Istanbul Technical University
FACULTY OF MECHANICAL ENGINEERING

MATERIAL TESTING

Laboratory Manual - 2006

Contents

Materials Laboratory Attendance

This attendance sheet will be signed by the test assistant after each test. If you have not studied the necessary material before coming to the laboratory or if you don't show the necessary interest during the test, the assistant will not approve your attendance and you will have to REPEAT THE TEST.

No.:	Name:		
EXPERIMENT	**GROUP**	**DATE**	**APPROVAL**
TENSILE			
HARDNESS			
CHARPY / FATIGUE			
MACROSCOPY / MICROSCOPY			
JOMINY			
NON-DESTRUCTIVE			

PREFACE

A. Introduction

In this course we are seeking to understand material properties through laboratory experiments. Usually the class is divided into groups. Each group will do a different experiment every week until all the required experiments are completed.

Each instructor will indicate the experiments to be conducted and advise on the nature of the lab report and time of submission. However, a typical format for a lab report is included below. It is important that all the information necessary to complete the lab report is obtained before students leave the lab.

B. Lab Report Requirements

GENERAL

The following suggestions should be helpful.

- Avoid personal pronouns.
- If you quote from a text, identify the text.
- View this report as though you were in industry and writing for your boss. Hence sloppiness will not be accepted.

FORMAT

1. TITLE

There should be a Title Page with title, authors, group number, date, for whom report was written.

II. ABSTRACT

It should be approximately half a typed page in length. An abstract should tell: What was done briefly how experiment was conducted to satisfy objectives and what the major conclusions or representative results are.

III. TABLE OF CONTENTS

Must have page numbers of different sections in the report..

IV. INTRODUCTION

A. Establish general interest in the subject.

B. Establish specific interest and justification for conducting this investigation leading to a statement of the specific objective(s).

C. Introduce the report itself. That is, tell the reader how the report is organized and what to expect.

V. THEORY

A. Present theoretical basis for the experiment or investigation.

B. Present equations used with clear indication of which variables were measured and which is calculated.

VI. EXPERIMENTAL APPARATUS

A. Diagram of the test set-up illustrating the general relationships among the various components of the system and the locations at which the measurements were taken.

B. Instrumentation (measurement systems) that was used should be stated and related to the measurement locations on the diagram (with a statement of the uncertainty associated with each measurement system).

VII. TEST PROCEDURE
VIII. DATA ANALYSIS
IX. RESULTS

Introduce results; that is, explain what is being presented. Don't just include the plots, charts, etc., without any explanation.

Tables and figures must be self-contained. They must be numbered and with a caption. Thus the reader can tell what a table or figure means without having to look through the text.

X. DISCUSSION OF RESULTS

A. Interpret and explain results

B. Point out most important results

Even if the results as presented seem obvious *to* you, you want *to* be sure your reader notices the most important features and trends, etc. State what you think the results show, prove, demonstrate or illustrate.

XI.CONCLUSION

Summarize your findings; that is, itemize the most important things that you found out, measured, observed. Anything that could be preceded by "It was found that" or "It was discovered that" is a finding, not a conclusion. Remember conclusions are generalizations based on results of a specific investigation.

XII. BIBLIOGRAPHY

Number your references in order.

XIII. APPENDICES

Extensive pages of data can go in Appendix.

C. Safety

1. Follow all safety instructions given in the class and in the laboratories.
2. Charpy machine can be lethal. Never leave the hammer in the up position until ready to break a specimen.
3. Furnaces. Be careful in touching and handling specimens. Use tongs for placing specimens in the furnace and removing them. Most specimens can be quenched in water after removal from furnace.
4. Tensile Testing. During the tensile test pieces can fly out during fracture.
5. Use safety eye shield when grinding specimens.
6. Do not remove specimens from abrasive cut-off machine until the wheel has stopped.
7. NO eating or drinking in the lab.

SAFETY IN THE LABORATORY

All students must read and understand the information in this document with regard to laboratory safety and emergency procedures prior to the first laboratory session. **Your personal laboratory safety depends mostly on YOU**. Effort has been made to address situations that may pose a hazard in the lab but the information and instructions provided cannot be considered all-inclusive.

Students must adhere to written and verbal safety instructions throughout the academic term. Since additional instructions may be given at the beginning of laboratory sessions, it is important that all students arrive at each session on time.

With good judgment, the chance of an accident in this course is very small. Nevertheless, research and teaching workplaces (labs, shops, etc.) are full of potential hazards that can cause serious injury and or damage to the equipment. Working alone and unsupervised in laboratories is forbidden if you are working with hazardous substances or equipment. With prior approval, at least two people should be present so that one can shut down equipment and call for help in the event of an emergency.

Safety training and/or information should be provided by a faculty member, teaching assistant, lab safety contact, or staff member at the beginning of a new assignment or when a new hazard is introduced into the workplace.

Emergency Response

1. It is your responsibility to read safety and fire alarm posters and follow the instructions during an emergency
2. Know the location of the fire extinguisher, eye wash, and safety shower in your lab and know how to use them.
3. Notify your instructor immediately after any injury, fire or explosion, or spill.
4. Know the building evacuation procedures.

Common Sense

Good common sense is needed for safety in a laboratory. It is expected that each student will work in a responsible manner and exercise good judgment and common sense. If at any time you are not sure how to handle a particular situation, ask your Teaching Assistant or Instructor for advice. **DO NOT TOUCH ANYTHING WITH WHICH YOU ARE NOT COMPLETELY FAMILIAR**!!! It is always better to ask questions than to risk harm to yourself or damage to the equipment.

Personal and General laboratory safety

1. Never eat, drink, or smoke while working in the laboratory.
2. Read labels carefully.

3. Do not use any equipment unless you are trained and approved as a user by your supervisor.
4. Wear safety glasses or face shields when working with hazardous materials and/or equipment.
5. Wear gloves when using any hazardous or toxic agent.
6. Clothing: When handling dangerous substances, wear gloves, laboratory coats, and safety shield or glasses. Shorts and sandals should not be worn in the lab at any time. Shoes are required when working in the machine shops.
7. If you have long hair or loose clothes, make sure it is tied back or confined.
8. Keep the work area clear of all materials except those needed for your work. Coats should be hung in the hall or placed in a locker. Extra books, purses, etc. should be kept away from equipment, that requires air flow or ventilation to prevent overheating.
9. Disposal - Students are responsible for the proper disposal of used material if any in appropriate containers.
10. Equipment Failure - If a piece of equipment fails while being used, report it immediately to your lab assistant or tutor. Never try to fix the problem yourself because you could harm yourself and others.
11. If leaving a lab unattended, turn off all ignition sources and lock the doors.
12. Never pipette anything by mouth.
13. Clean up your work area before leaving.
14. Wash hands before leaving the lab and before eating.

Electrical safety

1. Obtain permission before operating any high voltage equipment.
2. Maintain an unobstructed access to all electrical panels.
3. Wiring or other electrical modifications must be referred to the Electronics Shop or the Building Coordinator.
4. Avoid using extension cords whenever possible. If you must use one, obtain a heavy- duty one that is electrically grounded, with its own fuse, and install it safely. Extension cords should not go under doors, across aisles, be hung from the ceiling, or plugged into other extension cords.
5. Never, ever modify, attach or otherwise change any high voltage equipment.
6. Always make sure all capacitors are discharged (using a grounded cable with an insulating handle) before touching high voltage leads or the "inside" of any equipment even after it has been turned off. Capacitors can hold charge for many hours after the equipment has been turned off.
7. When you are adjusting any high voltage equipment or a laser which is powered with a high voltage supply, USE ONLY ONE HAND. Your other hand is best placed in a pocket or behind your back. This procedure eliminates the possibility of an accident where high voltage current flows up one arm, through your chest, and down the other arm.

Mechanical safety

1. When using compressed air, use only approved nozzles and never direct the air towards any person.
2. Guards on machinery must be in place during operation.
3. Exercise care when working with or near hydraulically- or pneumatically-driven equipment. Sudden or unexpected motion can inflict serious injury.

Chemical safety

1. Treat every chemical as if it were hazardous.
2. Make sure all chemicals are clearly and currently labeled with the substance name, concentration, date, and name of the individual responsible.
3. Never return chemicals to reagent bottles. (Try for the correct amount and share any excess.)
4. Comply with fire regulations concerning storage quantities, types of approved containers and cabinets, proper labeling, etc. If uncertain about regulations, contact the building coordinator.
5. Use volatile and flammable compounds only in a fume hood. Procedures that produce aerosols should be performed in a hood to prevent inhalation of hazardous material.
6. Never allow a solvent to come in contact with your skin. Always use gloves.
7. Never "smell" a solvent!! Read the label on the solvent bottle to identify its contents.
8. Dispose of waste and broken glassware in proper containers.
9. Clean up spills immediately.
10. Do not store food in laboratories.

Lasers safety

1. NEVER, EVER LOOK INTO ANY LASER BEAM, no matter how low power or "eye safe" you may think it is.
2. Always wear safety goggles if instructed by your Instructor or Teaching Assistant.
3. The most common injury using lasers is an eye injury resulting from scattered laser light reflected off of mountings, sides of mirrors or from the "shiny" surface of an optical table. The best way to avoid these injuries is to always wear your goggles and NEVER LOWER YOUR HEAD TO THE LEVEL OF THE LASER BEAM! The laser beam should always be at or below chest level.
4. Always use "beam stops" to intercept laser beams. Never allow them to propagate into the laboratory. Never walk through a laser beam. Some laser beams of only a few watts can burn a hole through a shirt in only a few seconds.
5. If you suspect that you have suffered an eye injury, notify your instructor or teaching assistant IMMEDIATELY! Your ability to recover from an eye injury decreases the longer you wait for treatment.

Additional Safety Guidelines

- Never do unauthorized experiments.
- Never work alone in laboratory.
- Keep your lab space clean and organized.
- Do not leave an on-going experiment unattended.
- Always inform your instructor if you break a thermometer. Do not clean mercury yourself!!
- Never taste anything. Never pipette by mouth; use a bulb.
- Never use open flames in laboratory unless instructed by TA.
- Check your glassware for cracks and chips each time you use it. Cracks could cause the glassware to fail during use and cause serious injury to you or lab mates.
- Maintain unobstructed access to all exits, fire extinguishers, electrical panels, emergency showers, and eye washes.
- Do not use corridors for storage or work areas.
- Do not store heavy items above table height. Any overhead storage of supplies on top of cabinets should be limited to lightweight items only. Also, remember that a 36" diameter area around all fire sprinkler heads must be kept clear at all times.
- Areas containing lasers, biohazards, radioisotopes, and carcinogens should be posted accordingly. However, do not post areas unnecessarily and be sure that the labels are removed when the hazards are no longer present.
- Be careful when lifting heavy objects. Only shop staff may operate forklifts or cranes.
- Clean your lab bench and equipment, and lock the door before you leave the laboratory.

TENSILE TESTING OF METALS

Objective

The tensile test measures the resistance of a material to a static or slowly applied force. This laboratory experiment is designed to demonstrate the procedure used for obtaining mechanical properties as modulus of elasticity, yield strength, ultimate tensile strength (UTS), toughness, uniform elongation, elongation and reduction in area at rupture. Besides the true stress- true strain curve can also be determined with the help of the tensile test.

Introduction

In this test the load is applied along only one axis, and the rate of loading is constant. This test is done on a universal mechanical testing machine which is typically screw-driven or hydraulically powered. In some cases the machine may be computer controlled. The primary data generated are load vs. elongation which are to be converted into stress vs. strain data.

In modern tensile testers, load is measured using a load cell, in older or simpler testing machines, a purely mechanical or hydraulical device may be employed for measuring the load. Strain can be measured from the displacement of the crosshead or directly from the specimen. Typical devices for measuring strain are mechanical dial indicators, electrically-resistive strain gages attached to the specimen, or extensometers that employ either an optical device, a strain gage or an inductive or capacitive transducer. Strain transducers have the advantage that they measure only the displacement in the gage length of the specimen. This eliminates error due to the deformation in the ends of the specimen, slack in the load train, and the stiffness of the testing machine.

There are different types of specimen depending on the type of the grips and on the form of the available material (sheet, rod, etc.). Generally all specimens have two main parts, the gage section and the ends. The dimensions of the specimens are standardized (TS, DIN, ASTM etc.) A good surface finish is required so that surface flaws do not provide stress concentrations to cause premature failure.

Engineering stress $S = \frac{Load}{A_O}$ True stress $\sigma = \frac{Load}{A_i}$

Engineering strain $e = \frac{\Delta l}{l_o}$ True strain $\varepsilon = \ln (l/l_o)$

0.2% yield stress is the stress for 0.2% permanent strain

$TS = \frac{Load\ \max}{A_o}$ True fracture stress $\sigma_f = \frac{Load_f}{A_f}$

$\%\ \text{elongation} = \frac{(l_f - l_o) \times 100}{l_o}$

$\%\ \text{reduction in area} = \frac{(A_o - A_l) \times 100}{A_o}$

Procedure

A servo-hydraulic or servo-mechanical testing machine is used. The specimen of known dimensions are loaded in the machine and strained at a constant rate. The load is measured by a load cell. The crosshead movement and/or strain are recorded; for strain measurement an extensometer is used.

The X-Y plots are obtained. However the computer can also plot an engineering stress-strain curve directly, using the appropriate conversion factors and specimen area and gauge length. After the specimen is broken, the final length and diameter are measured. The fracture type and the fracture surface are investigated, in order to determine the fracture mode.

Results

1. Plot a load - elongation curve for each specimen.
2. Determine the engineering stress-strain curve and the true stress- true strain curve.
3. Determine the 0.2% yield stress, UTS, % elongation, % reduction in area, modulus of elasticity. Determine the mathematical expression for the true stress true strain curve for the second material.
4. Identify the fracture mode, i.e. ductile or brittle and explain the reasons.
5. Find the mechanical properties of the tested material from Handbooks and make comparisons. Or if the material is not known try to guess it with the help of the mechanical properties.

Discussion

If the material is given compare your test results of strength and ductility with book values. Why is there a significant difference? Answer questions listed below.

Tensile Test Questions

1. Which modulus did you find from the initial portion of the stress-strain curve? If did not use an extensometer but determined strain from the crosshead movement, would the initial slope still allow you to determine an accurate modulus? Explain.
2. Write the definition using symbols for shear modulus, bulk modulus and Poisson's ratio. Write the equations relating these two modulus to Young's modulus.
3. What is the approximate value of Poisson's ratio for metals? What is the physical significance of Poisson's ratio, i.e. what does it represent resistance to?
4. What is the area under the stress-strain curve equivalent to? What does the area under the elastic portion of the stress-strain represent?
5. What % elongation and % reduction in area measures of?
6. Explain the different deformation mechanisms which are active in the different regions of the tensile stress-strain curve. (elastic, yielding, strain hardening, necking etc.)

References

1. Dieter, *Mechanical Metallurgy,* McGrawHill.
2. Dowling *E.D.,Mechanical Behavior of Materials,* Prentice-Hall.
3. Kayalı S, Ensari C. and .Dikey F., *Metalik Malzemelerin Mekanik Deneyleri,* İTÜ Yayını.

CHECKLIST FOR TENSILE REPORT

1. Neatness of bound report.
2. Organization of report in sections.
3. Introduction section.
    . What mechanical properties can be determined in a tensile test.
    . Why are tensile properties of materials important in engineering.
    . What properties can be determined.
    . What is the TS (Türk Standartları) standard number for this test.??
4. Experimental Procedure.
    . Describe specimen. What measurements are made.
    . What tensile machine is used.
    . Brief detail of test, i.e. what did you do.
    . Give details of the recording system for data. What data is produced.
    . What measurements are made after the test
5. Data Analysis.
    . Define all the properties you determined.
    . Describe the program used for data analysis.
    . Describe how you plot the engineering stress-strain curve.
    . How did you find 0.2% yield stress, UTS, true fracture stress, % elongation, % reduction in area and other properties
    . How did you determine the mathematical expression for the true stress - true strain curve.
6. Results
    . Display measured values of specimens. List values of all the mechanical properties determined in the test with correct units.
    . Show graphs of the stress strain curves. All axes identified with scales.
7. Discussion
    . Compare alloys, which is strongest, highest ductility, etc... Compare your results with values from a reference.
    . If your results are different, explain.
8. Conclusion
    . A brief summary of what you accomplished.
9. References, tables and figures.
10. Appendix
    . Original graph of load vs. strain correctly identified.

HARDNESS TESTING

Objective

To introduce the principles of indentation hardness testing, emphasizing the limitations and significance of the results.

Introduction

Hardness is generally considered as resistance to penetration. The harder the materials, the greater the resistance to penetration. Hardness is directly related to the mechanical properties of the material. Factors influencing hardness include microstructure, grain size, strain hardening, etc. Generally as hardness increases so does yield strength and ultimate tensile strength (UTS), thus specifications often require the results of hardness tests rather than tensile tests. The most popular methods are Brinell, Vickers and Rockwell hardness tests for metals and alloys.

Brinell Test

In a standard Brinell test 10 mm diameter hardened steel ball is forced to penetrate the material by 3000 kgf for steels and cast irons. The load and ball diameter selection is important depending on the hardness of materials and 500 kgf is used for softer materials with the same ball diameter. Keeping the ratio of load P to the square of diameter D^2 constant (30 for steels and cast irons and 5 for soft metals and alloys), different load and ball diameter combinations can be selected and used in Brinell hardness testing. The Brinell Hardness Number (BHN) is obtained by dividing the applied force P, in kgf; by the curved surface area of the indentation, which is actually a segment of sphere. The geometry of indentation is given in Figure-1, and the hardness is determined according to the relationship,

$$\text{BHN} = \frac{2P}{\pi D[D-(D^2-D^2)^{1/2}]}$$

where D is the diameter of the indenter ball and d is the average diameter of the indentation, both in mm.

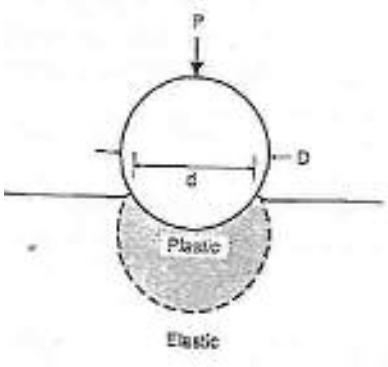


Figure-1: Geometry of deformation under a Brinell hardness indenter.

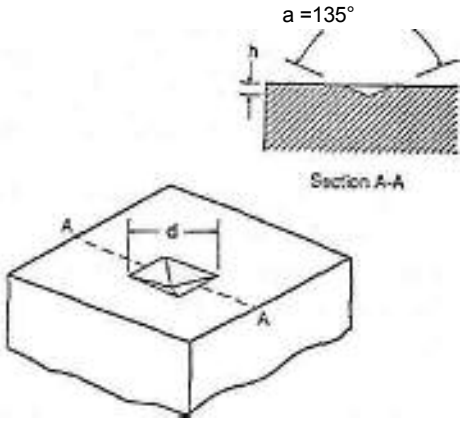


Figure-2: Vickers hardness indentation.

Vickers Test

The Vickers hardness test is based on the same principle as the Brinell test, except the indenter is a diamond pyramid with square base. The angle between the faces of pyramid is 136^0 as shown in Figure-2. The Vickers Hardness Number (VHN) of materials is obtained by dividing the applied force *P,* in kgf, by the surface of the pyramidal depression yielding the relationship

$$VHN=\frac{1.8544P}{d^2}$$ (in some sources VHN is cited as DPH)

where *d* is the average length of diagonals in mm. Due to the shape and hardness of indenter the method is applicable to metals and alloys with wide variety of hardness. Test load is selected between 1 and 120 kgf depending on the hardness of materials. It is also possible to apply micro hardness testing by keeping the force between 5 grf and 2 kgf in Vickers scale.

Rockwell Test

In the **Rockwell** test, a diamond cone or a hard steel ball is employed as the indenter depending on the hardness of materials. Diamond cone or *Brale* indenter with cone angle of 120^0 is used to test hard materials and the balls of sizes between 1.6 mm (1/16") and 12.7 mm (1/2") are used in testing softer materials. Rockwell tests differ from other indentation hardness tests in that the depth of indentation determines the hardness rather than the indentation size (see Figure-3). Therefore, surface condition of specimens is very important in Rockwell testing because of its high dependency on the accuracy in indentation depth measurements. In order to establish a reference position a *minor load* of 10 kgf. is first applied, and the major load is then applied. Additional penetration due to *major load* is measured and readings are obtained from a calibrated scale (dial) directly, which has a maximum value of 100, depending on the depth of penetration. Most commonly used Rockwell hardness scales are given in Table-l with typical applications. The hardness numbers are designated *HRX,* where *X* indicates the scale used (i.e. 50 HRC for 50 points on the C scale of dial). It should be noted that a Rockwell hardness number is meaningless unless the scale is not specified.

HR = E-e

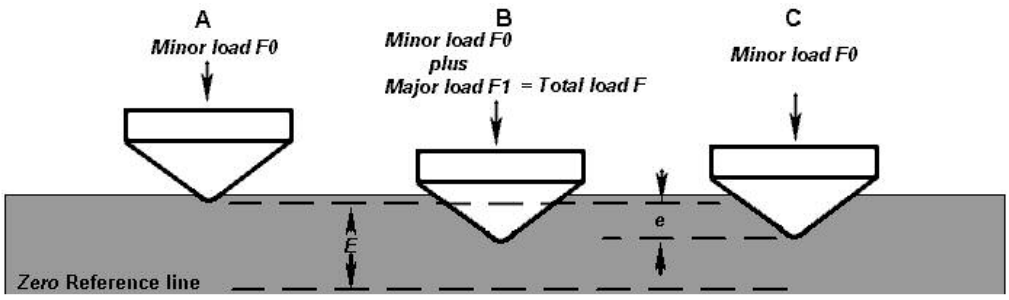


Figure-3: Increasing depth of penetration in the Rockwell test

Table-I: Commonly used Rockwell hardness scales.

Scale X	Indenter Type	Major Load (kgf)	Typical Applications
A	Diamond Brale	60	Tool Materials
D	Diamond Brale	100	Cast Irons, Sheet Steels
C	Diamond Brale	150	Hardened steels and cast irons, Ti alloys
B	1/16" Diameter Ball	100	Annealed steels, Cu and Al alloys
E	1/8" Diameter Ball	100	Al and Mg alloys, reinforced polymers
F	1/16" Diameter Ball	60	Soft sintered products
M	1/4" Diameter Ball	100	Very soft metals, polymers
R	1/2" Diameter Ball	60	Very soft metals, polymers

Since the deformations caused by an indenter are of similar magnitude to those occurring at the ultimate tensile strength in a tension test, some empirical relationships have been established between hardness and engineering ultimate tensile strength of metals and alloys. For example, for steels UTS can be **roughly estimated** from Brinell hardness as follows:

$$\text{UTS (in MPa)} = 3.45 \times \text{BHN}$$

Equipment

- Rockwell hardness tester
- Brinell hardness tester
- Microhardness (Vickers) tester
- Different test specimens

Procedure

1. Determine the proper Rockwell hardness scale,
2. calibrate the Rockwell hardness tester,
3. take five readings per specimen,
4. Perform Brinell hardness measurements on designated specimens (3 readings)
5. Using microhardness tester, determine the VHN at 0.20 mm distances from the surface to the center of case carburized specimen, until the hardness remains unchanged.
6. Determine the core hardness of the carburized steel.

.

Analysis

Calculate the range and mean in hardness values for each test specimen which will be considered in lab report.

Lab Report Requirements

1. Results
   - List hardness values of Rockwell and Brinell for each specimen.
   - List VHN versus distance from surface for carburized specimen.
   - Determine the effective carburizing depth that corresponds to 400 VHN

2. Discussion *(only those indicated will be answered in the lab report)*
   1. How do the Rockwell and Brinell tests actually measure hardness? Give any appropriate sketches and formulae. Are there any units involved? Describe the procedure for the Rockwell test, explaining the reason for the pre-load.
   2. What is the limitation on the thickness of specimens for a hardness test? Explain. Calculate the minimum thickness for one specimen for the Rockwell test and one for the Brinell test.
   3. What are the limitations for distance from specimen edge to indentation and distance between indentations? Explain why these limitations exist in both cases. .
   4. What surface condition is necessary for Brinell, Rockwell and Vickers?
   5. Why is the mean pressure (stress) under the indentor much greater than the yield stress? How much greater is it?
   6. What are the advantages of Vickers test against Brinell test?

References

1. Metals Handbook, 9th ed., *Mechanical Testing,* Vol. 8, 1990.
2. G. Dieter, *Mechanical Metallurgy,* S1 ed., Mc Graw Hill, 1986.
3. N. Dowling, *Mechanical Behavior of Materials,* Prentice Hall, 1993.
4. "An Evaluation of the Impression Test for Estimating the Tensile Properties of Metallic Materials, "H.N. Jones, *Journal of Testing and Evaluation,* Vol. 20, pp. 403-407, Nov. 1992.

IMPACT TESTING

Objective

To conduct Charpy V-notch impact test and determine the ductile-brittle transition temperature of steels.

Equipment

- Coolants
- Standard Charpy V-Notched Test specimens
- Impact tester
- Furnace

Introduction

Notched-bar impact test of metals provides information on failure mode under high velocity loading conditions leading sudden fracture where a sharp stress raiser (notch) is present. The energy absorbed at fracture is generally related to the area under the stress-strain curve which is termed as toughness in some references. Brittle materials have a small area under the stress-strain curve (due to its limited toughness) and as a result, little energy is absorbed during impact failure. As plastic deformation capability of the materials (ductility) increases, the area under the curve also increases and absorbed energy and respectively toughness increase. Similar characteristics can be seen on the fracture surfaces of broken specimens. The fracture surfaces for low energy impact failures, indicating brittle behavior, are relatively smooth and have crystalline appearance in the metals. On the contrary, those for high energy fractures have regions of shear where the fracture surface is inclined about 45° to the tensile stress, and have rougher and more highly deformed appearance, called fibrous fracture.

Although two standardized tests, the Charpy and Izod, were designed and used extensively to measure the impact energy, Charpy v-notched impact tests are more common in practice. The apparatus for performing impact tests is illustrated schematically in Figure-I. The load is applied as an impact blow from a weighted pendulum hammer that is released from a position at a fixed height h. The specimen is positioned at the base and with the release of pendulum, which has a knife edge, strikes and fractures the specimen at the notch. The pendulum continues its swing, rising a maximum height h' which should be lower than h naturally. The energy absorbed at fracture E can be obtained by simply calculating the difference in potential energy of the pendulum before and after the test such as,

$$E = m.g.(h-h')$$

where m is the mass of pendulum and g is the gravitational acceleration. The geometry of 55mm long, standard Charpy test specimen is given in Figure-2. If the dimensions of specimens are maintained as indicated in standards, notched-bar impact test results are affected by the lattice type of materials, testing temperature, thermo-mechanical history, chemical composition of materials, degree of strain hardening, etc.

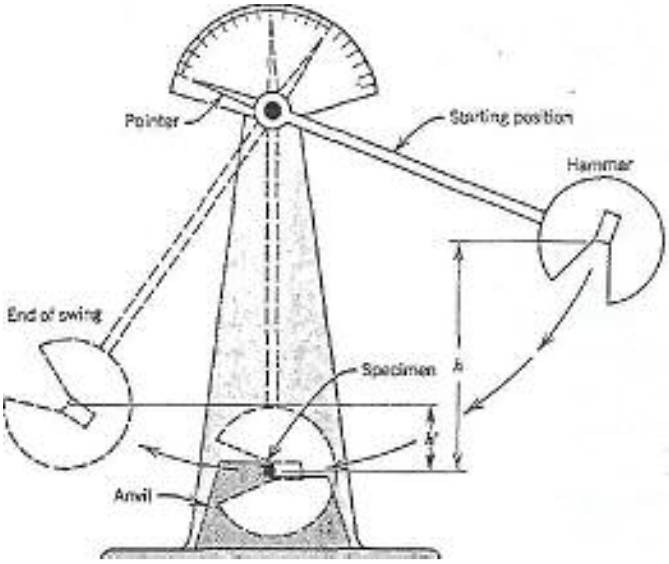


Figure-I: Apparatus for impact testing of materials.

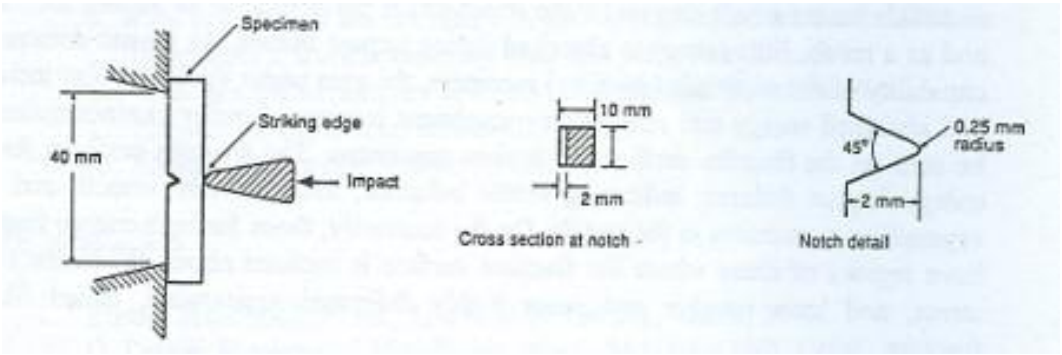


Figure-2: Specimen and loading configuration for Charpy V-notched impact test.

Body centered cubic (bcc) metals, particularly steels, often exhibit a decrease in impact energy as the temperature is lowered. The temperature at which a sharp decrease in impact energy occurs is called the ductile-brittle transition temperature (DBTT) as shown in Figure-3 schematically. This transition temperature is generally chosen as a lower limit for the application of such metals.

Some steels may show transition characteristics in their failure mode from ductile to brittle gradually as temperature is decreased, which is given in Figure-4 schematically. In this case different approaches may be used in determining transition temperature but the average energy concept is the most popular one. Determination of transition temperature can also be done by examining the fracture surfaces of specimens tested at different temperatures. For example the temperature, at which the fracture surface consists 50 percent cleavage (crystalline) and 50 percent ductile (fibrous) types of fracture, is called fracture appearance transition temperature (FATT). Another common criterion is to determine the transition temperature on the basis of an arbitrary energy absorbed. For example *20 J transition temperature* is an accepted criterion for low-strength ship steels.

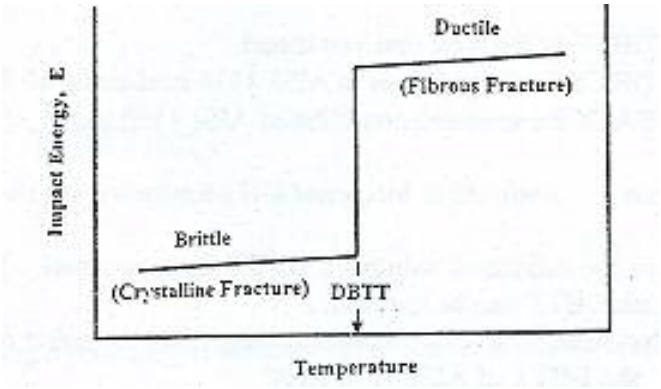


Figure-3: Typical ductile-brittle transition curve for annealed low carbon steel.

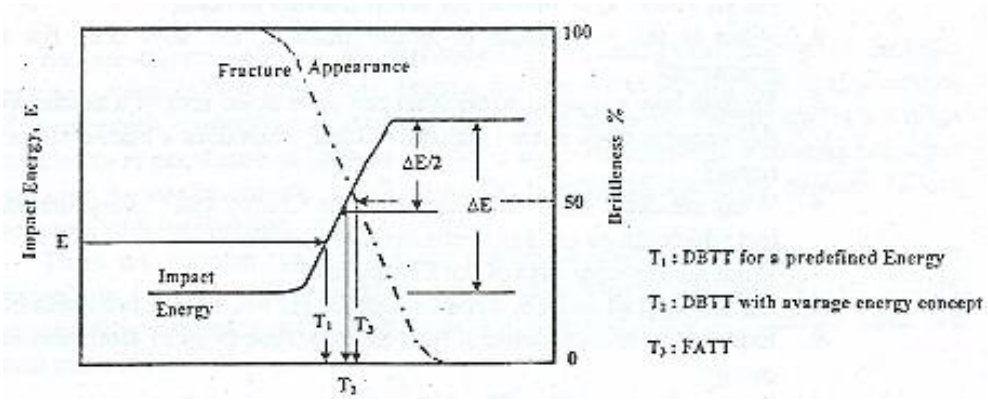


Figure-4: Various criteria of transition temperature obtained from Charpy tests.

Procedure

Note: Test one material with two specimens for each temperature,

1. Check the zero calibration of the impact tester.
2. First, test a specimen at room temperature.
3. Based on the room temperature result, decide whether to concentrate on higher or lower temperature.
4. Test specimens over a selected range of temperatures, attempting to establish a fully ductile test, a fully (or nearly) brittle test, and as many temperatures in between as possible. .
5, Note fracture energy and estimate the % brittleness from the appearances of fracture surfaces of the specimens.

Lab Report Requirements

1. Results

- Display the test data in a Table.
- Plot impact energy versus temperature and % brittleness versus temperature.
- Find DBTT of the steel that you tested.

2. Discussion *(the questions will be answered in the lab report)*

1. Give the estimated values of DBTT for your steel. Suggest 2 ways in which DBTT can be lowered.
2. What are the 3 basic factors which contribute to brittle fracture of steels? Do all 3 have to be present for brittle fracture to occur?
3. Explain how a triaxial stress state can arise at the root of a notch. Would this occur in thick or thin material? Thus, when does a biaxial stress state occur?
4. What are the main uses of the Charpy test?
5. List the ASTM and TS specifications for the two impact tests with titles.
6. Explain the relation between fracture toughness (K_{IC}) of steels and impact energy.
7. Explain the effect of carbon content on transition behavior of plain carbon steels in annealed condition.
8. Explain the effect of manganese on DBTT of steels.

References

1. Metals Handbook, 9th ed., *Mechanical Testing,* Vol. 8, 1990.
2. G. Dieter, *Mechanical Metallurgy,* SI ed., Mc Graw Hill, 1986.
3. N. Dowling, *Mechanical Behavior of Materials,* Prentice Hall, 1993.
4. ASTM and TS Standards.
5. ASM Metals Handbook, 9th ed. Vol. 12.

FATIGUE TESTING

Objective

To demonstrate how fatigue tests are conducted and how to interpret results.

Introduction

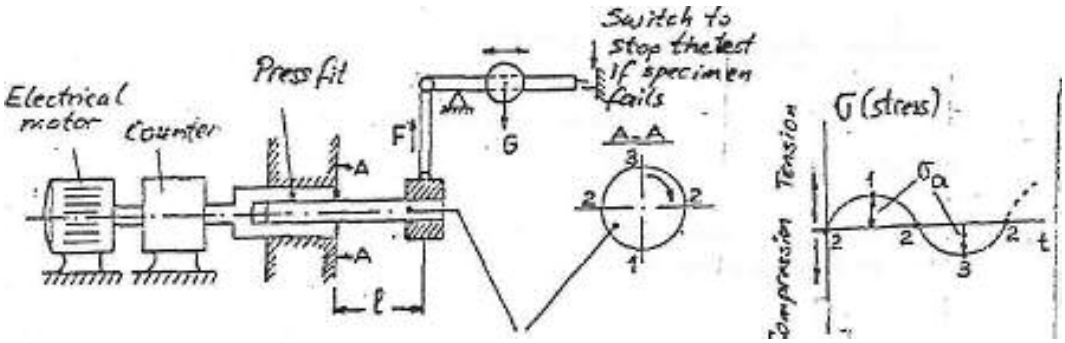
Fatigue failure accounts for the majority of mechanical failure of metallic materials subjected to cyclic loads. Fatigue failures result from repeated applications of stress which is usually well below the static yield stress. Fatigue cycles are often completely reversed state of stress, i.e. tension and compression in a rotating beam but can also be tension-tension. In all cases the number of cycles to produce failure increases with the lowering of the stress leve1.

There are different types of fatigue testing machines. The modem fatigue test frames are servo-controlled electro-hydraulic or electro-mechanical devices, Rotary bending fatigue testing machines are simple and low-cost practical machines which are used since 1850.

Equipment

- CJ Rotary bending fatigue testing machine
- Dartec 100kN servo-hydraulic testing system.

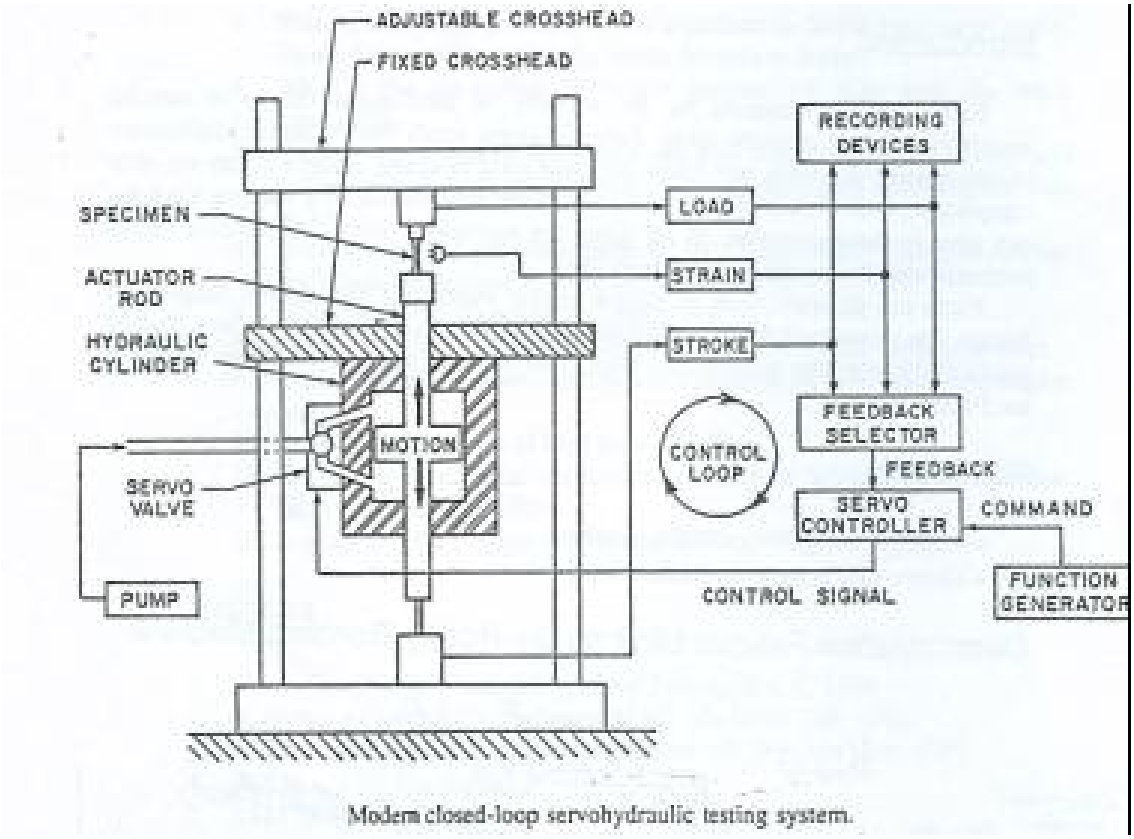
Determination Fatigue Limit on the Rotary Bending Machine



Each point on the surface of the rotating specimen will go trough the points 1, 2, 3, etc. and will be subjected to a dynamic stress. The stress - time curve is a sinusoidal curve with the amplitude σ_a.
The load F can be adjusted by positioning the sliding piece with the weight G.
The number of rotations is determined by a counter and the machine is stopped at failure.
The "stress amplitude - number of cycles" curve can be determined by repeating the test at different stress levels.

Fatigue Component Test on the Dartec Fatigue Tester

Here a component test is demonstrated. The fatigue loading of a spring is done in stroke controlled mode and the number of cycles to failure is determined.



Results

1. Plot all the available results on a S-N curve. Note the scatter.
2. Estimate the fatigue limit for this steel.

Discussion

Include in your discussion answers to the following questions.

1. What is distinctive about the surface appearance of a fatigue fracture? What information can be obtained observing the fracture surface?
2. What are the stages in a fatigue fracture?
3. Where do most fatigue cracks start? Why?

4. What is the mean stress and the R-ratio?
5. What is the difference about behavior of steel and Aluminum?
6. Why does improving surface finish improve fatigue properties?

References

1. *I.A.* Collins, *Failure of Materials in Mechanical Design*
2. ASM Metals Handbook, Vol. 10, 8th Ed., p. 102
3. G.E. Dieter, *Mechanical Metallurgy* (Chap. 12)

CHECKLIST FOR FATIGUE TEST REPORT

1. Table of Contents with page numbers.
2. Report organized into appropriate sections. Abstract, Introduction, etc.
3. Introduction section:
   . What are fatigue properties.. Why are fatigue properties important in engineering and how are they used.
4. Experimental Procedure:
   . Describe specimen and its preparation.
   . Describe fatigue machine make and model number.
   . Describe setup for test, starting and stopping.
5. Data Analysis:
   . Show formula and sample calculation.
   . Describe how you plot S-N curves. Estimate fatigue limit.
6. Results:
   . Display measured values in a table of all results.
   . Show S-N curves with proper labeling.
7. Discussion:
   . See if you can find any published values to compare your data with.
8. Conclusion:
   . A brief summary of what you did and the. result.
9. References

METALLOGRAPHY

Objective

To study the structural characteristics or constitution of a metal or an alloy in relation to its physical and mechanical properties.

Introduction

There are two examination methods in metallography:
I) Macroscopy
2) Microscopy

In macroscopy the examination of the structural characteristics or chemical characteristics of a metal or an alloy is done by the unaided eye or with the aid of a low-power microscope or binocular, usually under l0x.

In microscopy similar examination is done with the prepared metal specimens, employing magnifications with the optical microscope of from 100x to as high as 2000x.

Specimen preparation

1. Grinding

A small piece of specimen is cut by a metal-cutting-saw. After cutting operation, burrs on the edges of the specimen should be carefully removed by a fine file or coarse grinding paper.

The silicon carbide grinding papers are held flat in a unit containing water facility for lubrication purpose. Each unit contains four grades of papers, starting with grade 400 (coarse) and finishing with grade 1200 (fine). Grinding of the work piece is done by starting with the coarse papers and then continuing with the fine papers. In each stage, grinding is done by rubbing the specimen backwards and forwards on the grinding paper in one direction only, until the surface is completely ground, that is, until only grinding marks due to this particular paper can be seen to cover the whole surface.

The specimen is washed thoroughly to remove coarse silicon carbide particles before proceeding to a finer paper.

The direction of grinding is changed from paper to paper, so that the removal of previous grinding marks is easily observed. The extra time spent on each paper should be increased as the finer papers are used. At the end of the grinding sequence, the specimen is washed thoroughly and dried. Now, the specimen is ready for polishing.

2. Polishing

The polishing is done on rotating wheels covered by a special cloth. Alumina is employed as polishing agent. The 1-micron size is commonly used, but the total polishing time shortened by starting on the 7 or 3 micron grade.
The pad should be kept well supplied with lubricant. The specimen should be held

firmly in contact with the polishing wheel, but excessive pressure should be avoided. During polishing the specimen should be rotated or moved around the wheel so as to give an even polish. The specimen should be thoroughly cleaned and dried between each wheel.

3. Etching

Before etching, it is essential to ensure that the polished surface is grease and smear free. If the final polishing has involved the use of magnesia (in the form of an aqueous paste of fine magnesia) or alumina (in the form of an aqueous suspension of fine alumina), then thorough washing followed by drying off with acetone or alcohol will give a suitable surface, although it must not be fingered afterwards.

Etching is generally done by swabbing. Etching times will vary from specimen to specimen, however, a good general, procedure is to observe the surface during etching, and to remove the specimen when evidence of the grains first appears. Microscopical examination will then reveal whether the degree of etching is sufficient. Further etching can then follow to strengthen up the details as required.

After each etching, the specimen should be thoroughly washed in running water, followed by drying off with acetone or alcohol.

* As a guide the following etchants are commonly used:

Alcoholic Ferric Chloride	-copper alloys
Mixed Acids	-aluminum alloys
Nital (ethyl alcohol+ 2% HN03)	-iron and steel
Dilute HCI	-zinc alloys

A.MICROSCOPICAL EXAMINATION

The microstructural study of a material can provide information regarding the morphology and distribution of constituent phases as well as the nature and pattern of certain crystal imperfections. Optical metallography is a basic tool of material scientists, since the equipment is relatively inexpensive and the images can be obtained and interpreted easily. Distribution and morphology of the phases can be studied and, if their properties are known, a quantitative analysis of the micrographs provides some information about the bulk properties of the specimen. A limited study of line and surface informations is also possible with the optical microscope.

In order to obtain reproducible results, with good contrast in the image, the specimen surface is polished and subsequently etched with appropriate reagents before microscopic examination. In a polished specimen, the etching not only delineates grain boundaries, but also allows the different phases to be distinguished by differences in brightness, shape, and color of the grain. Differences in contrast may result from differences in light absorption characteristics of the phases. Etching results in preferential attack or preferential colouring of the surface. The preferential attack is electrochemical corrosion; it is

well known that different materials corrode at different rates. Grain boundaries are often anodic to the bulk metal in the interior of the grain and so are etched away preferentially and delineated. Staining is produced by the deposition of solid etch product on the specimen surface. This is formed by chemical reaction between the etchant and the specimen. Under favorable conditions the use of a proper etchant enables the identification of constituents. Failure analysis depends a great deal on metallographic examination.

Microstructural examination can provide quantitative information about the following parameters:

1) The grain size of specimens
2) The amount of interfacial area per unit volume
3) The dimensions of constituent phases
4) The amount and distribution of phases.

Magnifications up to 1000x can be obtained with a resolution of 2 μm. For grain size measurements, the grains along a line, circle, or within a known area are counted. It would be useful to obtain an average value of grain diameter from a microstructural section. In linear intercept method, the grains intercepted by a theoretical line on the specimen surface are counted (Fig. 1). The number of grain boundaries intersected per unit length of a test line (n_L) can be noted. The average grain size is indicated by the inverse of n_L, corrected for the magnification, M, of the micrograph. In general, then, the average grain diameter, d, is given by

$$d = C/n_L.M$$

where C is some constant greater than 1 (Typically, a value of C=1.5 is adequate).

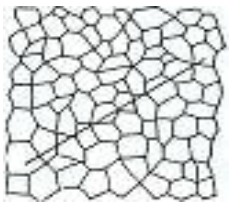


Fig.1 Linear intercept method for grain size determination

Experimental

Specimens are going to be polished and etched as explained above. With an unmounted specimen, even if it is almost level, it is best to fix it on a glass or metal slide by means of a piece of plasticine. The prepared surface is made level by means of a suitable levelling device.

The correct procedure is to start with low power examination in order to obtain an overall picture, and then successively higher magnifications are used to resolve the fine details. In focusing, the stage is gradually moved towards the objective and when the image appears, focusing is completed with the fine adjustment.

It is almost good practice to examine specimens first in the polished condition,

as certain features, such as the presence of inclusions, cracks, porosity, and sometimes even the different phases, are revealed. This is followed by an examination in the etched condition.

Do not examine one or two fields only. It should always be remembered that the structure of a given specimen exists in three dimensions, whereas the prepared surface represents a two-dimensional picture in the plane of the micro-section. This fact should be taken into account in the interpretation of the geometry of any particular configuration.

Results

The investigation result of the optical microscopy is going to be recorded as follows:

1. Examine each specimen and sketch typical microstructure
2. Estimate the carbon content of the steels.
3. Calculate the average grain diameter of the micrograph, using linear intercept method.

B. MACROSCOPIC EXAMINATION OF METALS

Objective

To examine the nature of inhomogenities and flow lines in a metal by unaided eye or with the aid of a low-powered microscope or magnifying glass.

Introduction

Metallurgical data obtained by a chemical and metallographic analysis of a metal or an alloy are usually not representative of the entire piece. These data represent the characteristics of the metal only at the particular section of the piece. The general distribution and variation in size of nonmetallic inclusions; the uniformity of structure; the location and extent of segregation; the presence of fabricating defects, such as seams or hammer bursts; and residual ingot defects, such as pipe can not be examined by microscopy.

The nature of inhomogenities in a metal, and the extent to which they exist therein, are best determined by macroetching a representative piece and subsequently examining the conditions thereby revealed with the unaided eye or with the aid of a low-powered microscope or magnifying glass. Such an examination is referred to as a macroscopic, or macro, examination. The magnification employed is usually not over 10x.

Macroetching sections may reveal conditions in the metal that are related to one or more of the following heterogeneous circumstances:

1. Crystalline heterogeneity, the presence and extent of which depend upon the manner of solidification and the crystalline growth of the metal or alloy.
2. Chemical heterogeneity, owing to impurities in the metal or alloy and to localized segregation of certain chemical constituents. Such segregation may be intentional (the introduction of carbon into the surface of steel during the process of case carburizing), or may be unintentional and undesirable, as for

example, the segregation of sulphur or phosphorus that is so often found in cast steels.

3. Mechanical heterogeneity, arising from cold-working or process that introduces permanent stresses into the metal. Such heterogeneity seldom occurs in cast metals, but its presence is of importance in cold-rolled metals, forging, etc.

Experiment

Three experiments will be performed:

1. Sulphur Printing:

Impurities may exist in steel products. It is desirable that their amounts should be minimal and homogeneously distributed within the product. These impurities degrade the mechanical properties of the steel, especially sulphur content in steel makes it brittle.

Sulphur may exist chemically in steel in one of two forms, either as manganese sulphide or as iron sulphide. Sulphur printing detects and permanently records the distribution of sulphur in steel.

The surface of interest to be tested for distribution of sulphur should be reasonably smooth and free from foreign matter such as dirt and grease. Grinding the surface on papers, numbers 400 to 1200 and subsequent thorough washing will generally produce a surface satisfactory for the purpose.

Photographic bromide paper is soaked in a 2% aqueous solution of sulphuric acid for approximately 3 or 4 min. The paper is removed from the acid solution and allowed to drain free from excess solution. The emulsion side of the paper is then placed in direct contact with the prepared specimen surface and allowed to remain in contact under moderately applied pressure for 1 or 2 min. Care must be taken that all entrapped air bubbles between the paper and the specimen surface are eliminated.

The reaction of the sulphuric acid with the sulphide regions of the steel produces hydrogen sulphide gas, which reacts with the silver bromide in the paper emulsion, forming a characteristic brown to gray-black deposit of silver sulphide. These reactions may be expressed as follows:

$$FeS + H2SO4 \sim FeS04 + H2S$$

or

$$MnS + H2SO4 \sim MnS04 + H2S$$

$$H2S + 2\ AgBr \sim Ag2S + 2\ HBr$$

When the reaction has proceeded for approximately the recommended length of time, the photographic paper is removed from the surface of the specimen, rinsed in clear running water, and then fixed permanently by placing it in a photographic fixing solution for about 15 min. When fixation is completed, the print is again washed in running water for approximately 30 min. and subsequently dried in the usual manner.

The examination of properly prepared sulphur print will disclose quite clearly, because of the presence of darkly colored areas of silver sulphide, the precise location of sulphur inclusions on the prepared surface of the metal. A grouping or gathering of such silver sulphide areas indicates the presence of sulphur

segregation, whereas a random dispersion of the spots denotes a more uniform, distribution of the sulphur inclusions.

2. **Flow lines:**

It is sometimes desirable to determine whether or not a finished piece has been forged, cut, or cast into shape and to note, in the event that it was forged, the direction of metal flow. Flow lines as revealed by macroetching in forgings are a natural consequence of applied mechanical working. If the flow pattern shows highly selective etching characteristics, it is likely that the material may be defective and may contain an excessive amount of inclusions and segregated areas.
A macroetched forged-material shows a directional flow pattern consisting of streaks and striations. The orientation of this pattern with respect to the plane of the prepared surface indicates the direction of metal flow during deformation. The flow lines are made visible because the elongated inclusions of impurities, such as oxides, sulphides and other elongated heterogeneous areas are selectively attacked by the etching reagent.

3. **Welded sections:**

It is often desirable, and frequently necessary, to determine the soundness of a welded joint and to observe macroscopically over a cross section of the weldment the various zones wherein structural changes have occurred. This is accomplished by macroetching the prepared surface with the usual hydrocWoric acid solution, or in some cases with a milder reagent such as 2 or 3 % nital (ethyl alcohol + 2% HN03).
In ferritic welds, the specimen of interest is prepared in a manner described for metallographic specimens and finally alternately polished and etched in saturated picral to remove disturbed metal. The prepared surface is then etched for 10 to 20 sec. in 5% nital, after which the surface is thoroughly washed and lightly rubbed on a metallographic polishing cloth until the columnar grains in the weld metal show distinctly. This procedure is repeated several times to lessen the light reflectivity characteristics of the surface and to produce some relief of the macrostructure. The specimen of interest is then etched by immersion for about 2 min. in saturated picral, followed by thorough washing in cold running water and swabbing with a tuft of cotton to remove the loosely adhering reaction products formed on the surface. The specimen is finally rinsed in alcohol and dried in a stream of warm air.

Specimens

1. Sulphur printing: a piece of rail material
2. Flow lines: done without a specimen, shown on blackboard
3.Welded sections: finding the location of weld section of a welded-material

Procedure

1. Sulphur printing: follow the instructions in the introduction section.

2. Flow lines:
3. Welded section: follow the instructions in the introduction section (for grinding the specimen use number 240 to 400 grinding papers then rub the specimen surface using a cotton tuft by 9g $FeCl_3$ + 6 cm3 HCl + 100 cm3 H2O solution until the weld section appears).

Results

1. Draw schematically sulphur inclusions in the rail material (Specimen 1).
2. Are the sulphur inclusions distributed homegeneously or as segregated points in the material? Discuss their effects on the mechanical properties of the material.

3 What causes the flow lines to appear. Do flow lines exist in casted materials? Why?
4. What do the flow lines indicate in terms of mechanical properties of the material?
5. Draw schematically welded-section of specimen 3.
6. What do you find out by examining the welded-sections? Can you talk about the weld quality, appearance and the welded materials, etc.? By inspecting the weld section, relate this result to the mechanical properties of the material.

References

1. Kehl, G.L., The Principles of Metallographic Laboratory Practice, 3rd Ed., 1949.
2. Güleç,Ş., Malzeme Ders Notlan, Makina Fakültesi, İTÜ.
3. Imperial College of Science and Technology, Department of Metallurgy and Materials Science, 2nd Year Materials Laboratory Notes for Mechanical and Aeronautical Engineers.
4. ASTM Standards and ASM Standards (they exist in our library, please consult with the librarian).

JOMINY HARDENABILITY TEST

Objective

To study hardness as a function of quench rate and investigate the hardenability of steels.

Introduction

The hardenability of a steel is defined as that property which determines the depth and distribution of hardness induced by quenching ftom the austenitic condition. The dependence of hardness upon quenching rate can be understood ftom the time-temperature-transformation characteristics of steel, and, for a particular steel, can be estimated from the T-T-T diagram.

A part may be hardened by quenching into water, oil, or other suitable medium. The surface of the part is cooled rapidly, resulting in high hardness, whereas the interior cools more slowly and is not hardened. Because of the nature of the T-T-T diagram, the hardness does not vary linearly from the outside to the center. Hardenability refers to capacity of hardening (depth) rather than to maximum attainable hardness.

The hardenability of a steel depends on

(1) the composition of the steel,
(2) the austenitic grain size, and
(3) the structure of the steel before quenching.

In general, hardenability increases with carbon content and with alloy content. The most important factor influencing the maximum hardness that can be obtained is mass of the metal being quenched. In a small section, the heat is extracted quickly, thus exceeding the critical cooling rate of the specific steel and this part would thus be completely martensitic. The critical cooling rate is that rate of cooling which must be exceeded to prevent formation of nonmartensite products. As section size increases, it becomes increasingly difficult to extract the heat fast enough to exceed the critical cooling rate and thus avoid formation of nonmartensitic products. Hardenability of all steels is directly related to critical cooling rates.

Procedure

Sample of medium carbon steel machined to the shape shown in Fig.2. It is a cylindirical bar with a 25 mm diameter and 100 mm length. The specimen is placed in the furnace at 900 ^{0}C for about $^{1}/_{2}$ hour. The water flow rate is adjusted so that the water column is approximately the distance 50 mm above the end of the pipe, when water is flowing freely.
After the sample has been austenitized, it is removed from the furnace and placed directly into the quenching apparatus. A jet of water is quickly splashed at one end of the specimen. After the entire sample has cooled to room temperature, the

scale oxidation is removed; two opposite and flat parallel surfaces are ground along the length of the bar. Rockwell C hardness measurements are then made every 2 mm and these readings are recorded.

Results

Plot a hardenability curve of Rockwell hardness vs. distance from the quenched end. (Fig. 3)

Discussion and Questions

1. Evaluate the hardenability of the steel used in this experiment using the plotted hardenability curve.
2. Predict the microstructure of the steel all along the bar in correlation with your hardness measurements. What is the ***ideal critical diameter*** and can it be determined with a Jominy test.
3. How is the role of carbon and various alloy elements on the hardenability of steels (Give examples of different hardenability curves).

References

1. Shackelford, IF, Introduction to Materials Science
2. Smith, W.F., Principles of Materials Science and Engineering
3. ASM, Heat Treater's Guide

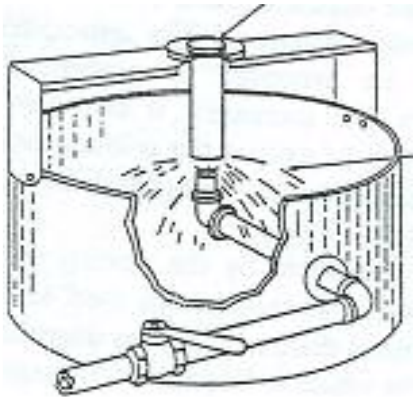


Fig.1 Schematic illustration of the Jominy end-quench test

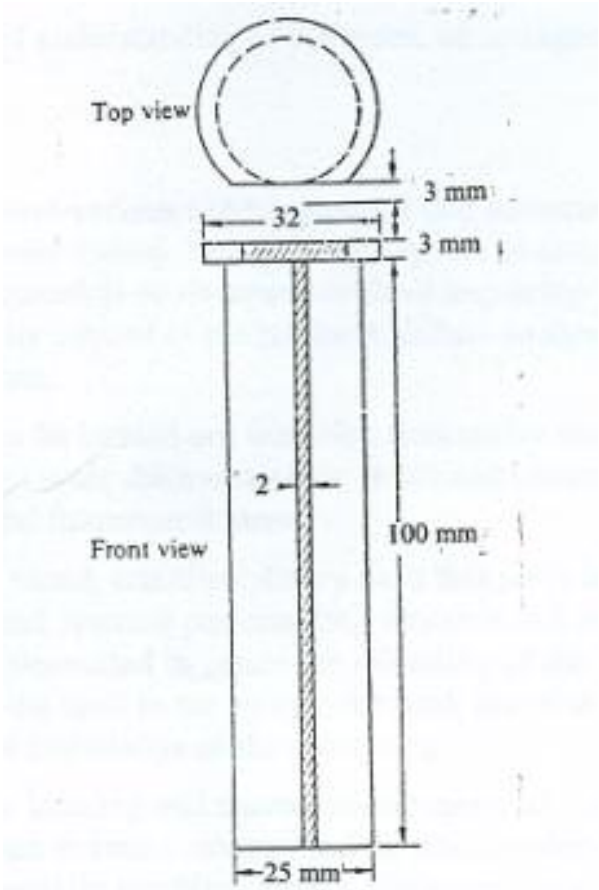


Fig.2 Standard-size sample.

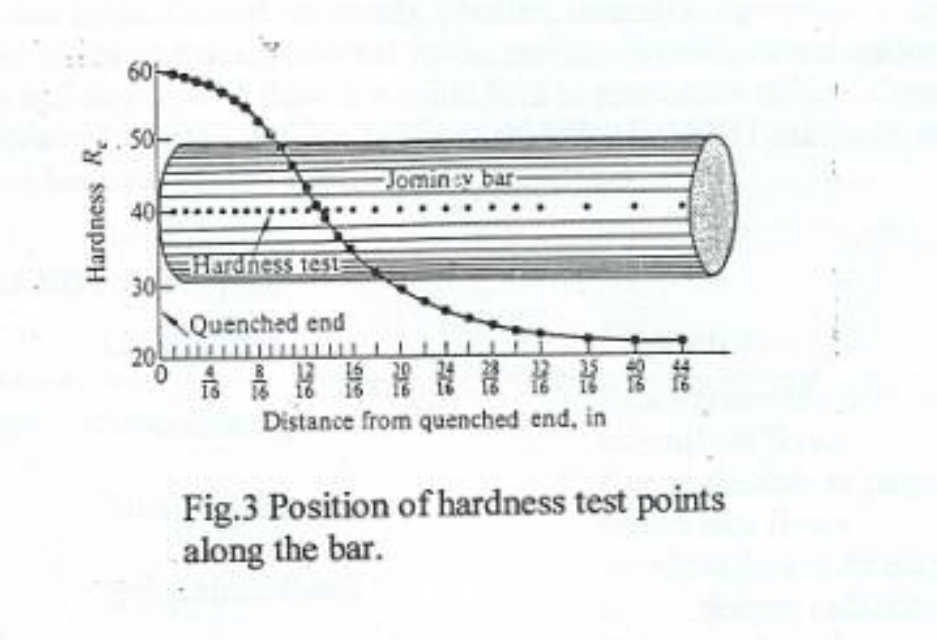


Fig.3 Position of hardness test points along the bar.

NON-DESTRUCTIVE TESTING

Objective

To gain experience with and understanding of the types, advantages and applications of various NDT methods. To be able to choose the best NDT method for a given part.

Introduction

Up to this point we have learnt various testing methods that somehow destruct the test specimens. These were, tensile testing, hardness testing, etc. In certain applications, the evaluation of engineering materials or structures without impairing their properties is very important, such as the quality control of the products, failure analysis or prevention of the engineered systems in service.

This kind of evaluations can be carried out with Non destructive test (NDT) methods. It is possible to inspect and/or measure the materials or structures without destroying their surface texture, product integrity and future usefulness.

The field of NDT is a very broad, interdisciplinary field that plays a critical role in inspecting that structural component and systems perform their function in a reliable fashion. Certain standards has been also implemented to assure the reliability of the NDT tests and prevent certain errors due to either the fault in the equipment used, the miss-application of the methods or the skill and the knowledge of the inspectors.

Successful NDT tests allow locating and characterizing material conditions and flaws that might otherwise cause planes to crash, reactors to fail, trains to derail, pipelines to burst, and variety of less visible, but equally troubling events. However, these techniques generally require considerable operator skill and interpreting test results accurately may be difficult because the results can be subjective.

These methods can be performed on metals, plastics, ceramics, composites, cermets, and coatings in order to detect cracks, internal voids, surface cavities, delamination, incomplete defective welds and any type of flaw that could lead to premature failure. Commonly used NDT test methods can be seen in table 1. These are universal NDT methods; however, very special tests have been developed for specific applications.

Table 1 Commonly used NDT techniques

Technique	Capabilities	Limitations
Visual Inspection	Macroscopic surface flaws	Small flaws are difficult to detect, no subsurface flaws.
Microscopy	Small surface flaws	Not applicable to larger structures; no subsurface flaws.
Radiography	Subsurface flaws	Smallest defect detectable is 2% of the thickness; radiation protection. No subsurface flaws not for porous materials
Dye penetrate	Surface flaws	No subsurface flaws not for porous materials
Ultrasonic	Subsurface flaws	Material must be good conductor of sound.
Magnetic Particle	Surface / near surface and	Limited subsurface capability, only for

	layer flaws	ferromagnetic materials.
Eddy Current	Surface and near surface flaws	Difficult to interpret in some applications; only for metals.
Acoustic emission	Can analyze entire structure	Difficult to interpret, expensive equipments.

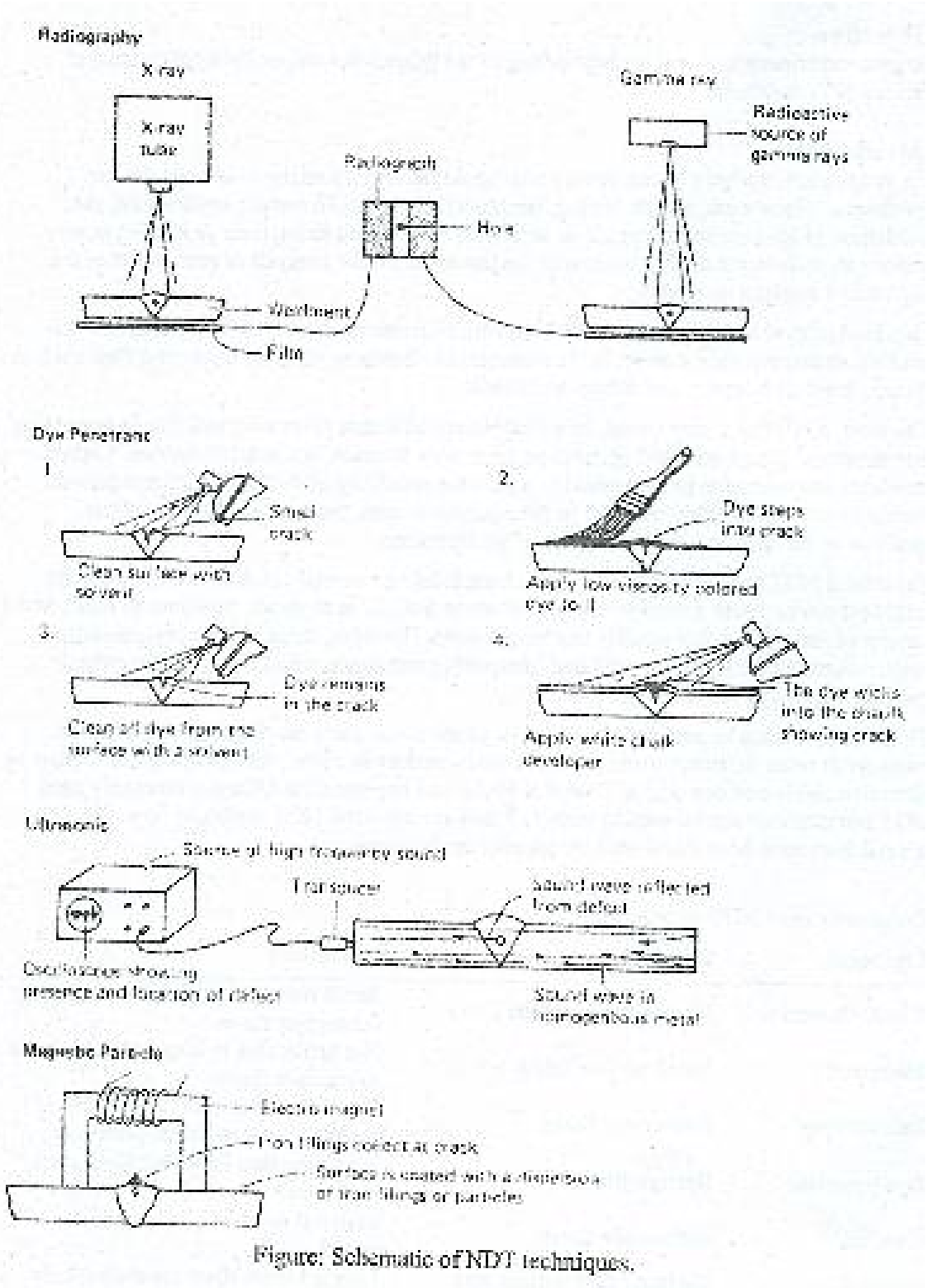


Figure: Schematic of NDT techniques.

Visual inspection:

VI is particularly effective detecting macroscopic flaws, such as poor welds. Many welding flaws are macroscopic: crater cracking, undercutting, slag inclusion, incomplete penetration welds, and the like. Like wise, VI is also suitable for detecting flaws in composite structures and piping of all types. Essentially, visual inspection should be performed the way that one would inspect a new car prior to delivery, etc. Bad welds or joints, missing fasteners or components, poor fits, wrong dimensions, improper surface finish, delaminations in coatings, large cracks, cavities, dents, inadequate size, wrong parts, lack of code approval stamps and similar proofs of testing.

Radiography:

Radiography has an advantage over some of the other processes in that the radiography provides a permanent reference for the internal soundness of the object that is radiographed.
The x-ray emitted from a source has an ability to penetrate metals as a function of the accelerating voltage in the x-ray emitting tube. If a void present in the object being radiographed, more x-rays will pass in that area and the film under the part in turn will have more exposure than in the non-void areas. The sensitivity of x-rays is nominally 2% of the materials thickness. Thus for a piece of steel with a 25mm thickness, the smallest void that could be detected would be 0.5mm in dimension. For this reason, parts are often radiographed in different planes. A thin crack does not show up unless the x-rays ran parallel to the plane 0 the crack. Gamma radiography is identical to x-ray radiography in function. The difference is the source of the penetrating electromagnetic radiation which is a radioactive material such m Co 60. However this method is less popular because of the hazards of handling radioactive materials.

Liquid (Dye) penetrant method:

Liquid penetrant inspection (LPI) is one of the most widely used nondestructive evaluation (NDE) methods. Its popularity can be attributed to two main factors, which are its relative ease of use and its flexibility. The technique is based on the ability of a liquid to be drawn into a "clean" surface breaking flaw by capillary action.
This method is an inexpensive and convenient technique for surface defect inspection. The limitations of the liquid penetrant technique include the inability to inspect subsurface flaws and a loss of resolution on porous materials. Liquid penetrant testing is largely used on nonmagnetic materials for which magnetic particle inspection is not possible.
Materials that are commonly inspected using LPI include the following; metals (aluminum, copper, steel, titanium, etc.), glass, many ceramic materials, rubber, plastics.
Liquid penetrant inspection is used to inspect of flaws that break the surface of the sample. Some of these flaws are listed below; fatigue cracks, quench cracks

grinding cracks, overload and impact fractures, porosity, laps seams, pin holes in welds, lack of fusion or braising along the edge of the bond line.

Magnetic particles:

Magnetic particle inspection is one of the simple, fast and traditional nondestructive testing methods widely used because of its convenience and low cost. This method uses magnetic fields and small magnetic particles, such as iron filings to detect flaws in components. The only requirement from an inspect ability standpoint is that the component being inspected must be made of a ferromagnetic material such iron, nickel, cobalt, or some of their alloys, since these materials are materials that can be magnetized to a level that will allow the inspection to be effective. On the other hand, an enormous volume of structural steels used in engineering is magnetic. In its simplest application, an electromagnet yoke is placed on the surface of the part to be examined, a kerosene-iron filling suspension is poured on the surface and the electromagnet is energized. If there is a discontinuity such as a crack or a flaw on the surface of the part, magnetic flux will be broken and a new south and north pole will form at each edge of the discontinuity. Then just like if iron particles are scattered on a cracked magnet, the particles will be attracted to and cluster at the pole ends of the magnet, the iron particles will also be attracted at the edges of the crack behaving poles of the magnet. This cluster of particles is much easier to see than the actual crack and this is the basis for magnetic particle inspection. For the best sensitivity, the lines of magnetic force should be perpendicular to the defect.

Eddy current testing:

Eddy currents are created through a process called electromagnetic induction. When alternating current is applied to the conductor, such as copper wire, a magnetic field develops in and around the conductor. This magnetic field expands as the alternating current rises to maximum and collapses as the current is reduced to zero. If another electrical conductor is brought into the close proximity to this changing magnetic field, current will be induced in this second conductor. These currents are influenced by the nature of the material such as voids, cracks, changes in grain size, as well as physical distance between coil and material. These currents form an impedance on a second coil which is used to as a sensor. In practice a probe is placed on the surface of the part to be inspected, and electronic equipment monitors the eddy current in the work piece through the same probe. The sensing circuit is a part of the sending coil.
Eddy currents can be used for crack detection, material thickness measurements, coating thickness measurements, conductivity measurements for material identification, heat damage detection, case depth determination, heat treatment monitoring.
Some of the advantages of eddy current inspection include; sensitivity to small cracks and other defects, ability to detect surface and near surface defects, immediate results, portable equipment, suitability for many different applications, minimum part preparation, no necessity to contact the part under inspection, ability to inspect complex shapes and sizes of conductive materials.

Some limitation of eddy current inspection; applicability just on conductive materials, necessity for an accessible surface to the probe, skillful and trained personal, possible interference of surface finish and roughness, necessity for reference standards for setup, limited depth of penetration, inability to detect of the flaws lying parallel to the probe coil winding and probe scan direction.

Ultrasonic Inspection:

Ultrasonic Testing (UT) uses a high frequency sound energy to conduct examinations and make measurements. Ultrasonic inspection can be used for flaw detection evaluation, dimensional measurements, material characterization, and more. A typical UT inspection system consists of several functional units, such as the pulser/receiver, transducer, and display devices. A pulser/receiver is an electronic device that can produce high voltage electrical pulse. Driven by the pulser, the transducer of various types and shapes generates high frequency ultrasonic energy operating based on the piezoelectricity technology with using quartz, lithium sulfate, or various ceramics. Most inspections are carried out in the frequency rang of 1 to 25MHz. Couplants are used to transmit the ultrasonic waves from the transducer to the test piece; typical couplants are water, oil, glycerin and grease.
The sound energy is introduced and propagates through the materials in the form of waves and reflected from the opposing surface. An internal defect such as crack or void interrupts the waves' propagation and reflects back a portion of the ultrasonic wave. The amplitude of the energy and the time required for return indicate the presence and location of any flaws in the work-piece.
The ultrasonic inspection method has high penetrating power and sensitivity. It can be used from various directions to inspect flaws in large parts, such as rail road wheels pressure vessels and die blocks. This method requires experienced personnel to properly conduct the inspection and to correctly interpret the results.
As a very useful and versatile NDT method, ultrasonic inspection method has the following advantages; sensitivity to both surface and subsurface discontinuities, superior depth of penetration for flaw detection or measurement, ability to single-sided access for pulse-echo technique, high accuracy in determining reflector position and estimating size and shape, minimal part preparation, instantaneous results with electronic equipment, detailed imaging with automated systems, possibility for other uses such as thickness measurements.
Its limitations; necessity for an accessible surface to transmit ultrasound, extensive skill and training, requirement for a coupling medium to promote transfer of sound energy into test specimen, limits for roughness, shape irregularity, smallness, thickness or not homogeneity, difficulty to inspect of coarse grained materials due to low sound transmission and high signal noise, necessity for the linear defects to be oriented parallel to the sound beam, necessity for reference standards for both equipment calibration, and characterization of flaws.

Acoustic Method:

There are two different kind of acoustic methods: (a) acoustic emission; (b) acoustic impact technique.

Acoustic emission:

This technique is typically performed by elastically stressing the part or structure, for example, bending a beam, applying torque to a shaft, or pressurizing a vessel and monitoring the acoustic responses emitted from the material. During the structural changes the material such as plastic deformation, crack initiation, and propagation, phase transformation, abrupt reorientation of grain boundaries, bubble formation during boiling in cavitation, friction and wear of sliding interfaces, are the source of acoustic signals. Acoustic emissions are detected with sensors consisting of piezoelectric ceramic elements. This method is particularly effective for continuous surveillance of load-bearing structures.

Acoustic impact technique:

This technique consists of tapping the surface of an object and listening to and analyzing the signals to detect discontinuities and flaws. The principle is basically the same as when one taps walls, desktops or countertops in various locations with a finger or a hammer and listens to the sound emitted. Vitrified grinding wheels are tested in a similar manner to detect cracks in the wheel that may not be visible to the naked eye. This technique is easy to perform and can be instrumented and automated. However, the results depend on the geometry and mass of the part so a reference standard is necessary for identifying flaws.

Procedure

Liquid penetrant method:

In this method the surfaces to be inspected should be free from any coatings, paint, grease, dirt, dust, etc.; therefore, should be cleaned with an appropriate way. Special care should be taken not to give additional damage to the surface to be inspected during the cleaning process. Otherwise, the original nature of surface could be disturbed and the results could be erroneous with the additional interferences of the surface features formed during the cleaning process.
Surface cleaning can be performed with alcohol. Special chemicals like cleaner-remover can also be applied if needed. In the experiment, only cleaner-remover will be sufficient. Subsequent to surface cleaning, the surface is let to dry for 2 minutes.

Commercially available cans of liquid penetrant dyes with different colors are used to reveal the surface defects.

Steps used in the experiment:
1. Clean the surface with alcohol and let surface dry for 5 min.
2. Apply the liquid penetrant spray (red can) to the surface and brush for further penetration. Then, wait for 20 min.
3. Wipe the surface with a clean textile and subsequently apply remover spray (blue can) to remove excess residues on the surface and wait for a few min.

4. Apply the developer spray (yellow can) at a distance of about 30cm from the surface. The developer will absorb the penetrant that infiltrated to the surface features such as cracks, splits, etc., and then reacted with it to form a geometric shape which is the negative of the geometry of the surface features from which the penetrant is sucked.
5. The polymerized material may be collected on a sticky paper for future evaluation and related documentation, if needed.

Magnetic particle:

In this experiment, commercially available magnetic powder manufactured for NDT inspection will be used. A strong U shape magnet will be used to provide the necessary magnetic field at the inspected area.

The following steps are applied during the experiment;

1. The surface of the specimen will be roughly cleaned wiping with a piece of textile.
2. The fluorescent magnetic spray will be applied on the surface being inspected.
3. Magnetic field will be applied with a strong magnet to the location of interest.
4. The spots where the fluorescent magnetic particles accumulated will be inspected under UV light.

Eddy current inspection:

For this experiment, Magnefest ED-51 0 type unit will be used. A pencil type prop will be used for the inspections. The inspection is performed with 2 MHz frequency and at the related calibration settings. The test blocks were previously prepared for this experiment. Any coatings or paints on the surface of inspected specimens should be treated with special procedures.

The following steps should be applied during the experiment:

l. Inspection area should be clean, smooth, free from any irregular or uneven paint, dirt, grease, etc.
2. There shouldn't be any visible damage or discontinuity.
3. During the inspection procedure the probe will be positioned near the inspection area, on the compensation point and lift off and zero will be adjusted if necessary.
4. The inspection will be carried out by using probe scans. The probe tip will be always at a right angle the inspection surface.
5. Any indication with indicator deflection to the right should be evaluated. All evaluated indications should be measured.
6. After this procedure, all evaluated indications with indicator deflections, will be classified as cracks and be recorded.

Ultrasonic inspection:

For this experiment,USM-2 type ultrasonic unit will be used. The props used supports to work at frequency of 5 MHz. Echo techniques will be employed to find the cracks.
Instrument will be tuned to a frequency of 5 MHz. An appropriate couplant used should not cause corrosion or other damage. During the inspection the calibration will be done on the reference standard, if needed. Two different test blocks will be employed in this test, sufficient amount of couplant will be applied to the transducer scan areas on the forward and after sides of the support fitting. The display will be monitored for crack indications. A crack signal will be similar to the following:

The following steps should be applied during the experiment:

1. The couplant should be applied on the inspected area.
2. For the circular test specimen, the prop will be placed in the corresponding space in the supporting fitting tool. Enough couplant should be used between the probe and tool.
3. For the flat specimen, no tool is needed, couplant only applied between the inspected surface and the probe.
4. Special attention should be paid on the location where possible cracks exist.
5. A discontinuity like a crack produces a peak on the screen.
6. Attention should also be given to the movement of the possible peak caused by the cracks on the specimen.

Report:

You are supposed to prepare a test report for this experiment obeying the report preparation rules. Therefore your report should contain abstract, introduction, experimental procedures, results, discussion, conclusion and references. The advantages and disadvantages of each NDT method must be stated precisely in your reports. You should also answer the questions asked to you at the end of the experiment installing the related parts of your report. You have to return your report on time.