Practical Workbook

MY-410: Fracture Mechanics and Failure Analysis

Name _____
Roll No _____
Batch_____
Year_____
Department_____

Department of Metallurgical Engineering
NED University of Engineering and Technology,
Karachi-75270, Pakistan

Practical Workbook

MY-410: Fracture Mechanics and Failure Analysis

UPDATED BY

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(Assistant Professors, MYD)

This is to certify that this practical book contains 40 pages.

Approved by:

Chairman MYD

Department of Metallurgical Engineering
NED University of Engineering and Technology,
Karachi-75270, Pakistan

CERTIFICATE

It is certified that Mr. / Ms._____student of class _____Batch_____, bearing Roll No. MY _____ has completed his / her coursework **FRACTURE MECHANICS & FAILURE ANALYSIS (MY-410) as** prescribed and approved by the Board of Review of the Metallurgical Engineering Department.

His/her performance is reflected by the performance rubrics of his/her practical workbook. The student's overall performance will address the assigned learning attribute.

_____

Course Teacher

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Experiment No. 1

Aim of the Experiment

To study the lab safety rules

Safety Rules

1. Always wear safety goggles to protect your eyes from possible injury. Wear glasses rather than contact lenses unless you have permission from the instructor.
2. Long hairs flying everywhere (into motors, or other testing equipment) are not allowed.
3. Tie your loose clothing and remove jewelry when you work at the lab station. Roll up loose sleeves that might fall into chemicals or become caught on equipment. Wear lab aprons.
4. Do not wear open-toed shoes or sandals in the lab.
5. Keep your lab work area clear of any materials that are not needed for performing the experiment. Texts, notebooks, backpacks, sweaters and other materials should be stored away from the work area. Push in stools when not in use and as you leave the lab area.
6. Handle all equipment as directed.
7. Handle all sharp instruments with extreme care. Remember that they are considered weapons if they go out of the room or are handled in an inappropriate manner. Never try to catch falling sharp instruments.
8. Use tongs or a clamp to pick up hot containers. Test the temperatures of equipment and containers that have been heated by placing the back of your hand near any object before picking it up. If you can feel heat, the object might be too hot to handle. Do not place hot apparatus directly on lab desks.
9. Dispose of materials only as directed.
10. Never eat, drink, or chew gum in the lab. Never eat or drink from lab equipment.
11. Perform only those experiments authorized by your teacher. Never do an experiment that is not called for in the laboratory procedures or your instructor.
12. Do not work alone in the lab. When entering the room, do not touch any equipment, chemicals in the laboratory area until you are instructed to do so.
13. Stand to the side and away from front of testing machines while testing.
14. Hands should be washed after the experiment has been completed.

Questions

Q1: What will you do in case of emergency or accident?

Q2: Why safety rules are important in the workplace of material testing lab?

Q3: How would you handle instruments with sharp edges or corners?

Q4: Write down the importance of lab safety rules?

Experiment No. 2

Aim of the Experiment

Follow the recommendation and use the techniques for handling and Preservation of Fracture Specimens

Introduction

The importance of proper sample preservation and handling in the process of accurate materials analyses cannot be over emphasized. If samples are not cared for properly, important information may destroyed, adulterated, or obscured. At the very least, improper handling introduces a measure of uncertainty into the analytical results. Thus, a few general principles are presented here to help preserve samples and the often critical data they contain. Please note that the principles presented here are not all encompassing. If you are uncertain how to best preserve and transfer a sample, contact the analytical laboratory directly for advice and instructions.

Causes to damage the fracture surface:

1. Chemical damage of the fracture surface that occurs after the fracture event is the result of environmental conditions present after the fracture.
2. Touching a fracture surface with the fingers will introduce moisture salts that may chemically attack the fracture surface.
3. Mechanical damage of the fracture surface that occurs after the fracture event usually results from handling or transporting of the fracture. It is easy to damage a fracture surface while opening primary cracks, sectioning the fracture from the total part, and transporting the fracture. Other common ways of introducing mechanical damage include fitting the two fracture halves together or picking at the fracture with a sharp instrument.

Commandments of sample preservation and handling

Don't Touch. Avoid touching the sample or area of interest with bare hands. Fingers inherently have significant amounts of organic and inorganic compounds that can contaminate the sample. Additionally, your fingers may pick up foreign material and transfer it to the sample or remove important deposits from the sample surface.

If you use your hands to handle small samples, wear gloves. However, even gloves may transfer a certain amount of foreign material. Use clean tweezers or other handling tools for small samples.

As a rule of thumb, keep handling to a minimum, including poking, prodding, or scratching with tools or instruments. Such equipment may contaminate or destroy important material. Fracture surfaces especially prone to physical damage that can inhibit accurate analysis. Simply touching mating fracture surfaces back together after a failure will destroy microscopic fracture features that may be the key to a conclusive determination of the fracture mode.

Choose samples wisely. Select samples for analysis that are representative of what you are trying to determine, i.e., typical contamination or typical material. In many cases, a control sample of "normal" material or components may be very useful as a comparison with failed or problem components. In some cases, several specimens may need to be submitted to determine commonalities or a range of conditions.

Preserve sample integrity. Obtain samples in a way that does not influence the measurements to be made. If a sample must be cut or removed from larger piece, care must be taken not to contaminate or alter the area of interest. For example, the heat generated by flame cutting a metal sample may alter its microstructure and mechanical properties. Scraping on a hard surface with a metal instrument can produce wear debris from the instrument which is added to the component surface or to the collected surface deposits.

Submit a sample of appropriate size. Thermal analysis may require only a few milligrams. Quantitative chemical analysis may require a large surface area of several square millimetres or a few grams of material. If in doubt as to appropriate sample size, contact the analytical laboratory.

Preserve sample. Special sample handling and storage are often required to prevent potential changes in sample morphology and/or composition between time of sampling and analysis. Oxidation, evaporation, thermal degradation, or chemical interaction may occur if samples are not properly preserved. Store samples in clean containers. This normally means new containers or those known to have been properly cleaned. Even if a previously used container appears clean, it may contain microscopic particles or liquids which could contaminate your sample and introduce uncertainty in the analytical results. If a sample must be shipped, package in such a way as to limit contamination or physical damage.

Avoid tape. Do not wrap samples or small particles in tape. Tape may leave an adhesive residue or remove critical sample constituents. Tape residue can create significant interference and uncertainty, particularly for analysis of organic compounds.

Identify and label. Clearly mark the sample containers to identify the contents. The source of the sample and, if applicable, its location within the source component should be recorded. Indicate the area of interest with a diagram rather than marking on the sample if possible. Data from the best preserved samples are meaningless if the sample and area of interest are not properly identified.

Obtain background data. Include significant background information about the sample and good instructions to the analyst with the sample. Provide a clear mandate for the analysis goals, i.e., explain why the analysis is requested. Background information about the sample that may help the analyst includes: where did it come from, what is it used for, and what has it been exposed to.

Provide control samples when possible. Submit a reference or control material(s) with the sample. A control sample will give you a baseline for comparison. If you are attempting to identify an unknown contamination, submit suspected sources of contamination along with the unknown for comparison. If an unusual condition is to be evaluated, comparison with a "normal" sample can be very useful.

Contact the analytical laboratory for specific sample preservation, handling, and shipping recommendations. Fractures, even those of hard or high strength metals, are fragile and subject to mechanical and environmental damage that can destroy important microstructural features. Thus, fractures must be handled with great care from sampling through analysis.

Specific guidelines for handling fractures

Fractures, even those of hard or high strength metals, are fragile and subject to mechanical and environmental damage that can destroy important microstructural features. Thus, fractures must be handled with great care from sampling through analysis.

First, a fracture surface should be preserved as soon as possible following the failure to prevent environmental attack, such as corrosion or oxidation. Ideally, the fracture and surrounding surfaces should be dried with air and stored in a dry environment. At a minimum, the fracture area should loosely cover to protect it from rain or incidental physical damage. The fracture should not be sealed in an airtight container where water could condense and corrode the fresh fracture surface. If adequate protection or storage in a dry environment is not possible, the fracture may be coated with oil, grease, or other material that will protect the surface, but not chemically attack it. (Do not coat surface if corrosion appears to a factor in the failure.) The coating used should be easily and completely removable for the subsequent analysis.

Do not try to fit two fracture halves together or pick at fracture surface, as this will mechanically damage critical surface features. If the fracture must be removed from a larger part, make the cut far away from the fracture site. Package so as to prevent any contact with the fracture surfaces. Small bumps and dings can significantly affect the fracture morphology. Wrap each component of the failure separately.

Questions

Q1: Why it is important to preserve the fractured surface?

Q2: How can the fracture surface be damaged?

Q3: How would you preserve and handle your sample?

Experiment No. 3

Aim of the Experiment

Follow the cleaning of fracture specimen via ultrasonically in an organic solvent

Theory

Fracture surfaces exposed to various environments generally contain unwanted surface debris, corrosion or oxidation products, and accumulated artifacts that must be removed before meaningful fractography can be performed. Before any cleaning procedures begin, the fracture surface should be surveyed with a low-power stereo binocular microscope, and the results should be documented with appropriate sketches or photographs. Low-power microscope viewing will also establish the severity of the cleaning problem and should also be used to monitor the effectiveness of each subsequent cleaning step. It is important to emphasize that the debris and deposits on the fracture surface can contain information that is vital to understanding the cause of fracture. Examples are fractures that initiate from such phenomena as SCC, LME, and corrosion fatigue. Often, knowing the nature of the surface debris and deposits, even when not essential to the fracture analysis, will be useful in determining the optimum cleaning technique.

Organic-solvent cleaning

Organic solvents, such as xylene, naphtha, toluene, Freon TF, ketones, and alcohols, are primarily used to remove grease, oil, protective surface coatings, and crack-detecting fluids from the fracture surface. It is important to avoid use of the chlorinated organic solvents, such as trichloroethylene and carbon-tetra-chloride, because most of them have carcinogenic properties. The sample to be cleaned is usually soaked in the appropriate organic solvent for an extended period of time, immersed in a solvent bath where jets from a pump introduce fresh solvent to the fracture surface, or placed in a beaker containing the solvent and ultrasonically cleaned for a few minutes. The ultrasonic cleaning method is probably the most popular of the three methods mentioned above, and the ultrasonic agitation will also remove any particles that adhere lightly to the fracture surface. However, if some of these particles are inclusions that are significant for fracture interpretation, the location of these inclusions relative to the fracture surface and the chemical composition of these inclusions should be investigated before their removal by ultrasonic cleaning.

Procedure: (write in your own words)

Observations

Observe and take photographs of the fracture specimen under the stereomicroscope every 3 minutes after cleaning (3 times at least).

3 min	**6 min**	**9 min**

Results

Questions

Q1: What are the other 5 common techniques are used for cleaning, in list their name?

Q2: Why chlorinated organic solvent are avoided for cleaning the fracture specimen?

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Psychomotor Domain Assessment Rubric-Level P3					
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Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
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Procedural Skills ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
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Laboratory Session No. _____ Date: _____

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

Experiment No. 4

Aim of the Experiment

Operate Stereo Microscope **under supervision** to determine Ductile and/or Brittle fracture using

Theory

Ductile & Brittle Fracture

Brittle fractures and ductile fractures are two of the best known failure modes. The factors that control both brittle and ductile fracture revolve around the energy that must be provided to extend the fracture by a microscopic distance and the amount of elastic strain energy that is concurrently made available by that microscopic crack extension. If the elastic strain energy being released exceeds the energy required for crack extension, then we have spontaneous fracture.

The crack stops growing either when it reaches the end of the part (the part breaks), or the energy required for crack extension exceeds the strain energy being released by that same crack extension and we have crack arrest. This happens, for example when a crack grows through an area under tensile stress and then stops when it runs into an area of stress that is reduced or compressive.

Ductile materials - extensive plastic deformation and energy absorption ("toughness") before fracture.

Brittle materials - little plastic deformation and low energy absorption before fracture.

Some Characteristics of Brittle Fracture

1. There is no gross, permanent deformation of the material, fracture surface is smooth and shiny.
2. The surface of the brittle fracture tends to be perpendicular to the principal tensile stress although other components of stress can be factors.
3. Characteristic crack advance markings frequently point to where the fracture originated.
4. The path the crack follows depends on the material's structure. In metals, transgranular and intergranular cleavage are important.

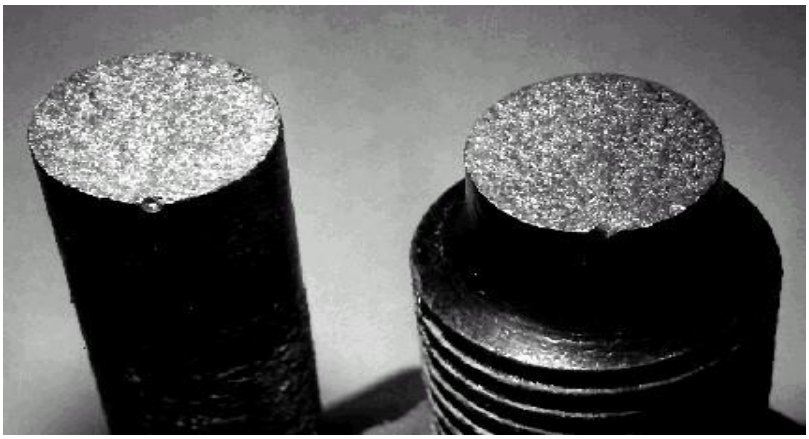

Figure 1: Brittle fracture in mild steel

Some Characteristics of Ductile Fracture

1. There is permanent deformation at the tip of the advancing crack that leaves distinct patterns.
2. As with brittle fractures, the surface of a ductile fracture tends to be perpendicular to the principal tensile stress, although other components of stress can be factors.
3. In ductile, crystalline metals and ceramics it is microscopically resolved shear stress that is operating to expand the tip of the crack.
4. The fracture surface is dull and fibrous.
5. There has to be a lot of energy available to extend the crack.

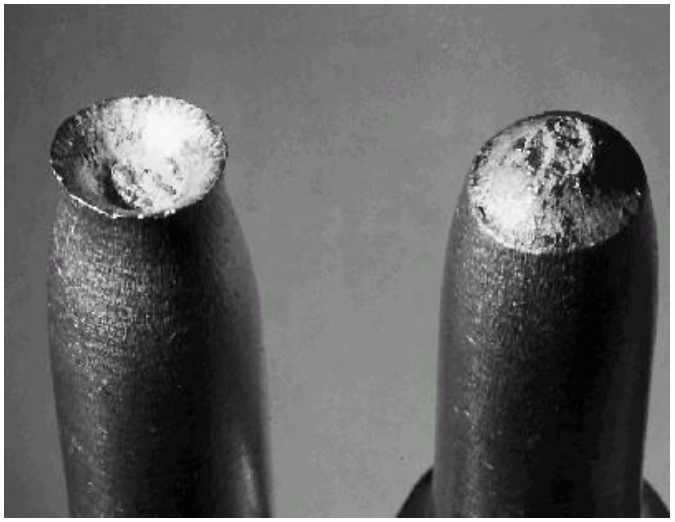

Figure 2: Cup-and-cone fracture in Al

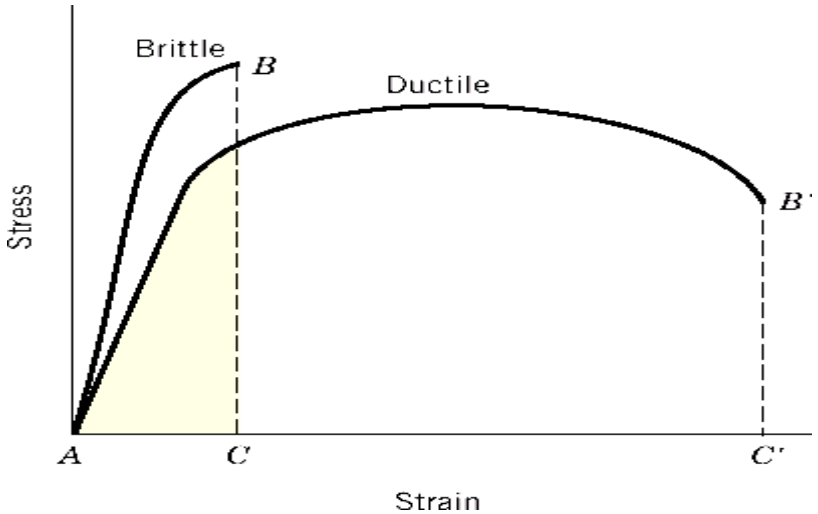

Figure 3: Stress-strain behaviour for ductile and brittle materials

Stereo microscope

The stereo microscope uses two separate optical paths with two objectives and two eyepieces to provide slightly different viewing angles to the left and right eyes. In this way it produces a three-dimensional visualization of the sample being examined. The stereo microscope is often used to study the Fracture surfaces of solid specimens and to carry out close inspection of the failed part.

Stereoscopes with specially equipped illuminators can be used for dark field microscopy, using either reflected or transmitted light. Great working distance and depth of field here are important qualities for this type of microscope. Both qualities are inversely correlated with resolution: the higher the resolution (i.e., the shorter the distance at which two adjacent points can be distinguished as separate), the smaller the depth of field and working distance. A stereo microscope has a useful magnification up to 50×.

There are two major types of magnification systems in stereo microscopes. One is fixed magnification in which primary magnification is achieved by a paired set of objective lenses with a set degree of magnification. The other is zoom or pancreatic magnification, which are capable of a continuously variable degree of magnification across a set range. Zoom systems can achieve further magnification through the use of auxiliary objectives that increase total magnification by a set factor. Also, total magnification in both fixed and zoom systems can be varied by changing eyepieces.

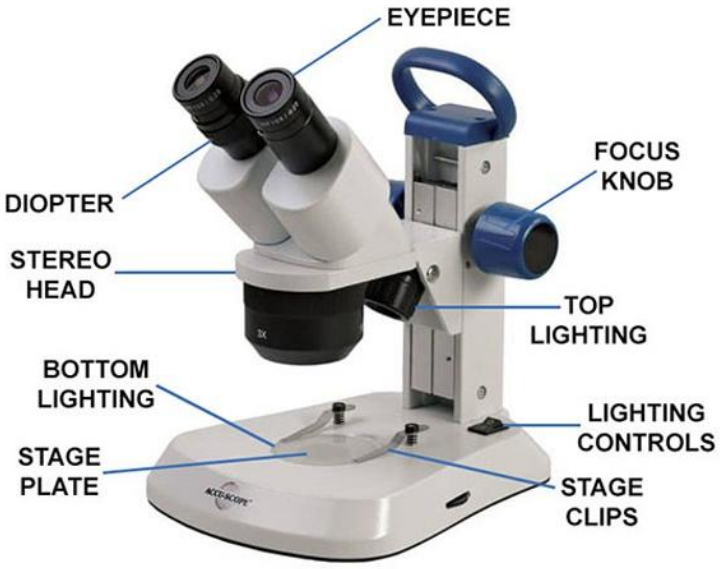

Figure 4: Stereo Microscope

Observations

Results

Questions

1. Observe the brittle fracture surface at 10x, 20x, 40x magnifications on stereo microscope and write down your comments.

2. Observe the ductile fracture surface at 10x, 20x, 40x on stereo microscope and write down your comments.

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Experiment No. 5

Aim of the Experiment
Study of Ductile and Brittle fracture using Scanning Electron Microscope (SEM)

Introduction
We are already familiar with properties of ductile and brittle materials. In this experiment we will examine the fracture surfaces at higher magnification using Scanning Electron microscope (SEM). SEM plays an important role in failure+*- analysis because it provides us information at very high magnification and higher depth of field.

The Scanning Electron Microscope (SEM) is a microscope that uses electrons rather than light to form an image. There are many advantages to using the SEM instead of a light microscope.
The SEM has a large depth of field, which allows a large amount of the sample to be in focus at one time. The SEM also produces images of high resolution, which means that closely spaced features can be examined at a high magnification. Preparation of the samples is relatively easy since most SEMs only require the sample to be conductive. The combination of higher magnification, larger depth of focus, greater resolution, and ease of sample observation makes the SEM one of the most heavily used instruments in research areas today.

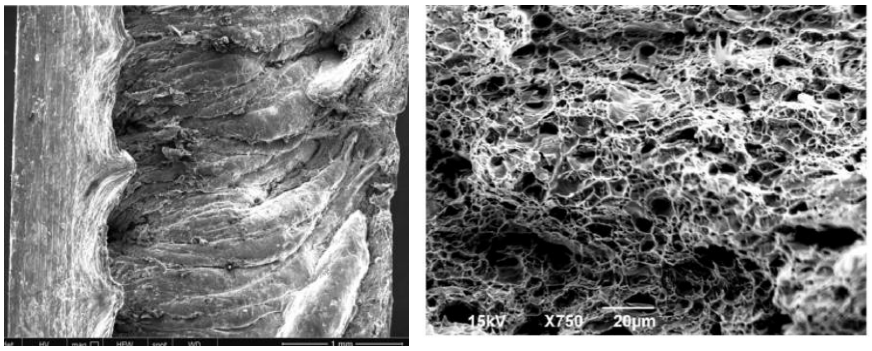


Figure 1: Micrographs of brittle and ductile fracture

Characteristics of a SEM
Magnification
Magnification is the ratio of scanned area to the display area. For most SEM: 10-200,000x (or more).
Useful Magnification: ~20,000x

Resolution
Theoretical Limit of Resolution: 50 Å (5 nm) Practical Resolution: 200 Å (20 nm)
The resolving power of the SEM depends primarily on the effective beam diameter of the probe (spot size). For two points having an inter-point distance, *d*, to be resolved, spot size must be smaller than *d*.

Depth of Field
Depth field of the SEM is the greatest among microscopes:
20 mm at 10X
5 μm at 10,000X
Large depth of field is a great advantage for keeping in focus all parts of a rough Topography, but a compromise must be made between field depth and resolution.

Procedure

A detailed explanation of how a typical SEM functions follows (refer to the diagram below):

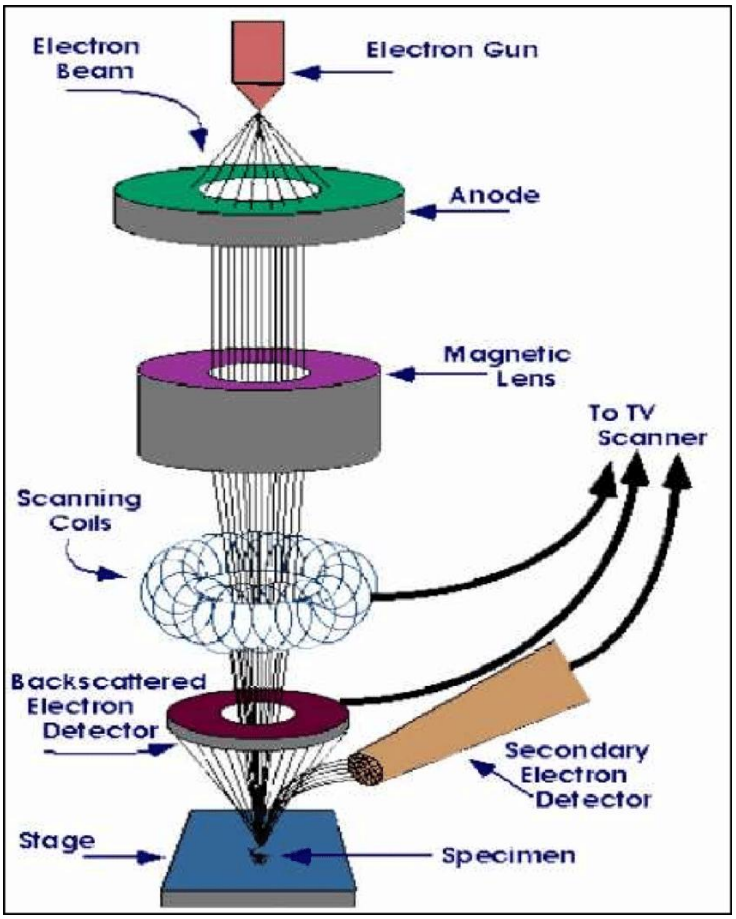


Figure 2: Schematic of SEM

1. The "Virtual Source" at the top represents the electron gun, producing a stream of monochromatic electrons.
2. The stream is condensed by the first condenser lens (usually controlled by the "coarse probe current knob"). This lens is used to both form the beam and limit the amount of current in the beam. It works in conjunction with the condenser aperture to eliminate the high-angle electrons from the beam
3. The beam is then constricted by the condenser aperture (usually not user selectable), eliminating some high-angle electrons
4. The second condenser lens forms the electrons into a thin, tight, coherent beam and is usually controlled by the "fine probe current knob"
5. A user selectable objective aperture further eliminates high-angle electrons from the beam
6. A set of coils then "scan" or "sweep" the beam in a grid fashion (like a television), dwelling on points for a period of time determined by the scan speed (usually in the microsecond range)
7. The final lens, the Objective, focuses the scanning beam onto the part of the specimen desired.
8. When the beam strikes the sample (and dwells for a few microseconds) interactions occur inside the sample and are detected with various instruments
9. Before the beam moves to its next dwell point these instruments count the number of interactions and display a pixel on a CRT whose intensity is determined by this number (the more reactions the brighter the pixel).
10. This process is repeated until the grid scan is finished and then repeated, the entire pattern can be scanned 30 times

Observations

Results

Questions

1. Examine the brittle fracture surface at very high magnifications i.e., at above 2000x. Give comments about your observation.

2. Examine the ductile fracture surface at very high magnifications i.e., at above 2000x. Give comments about your observation.

3. How can you explain the different fracture surface appearances?

Experiment No. 6

Aim of the Experiment

To carry out the analysis of fatigue failure

Theory

Fatigue

Fatigue is a form of failure that occurs in structures subjected to dynamic and fluctuating stresses (e.g., bridges, aircraft, and machine components). Under these circumstances it is possible for failure to occur at a stress level considerably lower than the tensile or yield strength for a static load. The term "fatigue" is used because this type of failure normally occurs after a lengthy period of repeated stress or strain cycling. Fatigue is important in as much as it is the single largest cause of failure in metals, estimated to comprise approximately 90% of all metallic failures; polymers and ceramics (except for glasses) are also susceptible to this type of failure. Furthermore, fatigue is catastrophic and insidious, occurring very suddenly and without warning.

Mechanism

Fatigue failures generally involve three stages:
1. Crack Initiation,
2. Crack Propagation, and
3. Fast Fracture

1. **Crack Initiation:** The initial crack occurs in this stage. The crack may be caused by surface scratches caused by handling, or tooling of the material; threads (as in a screw or bolt); slip bands or dislocations intersecting the surface as a result of previous cyclic loading or work hardening.
2. **Crack Propagation:** The crack continues to grow during this stage as a result of continuously applied stresses
3. **Failure:** Failure occurs when the material that has not been affected by the crack cannot withstand the applied stress. This stage happens very quickly.

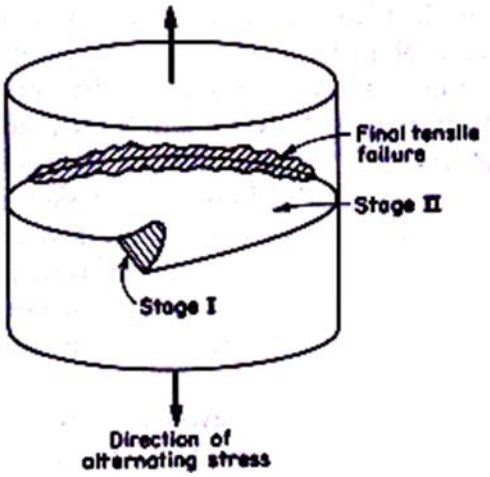


Figure 1: A diagram showing location of the three steps in a fatigue fracture under axial stress

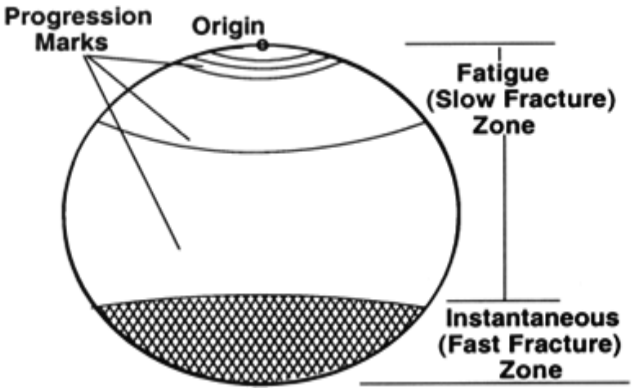


Figure 2: Macroscopic surface features

S-N curve

Data obtained by fatigue testing are plotted as stress versus the logarithm of the number of cycles to failure. For many metals and alloys, stress diminishes continuously with increasing number of cycles at failure; fatigue strength and fatigue life are the parameters used to characterize the fatigue behavior of these materials. On the other hand, for other metals/alloys, at some point, stress ceases to decrease with, and becomes independent of, the number of cycles; the fatigue behavior of these materials is expressed in terms of fatigue limit.

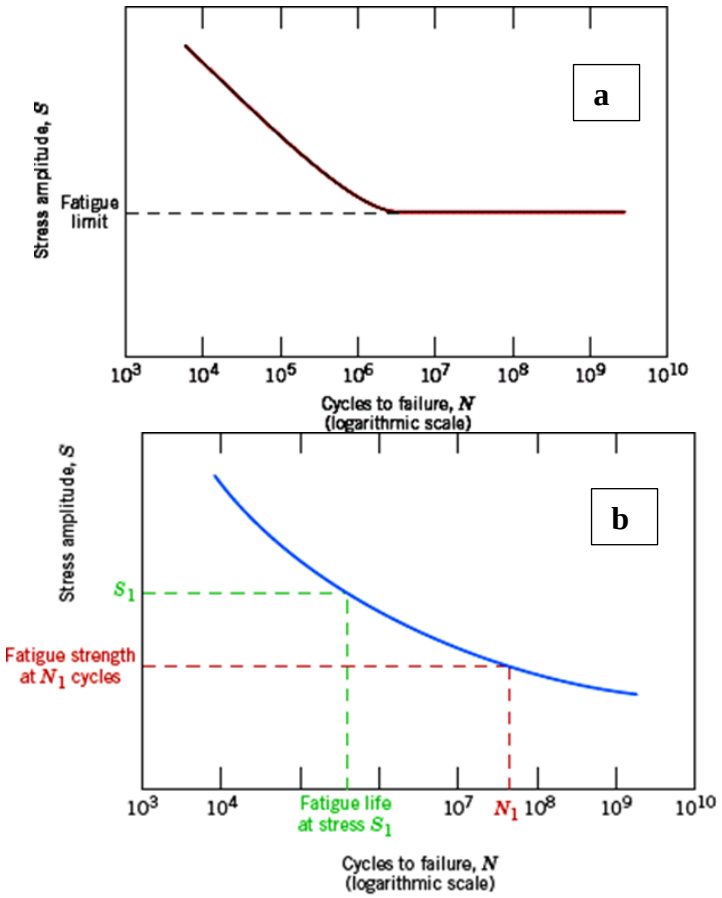


Figure 3(a & b): shows the stress versus the logarithm of the number of cycles to failure

Modes of failure

Applied stresses may be axial (tension-compression), flexural (bending) or torsional (twisting) in nature. In general, there are three possible fluctuating stress-time modes possible. The simplest is completely reversed constant amplitude where the alternating stress varies from a maximum tensile stress to a minimum compressive stress of equal magnitude. The second type, termed repeated constant amplitude, occurs when the maxima and minima are asymmetrical relative to the zero-stress level. Lastly, the stress level may vary randomly in amplitude and frequency which is merely termed random cycling.

Factors Affecting Fatigue Properties

Fatigue cracks initiate at the surface of the stressed material, where the stresses are at a maximum. Any design or manufacturing defect at the surface concentrates stresses and encourages the formation of a fatigue crack.

Similarly, temperature influences the fatigue resistance. As the temperature of the material increases, the strength decreases and consequently both fatigue life and endurance limit decrease.

Fatigue testing

For good testing we need more accurate control of the cyclic load and this can be done by a rotating bending machine, shown in Figure. In this machine, a cylindrical smooth specimen is mounted and loaded from both ends using rotating chucks. A weight is suspended from one side of the specimen to vary the bending stresses experienced by the specimen surface.

Initially, the specimen will experience tensile stresses at its top surface and compressive stresses at its bottom. As the specimen rotates 180 degrees, the stresses will be reversed, and the top will be under compressive stresses while the bottom will be under tensile stresses. When the specimen completes one full rotation, the specimen surfaces would have experienced one full loading cycle.

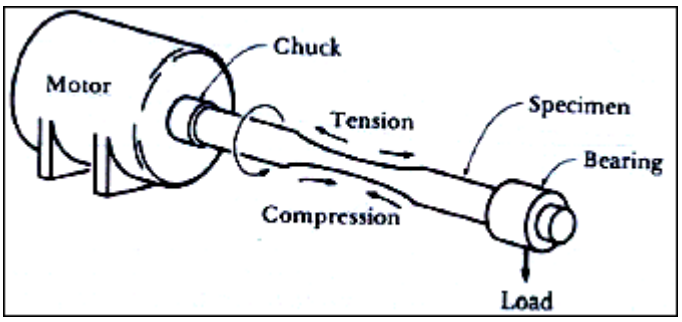


Figure 4: Fatigue rotating bending machine

Procedure

Because fatigue testing is time consuming and requires a large number of specimens to generate an S-N curve, we will limit testing to few samples as a demonstration. The following procedure is followed:

1. Measure the dimension of the steel specimen provided to you by your instructor.
2. Write down the surface finish of the specimen (ask your instructor).
3. Mount the specimen in the rotating bending machine.
4. Record the weight and measure the distance needed to calculate the bending moment.
5. Zero the counter.
6. Start the machine and wait until the specimen is broken.
7. Write down the number of cycles to failure.
8. Repeat the test with different weights.

9. Observe the fractured specimen in the optical and in the scanning electron microscope.
10. Plot the S-N data in the full S-N curve for the same material.
11. Note and discuss any disagreement between your data and the supplied S-N curve.

Observations

_____

_____

_____

_____

_____

Results:

_____

_____

_____

_____

Questions

Q1: Why do materials behave differently under dynamic loads compared to static loads?

Q3: What factors affects the fatigue life of material?

Q4: How the fatigue life of component can be improved?

Q6: Which kind of failure, brittle like or ductile like, does fatigue cause?

Q8: What does “endurance limit” mean in a S-N fatigue curve?

Experiment No. 7

Aim of the Experiment

Operate under supervision to determine the ductile-brittle transition temperature, DBTT, therefore determining the impact energy for the type of specimen provided, at different temperature

Apparatus/Materials

Charpy impact testing machine, beaker of boiling water, one of ice water, Dewar flask of liquid nitrogen, standard V-notch Charpy impact specimens.

Theory

Fracture

The ultimate mechanical failure is fracture. We commonly categorize fracture as being either ductile or brittle. Little energy is required to fracture brittle materials, such as glass, polystyrene, and some of the cast iron. Conversely, tough materials, such as rubber and many steels, absorb considerable amounts of energy in the fracture process.

Brittle fracture requires energy to separate atoms and expose new surfaces along the fracture path.

Ductile failure requires not only the energy just mentioned but much more additional energy to deform plastically the material ahead of the fracture.

The Ductile to Brittle Transition

The notched-bar impact test can be used to determine whether or not a material experiences a ductile-to-brittle transition as the temperature is decreased. In such a transition, at higher temperatures the impact energy is relatively large since the fracture is ductile. As the temperature is lowered, the impact energy drops over a narrow temperature range as the fracture becomes more brittle.

Generally, fracture behavior of BCC structured metals such as mild steels varies with temperature. At low temperature, BBC metals fracture in a brittle mode and becomes more ductile as the temperature increases. FCC structure metals such as stainless steels, copper and aluminum however do not show a dramatic change in fracture behavior with increasing temperature.

Therefore, an investigation of fracture behavior in BCC structure metals is concerned with the ductile to brittle transition temperature (DBTT) curve. This curve shows three different regions of lower shelf, upper shelf and transition region as shown in figure 1. If we first consider fracture surfaces of samples tested at low temperatures, the brittle fracture surfaces consisting primarily of cleavage facets and in some cases with small areas of ductile dimple as illustrated in figure 2.

Cleavage fracture requires less energy to produce flat fracture surfaces of the cleavage facets. As the temperature increases, the area of cleavage facets is reduced as opposed to increasing regions of ductile dimples or ductile tearing. Within a transition range, the absorbed energy increases rapidly, and the specimen fracture surfaces now show a mixed mode of ductile and brittle features. The percentage of ductile and brittle features in this region depends on the test temperatures. The higher the temperature, the more ductile areas will result. In the upper shelf region according to the DBTT curve, the fracture surfaces become fully ductile (100% fibrous). The fracture surface appears relatively rough, dull and gray due to micro void formation and coalescence. This type of fracture surface provides the highest energy absorption due to extensive plastic deformation.

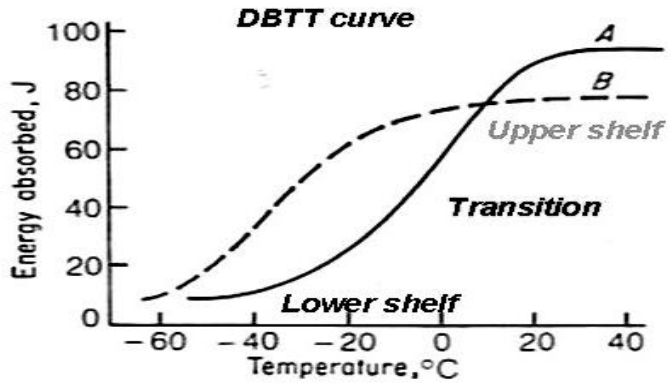
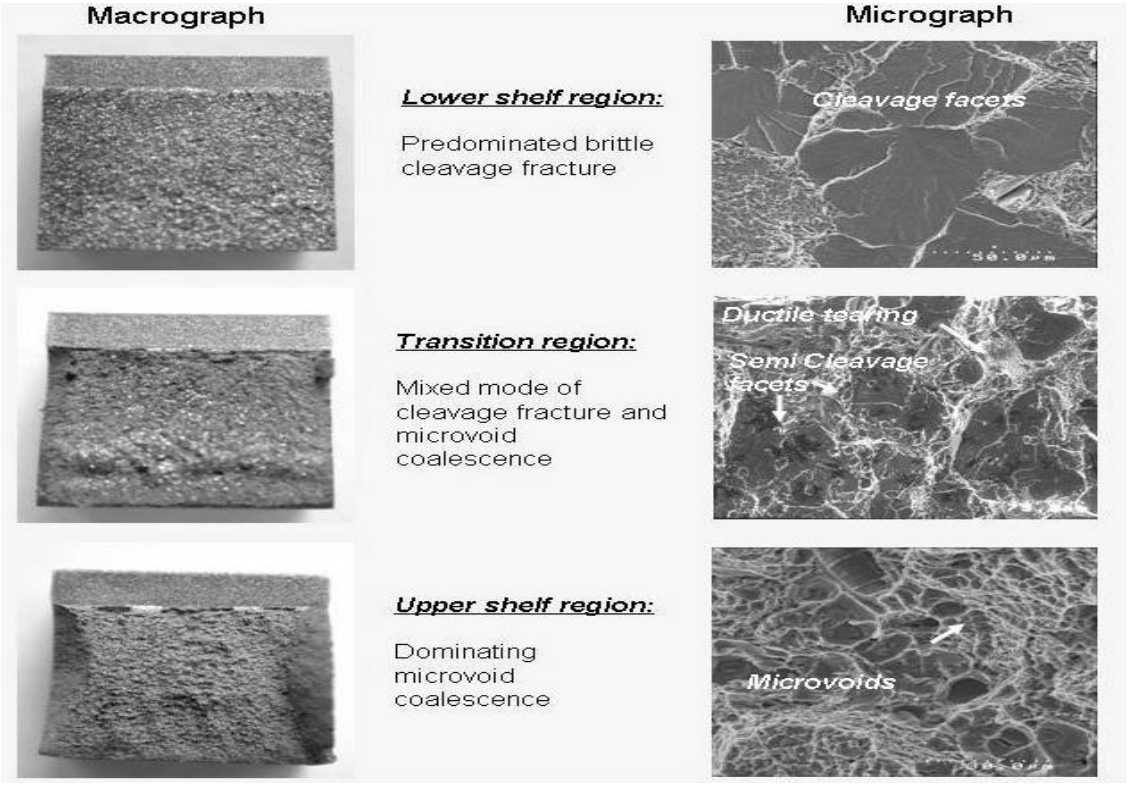


Figure 1**:** Effect of temperature on energy absorption during material fracture



. Figure 2**:** Fracture surfaces at different temperatures

Criteria for the determination of transition temperature

As mentioned previously, the absorbed energy of BCC metals changes drastically within the transition region, we therefore have to identify a transition temperature, which can be used to determine the suitable service temperature of particular materials in order to avoid metal failure in a catastrophic manner. There are several criteria for the identification of the transition temperature.

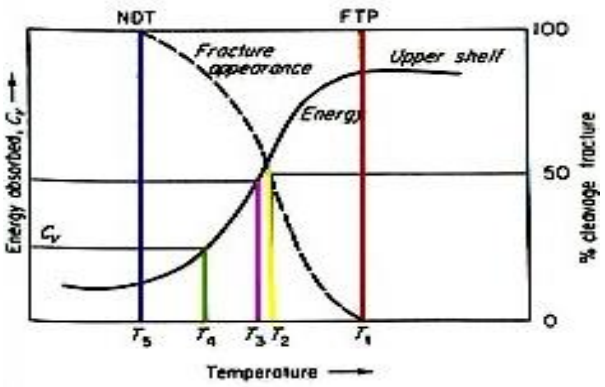


Figure 3: Different criteria used to determine the transition temperature

• **T1 Transition temperatur*e*** is the temperature at which the test sample absorbs the most fracture energy and possesses 100% fibrous fracture surfaces. This means brittle fracture is neglected in this case and is considered to be the safest among other criteria. The *T1* transition temperature is also called the fracture transition plastic or FTP.
• **T2 Transition temperature** is the temperature at which the percentage of cleavage and ductile fractures are equal. This transition is also called fracture appearance transition temperature or FATT because the fracture surface area is used as an indicator to determine the transition temperature.
• **T3 Transition temperature** is the temperature correlating to an average absorbed energy value of upper and lower shelf energy absorption. At or above this temperature, there is a correlation that less than 70% of the brittle cleavage fracture that indicates a high probability at which failure will not occur if the stress does not exceed about one-half of the yield stress.
• **T4 Transition temperature** is the temperature at which the absorbed energy (*Cv*) equals 20J.
• **T5 Transition temperature** is the temperature at which there is none of the ductile dimples appearing on the fracture surfaces. This temperature is also called nil ductility temperature or NDT since there is no plastic deformation during fracture.

Liquid nitrogen
Liquid nitrogen is used for many different applications in the department of Materials Science and Engineering. Liquid Nitrogen used for undergraduate labs (quenching, thermodynamics, heat capacity of metals, and cooling Charpys for Ductile to Brittle Transition). Liquid Nitrogen is also used for instrumentations (Glow discharge optical emission spectrometry and Inductively coupled plasma) which uses the gas produced from the boiling of the Liquid nitrogen in a high pressure liquid nitrogen dewar.

Hazards of Liquid Nitrogen: Liquid nitrogen temperature is (-196°C), and at this temperature cause severe tissue damage if skin comes in contact with the liquid.
Inhalation of nitrogen in excessive amounts can cause dizziness, nausea, vomiting, loss of consciousness, and death.

Safety Precautions
1. Stand to the side and away from front of Charpy machine while testing. It is preferable to have two people lift the hammer.
2. Always use tongs to transfer specimens into and out of the various temperature baths (i.e., liquid N_2, boiling H_2O, etc.) for the ductile-brittle transition experiment.

Procedure

1. Place two specimens in each bath and allow it to come to the temperature of the bath before testing.
2. Put the specimen handling tong in the same bath as specimen.
3. Measure the temperature of the bath with thermocouple.
4. Move the pendulum of the impact tester to its highest position and ascertain that it is surely locked in this position.
5. The specimens should be transferred from the bath to the anvil as fast as possible; otherwise the temperature of the specimen will change too much (for the low temperatures the specimens will warm up somewhat anyway).
6. Use tongs to transfer the specimen and let the tongs' temperature equilibrate in the bath before removing the specimen.
7. The specimen should be placed on the anvil with its notch on the side opposite where the hammer will hit, and the notch should be in the middle between the supports.
8. Release the pendulum by turning the black knob clockwise as soon as possible.
9. Stop the pendulum with beak by pushing the red knob up. The pointer on the dial should read zero, because the pendulum will not have lost any of its energy. If it does not read zero, contact the TA.
10. Note the amount of energy lost in the fracturing process and inspect and describe the fracture surface.
11. The surface should change from dull for ductile fracture, to shiny for brittle_fracture. Explain this behaviour in your report.

Determination of DBTT

Since it is often required or important to determine the ductile-to-brittle transition temperature, impact test results are plotted against test temperature. Somewhere in that transition zone between the high-energy and low-energy values is an energy value that can be defined as the transition temperature.

When the transition is very pronounced, this value is easily determined. However, because the more common case is a less sharply defined transition, an energy value may be specified below which the material is considered to be brittle (below the ductile-to-brittle transition temperature). Such a value may vary with material type and requirements, but the value of 20 J (15 ft · lbf) is often used as a specified value.

Fracture Appearance Method

Other methods of specifying ductile-to-brittle transition temperature are sometimes presented along with the energy values obtained. The first of these auxiliary tests is the fracture appearance method. The fractured impact bars are examined, and the fractures compared with a series of standard fractures or overlays of such fractures. By this method the percentage of shear fracture is determined.

The amount of shear fracture can also be determined in another way. This is done by carefully measuring the dimensions of the brittle cleavage exhibited on the specimen fracture surface (Fig. 1), and then referring to Table 1. The percentage of shear can be plotted against test temperature and the transition temperature can be ascertained using the shear percentage value specified.

Because these tables are set up for finite measurements or dimensions *A* and *B* (Fig. 1), 100% shear is to be reported when either *A* or *B* is zero.

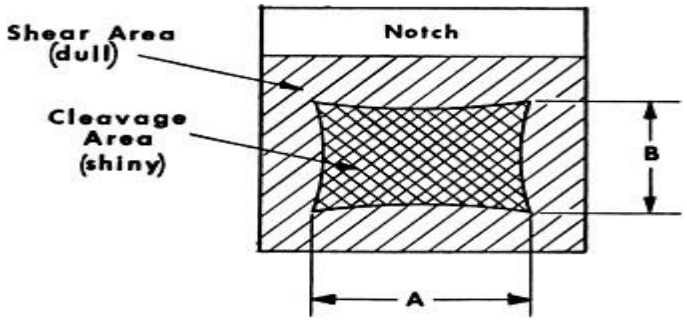


Figure. 4 Sketch of a fractured impact test bar. The method used in calculating percent shear involves measuring average dimensions A and B to the nearest 0.5 mm (0.02 in.) and then consulting a chart (Table 1) to determine the percent shear fracture.

Table 1 Tables of percent shear for measurements made in both inches and millimetres for impact-test specimens

***Dimensions B*, in.**	Dimension *A*, in.																	
	0.05	**0.10**	**0.12**	**0.14**	**0.16**	**0.18**	**0.20**	**0.22**	**0.24**	**0.26**	**0.28**	**0.30**	**0.32**	**0.34**	**0.36**	**0.38**	0.40
0.05	98	96	95	94	94	93	92	91	90	90	89	88	87	86	85	85	**84**
0.10	96	92	90	89	87	85	84	82	81	79	77	76	74	73	71	69	**68**
0.12T	a	b		l		e			2			T	a		b		l
0.14	94	89	86	84	82	80	77	75	73	71	68	66	64	62	59	57	**55**
0.16	94	87	85	82	79	77	74	72	69	67	64	61	59	56	53	51	**48**
0.18	93	85	83	80	77	74	72	68	65	62	59	56	54	51	48	45	**42**
0.20	92	84	81	77	74	72	68	65	61	58	55	52	48	45	42	39	**36**
0.22	91	82	79	75	72	68	65	61	57	54	50	47	43	40	36	33	**29**
0.24	90	81	77	73	69	65	61	57	54	50	46	42	38	34	30	27	**23**
0.26	90	79	75	71	67	62	58	54	50	46	41	37	33	29	25	20	**16**
0.28	89	77	73	68	64	59	55	50	46	41	37	32	28	23	18	14	**10**
0.30	88	76	71	66	61	56	52	47	42	37	32	27	23	18	13	9	**3**
0.31	**88**	**75**	**70**	**65**	**60**	**55**	**50**	**45**	**40**	**35**	**30**	**25**	**20**	**18**	**10**	**5**	**0**
Dimension *B*, mm	Dimension *A*, mm																	
	1.0	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**9.0**	**9.5**	10
1.0	99	98	98	97	96	96	95	94	94	93	92	92	91	91	90	89	89	88	**88**
1.5	98	97	96	95	94	93	92	92	91	90	89	88	87	86	85	84	83	82	**81**
2.0	98	96	95	94	92	91	90	89	88	86	85	84	82	81	80	79	77	76	**75**
2.5	97	95	94	92	91	89	88	86	84	83	81	80	78	77	75	73	72	70	**69**
3.0	96	94	92	91	89	87	85	83	81	79	77	76	74	72	70	68	66	64	**62**
3.5	96	93	91	89	87	85	82	80	78	76	74	72	69	67	65	63	61	58	**56**
4.0	95	92	90	88	85	82	80	77	75	72	70	67	65	62	60	57	55	52	**50**
4.5	94	92	89	86	83	80	77	75	72	69	66	63	61	58	55	52	49	46	**44**
5.0	94	91	88	85	81	78	75	72	69	66	62	59	56	53	50	47	44	41	**37**
5.5	93	90	86	83	79	76	72	69	66	62	59	55	52	48	45	42	38	35	**31**
6.0	92	89	85	81	77	74	70	66	62	59	55	51	47	44	40	36	33	29	**25**
6.5	92	88	84	80	76	72	67	63	59	55	51	47	43	39	35	31	27	23	**19**
7.0	91	87	82	78	74	69	65	61	56	52	47	43	39	34	30	26	21	17	**12**
7.5	91	86	81	77	72	67	62	58	53	48	44	39	34	30	25	20	16	11	**6**
8.0	**90**	**85**	**80**	**75**	**70**	**65**	**60**	**55**	**50**	**45**	**40**	**35**	**30**	**25**	**20**	**15**	**10**	**5**	**0**

Unlike Charpy energy, fracture appearance is indicative of how a specimen failed. It is therefore useful when attempting to correlate results of Charpy testing with other toughness test methods that use different specimen geometries and loading rates. However, the fracture-appearance method can also be subjective. In test survey of specimens, best result is achieved when operators are experienced, samples are close to the fracture-appearance transition, and when simple, two-dimensional figures are used for assessment.

Note: the appearance of the fracture surfaces of the tested Charpy specimens. A gray fibrous or dull appearance denotes ductile fracture. A bright, shiny appearance indicates brittle fracture (cleavage). Is there much deformation associated with the fracture? If so, it is ductile. If not, the behaviour is brittle. Do you see evidence of pre-existing flaws or cracks at the fracture plane? Is there evidence of "temper embrittlement?

Specimen / Energy (J)	Test Temperature (^{o}C)	Test Medium
1	-196	LN_2
2	0	Ice Water
3	25	Ambient
4	100	Boiling Water

Questions

Q1: What is ductile to brittle transition temperature?

Q2: Why would steel that is normally capable of sustaining great loads and capable of ductility greater than 20 percent suddenly, when cool, become so brittle that it could be shattered by a minor blow or similar impact?

Q3: Why do bcc metals undergo a ductile-to-brittle transition while FCC metals do not? What is the reputation of HCP metals in regard to toughness?

F/OBEM 01/05/00

NED University of Engineering & Technology
Department of Metallurgical Engineering
Course Code and Title: MY-410 Fracture Mechanics & Failure Analysis

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
Observation's Use ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
Equipment Handling ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
Group Work ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Laboratory Session No. _____ Date: _____

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

Experiment No. 8

Aim of the Experiment

To carry out the creep testing of given sample.

Theory

Creep

Time-dependent permanent deformation of a material under constant loading at high temperatures called creep and the resulting strain is a function of the applied stress, temperature, and time. The temperature at which a material starts to creep depends on its melting point. It is found that creep in metals starts when the temperature is > 0.3 to 0.4 T_m (the melting temperature in Kelvin). Most metals have high melting points and hence they start to creep only at temperatures much above room temperature. This is the reason why creep is less familiar phenomena than elastic or plastic deformation. For example, creep of carbon steels is important at temperatures above 500 C°, aluminium starts to creep above 100 C°, and since lead is a low melting metal (T_m = 600 K) it creeps even at room temperature. Boilers, gas turbine engines, and ovens are some of the systems that have components that experience creep. An understanding of high temperature materials behaviour is beneficial in evaluating failures in these types of systems.

Stress-rupture

Fracture of a material due to creep. Stress Rupture is the sudden and complete failure of a material held under a definite constant load for a given period of time at a specific temperature. Loads may be applied by tensile bending, flexural, biaxial or hydrostatic methods.

Importance of Creep Deformation

Creep is an important consideration in any application where a component must support a load at temperatures where $T_{abs} / T_M P_{abs} > 0.4$. A jet engine is one good example where a material operates at very high temperatures about 1100 K, or Kelvin degrees). Because the engine temperatures are so high, the alloys used for the turbine blades operate at temperatures very close to their melting temperatures. They are called **s**uperalloy**s**. In order to demonstrate creep in alloys without using very high temperatures, we can observe creep in low melting point alloys at temperatures near room temperature (about 300 K).

Creep Test

The main objective in a creep test is to measure how a given metal or an alloy will perform under constant load, at elevated temperatures. In a creep test, a tensile specimen (with similar dimensions as a tensile test specimen) is subjected to a constant load inside a furnace where the temperature is maintained constant.

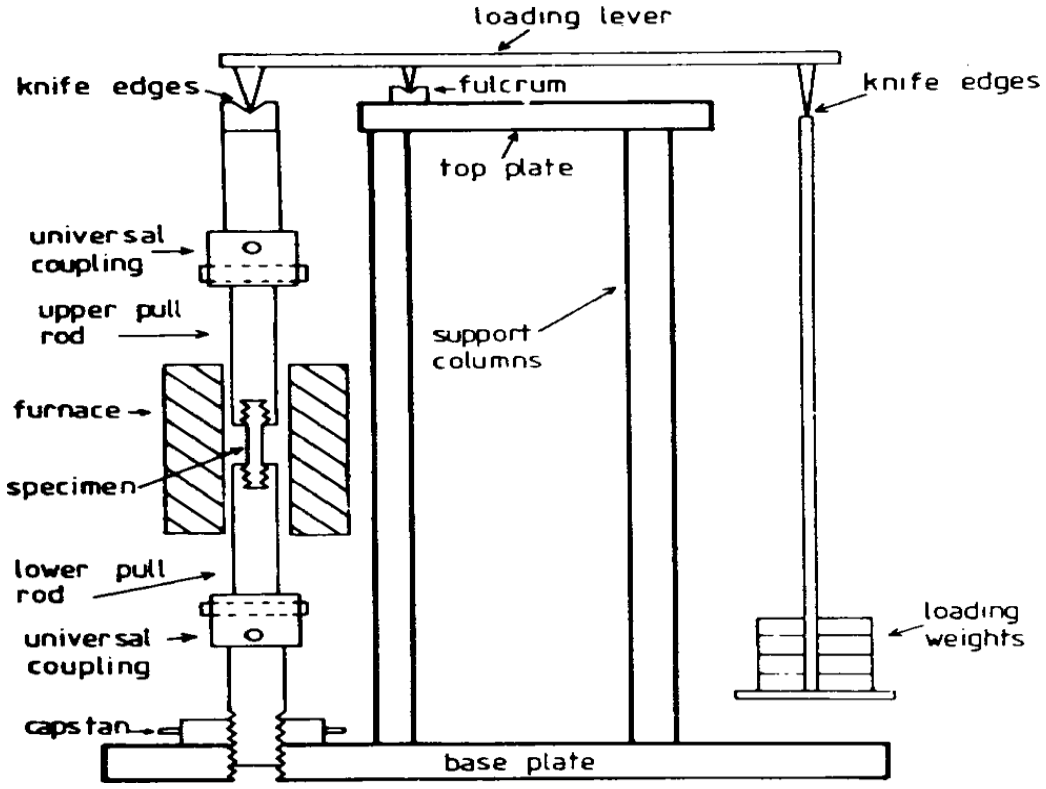


Figure1. Typical creep setup

Creep curve

The resulting deformation or strain is measured and plotted as a function of elapsed time. Figure 2 shows a schematic creep curve for a metal tested at constant load until rupture.

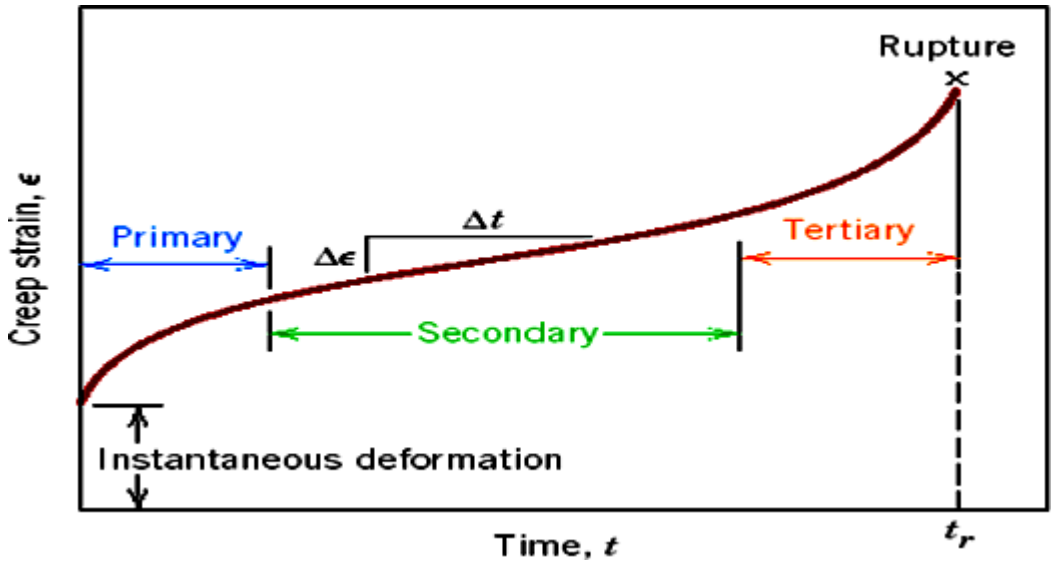


Figure 2: creep curve

Metals, polymers, and ceramics all show similar strain-time behaviours. The instantaneous strain is purely elastic. The creep curve in Figure 3 demonstrates three regions of strain-time behaviour:

1. **Primary creep:** This is the deformation that occurs just after the load is applied. In this region, the curve is downward. This means the deformation rate is decreasing. During primary creep, the internal structure of the alloy is changing in response to the applied load.

2. Secondary creep: There is often a stage where the slope of the creep curve remains approximately constant, like a straight line. This is the period of secondary creep (also called **steady state creep**). During secondary creep, the internal structure of the alloy remains approximately constant.

3. **Tertiary creep:** At the end of secondary creep, the plot begins to curve upward. This signals the onset of failure for the alloy and is called tertiary (third stage) creep. During this period, small cavities begin to form and grow inside the alloy. Growth and inter-linkage of these cavities eventually lead to failure of the alloy.

Procedure

The testing procedure is as follows:

1. Note down the specimen cross-sectional area and its gauge length.
2. Carefully mount the specimen in the upper and lower grips.
3. Attach the furnace to provide heat and strain gauge to measure elongation.
4. Zero the dial gauge (which measures the elongation in mm).
5. Gently apply the load as per the instruction of your instructor.
6. Perform the test at least twice at two different loads and temperatures.
7. Immediately record the instantaneous, elongation on the dial.
8. Record the elongation every 30 seconds until failure.
9. Repeat the tests at the same loads used above but at higher temperatures.

Observations

Results

Questions

Q1: What factors affect the creep deformation?

Q2: What is the mechanism of creep deformation?

Q3: Cite three metallurgical / processing techniques that are employed to enhance the creep resistance of metal alloys.

Q4: What do you mean by creep rate and rupture time?

Experiment No. 9

Aim of the Experiment

To practice and investigate the inclusions/ defected parts via stereomicroscope.

Materials /Apparatus

Defected parts, Stereomicroscope.

Theory

Stereo Microscopy

A stereo microscope, also known as a dissecting microscope, provides a three-dimensional view of a specimen at relatively low magnifications (typically between 10x to 100x). This type of microscope is ideal for examining surface structures, fractures, and inclusions because it allows for the observation of fine details and textures without requiring thin sections or extensive sample preparation.

Fractures in materials can occur due to various factors including mechanical stress, thermal effects, or material flaws. The study of fractures involves understanding different fracture types (such as brittle or ductile fractures), their propagation patterns, and the material's response to stress.

- Brittle Fractures: These fractures occur with minimal plastic deformation and are often characterized by rapid crack propagation. They typically produce a granular or crystalline fracture surface.
- Ductile Fractures: These fractures involve significant plastic deformation before failure, resulting in a fibrous appearance on the fracture surface. They generally exhibit necking and elongation.

Casting defects occur during the metal casting process and can significantly affect the quality and performance of cast products. These defects arise from issues in mold preparation, metal pouring, or cooling processes. Common casting defects include:

- Porosity: Small voids or air pockets within the casting, often caused by trapped gases or inadequate filling of the mold. Porosity can weaken the material and reduce its strength.
- Cold Shuts: Areas where two streams of molten metal fail to fuse properly, resulting in a visible seam or discontinuity. Cold shuts are usually caused by improper temperature control or mold design.
- Shrinkage Cavities: Void spaces that form due to the contraction of metal as it cools and solidifies. These defects are often found in thicker sections of the casting and can affect structural integrity.
- Hot Tears: Cracks that develop in the casting as it cools and contracts. Hot tears typically occur in areas of the casting that cool unevenly or too quickly.
- Inclusions: Foreign materials or impurities trapped in the cast metal. These can include sand, slag, or other contaminants that affect the material's properties.

Sample Preparation and Analysis

Theory: Proper sample preparation is crucial for accurate observation. This includes cleaning the sample to remove any contaminants, mounting it in a stable manner, and adjusting the microscope settings to optimize visibility.

- Cleaning: To prevent interference from residues that could obscure features or lead to inaccurate observations.
- Mounting: Ensures the sample remains stationary and properly aligned during examination.

Documentation and Interpretation

Theory: Accurate documentation involves capturing images, making detailed notes, and interpreting the findings based on observed features. This documentation aids in identifying potential causes of defects and suggests improvements in material processing or product design.

- **Photographic Evidence**: High-resolution images help in detailed analysis and comparison.
- **Notes and Measurements**: Detailed observations and measurements are essential for identifying defect patterns and making informed conclusions.

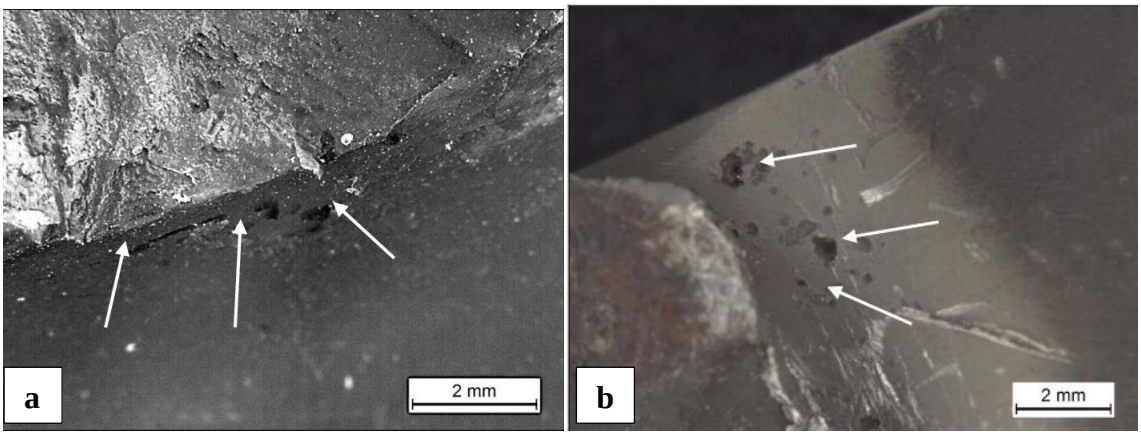


Figure 1(a) & (b): shows severe pitting corrosion at the blade root and arrows indicate the pits at the blade root respectively.

Observations

Results

Questions

Q1. What is the primary advantage of using a stereo microscope compared to a compound microscope?

Q2. What types of lighting are commonly used in stereo microscopy, and how do they affect the observation of surface features?

Q3. What are some common types of defects or features you might observe in materials using a stereo microscope, and how do you identify them?

Q4: What precautions should be taken while using a stereo microscope to ensure accurate observations?

Complex Engineering Activity (Open Ended Lab)

Subject: MY- 410: Fracture mechanics and Failure Analysis **Max. Marks:** 10 **Type:** Group

Title: Evaluate the fracture surface features and cause of the failure of fractured sample

Linkage to Course Learning Outcome				
CLO No.	**Description of CLO**	**Domain**	**Taxonomy Level**	**PLO**
CLO-4	To practice various tools and techniques for root cause analysis of a fractured part.	Psychomotor	P3	PLO-5 (Modern Tool and Usage)
Sr.no.	**Problem Description**			
1.	Evaluate the fractured surface features and cause of the failure of the fractured sample.			
Sr.no.	**Constraints/Assumptions**			
1.	Choose fractured sample from engineering applications. Your report should be consist of • Background data • Service condition • Chemical analysis • Metallographic techniques • Microscopic techniques etc.			
Sr.no.	**Identification of Areas where the use of computational/modern Tools usage is required**			
1.	Use testing procedures to find out the cause of fractured sample.			
2.	Microstructural analysis of sample via microscope			
3.	Hardness measurement via hardness tester			
Sr.no.	**Expected Outcomes**			
1.	Evaluate available case studies to find optimal material for specific bicycle application			
2.	Correct measurement of phase proportion grain size and hardness of the samples to achieve optimal pressing			
3.	Detail Report with proper formatting and references. IEE reference style will be followed			

Complex Engineering Activities

Preamble: Complex activities mean (engineering) activities or projects that have some or all of the following characteristics listed below:

Sr.No.	Attribute	Description	Apply
1.	Range of resources	Involve the use of diverse resources (for this purpose, resources include people, money, equipment, materials, information, and technologies).	Yes
2.	Level of interaction	Require resolution of significant problems arising from interactions between wide-ranging or conflicting technical, engineering, or other issues.	Yes
3.	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.	Yes
4.	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	Yes
5.	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	Yes

NED University of Engineering & Technology
Department of Metallurgical Engineering
Course Code &Title: MY: 410 Fracture Mechanics and Failure Analysis
Assessment Rubric for Complex Engineering Activity (OEL)

Student's Name: _____ Roll No.: _____

Criterion	Level of Attainment				
	Below Average (1)	**Average (2)**	**Good (3)**	**Very Good (4)**	**Excellent (5)**
Range of resources (literature review)	No use of reference/ unreliable reference	Use of one reference	Use of two references	Use of three references	Use of multiple references
Range of resources (use of equipment)	No use of equipment/apparatus for analysis	Use of equipment/ apparatus but the analysis was wrong	Use of equipment/ apparatus and the analysis was correct	Use of equipment/ apparatus and software of but the analysis was wrong	Use of equipment/ apparatus and software and the analysis was correct
Response of Assessment question	No response in the report	One correct response with reference	Two/Three correct response with reference	Four correct response with reference	Five correct response with reference
Report writing	Do not followed the provided guidelines	Somehow followed the provided guidelines	N.A	Followed the provided guidelines with some mistakes	Completely followed the provided guidelines

Total Score = _____

Instructor's Signature: _____