance to permanent deformation. It can be determined either statistically or dynamically. Static hardness test can be further classified as follows:

a) Hardness as the force per unit area, which is used in Brinell and Vickers indentation experiments.
b) In the Rockwell hardness experiment, the hardness of a material is calculated from the depth of penetration of the indenter into the material.

Significant information can be obtained from the hardness number of a specimen. Uniform hardness numbers are nearly always a sufficient guarantee of the uniform quality of the finished products. In this test the depth of the penetration of the given indenter under a specified load is measured. The type of indenter and load used depend upon the material to be tested. Rockwell hardenss has many scales depending on the applied load and the type of indenter. Scale B (denoted HRB) is used for the materials having hardness number upto that of mild steel. In HRB scale, the indenter is a hardened steel ball of 1/ 16" dia. An initial load of 10 kg is applied on the ball. An additional load of 90 kg is then applied (major load). Similary, HRC scale is used for alloy steels, which are much harder to penetrate. In this case, the indenter is a diamond cone of 120 degree included angle and a 150 kg major load is applied.

Procedure:

1. Keep the specimen on the machine platform. Ensure that the surface of indentation is parallel to the platform.
2. Turn the table upward so that distance between the indenter and specimen is less than 8mm.
3. Select the HRB/HRC scale with the help of touch screen display buttons.
4. Press the start button, it will automatically go down into the specimen to make the impression and will display the HRC value.
5. Brinnel Hardness Number (BHN) can also be found after changing the scale.
6. Take atleast 3 readings for each material.

Report:

1. Report the Rockwell hardness number for the given metals.
2. Compare these values with the values available in any metals handbook.
3. Also, report your observations based on the hardness values as well as the indent process vis a vis permanent deformation.

Charpy Impact Test

Objectives:

a) To study the impact resistance of metals using Impact testing machine of the Charpy type.

b) To determine the variation of impact strength of a material with change in temperature.

Equipment and tools:

Impact testing machine, scale, standard charpy specimens, furnace and thermocouple, liquid nitrogen.

Theory: Some materials like cast iron, glass and some plastics which offer considerable resistance to static load, often shatter easily when a sudden load (impact) is applied. The impact strength is defined as the resistance of the materials to shock dynamic load. The impact testing is to find out the energy absorbed by a specimen when brought to fracture by hammer blow and gives a quality of the material, particularly its brittleness. Highly brittle materials have low impact strength.. Temperature also influences impact strength of the materials. The area under the stress strain curve in a static tensile test is measure of the energy absorbed per unit volume of the material, called the modules of toughness. This is also a measure of the impact strength of the material. Impact test can also be used to determine the transition temperature for ductile to brittle behavior.

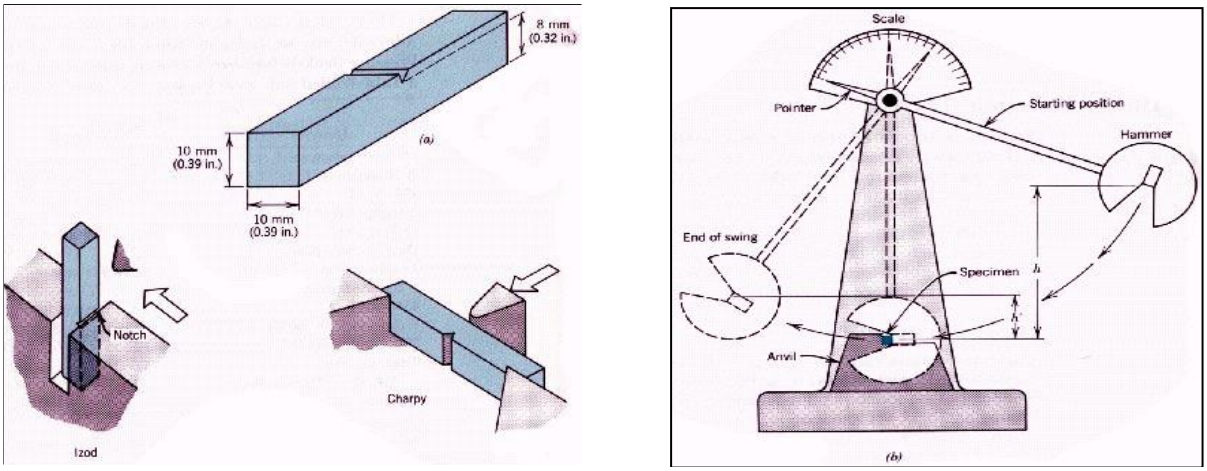


Figure 1: Schematic Drawing of a Standard Impact-Testing Apparatus [Callister, 1991]

The impact load can be applied in many ways. Allowing a standard mass to fall on the specimen from progressively increasing heights until fracture occurs. For laboratory testing, Charpy and Izod impact tests are used (Figure1). In the Charpy test, the specimen is supported as a simply supported beam and a notch is cut across the middle of one face, and the mass hits the opposite face directly behind the notch. While in Izod impact test, the specimen is a cantilever, clamped upright in an anvil, with a V-notch at the level of the top of the clamp. These notched specimens are fractured with a standard blow from a pendulum hammer and energy absorbed is measured. In addition to these beam type of specimens there are also tension and shear or torsion specimen, which can be used with special type of testing machines. In any case, the distribution of stress throughout the impact test specimen is not known and the test results are therefore mainly comparative, even though they have some correlation with the fracture toughness.

A typical ductile-to-brittle transition curve obtained after performing a number of tests at different temperatures is shown in Figure 2. As the temperature is reduced through the transition range, the fracture surface changes from one having a 'fibrous' or 'silky' appearance with much distortion at the sides, to one of completely crystalline appearance with negligible distortion. There is a strong correlation between the energy absorbed and the proportion of the cross-section which suffers deformation in fracture, and the fracture surface is frequently described in terms of the percentage of its area which is crystalline in appearance. Usually fracture surface appearances with crystallinity increases as the temperature is reduced.

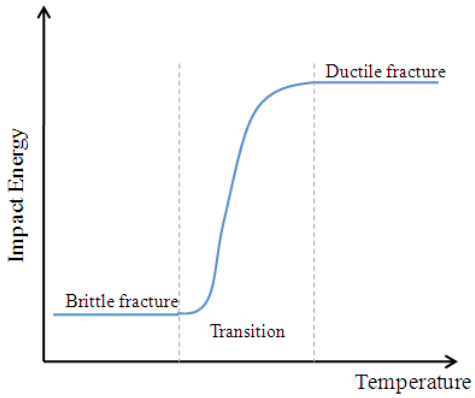


Figure 2: Typical Ductile-to-Brittle Transition Curve

Procedure:

1. Note down the dimensions of the specimen and find the working area of the specimen at the place of notch.
2. With no specimen on the anvil, raise the pendulum to an initial reading R1 in the dial and release it.
3. Note the reading R2 of the dummy pointer on the dial. The difference is the energy loss due to friction.
4. Now place the specimen accurately in position on the anvil.
5. Raise the pendulum to the same initial height and release. The pendulum swings to the other side rupturing the specimen.
6. Note the reading R3 on the dummy pointer on the dial.
7. Tabulate the reading.
8. Repeat the procedure for change in temperature and examine the variation of impact strength.

Report:

1. Find out the energy loss due to friction in joule.
2. Find out the energy of rupture in J for various specimens.
3. Find the impact strength, Energy absorbed / area, (J/m2)
4. Plot the variation of impact strength with the change in temperature.
5. Write your observations in a bulleted list based on the data you obtained and the results computed from that data.

References:

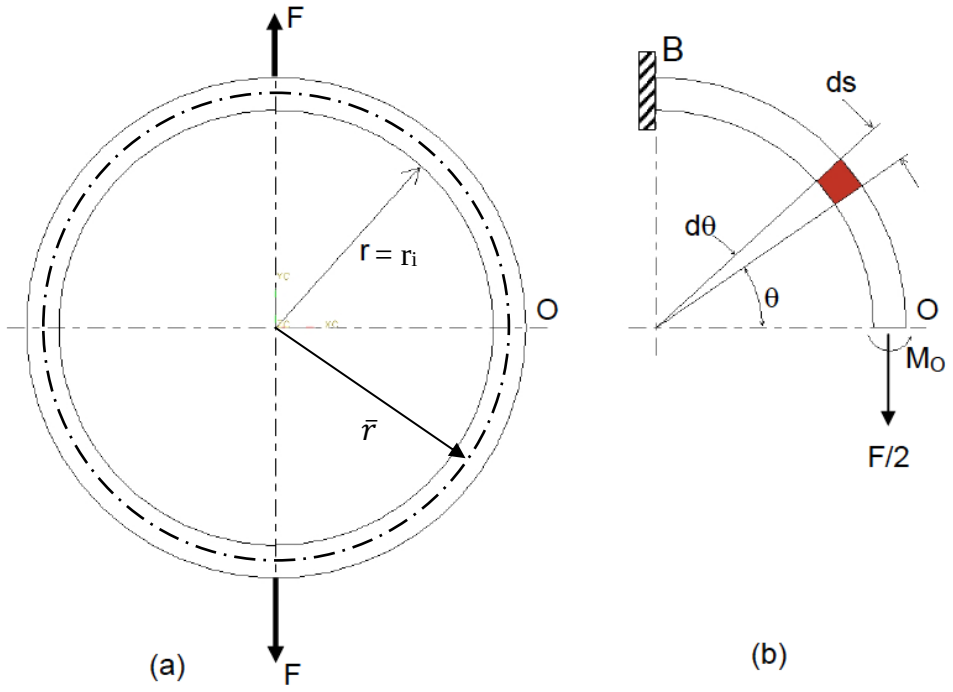
Callister, W. D., Materials science and engineering: An introduction, Wiley (New York), 1991.

Strains in a Ring under Combined Bending and Extension

Objective: (a) To measure strains using bonded foil strain gauges in combination with a Wheatstone Bridge. (b) Compare with linear elastic solution in a "proving" ring (circular beam with rectangular cross-section) subjected to combined extension and bending with strains measured from experiment.

Equipment and Tools: Venier calipers, strain measuring bridges with bonded foil gauges, circular ring, weights and weight hanger.

Theory:A thin ring of internal radius r_i subjected to a diametrical pull F is shown in the figure (a) below. Using symmetry the free body diagram of a quarter ring is shown in figure (b). At $\theta = 0$, the shear force is zero and hence only an axial load of $F/2$ and bending moment M_0, which is indeterminate are acting on the cross-section. Using energy method, the bending moment at any θ can be calculated and is given by:
$M_\theta = \frac{Fr}{2}\left(cos\theta - \frac{2}{\pi}\right)$, which gives at $\theta = 0$, $M_0 = \frac{Fr}{2}\left(1 - \frac{2}{\pi}\right)$.



Unlike in a straight beam the neutral axis does not coincide with the centroid of the cross-section in the case of a curve beam. So, it is important to know the location of the neutral axis. By definition neutral axis is the fiber along which there is not stress due to bending, which is found by setting the integral of axial force over the entire cross-section equal to zero. This gives us the location of the neutral axis as:

$$R = \frac{\int dA}{\int \frac{dA}{r}} = \frac{A}{\int \frac{dA}{r}} = \frac{bh}{\int_{r_i}^{r_o} bdr/r} = \frac{h}{ln\left({}^{r_o}/_{r_i}\right)} = \frac{r_o - r_i}{ln\left({}^{r_o}/_{r_i}\right)}$$

where, b is the width of the ring, r_i and $r_o$are the inner and outer radii of the ring with $h = r_o - r_i$. So, at any r from the center of the ring, the axial stress due to bending at is given by:

$$\sigma_b(r) = E\varepsilon = E\kappa\frac{R-r}{r} = \frac{M}{A(\bar{r}-R)}\left(\frac{R-r}{r}\right) = \frac{M(R-r)}{Ar(\bar{r}-R)} = \frac{My}{A(R-y)(\bar{r}-R)} = \frac{My}{A(R-y)e}$$

Here, y is the distance of the fiber from the neutral axis, $e = \bar{r} - R$ is the eccentricity, $\bar{r} = \int \frac{rdA}{A}$, κ is the curvature, E is the elastic modulus. The value of $\bar{r}$ for the rectangular beam is the mean of the inner and outer radii, i.e., $\bar{r} = \int_{r_i}^{r_o} brdr/bh = \frac{r_o + r_i}{2}$.

Note that the maximum value of bending moment is at the point of application of the load. Since, we are using linearized elasticity on a curved beam and an axial load $F/2$ is acting on the cross-section, the stress in the cross-section is due to combined bending and axial loads. The combined axial stress at any fiber on beam is given by:

$$\sigma(r) = \frac{F}{2A} + \frac{My}{A(R-y)e}$$

The stress at the horizontal cross-section, i.e., at $\theta = 0$, using $r = R\text{-}y$, is then give by

$$\sigma(r) = \frac{F}{2A} + \frac{M_0 y}{A(R-y)e} = \frac{F}{2A} + Fr\left(\frac{1}{2} - \frac{1}{\pi}\right)\frac{y}{A(R-y)e} = \frac{F}{2A} + F\left(\frac{1}{2} - \frac{1}{\pi}\right)\frac{y}{Ae}$$

which implies the strain at the inner and outer surfaces of the ring at $\theta = 0$ are:

$$\varepsilon_i = \frac{F}{2EA} + F\left(\frac{1}{2} - \frac{1}{\pi}\right)\frac{(R-r_i)}{AEe} \; and \; \varepsilon_o = \frac{F}{2EA} + F\left(\frac{1}{2} - \frac{1}{\pi}\right)\frac{(R-r_o)}{AEe}$$

Procedure:

Measure the dimensions of the ring. Mount ring on a fixture. Connect the strain gauges to strain measuring bridge. Load the ring in diametrical opposite direction and note the strain value at various loads. Note, before starting the measurements, balance the Wheatstone bridge. If the bridge is not automatically balancing, report to the TA as there could be a problem with the strain gauge.

Report:

1.Plot the load-unload strains on all the four gauges.

2. Compare them with theoretical values.

3. Write your observations based on the results.

Torsion of a Circular Shafts

Objective: The aim of experiment is to obtain torque-twist relationship for an aluminum circular shaft and compare the result with theoretical predictions.

Equipment and Tools: Torsion setup, solid circular rod of Al, Vernier calipers.

Theory: **Inelastic torsion:**Figure below shows the typical stress-strain relationship for metals. The initial portion is linear where the material response is elastic. Once the stress exceeds *yield stress*, the relationship is no longer linear and the material response is referred to as plastic. The material displays strain-hardening, whereby the slope of curve beyond yield point increases with strain. For our analysis here, we will approximate this strain hardening response by a horizontal line. Such material response is called elastic-perfectly plastic material behavior.

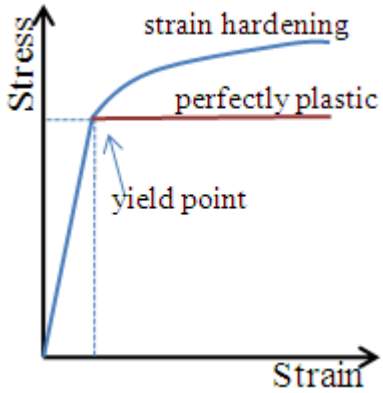


Figure E2.1: Stress-strain relationship in metals

When metal shaft is subjected to sufficiently high torque, plastic deformation starts at outermost fiber first and moves inwards as torque is increased further. Evidently for a particular torque value, the entire cross section is in a state of a plastic deformation. For an elastic perfectly plastic shaft, beyond this point, the shaft cannot resist further torque applied. Such a torque value is called limiting torque (T_L) for the shaft. The Torque (T)-twist (θ), for perfectly plastic material is given by,

$$T = (4/3)\, T_Y\, (1 - 0.25(\theta_Y/\theta)^3)$$

where T_Y and θ_Y represent, respectively, the torque and the angle of twist at the onset of yield. The torque T_Y is given by

$$T_Y = (J*\tau_Y)\ /R$$

where J is polar moment of inertia of the circular shaft and $\tau_Y$is the yield stress in shear. Thus limit torque is given by $T_L = (4/3)\, T_Y$, when $\theta_Y = 0$.

One of our objectives is to estimate the deviation between results obtained for a perfectly plastic material and the experimental results. The real material will most likely strain-harden and cause deviations from the perfectly plastic material predictions.

Procedure: Mount the sample in the torsion setup, choose the gauge length and set the optical encoder for measuring the twist angle. Load the sample at a constant rate of twist and collect the torque vs. twist angle data.

Report: (a) Plot the torque vs. twist angle and extract the approximate value of torque at yield. (b) Compute the limiting torque from the plot when the torque vs. twist angle plot becomes flat (no hardening) and compare this value with the theoretical value.

References

Beer, F., Johnston, Jr.,E.,R., Dewolf, J., Mechanics of Materials, McGraw-Hill , 2005.
Timoshenko, S.P., Goodier, J.N., Theory of Elasticity, Mcgraw-Hill.
Srinath, L.S., Advanced mechanics of Solids, Tata-Mcgraw-Hill, 2002.

List of key words associated with the experiments

Impact test
Toughness, impact energy, Charpy impact test, toughness variation with temperature, thermocouple

Hardness test
Hardness, Rockwell hardness, HRB & HRC, ball indenter, diamond cone indenter

Torsion test
Torsion of circular sections, shear modulus, yield stress in shear, torque v/s angle of rotation diagram, torsional stress distribution over the section

Photoelasticity test
Circular and plane polariscope, stress concentration, isoclinics, isochromatics, birefringence, stress optic law

Determination of strain in circular ring
Strain gauge, strain indicator, stresses in curved beams, wheatstone's bridge, quarter bridge

Tension test
Load cell, Universal testing machine, extensometer, Load v/s strain plot, stress v/s strain curve for mild steel, Young's modulus, proportionality limit, elastic limit

Digital Image Correlation
Speckle pattern, subset, region of interest, camera, lens, alignment, correlation, displacement field

Rotating bending Fatigue test
Mean stress, stress amplitude, Endurance limit, Stress v/s Life plot for metals, notch sensitivity, stress concentration

Large deflection of cantilever beam
Euler- Bernoulli beam theory, Nonlinear beam theory, large deflections, load v/s horizontal/ vertical deflection curves

Reciprocal and superposition theorem
Deflection of simply supported beam, Betti principle, Maxwell reciprocal theorem, superposition theorem, differential equation of the deflection curves

Curved beam bending
Superposition, curvature, beam, combined loading, neutral axis, strain gauge, Wheatstone bridge

Compression Experiment
Compliance, compressive stress, elastic modulus, buckling, shearing, platen