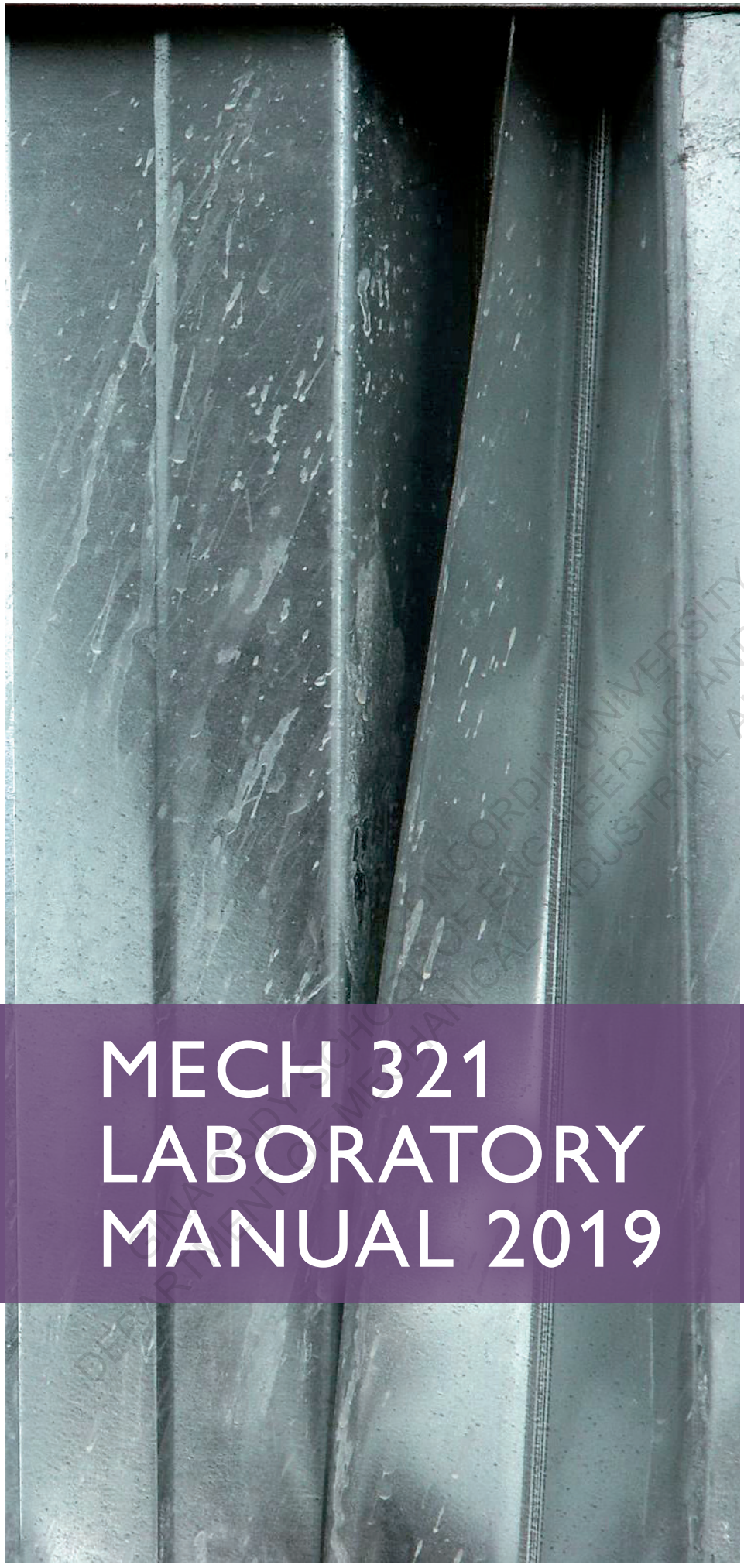

MECH 321 LABORATORY MANUAL 2019

PROPERTIES & FAILURE OF MATERIALS

H 1058

UNIVERSITÉ Concordia UNIVERSITY

GINA CODY
SCHOOL OF ENGINEERING AND COMPUTER SCIENCE

Department of Mechanical, Industrial and Aerospace Engineering

EMERGENCY • URGENCE

Security **514-848-(3717)** Sécurité

BUILDING EVACUATION

When you hear the fire alarm, YOU MUST LEAVE THE BUILDING IMMEDIATELY.

1. Stop your work.
2. Gather all your personal belongings.
3. Calmly leave the room, closing doors and windows behind you, and go to the nearest emergency exit door or stairwell.
4. Once outside, move away from the building.

Help mobility impaired people

If you encounter a mobility impaired person that can not use the emergency stairwells during an evacuation, the following procedure must be used:

1. Escort the person to the nearest emergency stairwell, remaining outside the stairwell.
2. Use a telephone (Fire Department, emergency or cellular) to contact Security and advise them that you are with a disabled person; if not available, send somone to advise Security.
3. Security personnel or Emergency Responders (CERT members) will come to assist you.
4. In the presence of danger, such as smoke, alert Security and move the person inside the stairwell ensuring the door is closed behind you.

ÉVACUATION DES LIEUX

Dès que vous entendez l'alarme incedie, QUITTEZ LE BÂTIMENT IMMÉDIATEMENT.

1. Cessez toute activité.
2. Rassemblez vos effets personnels.
3. Quittez la salle dans le calme, en fermant les portes et fenêtres derrière vous, et dirigez-vous vers l'escalier ou l'issue de secours le plus proche.
4. Une fois à l'extérieur, éloignez-vous du bâtiment.

Aidez aux personnes à mobilité réduite

Si vous rencontrez une personne à mobilité réduite qui ne peut utiliser les escaliers de secours pendant l'évacuation, suivez cette procédure:

1. Accompagnez-la jusqu'à l'escalier de secours le plus proche en demeurant à l'extérieur de la cage d'escalier.
2. Utilisez un téléphone (service des incendies, urgence ou cellulaire) ou dépêches quelqu'un pour aviser la Sécurité que vous êtes avec une personne à mobilité réduite.
3. Attendez que le personnel de la Sécurité ou les intervenants d'urgence viennent vous aider.
4. S'il y a présence d'un danger (de la fumée, par example), contactez la Sécurité et emmenez la personne à l'intérieur de la cage d'escalier en vous assurant de refermer la porte derrière vous.

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CONTACTS

LABORATORY INSTRUCTOR *(Fill in by student)*

Name: _____

E-Mail: _____

Office: _____

Phone: _____

Lab Section: _____ Lab Day & Time: _____ Week: _____

LABORATORY PARTNERS *(Fill in by student)*

Name: _____

E-Mail: _____

Phone: _____

Name: _____

E-Mail: _____

Phone: _____

Name: _____

E-Mail: _____

Phone: _____

LABORATORY TECHNICIANS

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LABORATORY SPECIALIST

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TECHNICAL/SAFETY OFFICER

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Phone: 514-848-2424 x8797

LABORATORY COORDINATOR

Name: Petre Tzenov
E-Mail: petre.tzenov@concordia.ca
Office: EV 004.183
Phone: 514-848-2424 x8670

LABORATORY CALENDAR

Laboratory Calendar is subject to change after time of printing this manual.

		MON	TUES	WED	THURS	FRI	
JANUARY	WEEK 1	7	8	9	10	11	
	WEEK 2	14 Lab TJ-X: 9:00-10:50 Lab XR-X: 13:15-15:05 Lab XP-X: 15:15-17:05	15 Lab TL-X: 9:00-10:50 Lab XJ-X: 11:45-13:35	16 Lab XN-X: 11:45-13:35	17 Lab TP-X: 9:00-10:50 Lab XL-X: 11:45-13:35	18 Lab TR-X: 11:45-13:35 Lab TN-X: 14:45-16:35	EXPERIMENT 1
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	WEEK 1	4 Lab TI-X: 9:00-10:50 Lab XQ-X: 13:15-15:05 Lab XO-X: 15:15-17:05	5 Lab TK-X: 9:00-10:50 Lab XI-X: 11:45-13:35	6 Lab XM-X: 11:45-13:35	7 Lab TO-X: 9:00-10:50 Lab XK-X: 11:45-13:35	8 Lab TQ-X: 11:45-13:35 Lab TM-X: 14:45-16:35	
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ACKNOWLEDGEMENTS

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The author gratefully acknowledges Marc Bourcier for the design layout of this manual and excellent photos.

GENERAL LABORATORY SAFETY RULES

FOLLOW RELEVANT INSTRUCTIONS

- Before attempting to install, commission or operate equipment, all relevant suppliers'/manufacturers' instructions and local regulations should be understood and implemented.
- It is irresponsible and dangerous to misuse equipment or ignore instructions, regulations or warnings.
- Do not exceed specified maximum operating conditions (e.g. temperature, pressure, speed etc.).

INSTALLATION/COMMISSIONING

- Use lifting table where possible to install heavy equipment. Where manual lifting is necessary beware of strained backs and crushed toes. Get help from an assistant if necessary. Wear safety shoes where appropriate.
- Extreme care should be exercised to avoid damage to the equipment during handling and unpacking. When using slings to lift equipment, ensure that the slings are attached to structural framework and do not foul adjacent pipe work, glassware etc.
- Locate heavy equipment at low level.
- Equipment involving inflammable or corrosive liquids should be sited in a containment area or bund with a capacity 50% greater than the maximum equipment contents.
- Ensure that all services are compatible with equipment and that independent isolators are always provided and labelled. Use reliable connections in all instances, do not improvise.
- Ensure that all equipment is reliably grounded and connected to an electrical supply at the correct voltage.
- Potential hazards should always be the first consideration when deciding on a suitable location for equipment. Leave sufficient space between equipment and between walls and equipment.
- Ensure that equipment is commissioned and checked by a competent member of staff permitting students to operate it.

OPERATION

- Ensure the students are fully aware of the potential hazards when operating equipment.
- Students should be supervised by a competent member of staff at all times when in the laboratory. No one should operate equipment alone. Do not leave equipment running unattended.
- Do not allow students to derive their own experimental procedures unless they are competent to do so.

MAINTENANCE

- Badly maintained equipment is a potential hazard. Ensure that a competent member of staff is responsible for organizing maintenance and repairs on a planned basis.
- Do not permit faulty equipment to be operated. Ensure that repairs are carried out competently and checked before students are permitted to operate the equipment.

ELECTRICITY

- Electricity is the most common cause of accidents in the laboratory. Ensure that all members of staff and students respect it.
- Ensure that the electrical supply has been disconnected from the equipment before attempting repairs or adjustments.
- Water and electricity are not compatible and can cause serious injury if they come into contact. Never operate portable electric appliances adjacent to equipment involving water unless some form of constraint or barrier is incorporated to prevent accidental contact.
- Always disconnect equipment from the electrical supply when not in use.

AVOIDING FIRES OR EXPLOSION

- Ensure that the laboratory is provided with adequate fire extinguishers appropriate to the potential hazards.
- Smoking must be forbidden. Notices should be displayed to enforce this.
- Beware since fine powders or dust can spontaneously ignite under certain conditions. Empty vessels having contained inflammable liquid can contain vapor and explode if ignited.
- Bulk quantities of inflammable liquids should be stored outside the laboratory in accordance with local regulations.
- Storage tanks on equipment should not be overfilled. All spillages should be immediately cleaned up, carefully disposing of any contaminated cloths etc. Beware of slippery floors.
- When liquids giving off inflammable vapors are handled in the laboratory, the area should be properly ventilated.
- Students should not be allowed to prepare mixtures for analysis or other purposes without competent supervision.

HANDLING POISONS, CORROSIVE OR TOXIC MATERIALS

- Certain liquids essential to the operation of equipment, for example, mercury, are poisonous or can give off poisonous vapors. Wear appropriate protective clothing when handling such substances.
- Do not allow food or drink to be brought into or consumed in the laboratory. Never use chemical beakers as drinking vessels
- Smoking must be forbidden. Notices should be displayed to enforce this.
- Poisons and very toxic materials must be kept in a locked cupboard or store and checked regularly. Use of such substances should be supervised.

AVOID CUTS AND BURNS

- Take care when handling sharp edged components. Do not exert undue force on glass or fragile items.
- Hot surfaces cannot, in most cases, be totally shielded and can produce severe burns even when not visibly hot. Use common sense and think which parts of the equipment are likely to be hot.

EYE/EAR PROTECTION

- Goggles must be worn whenever there is risk to the eyes. Risk may arise from powders, liquid splashes, vapors or splinters. Beware of debris from fast moving air streams.
- Never look directly at a strong source of light such as a laser or Xenon arc lamp. Ensure the equipment using such a source is positioned so that passers-by cannot accidentally view the source or reflected ray.
- Facilities for eye irrigation should always be available.
- Ear protectors must be worn when operating noisy equipment.

CLOTHING

- Suitable clothing should be worn in the laboratory. Loose garments can cause serious injury if caught in rotating machinery. Ties, rings on fingers etc. should be removed in these situations.
- Additional protective clothing should be available for all members of staff and students as appropriate.

GUARDS AND SAFETY DEVICES

- Guards and safety devices are installed on equipment to protect the operator. The equipment must not be operated with such devices removed.
- Safety valves, cut-outs or other safety devices will have been set to protect the equipment. Interference with these devices may create a potential hazard.
- It is not possible to guard the operator against all contingencies. Use commons sense at all times when in the laboratory.
- Before staring a rotating machine, make sure staff are aware how to stop it in an emergency.
- Ensure that speed control devices are always set to zero before starting equipment.

FIRST AID

- If an accident does occur in the laboratory it is essential that first aid equipment is available and that the supervisor knows how to use it.
- A notice giving details of a proficient first-aider should be prominently displayed.
- A short list of the antidotes for the chemicals used in the particular laboratory should be prominently displayed.

LABORATORY PROTOCOL

GENERAL

Each experiment presented in this manual is performed on a bi-weekly basis. The order of performance of each experiment is followed unless specified otherwise by the laboratory instructor.

Students are divided into groups of three or four to perform the experiment. Each group is required to work together throughout the semester. In other words, no switching groups in mid-stream.

The student must come to the laboratory at their registered section; otherwise, he/she is not allowed to attend unless prior permission is given by the Laboratory Specialist.

THE STUDENT MUST ALWAYS BRING A COMPLETE AND ATTACHED COPY OF THE LAB MANUAL TO EACH EXPERIMENT. EXPERIMENT EXCERPTS, UNATTACHED OR NO LAB MANUAL DOES NOT QUALIFY AND IS SUBJECT TO PENALTY. Bring a USB flash drive to copy data files when required.

In order that the laboratory session is conducted in the most meaningful manner possible, it is imperative that each student read, study, and understand the experiment to be conducted prior to coming to the laboratory. The student should also read and understand the laboratory safety guidelines. Failure to follow these guidelines will result in expulsion from the laboratory.

An attendance sheet is circulated and it is the responsibility of the student to sign it at each lab session. The lab instructor is not expected to remember if the student attended and later forgot to sign the attendance sheet.

The student is required to complete all given laboratory tasks within the allotted laboratory time (110 minutes). There are no extension or makeup sessions outside the scheduled time.

At the end of each experiment, the laboratory instructor must sign the completed data sheet provided in this manual. This signed sheet must be incorporated at the end of the laboratory report to be submitted by the group to receive credit.

No food or drink allowed in the laboratory. Cellular phones must be turned off during the experiment.

COMING LATE

All issues coming late to the laboratory are handled by the Laboratory Specialist.

Arriving late for whatever reason to the laboratory is deducted 20% for the experiment.

Arriving 30 minutes after the start of the scheduled lab results in a zero grade for the experiment and are not allowed to enter the laboratory.

There are no makeup experiments for coming late to the laboratory.

MISSING AN EXPERIMENT

All issues missing an experiment are handled by the Laboratory Specialist.

There are no makeup experiments except for statutory holidays.

Missing an experiment, for any reason, results in a zero grade unless the student provides a valid medical note (i.e. no other type of notes are accepted) to the Laboratory Specialist specifying he/she was not able to come to the laboratory on the date in question.

Once the note is verified, arrangements are made to make up the experiment with another section. The student must contribute in writing the lab report with his/her original lab group. If it is not possible to make up the experiment due to schedule conflicts, the student receives a final lab grade based only on the experiments performed during the semester. There is a limit of one experiment missed with an approved note for the semester. Afterwards, it is a zero grade for each missed experiment for whatever reason.

LATE REGISTRATION

Registering late for the course (i.e. after the labs have started at the beginning of the semester) must attend their registered section without exception. If a student officially registers for a lab section which has completed the first experiment, the student must notify the Laboratory Specialist either by e-mail or in person. The Laboratory Specialist will make arrangements for the student to possibly attend another lab section for this one time only. The student returns to his his/her registered lab section for the next experiment.

DROPPING COURSE DURING THE SEMESTER

Out of courtesy, the student should advise his/her laboratory partners in the event of this occurrence. The student's previous performed experiments are deleted from the record.

If a group reduces to one student then he/she is moved to another group. Two members in a group is still valid.

LABORATORY REPORTS

GENERAL

Each group submits a complete written report covering each experiment performed. The report is to be the group's own work. The report is written in the third person, past tense (for procedures executed, data taken, and results obtained) and should be self-sufficient. In other words, the reader should not need to consult the references in order to understand the report. Correct English and spelling should be used. The reports are practice for writing technical reports similar to those, which are required by engineers engaged in industry and engineering practice.

The reports must be typed using a word processor and stapled only (i.e. no paper clips). All pages, equations, figures, graphs and tables must be numbered. Figures, tables, graphs, etc., must have titles and be introduced in a sentence in the text of the report. Figures must have axis labels that name the variable as well as giving its symbol and units if appropriate.

Figures, graphs, and tables must be neat and clear. Figures and graphs should be generated on the computer through drawing and plotting software. Choose scales that are appropriate to the range of data and that can be easily read. Leave room on the paper for scales, labels, and titles.

SPECIFICATIONS

In order to observe the accepted rules of good writing form, the following specifications for the general makeup of the report are suggested:

- Use 8 ½ x 11 inch white paper.
- Write the report with a word processor.
- Use Times Roman or Arial fonts, Size 12 with 1.5 spacing.
- Use one side of the paper only.
- A SINGLE GRAPH SHOULD BE REPRESENTED USING THE ENTIRE SHEET OF PAPER. MULTIPLE GRAPHS ON ONE SHEET ARE NOT ACCEPTABLE.
- Graphs axes should be clearly labeled, including units where appropriate.
- Discrete experimental data that are plotted on appropriate graphs should be designated with small symbols, such as circles, to distinguish these data from those represented by curves fitted through them either intuitively or statistically or by mathematical model. If more than one dependent variable (ordinate) is presented on a graph, each variable should have a different symbol.
- When mathematically fitting curves to experimental data, use appropriate judgment. Just because a 6th order polynomial can fit exactly to 7 points does not mean that it is the appropriate curve for this experimental data (i.e. the distribution may actually be linear or quadratic). Instead look at the trend of the data and avoid the pitfall of many students in letting the computer chose the best curve fit. As a general rule, the lower the complexity of the curve fit that represents the data trends, the better.

FORMAT

The following report outline is required for content and order of presentation:

- TITLE PAGE: Must include lab title, date performed, student names with corresponding identification numbers and lab section.
- OBJECTIVE: State the objective(s) clearly in a concise manner in your own words.
- INTRODUCTION: Background information preparing the reader as to what is done during the experiment. Do not copy what is written in the manual. Any theory mentioned or relevant information must be referenced.
- PROCEDURE: A general description of the procedure should be given. This description should be comprehensive, but brief. It should include a generic list of equipment used and a sketch to show how the equipment items are related. The enumeration and detailed description of multitudinous mechanical operations or sequence of such operations such as closing switches, reading instruments, turning knobs and so forth, should in general be avoided. However, when a specific method of mechanical operation or sequence of such operations is necessary in order to insure the validity or accuracy of the test data, it is important that the essential details be included in the description. Note that it is unacceptable to simply use or copy the procedural instructions from the manual.
- RESULTS: Answer all the questions posed in the laboratory manual. All observed and calculated data should be tabulated when possible. Headings and subheadings (titles) identifying items of data or sets of data should be used.
    - SAMPLE CALCULATIONS: Show a sample of a complete calculation of each type involved in the determination of calculated data and the solution of problems. These sample calculations should be first shown in symbolic form with all symbols properly defined. Then numerical data should be used with units shown in the actual calculations.
    - GRAPHS: See Specifications section.
- DISCUSSION: MOST IMPORTANT SECTION OF THE ENTIRE REPORT. IT SHOULD BE A COMPLETE DISCUSSION OF THE RESULTS OBTAINED. Part of this discussion should deal with the accuracy or reliability of the results. It is suggested that this section consist, when applicable, of a careful treatment of the effect upon the results of the following:
    - Comparison of the results obtained with those that would reasonably have been expected from a consideration of the theory involved in the problem. Whenever the theory is apparently contradicted, the probable reasons should be discussed.
    - Errors resulting from the necessity of neglecting certain factors because of physical limitations in the performance of the test.
    - When results are given in graphical form as curves, the shape of each curve should be carefully explained. Such an explanation should state the causes or the particular shape the curve may have. It is not sufficient simply to state that a particular curve has positive slope, the reason for such a slope should be given. If the slope is not constant, that is, if the curve is not a straight line, its nonlinearity should also be explained.
    - Any original conclusions drawn as a consequence of the laboratory procedure and a study of the results obtained should be given in this section and should be justified by the discussion.
    - Constructive criticism of any phase of the experiment that may seem pertinent may also be included here.

- CONCLUSIONS: In this section the conclusions which were supported and drawn in the Discussion are succinctly restated, usually as a numbered list. No new information should appear in this section. All justification of conclusions should have occurred in prior sections.
- REFERENCES: Whenever referrring to published sources of this kind, for example when quoting technical specifications or specialist theory, full particulars of the source in a numbered list of references must be included. Below are several examples that show the correct format for journals, books and web sites.
    - Journal: [1] Hamilton, R. J., & Bowers, B. , The Kinetic Theory of Molecular Gases: A Roy Model Exemplar. Physical Science Quarterly, 20, 2007, pp 254-264.
    - Book: [2] Hyde, J. S. & Delamater, J., Introduction to Physics, (10th edition) New York: McGraw-Hill, 2008, pp 220-227.
    - Website: [3] cms.mit.edu/research/index.php (Accessed October 2009)

  Note: Every item in the reference list must be referred to by inserting its number in the appropriate section of text. This is done using square brackets.
- APPENDICES: Materials that support the report but are not essential to the reader's understanding of it are included here. The laboratory data sheet should be an appendix.

ORIGINALITY FORM

This form must be completed by each student and submitted to the lab instructor separately with the *first* lab report *one time only*. Failure to submit this form results in a zero grade for the experiment. A copy of the form can be found at the end of this manual. For more information, go to *encs.concordia.ca/current-students/forms-and-procedures/expectation-of-originality.*

PLAGIARISM

The student is responsible for their own work and is expected to write their own thoughts. Plagiarism is a serious problem. If caught plagiarizing, the student forfeits the right to attend the laboratory, receive a failing lab grade and be removed from the university by due process as stated in the student handbook.

Plagiarism is any portrayal of information as your own when not truly yours. Plagiarism is rewriting another student's report. Plagiarism is turning in the same report from a previous year even if a few words are moved around. Plagiarism is forgetting to cite information that was obtained outside your brain. Plagiarism is cheating.

Avoid plagiarism by signing the "Originality Form" and submitting it to the lab instructor as a separate attachment with the *first* lab report *one time only*. The signed form claims this is the product of your own work, that the material presented has been created by the student and properly cited and that no other person created or prepared the lab report.

SUBMISSION

Each group must submit their report to the laboratory instructor at the following laboratory session (i.e. exactly 2 weeks from the performance date of the experiment; mid-term break does NOT count as a week). If a lab report deadline falls on a statutory holiday, the report is to be submitted to the Laboratory Specialist the following day.

Submission of a late report is not accepted under any circumstances resulting in a zero grade for the experiment.

Electronic submissions by e-mail (i.e soft copies) are considered invalid. The lab instructor or Laboratory Specialist immediately disregards these type of submissions and have no weight. Hard copies of lab reports are the only form accepted.

The corrected report is returned to the group in the next experiment for viewing only. The lab instructor keeps the lab report.

GRADING

The grading breakdown for each lab report out of 100 marks is as follows:

- Presentation (20%)
- Results (40%)
- Discussion/Conclusion (40%)

EXPERIMENT

1

TENSILE TESTING OF MATERIALS

OBJECTIVES

- Understand the principle of a uniaxial tensile testing and gain experience on operating the tensile testing machine to achieve the required tensile properties.
- Explain load-displacement and stress-strain relationships and represent them in graphical forms.
- Evaluate the values of tensile strength, yield strength, % elongation, fracture strain and Young's Modulus of the selected metals when subjected to uniaxial tensile loading.
- Explain deformation and fracture characteristics of different materials such as aluminum, steels, brass or ABS when subjected to uniaxial tensile loading.

INTRODUCTION

UNIAXIAL TENSILE TESTING

The uniaxial tensile test is known as a basic and universal engineering test to achieve material parameters such as tensile strength, yield strength, % elongation, % area of reduction and Young's modulus. These important parameters obtained from the standard tensile test are useful for the selection of engineering materials for applications.

Tensile testing is carried out by applying a longitudinal, or axial, load at a specific extension rate to a standard tensile specimen with known dimensions (gauge length and cross sectional area perpendicular to the load direction) until failure. The applied tensile load and extension are recorded simultaneously during the test for the calculation of engineering stress and engineering strain. A range of universal standards provided by professional societies such as American Society of Testing and Materials (ASTM), British Standard, JIS standard and DIN standard are selected based on preferential uses. Each standard may contain a variety of test standards suitable for different materials, dimensions and fabrication history. For instance, ASTM E8: is a standard test method for tension testing of metallic materials and ASTM B557 has standard test methods of tension testing wrought and cast aluminum and magnesium alloy products

The equipment used for tensile testing ranges from simple devices to complicated controlled systems. The so-called universal testing machines are commonly used, which are driven by mechanical screw or hydraulic systems. A more modernized closed-loop servo-hydraulic machine provides variations of load, strain, or testing machine motion (stroke) using a combination of actuator rod and piston. Most of the machines used nowadays are linked to a computer-controlled system in which the load and extension data can be graphically displayed together with the calculations of stress and strain.

General techniques utilized for measuring loads and displacements employs sensors providing electrical signals. Load cells are used for measuring the load applied while strain gauges are used for strain measurement. A change in a linear dimension is proportional to the change in electrical voltage of the strain gauge attached on to the specimen.

THEORY

STRESS AND STRAIN RELATIONSHIP

When a specimen is subjected to external tensile loading, the metal will undergo elastic and plastic deformation. Initially, the metal will elastically deform giving a linear (usually) relationship between load and extension. These two parameters are then used for the calculation of the engineering stress and engineering strain to give a relationship as illustrated in Figure 1.1 using Equations 1.1 and 1.2 as follows:

$$\sigma = \frac{F}{A_o} \tag{1.1}$$

$$\varepsilon = \frac{L_f - L_o}{L_o} = \frac{\Delta L}{L_o} \tag{1.2}$$

where

σ	engineering stress
ε	engineering strain
F	external axial tensile load
A_o	original cross-sectional area of the specimen
L_o	original length of the specimen gauge length
L_f	final length of the specimen gauge length

YOUNG'S MODULUS

During elastic deformation, the engineering stress-strain relationship follows Hooke's Law and the slope of the curve indicates the Young's modulus (E):

$$E = \frac{\sigma}{\varepsilon} \tag{1.3}$$

Young's modulus is of importance where limited deflection of materials is critical for the required engineering application. For example, the amount of deflection in structural beams is crucial for the design in engineering components or structures such as bridges, building, ships, etc. The applications of a tennis racket and a golf club also require specific values of spring constants or Young's modulus values.

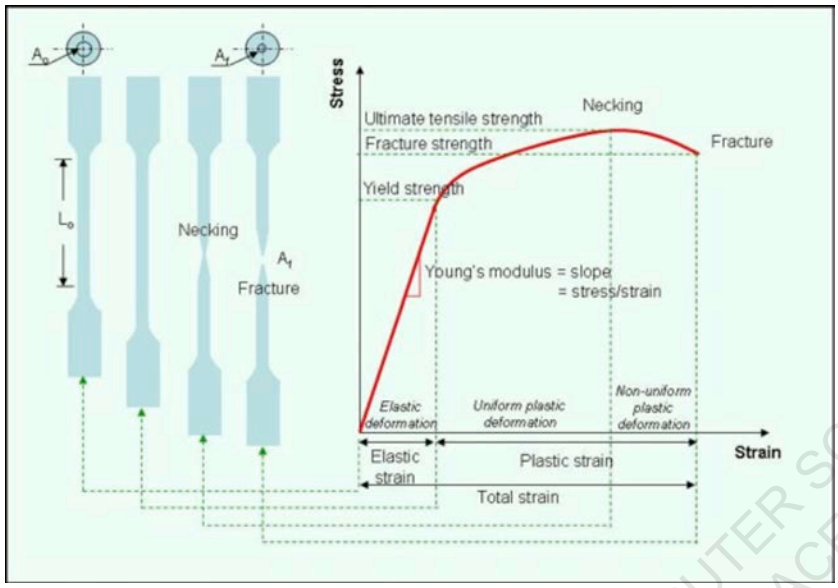


Figure 1.1: Stress-strain relationship under uniaxial tensile loading

POISSON'S RATIO

Poisson's ratio (ν) relates the lateral strain $\varepsilon_{lateral}$ to the axial strain ε_{axial} during a uniaxial tensile test:

$$\nu = -\frac{\varepsilon_{lateral}}{\varepsilon_{axial}} \tag{1.4}$$

Most metals exhibit a Poisson's ratio of around 0.3. The magnitude of these properties is of fundamental importance in the design of mechanical components since they relate the lateral deformation of a material with the axial deformation and thus the magnitude of the applied load.

YIELD STRENGTH

By considering the stress-strain curve beyond the elastic portion, if the tensile loading continues, yielding occurs at the beginning of plastic deformation. The yield stress, σ_y, can be obtained by dividing the load at yielding (F_y) by the original cross-sectional area of the specimen (A_o) as shown in Equation 1.5:

$$\sigma_y = \frac{F_y}{A_o} \tag{1.5}$$

The determination of the yield strength at 0.2% offset or 0.2% strain can be carried out by drawing a straight line parallel to the slope of the stress-strain curve in the linear section, having an intersection on

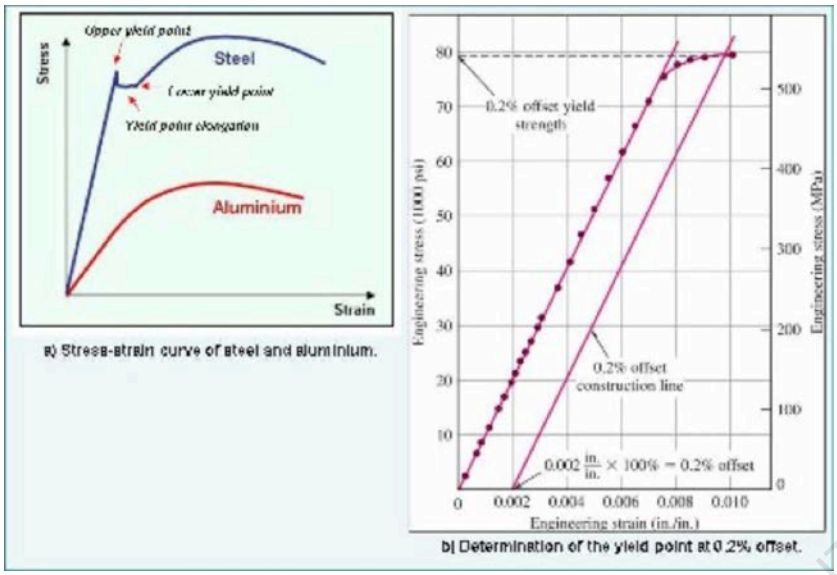


Figure 1.2: a) Comparative stress-strain relationships of low carbon steel and aluminum alloy and b) the determination of the yield strength at 0.2% offset.

TENSILE STRENGTH

Beyond yielding, continuous loading leads to an increase in the stress required to permanently deform the specimen as shown in the engineering stress-strain curve. At this stage, the specimen is strain hardened or work hardened. The degree of strain hardening depends on the nature of the deformed material, crystal structure and chemical composition, which affects the dislocation motion.

If the load is continuously applied, the stress-strain curve will reach the maximum point, which is the tensile strength (formerly known as Ultimate Tensile Strength or UTS). At this point, the specimen can withstand the highest stress before necking takes place. This can be observed by a local reduction in the cross- sectional area of the specimen generally observed in the gauge length.

FRACTURE STRENGTH

After necking, plastic deformation is not uniform and the stress decreases accordingly until fracture. The fracture strength can be calculated from the load at fracture divided by the original cross-sectional area.

TENSILE DUCTILITY

Tensile ductility of the specimen can be represented as % Elongation or % Reduction in Area as expressed in the equations given below:

$$\% \, Elongation = \frac{\Delta L}{L_o} \times 100 \tag{1.6}$$

$$\% \, Reduction \, in \, Area = \frac{A_o - A_f}{A_o} \times 100 \tag{1.7}$$

where A_f is the cross sectional area of the specimen at fracture.

The fracture strain of the specimen can be obtained by drawing a straight line starting at the fracture point of the stress-strain curve parallel to the slope in the linear relation. The interception of the parallel line at the x axis indicates the fracture strain of the specimen being tested.

WORK HARDENING EXPONENT n

Furthermore, material behavior beyond the elastic region where stress-strain relationship is no longer linear (uniform plastic deformation) can be shown as a power law expression as follows:

$$\sigma = K\varepsilon^n \tag{1.8}$$

where

σ true stress

ε true strain

n strain hardening exponent

K strength coefficient

The strain-hardening exponent values, n, of most metals range between 0.1-0.5, which can be estimated from a slope of a log true stress-log true strain plot up to the maximum load. Equation 1.7 can then be written as follows:

$$\log \sigma = n \log \varepsilon + \log K \tag{1.9}$$

High value of the strain-hardening exponent indicates an ability of a metal to be significantly strengthened during plastic deformation whereas a low value (zero) indicates “perfectly plastic solid” that does not strengthen or work-harden at all during plastic deformation

EQUIPMENT

UNIVERSAL TENSILE MACHINE

A custom built, in-house tensile testing machine is the device for measuring force and displacement for various materials as the materials are stretched (see Figure 1.3). The device has a built-in load cell (strain gauge transducer). Displacement data can be measured using several modules included with the device:

- Extensometer
- Linear Variable Differential Transformer
- Optical Encoder
- Strain Gauge

A crank-and-gear system raises or lowers the load bar on two leadscrews (also known as power screws or translation screws). Force data from the load cell and displacement data from each module can be recorded, displayed and analyzed using the customized LabView software.

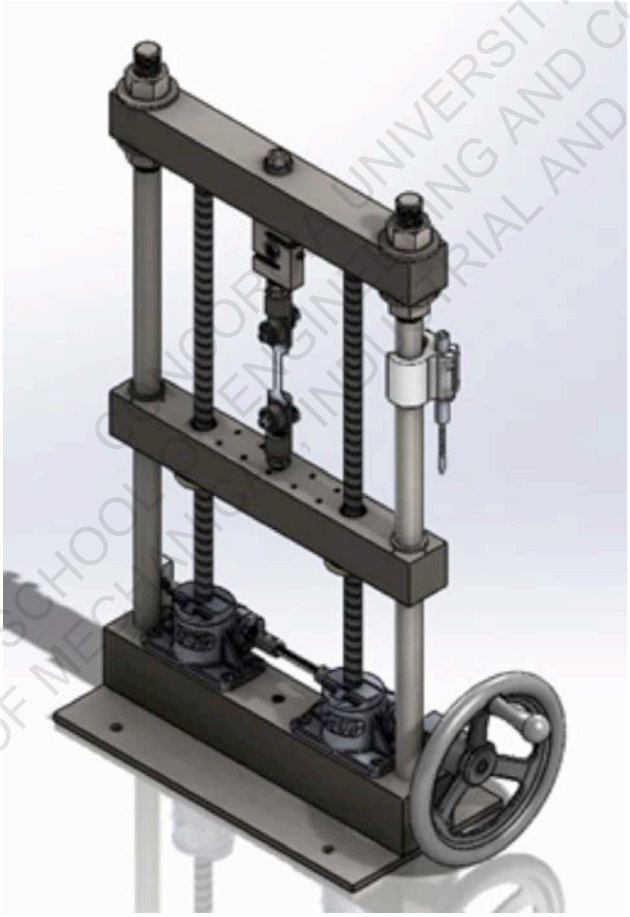


Figure 1.3: Tensile Testing Machine

EXTENSOMETER

An extensometer is a device that is used to measure changes in the length of an object (see Figure 1.4). It is useful for stress-strain measurements and tensile tests. Contact or clip on extensometers have been used for many years. These devices are used for applications where high precision strain measurement is required (most ASTM based tests). They come in many configurations and can measure displacements from very small to relatively large (less than 1 mm to over 100 mm). They have the advantage of lower cost and ease of use, however, they can influence small and delicate specimens.

Figure 1.4: Extensometer

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER (LVDT)

The LVDT is a type of electrical transformer used for measuring linear displacement (position) (see Figure 1.5). LVDTs are robust, absolute linear position/displacement transducers; inherently frictionless, they have a virtually infinite cycle life when properly used. The LVDT converts a position or linear displacement from a mechanical reference (zero, or null position) into a proportional electrical signal containing phase (for direction) and amplitude (for distance) information. The range of our model LVDT is 15 mm. The LVDT operation does not require an electrical contact between the moving part (probe or core assembly) and the coil assembly, but instead relies on electromagnetic coupling.

Figure 1.5: LVDT Displacement Sensor

STRAIN GAUGE

The majority of strain gauges are foil types, available in a wide choice of shapes and sizes to suit a variety of applications. They consist of a pattern of resistive foil which is mounted on a backing material as shown in Figure 1.6. They operate on the principle that as the foil is subjected to stress, the resistance of the foil changes in a defined way.

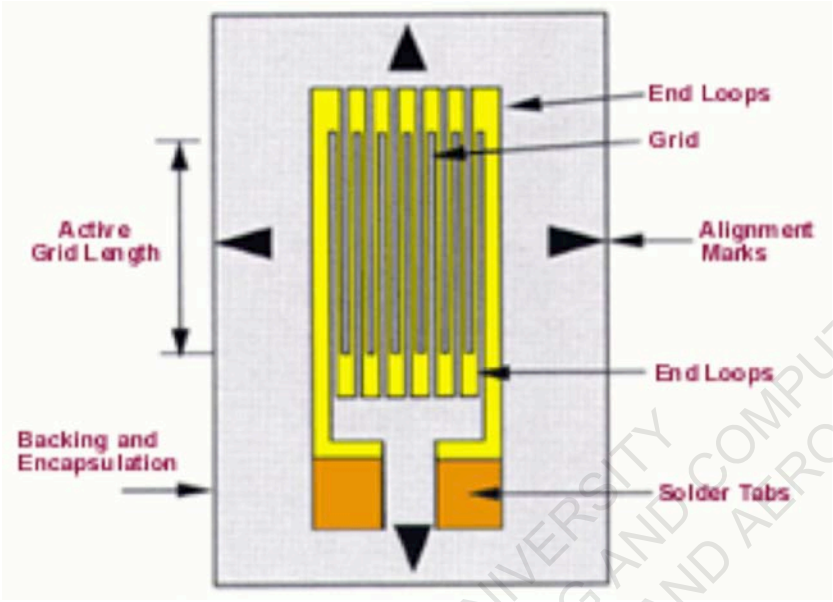


Figure 1.6: Strain Gauge

The strain gauge is connected into a Wheatstone Bridge circuit with a combination of four active gauges (full bridge), two gauges (half bridge), or, less commonly, a single gauge (quarter bridge). In the half and quarter circuits, the bridge is completed with precision resistors. The complete Wheatstone Bridge is excited with a stabilized DC supply and with additional conditioning electronics, can be zeroed at the null point of measurement. As stress is applied to the bonded strain gauge, a resistive changes takes place and unbalances the Wheatstone Bridge. This results in a signal output, related to the stress value. As the signal value is small, (typically a few millivolts) the signal conditioning electronics provides amplification to increase the signal level to 5 to 10 volts, a suitable level for application to external data collection systems such as recorders or PC Data Acquisition and Analysis Systems.

OPTICAL ENCODER

An optical encoder is an electromechanical device which has an electrical output in digital form proportional to the angular position of the input shaft (see Figure 1.7). Optical encoders enable an angular displacement to be converted directly into a digital form. An optical encoder is an angular position sensor: It has a shaft mechanically coupled to an input driver which rotates a disc rigidly fixed to it. A succession of opaque and clear segments are marked on the surface of the disc. Light from infrared emitting diodes reaches the infrared receivers through the transparent slits of the rotating disc. An analogue signal is created. Then electronically, the signal is amplified and converted into digital form. This signal is then transmitted to the data processor.

Figure 1.7: Optical Encoder

LOAD CELL

A load cell is defined as a transducer that converts an input mechanical force into an electrical output signal (see Figure 1.8). Load cells are also commonly known as load transducers or load sensors. S-Type load cells are low-cost and high performance side mounted load cells suitable for a number of weighing and general force measurement applications. The capacity of our model load cell is 5000 lbs.

Figure 1.8: Load Cell

MATERIAL

TENSILE SAMPLES

The tensile samples were machined on a water jet cutter from flat sheet of different thickness as shown in Figure 1.9. All samples have an overall length of 8.0 inches.

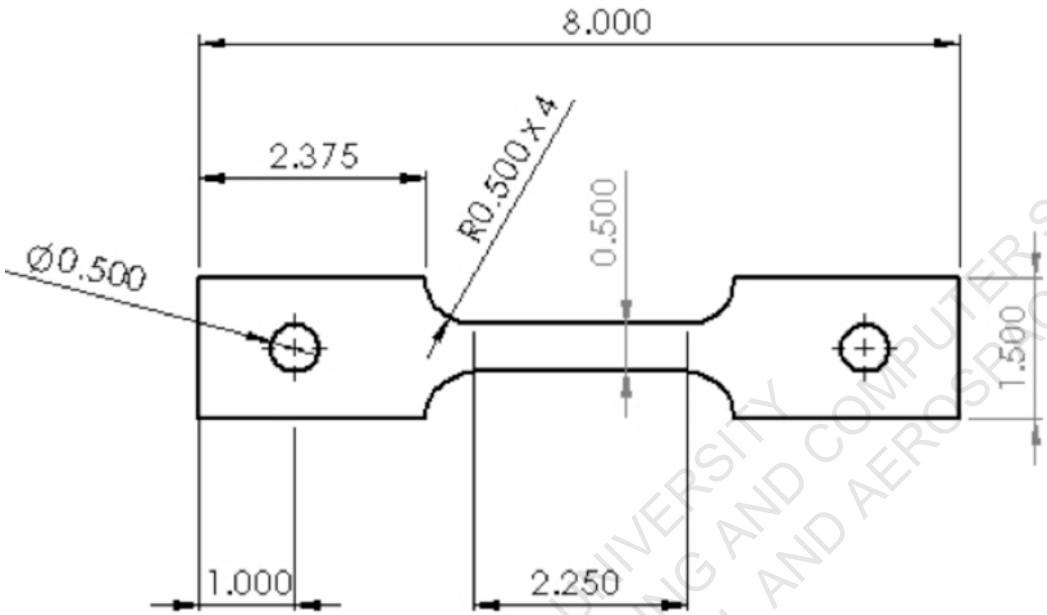


Figure 1.9: Tensile Specimen Geometry (Dimensions in Inches)

The material to be tested on the tensile machine are:

1. Aluminum 6061-T6 (axial and lateral strain gauges attached)
2. Brass
3. 4130 Steel
4. ABS

PROCEDURE

PRE-TESTING

1. Identify each material associated with the 5 tensile test specimens.
2. Sand all edges of the gauge length on each specimen with provided sandpaper.
3. Using a marker, mark up the gauge length on each specimen and measure the original gauge length. Record the data on the data sheet
4. Measure the width and thickness at various areas of each specimen and take an average. Record the data on the data sheet.

TESTING

1. Mount one specimen on the tensile machine by aligning the holes with the pins.
2. Place the spacers and nuts and tighten the specimen onto the grips.
3. Mount the extensometer with the PIN IN. The pin is preset at 50 mm gauge length.
4. Align the gauge marks with the extensometer knife edges.
5. Wrap the elastic bands around the sample and the extensometer knife edges.
6. REMOVE THE PIN from the extensometer.
7. ALUMINUM SPECIMEN ONLY (PRE-ATTACH STRAIN GAUGES)): Connect both AXIAL and LATERAL strain gauge wiring to the electronic control box jacks located next to the tensile machine. Identify the AXIAL and LATERAL strain gauges on the specimen and its corresponding black, white and red wires. Insert the individual bare wire ends to the matching color jacks and tighten on the control box with the label “AXIAL STRAIN GAUGE” and “LATERAL STRAIN GAUGE”.
8. Turn the switch ON the electronic control box located on the back panel. The pilot light on the top panel is now ON.

Figure 1.10: Mounting Tensile Sample

9. Click  icon on the desktop.

10. Press  icon on the computer screen to start the program (i.e. LabView). The front panel display screen (see Figure 1.11) is customized for the tensile machine in the laboratory.

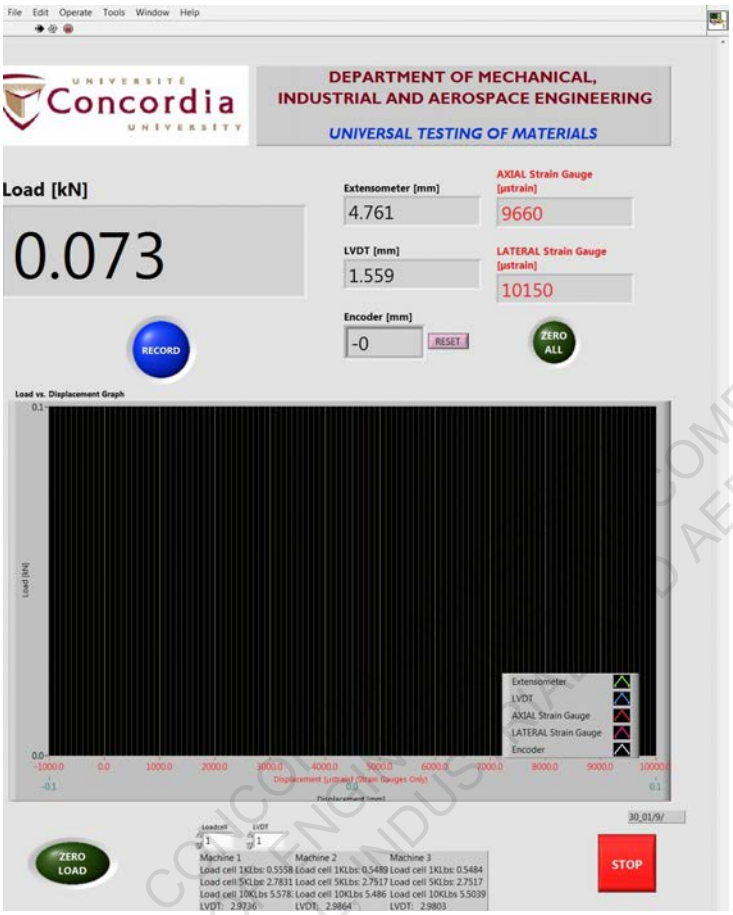


Figure 1.11: Front Panel Display

11. Press the  icon to zero all the displacement measuring devices. The load transducer has been already zeroed prior to coming to the laboratory. DO NOT PRESS "ZERO LOAD" AGAIN!

12. Perform a hard reset on the encoder by pressing the button next to the encoder display.

13. Press the  button to record all the load and displacement data. Select the lab section folder to save your data file (see Figure 1.12). Type the material tested as the filename, for example, *Brass.lvm*.

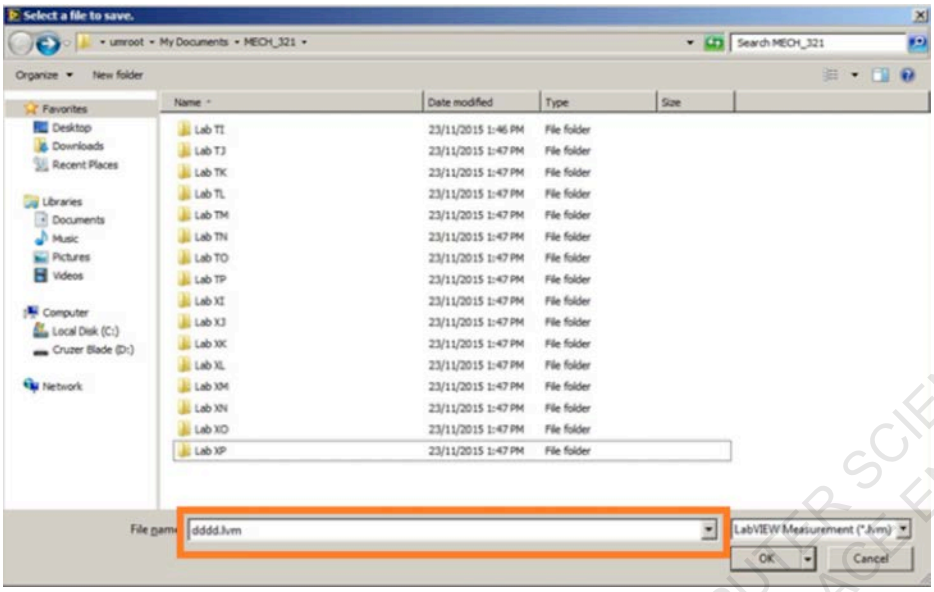


Figure 1.12: Saving Data File

13. Turn the crank on the tensile machine CCW approximately 1/8 turn displacement. A smaller displacement results in more data points in the elastic region. Use the encoder display as a guide (1/8 turn ≈ 0.125 mm on the encoder) to set the position. The lab instructor might alter the initial crank displacement depending on the material to be tested.
14. When the LVDT numeric display is stable, press the RECORD button to record the data.
15. Turn the crank another 1/8 turn CCW. Wait a few seconds for the LVDT numeric display to stabilize and the press the RECORD button. Notice the load versus displacement data is plotted on the computer screen.
16. Repeat turning the crank 1/8 turn CCW and press the RECORD record until fracture always waiting for the LVDT display to stabilize each time. The crank displacement can be increased once the material is in the plastic region.
17. When the specimen fractures, press the RECORD button to record the final set of data and then the STOP button to end the program.
18. Repeat the Test Procedure for the other specimens.

POST-TESTING

1. Dismount the specimen from the tensile machine. Carefully unhook the extensometer from the broken specimen and unscrew both nuts and remove spacers from the grips.

2. Place the two halves of the broken specimen together and measure the final gauge length. Record the data on the data sheet.

3. Measure the minimum cross sectional area (slightly difficult) of the fractured specimen. Record the data on the data sheet.

4. Sketch the specimen fracture on the data sheet.

RETRIEVE ALL DATA

All *.lvm type files are text files which can be easily imported to Excel as shown in Table 1.1. Note, the negative value for the LATERAL strain gauge. This indicates a compressive force.

Table 1.1: Sample Data File

Load [kN]	Extensometer [mm]	LVDT [mm]	AXIAL Strain Gauge* [μstrain]	LATERAL Strain Gauge* [μstrain]	Encoder [mm]
0.010434	0.002083	0.096326	72.9909	-0.0347	0.1323
0.017511	0.003914	0.221528	125.847	-0.0387	0.2541
0.115801	0.011792	0.351663	184.527	-0.05419	0.3822
0.396093	0.033176	0.47527	279.383	-0.103233	0.5103
0.62763	0.049655	0.493944	574.803	-0.13778	0.6195
0.96361	0.072584	0.604404	1042.451	-0.196733	0.7287
1.312711	0.097462	0.702203	1546.996	-0.246923	0.8358
⋮	⋮	⋮	⋮	⋮	⋮

** Valid for Aluminum specimen only. Disregard data for other specimen material.*

The data can be retrieved by going to File Explorer in Windows and choose the folder:

*My Documents/MECH 321/ Lab **/*

** is your lab section. Select all the data files in the folder and copy to a USB flash drive.

RESULTS

1. Define the following terms, including a description of how they are calculated from the stress vs. strain data, and what information they provide about the material.

    a. Poisson's ratio
    b. Yield strength
    c. Tensile strength
    d. Fracture strength
    e. Tensile ductility
    f. Strain hardening exponent

2. Plot the engineering stress vs. strain curves from the raw data for each material and displacement measuring device (extensometer, LVDT and strain gauge). Each graph should represent one material with various plots depicting each measuring device.

3. Tabulate ALL your results for each material and from each displacement measuring device. Include the following:

    a. Yield stress
    b. Tensile stress
    c. Fracture stress
    d. Young's Modulus
    e. % Elongation
    f. % Reduction in area
    g. Poisson's ratio (strain gauge only)

4. Are there any differences in the results using the various measuring devices? Elaborate in your answer.

5. Explain the fracture characteristics of each specimen. Is it ductile or brittle fracture?

6. Calculate the strain hardening exponent? How is this value related to the ability of metal to be mechanically formed?

REFERENCES

- Callister Jr., W.D., Materials Science and Engineering An Introduction, 6th Edition, John Wiley & Sons, 2003, pp 111–132.

DATA SHEET
EXPERIMENT 1: TENSILE TESTING OF MATERIALS

PHYSICAL DATA

Material:	Aluminum 6061-T6
Original Gauge Length [mm]:	
Average Width [mm]:	
Average Thickness [mm]:	
Final Gauge Length [mm]:	
Final Area [mm^2]:	

Material:	Brass
Original Gauge Length [mm]:	
Average Width [mm]:	
Average Thickness [mm]:	
Final Gauge Length [mm]:	
Final Area [mm^2]:	

Material:	4130 Steel
Original Gauge Length [mm]:	
Average Width [mm]:	
Average Thickness [mm]:	
Final Gauge Length [mm]:	
Final Area [mm^2]:	

Material:	ABS
Original Gauge Length [mm]:	
Average Width [mm]:	
Average Thickness [mm]:	
Final Gauge Length [mm]:	
Final Area [mm^2]:	

FRACTURE SKETCHES

Aluminum 6061-T6

Brass

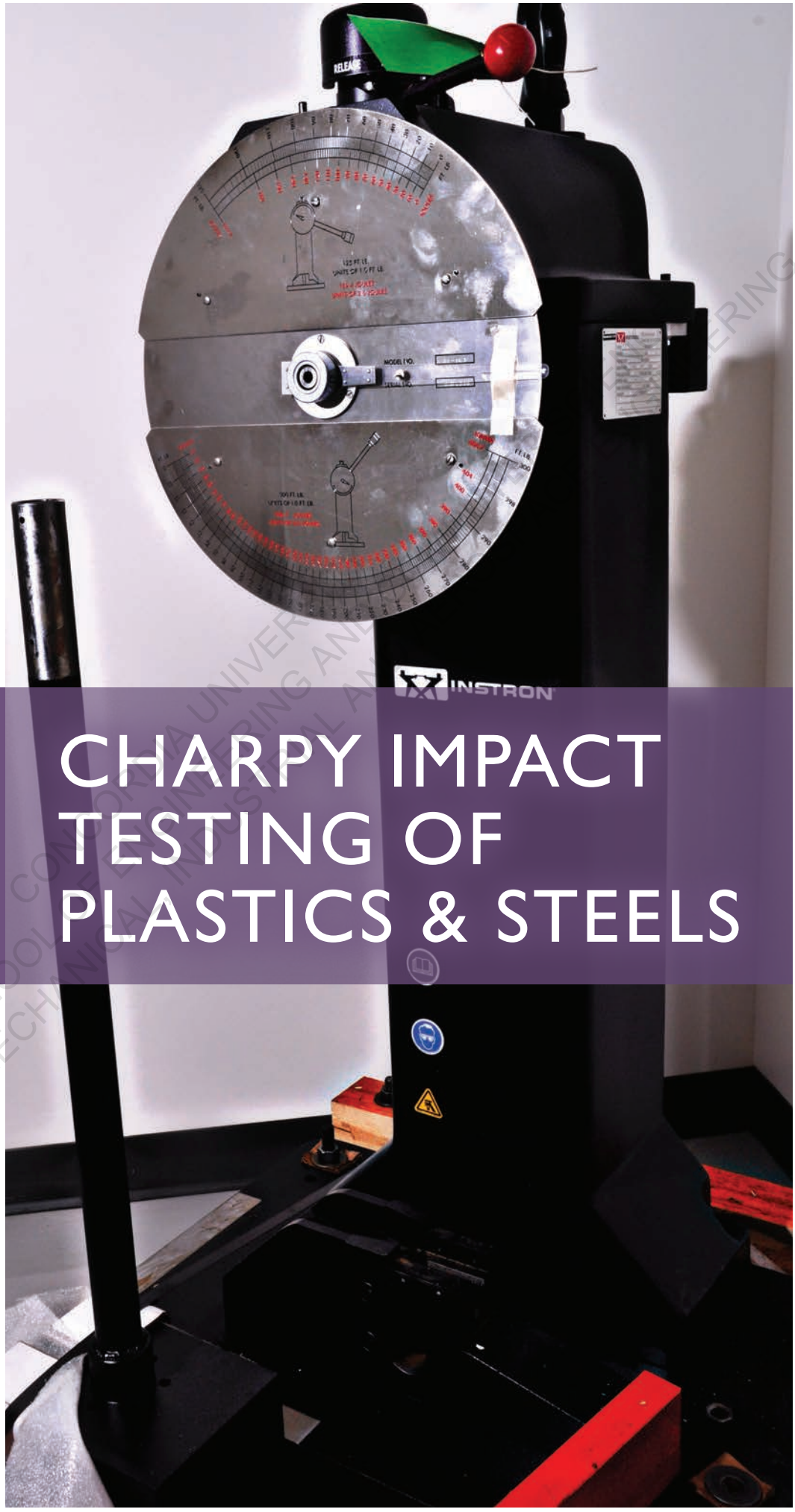
4130 Steel

ABS

EXPERIMENT

2

CHARPY IMPACT TESTING OF PLASTICS & STEELS



INTRODUCTION

Various types of notched-bar impact tests are used to determine the tendency of a material to behave in a brittle manner. This type of test will detect differences between materials, which are not observable in a tension test. The results obtained from notched-bar tests are not readily expressed in terms of design requirements, since it is not possible to measure the components of the triaxial stress condition at the notch. Furthermore, there is no general agreement on the interpretation or significance of results obtained with this type of test.

Investigators of brittle fracture of metals have used a large number of notched-bar test specimens of different design. Two classes of specimens have been standardized for notched-impact testing. Charpy bar specimens are used most commonly in the United States, while the Izod specimen is favored in Great Britain. The Charpy specimen has a square cross section (10 x 10 mm) and contains a 45° V-shaped notch, 2 mm deep with a 0.25 mm root radius. The specimen is supported as a beam in a horizontal position and loaded behind the notch by the impact of a heavy swinging pendulum. The specimen is forced to bend and fracture at a high strain rate. The Izod specimen, which is rarely used today, has either a circular or a square cross section and contains a V-notch near the clamped end. The difference in loading between the Charpy and Izod tests is shown in Figure 2.1.

An impact test can be used to assess a material's fracture resistance. Several such tests have been devised although in the United States the Charpy Impact Test is the one most widely used. In the Charpy test, a hammer is mounted on a very nearly frictionless pendulum. It is released from a specified height, h, and strikes the sample to be evaluated at the bottom of its arc. When it does so, the material is subjected to a high strain rate, which favors fracture rather than flow. Moreover, the notch on the specimen on the side of the bar subjected to impact tensile loading induces a tri-axial state of stress in its vicinity and this also tends to promote fracture vis-a-vis flow. Thus, an impact test is associated with a high strain rate and a strong degree of tri-axial loading, and as such it is a rather severe test of a material's toughness. Additionally, the sample test temperature can be varied, thereby allowing the determination of the temperature variation of the toughness.

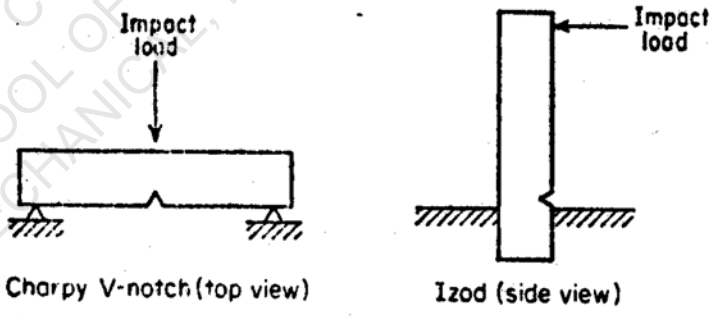


Figure 2.1: Sketch showing method of loading in Charpy and Izod tests

Subsequent to striking and then breaking the sample, the hammer rises to a height, h', which is less than that from which it was released. The difference in potential energy = mg(h - h'), is the energy expended in fracturing the sample and is one datum obtained from the test.

Visual inspection of the impacted specimen's fracture surface also provides useful information. The surface may be fibrous (indicating microscopic shear or rupture) or shiny and "crystalline" (giving evidence of microscopic cleavage). Or, for those materials that undergo a change in fracture mode with temperature, the surface may be part fibrous and part cleavage. The cleavage portion is found in the central section of the specimen and is surrounded on its periphery by a region of fibrous (or shear lip) failure, with the percentage of fibrous fracture increasing with temperature (see Figure 2.2).

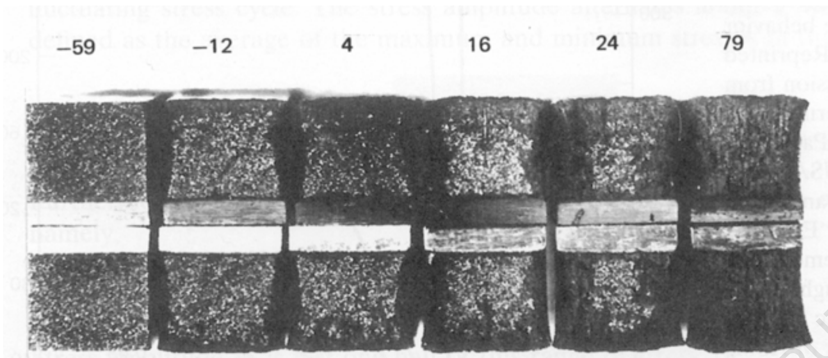


Figure 2.2: Photograph of fracture surfaces of A36 steel Charpy V-notch specimens tested at indicated temperatures [°C]

The temperature variation of the impact energy for a low-to-moderate strength BCC material (e.g., most steels) shows a typical ductile-to-brittle transition. This is a macroscopic manifestation of the changes in microscopic deformation and fracture modes that take place with increasing temperature. To a certain extent, the temperature variation of the impact energy for these materials parallels that of the fracture toughness, and because of this the impact test is a good qualitative tool in assessing fracture resistance for this material class. As mentioned, the BCC transition metals show a change in fracture mode from cleavage to fibrous with increasing temperature, and the temperature at which this occurs is related to (but not equal to) the transition temperature as defined by changes in impact energy.

For high-strength materials, the impact energies are low, as shown in Figure 2.3. For high-strength materials other than carbon steels (e.g., Ti and Al alloys) the impact energy is fairly temperature insensitive and for the same reasons that it is for their lower strength counterparts. The low impact energies attest to the ease with which fracture is initiated and propagated in high-strength materials. This can lead to in-service macroscopically "brittle" fracture in the sense that it is a low-energy one. High-strength steels display a greater temperature variation of impact energy than do high-strength nonferrous alloys. This is because steels undergo the microscopic brittle-to-ductile transition. However, their maximum (or upper shelf) impact energies are still low which is a reflection of their low energy ductile fracture at higher temperatures. The change in microscopic fracture mode is noted by the appearance of the impact energy sample fracture surface. A rather sharp transition from cleavage to fibrous fracture takes place in contrast to the broad, diffuse variation in impact energy over this same range in temperature.

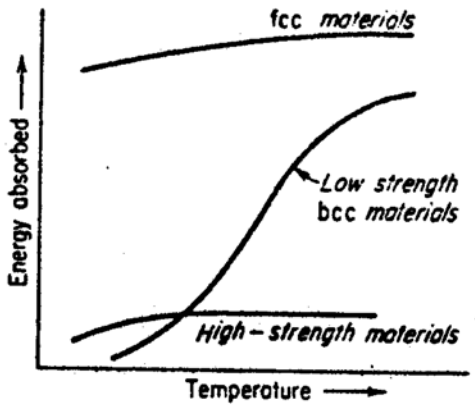


Figure 2.3: Effect of temperature on impact behavior

PLASTICS

Thermoplastic components are designed for use at room temperature. It might appear that the data on the impact properties at this temperature would provide sufficient information for design. However this approach is naïve since even indoors, temperatures can vary which can have significant effect on impact behavior. For components used outdoors, the situations gets much worse with conditions varying from sub-zero to tropical. In common with metals, many plastics exhibit a transition from ductile behavior to brittle as the temperature is reduced.

Figure 2.4 is typical of the effects of temperature on common plastics. Apart from the changes in impact strength with temperature, one can also learn from this diagram that the ranking of the materials is once again influenced by the test conditions. For example, at 20°C polypropylene is superior to acetal whereas at -20°C its impact strength is poor in comparison to acetal.

Some plastics experience the change from ductile to brittle behavior over a relatively narrow temperature range. This allows a ductile/brittle transition temperature to be quoted. In other plastics, this transition is much more gradual so that it is not possible to attribute it to a single value of temperature. In these circumstances it is common to quote a brittleness temperature, TB (1/4) . This temperature is defined as the value at which the impact strength of the material with a sharp notch (1/4 mm tip radius) equals 10 kJ/m^2. This temperature gives an indication of the temperature above which there are no problems with impact failures. It does not mean that the material should not be used below TB (1/4) because it refers only to the sharp notch case. When the material has a blunt notch or is un-notched, its behavior is still good below TB (1/4).

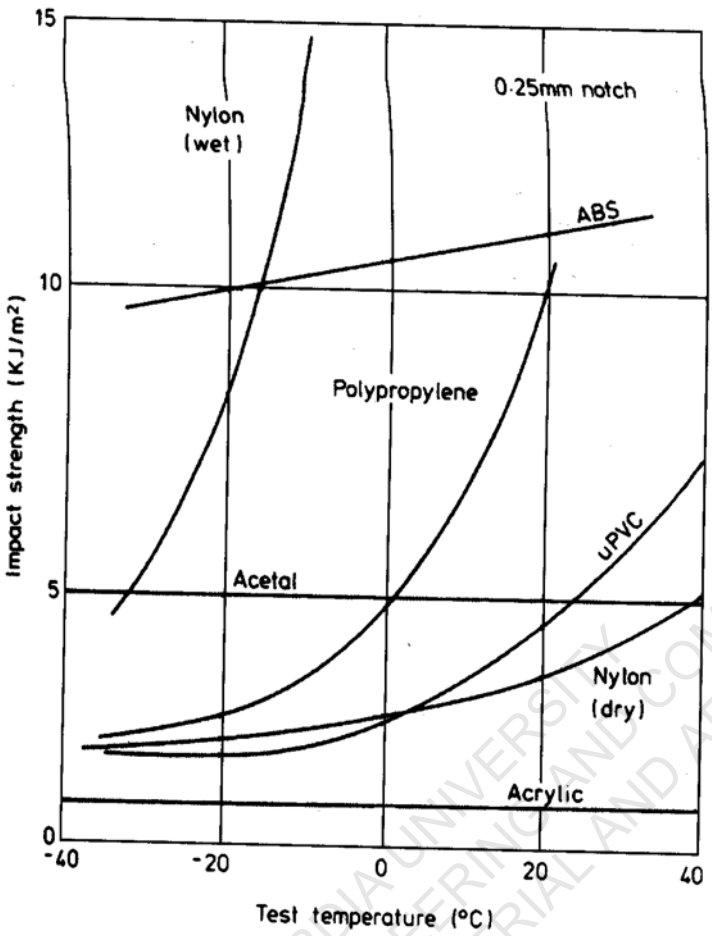


Figure 2.4: Variation of impact strength with temperature for several thermoplastics.

Other factors, which can affect impact behavior, are fabrication defects such as internal voids, inclusions and additives such as pigments, all of which can cause stress concentrations within the material. In addition, internal welds caused by the fusion of partially cooled melt fronts usually turn out to be areas of weakness. The environment may also affect the impact behavior. Plastics exposed to sunlight and weathering for prolonged periods tend to become brittle due to degradation. Simple fluids affect some plastics, for example, heating oils act as plasticizers for polyethylene. The effect which water can have on the impact behavior of nylon is also spectacular as illustrated in Figure 2.4.

The surface finish of the specimen may also affect impact behavior. Machined surfaces usually have tool marks, which act as stress concentrations whereas molded surfaces have a characteristic skin which can offer some protection against crack initiation. If the molded surface is scratched, then this protection no longer exists.

MATERIAL

- 1018 steel
- Stainless Steel 304
- Plexiglass
- HDPE (high density polyethylene)

Both steel samples are 2.5 (L) x 0.4375 (w) x 0.4375 (D) (all in inches) while the two plastic samples are 5.0 (L) x 0.5 (w) x 0.5 (D) (all in inches). All samples have a 0.085 inch deep 45° V-groove cut (Notch) across one face at the centre of the specimen length (see Figure 2.5).

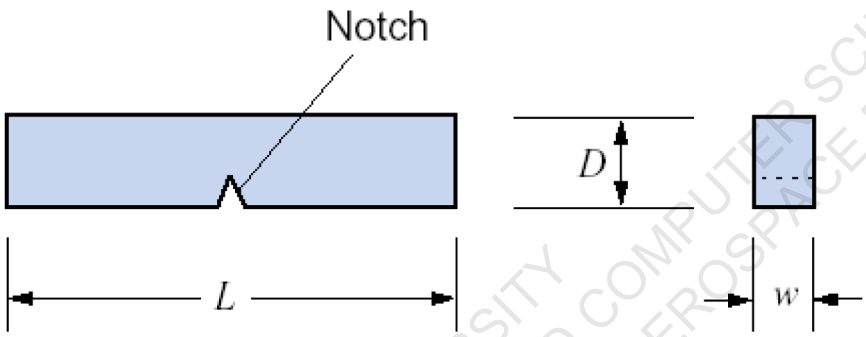


Figure 2.5: Geometry of Charpy impact specimen

APPARATUS

The specimens are tested on two impact machines:

TMI MODEL 43-02 IMPACT TESTER

The TMI model illustrated in Figure 2.6 is used to impact the plastic specimens only. The TMI tester conforms to all requirements of ASTM D-256. Height of release of the pendulum is 2 ft, giving a striking velocity of 11 ft/s. Hammers are interchangeable and are secured to the spindle of the instrument by socket-head screws. Removable specimen holders for Charpy and Izod tests and a stop for the tension impact test are screwed down to the base of the instrument. The impact tester provides a means of striking a specimen with a known force delivered by a pendulum-type hammer and measuring the energy absorbed by the specimen in fracturing in [ft-lb_f/inch].

Figure 2.6: TMI Impact Tester configured for Charpy Impact.

INSTRON SI-1K3 IMPACT TESTER

The pendulum impact tester illustrated in Figure 2.7 is designed for testing metals in accordance with ASTM E23. This tester provides energy ranges from 25 to 300 ft-lbs. The model consists of a heavy steel base on which the specimen holder (anvil) and a heavy-duty cast steel upright are mounted. On top of the upright, a head assembly contains a shaft supported by precision ball bearings to which the pendulum is attached. A single lever located on top of the head assembly performs three functions: brake, release, and latch. A stop pin prevents accidental release of the pendulum or application of the brake. The heavy pendulum (weight = 66.6 lbs; length = 31.5 inch) can be latched in two separate locations known as "high latch" (4.51 ft) and "low latch" (1.88 ft). Since the developed energy is a function of the height from

which the pendulum is released, each hammer has dual capacities, one from the high latch and another from the low latch. The impact velocity from the "high latch" position is 17 ft/sec and from the "low latch" position is 11 ft/sec. Both positions comply with the velocity range of ASTM E23.

Figure 2.7: Instron SI-1 series Impact Tester

PROCEDURE

PLASTICS

1. Practice the proper method to grip the specimen using the special purpose tongs provided. Also learn to mount the specimen properly on the TMI impact testing machine.
2. Raise the pendulum. Keep all parts of your body well away from under the pendulum until the test is completed.
3. Remove specimen from medium using the tongs, without any loss of time, mount it onto the impact testing machine.
4. Keeping a good distance from the machine, turn the operating lever to the "Release" position. The pendulum will swing down, hit the specimen, break it and swing up to the other side.
5. Read on the scale the value of the impact energy absorbed by the specimen for the fracture.

Record this value. Note the computerized Charpy testing machine outputs the fracture energy in [ft-lbf/inch] based on the specimen width given to it. Therefore, the specimen width (this is the vertical measurement when the specimen is mounted in the testing machine) is used to calculate the actual energy absorbed in [ft-lb_f].

6. Repeat the steps 2 to 5 at the various temperatures specified by the lab instructor. The temperatures can be achieved by immersing the specimen into constant temperature baths of liquid nitrogen, dry ice, freezer, ice and boiling water.
7. Repeat the steps 2 to 6 for the specimens of different materials specified at the beginning.
8. Gather the broken halves and label them as a set. Determine approximately the percent brittle failure. Record the percentage on the data sheet.
9. Study the fracture surface of all the specimens of any one material and sketch them, neatly differentiating between the ductile and brittle fracture areas.

STEELS

1. For safety reasons, impact tests on the Instron impact machine is performed by the lab technician.
2. Record the impact energy in ft-lb_f on the data sheet for each steel and different temperature medium.
3. Gather the broken halves and label them as a set. Determine approximately the percent brittle failure. Record the percentage on the data sheet.
4. Study the fracture surface of all the specimens of any one material and sketch them, neatly differentiating between the ductile and brittle fracture areas.

RESULTS

1. Plot the average Charpy impact energy (y-axis) versus temperature (x-axis) for each material. Draw a smooth curve through the points. Average values are taken from the data in other lab sections. The lab instructor will forward one week's worth of raw data to one team member in each lab group. Show the steel curves on one graph and the plastics on another graph.
2. Obtain the transition temperature from the fracture appearance (50% brittle fracture) corresponding to the midpoint of brittle fracture for each material. Record these values by the side of the corresponding curve.
3. Include your sketches of the fracture surfaces here. Label them correctly showing the temperature at which the test was done and the extent of the brittle and ductile fracture surfaces. Calculate roughly the percentage of brittle fracture in each sketch.
4. Explain the transition from ductile to brittle fracture at lower temperatures using the fracture surface sketches which you have made.
5. What is the significance of the transition temperature data for the design of any mechanical component? Provide examples.
6. Would the impact transition temperature (glass transition temperature for plastics) be a concern for the material listed below? Keep in mind the crystal structures of the metals when explaining your answer (i.e., what types of crystal structure experience tough-to-brittle transition?)
    a. Copper water pipe
    b. Chromium-plated brass faucet
    c. P.V.C. (polyvinyl chloride) garbage can
    d. Pipeline steel
7. What four (4) factors affect Charpy impact energy?

REFERENCES

- Callister Jr., W.D., Materials Science and Engineering An Introduction, 6th Edition, John Wiley & Sons, 2003, pp 207–210.
- Crawford, R.J., Plastics Engineering, 3rd Edition, Butterworth-Heinemann, Oxford, 1998.

DATA SHEET
EXPERIMENT 2: CHARPY IMPACT TESTING OF PLASTICS AND STEELS

MEDIUM: LIQUID NITROGEN

Temperature [°C]: _____

1018 Steel	Stainless Steel 304	Plexiglass	HDPE
Sketch Cross Section	Sketch Cross Section	Sketch Cross Section	Sketch Cross Section
Energy [ft-lb_f]	Energy [ft-lb_f]	Energy [ft-lb_f/inch]	Energy [ft-lb_f/inch]
Brittle Fracture [%]	Brittle Fracture [%]	Brittle Fracture [%]	Brittle Fracture [%]

MEDIUM: DRY ICE

Temperature [°C]: _____

1018 Steel	Stainless Steel 304	Plexiglass	HDPE
Sketch Cross Section	Sketch Cross Section	Sketch Cross Section	Sketch Cross Section
Energy [ft-lb_f]	Energy [ft-lb_f]	Energy [ft-lb_f/inch]	Energy [ft-lb_f/inch]
Brittle Fracture [%]	Brittle Fracture [%]	Brittle Fracture [%]	Brittle Fracture [%]

MEDIUM: FREEZER

Temperature [°C]: _____

1018 Steel	Stainless Steel 304	Plexiglass	HDPE
Sketch Cross Section	Sketch Cross Section	Sketch Cross Section	Sketch Cross Section
Energy [ft-lb_f]	Energy [ft-lb_f]	Energy [ft-lb_f/inch]	Energy [ft-lb_f/inch]
Brittle Fracture [%]	Brittle Fracture [%]	Brittle Fracture [%]	Brittle Fracture [%]

MEDIUM: ICE

Temperature [°C]: _____

1018 Steel	Stainless Steel 304	Plexiglass	HDPE
Sketch Cross Section	Sketch Cross Section	Sketch Cross Section	Sketch Cross Section
Energy [ft-lb_f]	Energy [ft-lb_f]	Energy [ft-lb_f/inch]	Energy [ft-lb_f/inch]
Brittle Fracture [%]	Brittle Fracture [%]	Brittle Fracture [%]	Brittle Fracture [%]

MEDIUM: ROOM

Temperature [°C]: _____

1018 Steel	Stainless Steel 304	Plexiglass	HDPE
Sketch Cross Section	Sketch Cross Section	Sketch Cross Section	Sketch Cross Section
Energy [ft-lb_f]	Energy [ft-lb_f]	Energy [ft-lb_f/inch]	Energy [ft-lb_f/inch]
Brittle Fracture [%]	Brittle Fracture [%]	Brittle Fracture [%]	Brittle Fracture [%]

MEDIUM: BOILING WATER

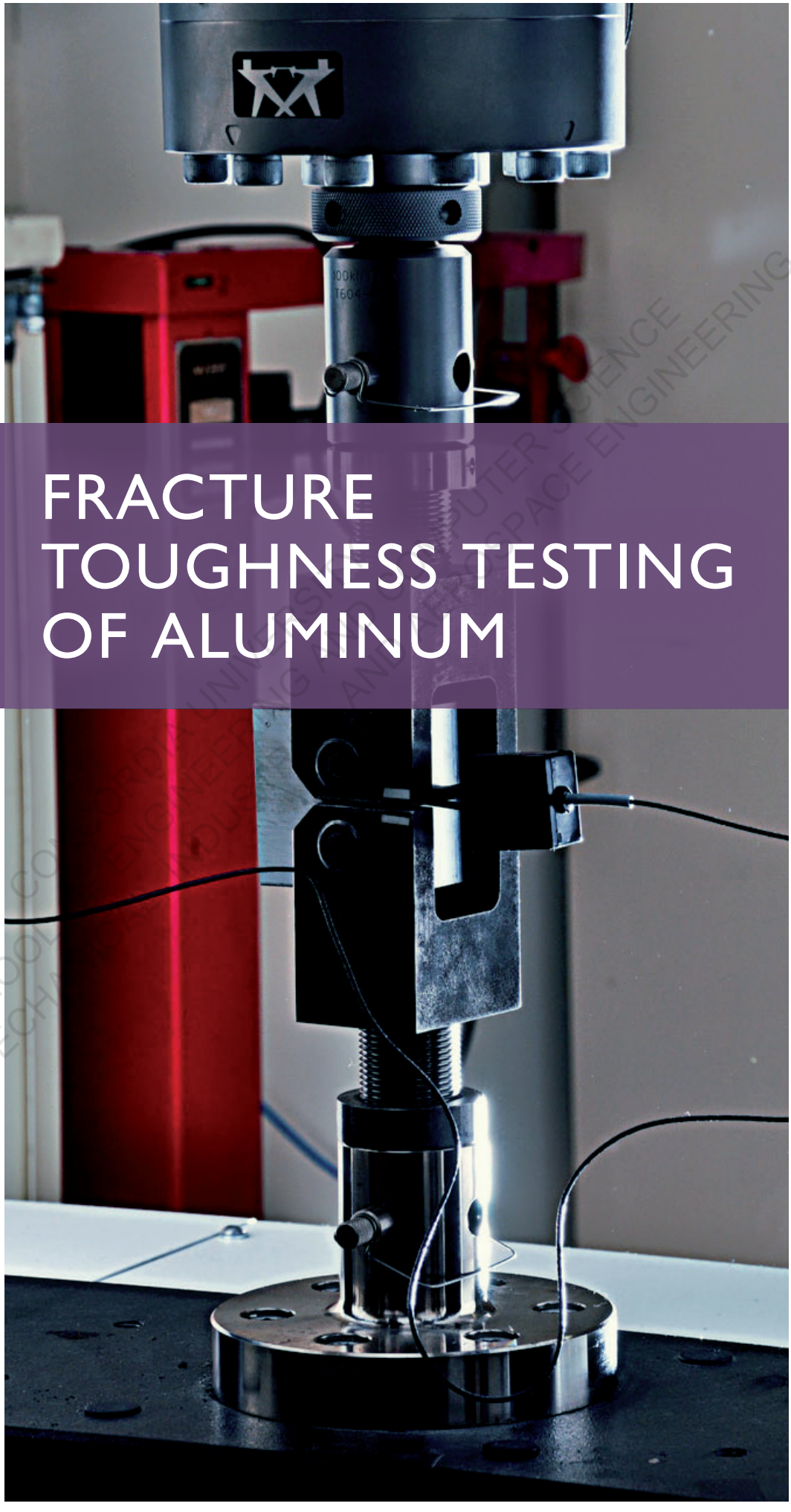
Temperature [°C]: _____

1018 Steel	Stainless Steel 304	Plexiglass	HDPE
Sketch Cross Section	Sketch Cross Section	Sketch Cross Section	Sketch Cross Section
Energy [ft-lb_f]	Energy [ft-lb_f]	Energy [ft-lb_f/inch]	Energy [ft-lb_f/inch]
Brittle Fracture [%]	Brittle Fracture [%]	Brittle Fracture [%]	Brittle Fracture [%]

EXPERIMENT

3

FRACTURE TOUGHNESS TESTING OF ALUMINUM



INTRODUCTION

Ships, aircraft and rockets are extremely complex engineering systems with many thousands of components. In the construction of such systems, it is impossible to avoid the presence of flaws such as cracks. Understanding the strength of materials in the presence of cracks is thus key to developing reliable aerospace and ocean engineering hardware. This experiment is designed to illustrate how strength in the presence of cracks, termed Fracture Toughness, is characterized and measured. You will get to measure the fracture toughness of aluminum - the dominant material used to build aircraft and spacecraft.

STRESS AROUND A CRACK

Consider the idealized situation shown in Figure 3.1. This shows a uniform material of infinite extent that contains a semi-infinite horizontal crack coincident with the negative x-axis. The crack is being pulled apart by a stress acting in the y direction σ_y, that far away from the crack is uniform throughout the material. The stress concentration near the crack may be determined analytically if the crack tip is assumed sharp and the material is allowed to deform only in a linear elastic fashion. Such an analysis shows that, along the positive x-axis,

$$\sigma_y = \frac{K}{\sqrt{2\pi x}} \tag{3.1}$$

thus the stress increases to infinity at the crack tip. Note that the overall magnitude of the stress field around the crack is controlled by the parameter K, called the stress intensity. In this idealized situation, K is proportional to the uniform tension being applied to the material.

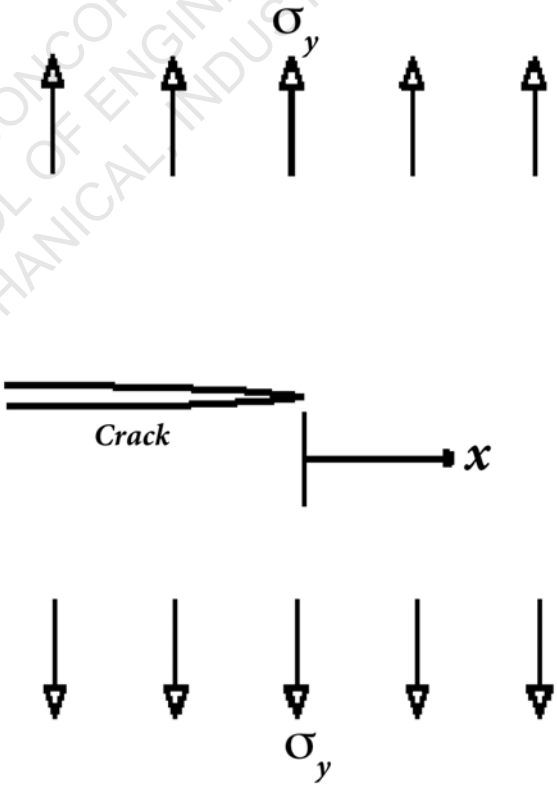


Figure 3.1: Crack in a perfectly elastic material under load

The real situation is of course more complicated. Consider the cracked material specimen in Figure 3.2. Immediately surrounding the crack, the large stresses and the above equation are not realized because the material does not behave in a linear elastic fashion here. In a metal, plastic yielding occurs to relieve and redistribute the stresses. In other materials, such as polymers or ceramics, different types of deformation, such as micro-cracking, may occur. The above equation is also unrealistic far from the crack where the shape of the specimen and the loading conditions determine the stress field. In between these regions, however, is a region where the crack dominates the stress field and the material deforms elastically. This is called the region of K dominance. Equation 3.1 is valid here. As long as the plastic zone remains small compared to the specimen size, the region of K dominance controls the behavior of the crack. This means, for example, that we can use the stress intensity K to characterize the strength of the stress field surrounding the crack.

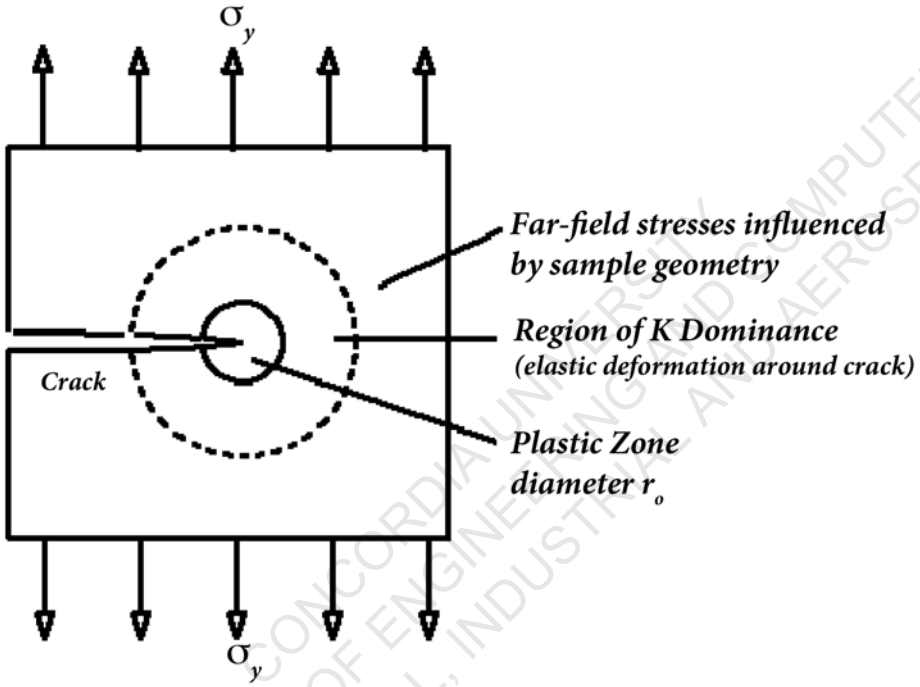


Figure 3.2: Crack in a real specimen under load.

FRACTURE AND FRACTURE TOUGHNESS

Suppose the load on the specimen in Figure 3.2 increased until it fractures, i.e. the crack grows. The resistance to fracture may be characterized by the stress intensity at fracture K_C, called the fracture toughness. The fracture toughness and the manner in which the crack grows is heavily dependent upon the material thickness.

Consider a specimen having a thickness t that is small compared to the diameter of the plastic zone r_o (see Figure 3.3). As the crack is pulled apart, the plastic zone will undergo Poisson contraction, relieving stresses σ_z acting through the sample in the z direction. We call this situation plane stress because stresses are only acting in the x-y plane. With large σ_y and σ_z near zero, the shear stress on the 45° plane between the y and z-axes is at a maximum. The crack therefore tends to orient itself along this plane as it grows. This type of crack growth is usually stable and gradual and is characterized as tearing.

Now consider a specimen having a thickness t that is large compared to ro (see Figure 3.4). As the crack is pulled apart, the material above and below the plastic zone prevents Poisson contraction from occurring throughout most of the sample. This sets up large σ_z stresses in the plastic zone. We call this situation plane strain because material is straining only in the x-y plane. With σ_z comparable to σ_y, the shear stresses are small so the crack tends to orient itself in a plane perpendicular to σ_y as it grows. This type of growth is usually unstable and is characterized as cleavage. Note that even with a thick sample there will be thin regions close to its surfaces where Poisson contraction will take place and failure on 45° planes will occur.

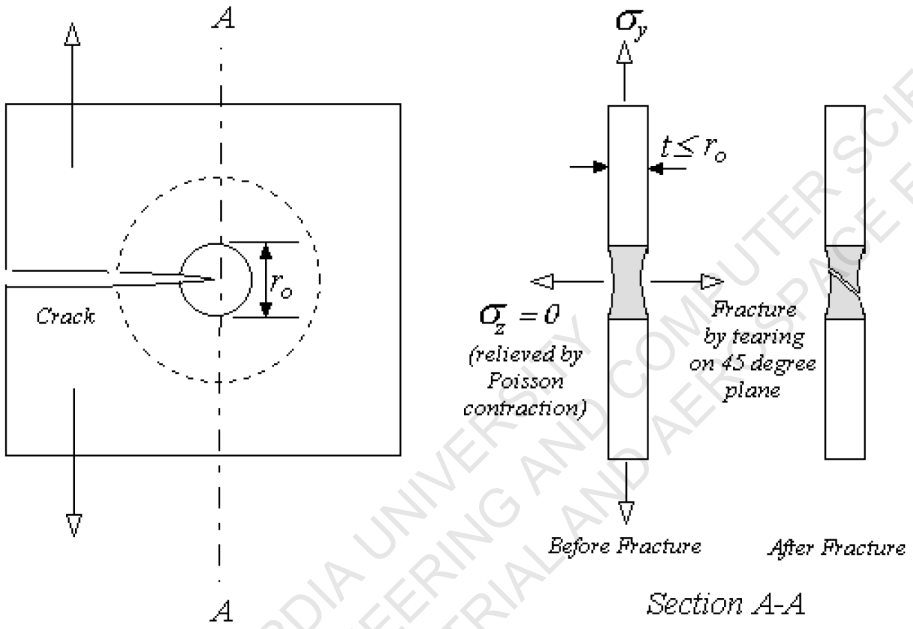


Figure 3.3: Plane stress fracture

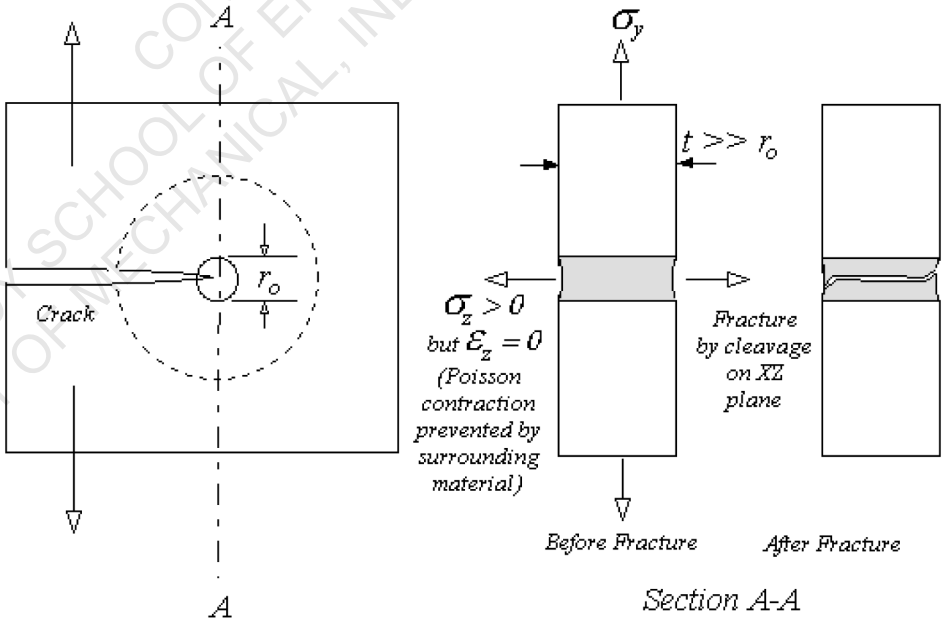


Figure 3.4: Plane strain fracture

Thicknesses between those that result in plane strain or plane stress are termed mixed, with plane strain occurring in the interior and plane stress some significant distance from the surface. Because the Poisson contraction in a thin specimen relieves some of the stress, the fracture toughness of such a sample is relatively high. As the sample thickness increases and the form of the stress distribution changes the fracture toughness falls, asymptoting to a constant value for plane strain. Because of its independence of sample thickness this asymptote, termed the plane strain fracture toughness K_{IC}, is considered a material property.

MATERIAL

Two specimens of 6061-T6 aluminum of nominal thickness 1 inch and 1.5 inch are tested. Each sample contains a notch or "machined crack" (see Figure 3.5). Another two specimens (same material) of 1.5 inch and 2 inch nominal thickness are also tested where at the tip of the notch a true crack has been produced by repeatedly loading (fatiguing) the specimen.

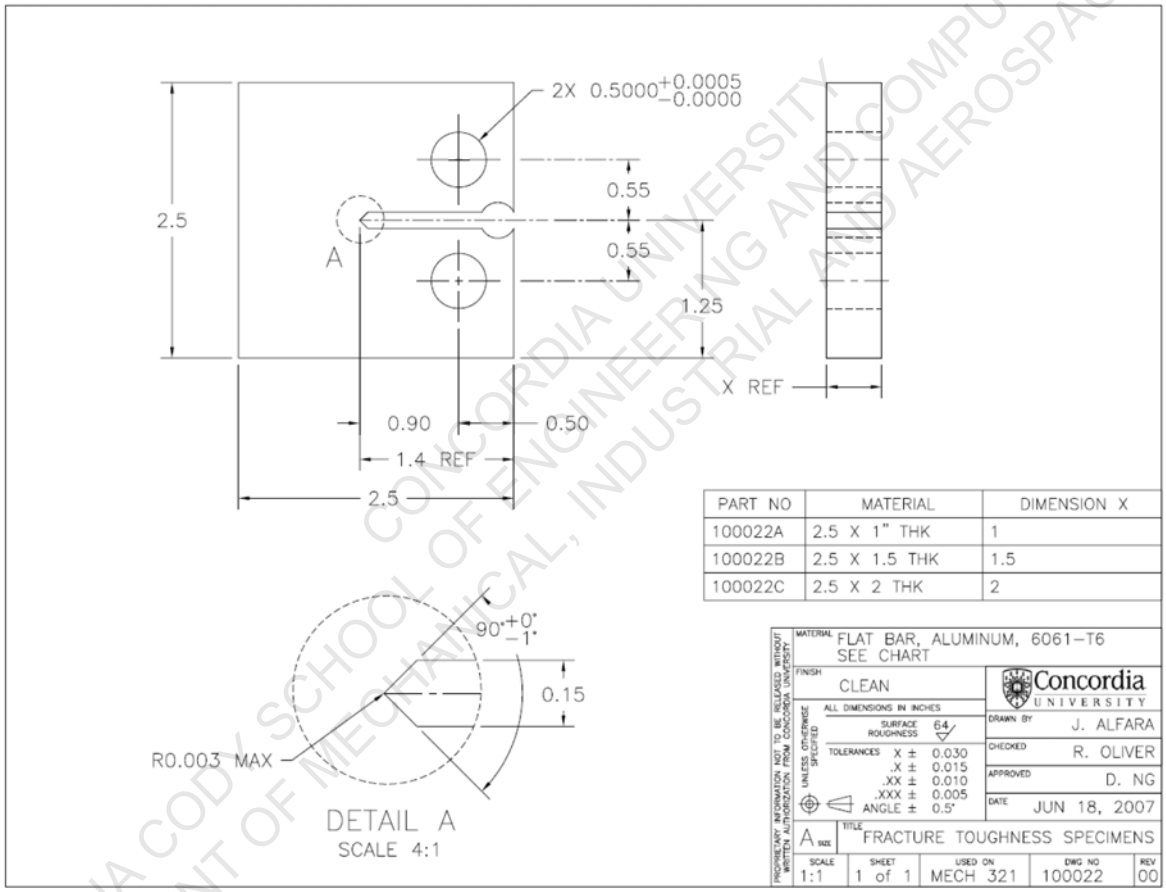


Figure 3.5: Fracture Toughness Specimen

APPARATUS

An electro-mechanical, uniaxial tensile machine (Instron® Model 3382) with a load capacity of 100 kN is used to deform the steel samples. The specimen is held between two clevis grips where the upper grip is attached to a crosshead. The crosshead is connected to a dual column frame with a ball screw in each column. With an electric motor, the crosshead can move up or down at a prescribed speed selected by the user (see Figure 3.6).

Figure 3.6: Instron® tensile machine (Model 3382)

The tensile machine has been fitted with the necessary instrumentation to measure the force applied to the specimen. The force applied to the specimen is measured by a load cell which is located between the upper grip and crosshead. The load cell output is an electrical signal whose voltage is proportional to the measured load. The displacement of the crosshead is measured by a displacement transducer (called Direct Current Linear Variable Differential Transformer, or DC-LVDT for short) whose output is also an electrical signal whose voltage is proportional to the distance traveled by the crosshead. Your lab instructor will review with you the experimental set-up and the operation of the equipment.

To measure the crack opening, a crack opening displacement (C.O.D) gauge is mounted onto the fracture toughness specimen surface using its knife edges. The C.O.D gauge gives a precise indication of the relative displacement of two accurately located knife edges which span the starter notch of the specimen. These lightweight gauges are self-supporting during testing and self-release on specimen fracture. The rugged casing provides protection from mechanical damage. Its output is an electrical signal that is proportional to the measured strain. The C.O.D gauge has been calibrated and conforms to the ASTM E 399 standard.

The output of each transducer will be monitored using a computer-based data acquisition system. Real time data of the load, crosshead displacement and C.O.D gauge are displayed on the computer monitor using the BlueHill® software provided by Instron®. A high definition video camera is also installed (not shown in Figure 3.6) for better viewing of the crack opening on a separate monitor as each sample is tested.

PROCEDURE

DETERMINING THE SAMPLE DIMENSIONS

1. Measure the height and width (to hole centers) of each of your samples using the caliper provided.
2. Measure the thickness of each sample using the micrometer.
3. Measure the total crack length from the hole centers, a_i. The fatigue crack is unlikely to be clearly visible until the fracture surfaces are examined after the sample is broken.
4. Save the raw data for all 4 specimens on USB flash drive provided by each lab group.
5. Make a sketch of the broken sample.

MOUNTING THE SPECIMEN

Load is applied to the specimen through two half-inch diameter dowel pins. The pins pass through the holes in the specimen and matching holes in two clevis grips. Two pairs of clevis grips (with 1 inch and 2 inch slots) are available. Select the pair of grips that match the specimen under test. Mount one to the base of the testing machine and one to the crosshead using the dowel pins provided. If necessary get the operator to move the crosshead up to give you enough space. Make sure that the flat side of both grips faces to the left. Place the specimen in the slot in the lower grip. Note that the dowel pin should be a snug fit, but you should be able to push it in by hand. Don't be tempted to hammer the pin in or you may never get it out. Have the operator lower the crosshead slowly until the holes in the sample and upper grip line up accurately enough to push a dowel pin through them.

RUNNING THE TEST

Set the computer program ready to take data. Ask the operator to begin the test. As the test begins, watch the sample deform on the monitor. A high definition camera is used to view the sample more clearly. As the load on the sample increases, you will begin to see its surface dimple around the crack. This dimpling is produced by Poisson contraction of the material in the plastic zone. As the sample begins to fracture, different things will happen depending on its thickness. The sample may fail suddenly, or it may tear. In the latter case you may hear a popping sound. This is the sound of the crack intermittently growing. The test continues until fracture. At this time, the crosshead is raised to completely separate the two halves of the sample. Remove the remains of the sample from the testing machine and the data is collected and saved on the computer.

ANALYSIS

Record your analysis on the data sheet.

EXAMINATION OF THE SPECIMEN

Look over the fracture surfaces. The initial crack should be fairly obvious. Measure its average length a_i, allowing for the 0.9 inch distance from the end of the machine crack to the hole centers, noting particularly if it is not uniform through the specimen thickness. Look at and sketch (in plan view and cross section) the fracture itself. How much of the fracture occurs on a 45° plane?

IDENTIFYING THE LOAD AT FRACTURE

Compare your P-v diagram with the samples shown in Figure 3.7. Initially the P-v diagram is linear because the sample deforms elastically. At fracture the crack will grow changing the sample stiffness and causing the P-v diagram to depart from a straight line. How this departure occurs depends on how the sample fractures. If cleavage is dominant then there will be a sharp break in the P-v diagram at fracture (Figure 3.7, type III). If tearing is dominant (Figure 3.7, type I) then the P-v diagram will become curved as fracture begins. A mixture of fracture mechanisms will produce a smooth curve punctuated by discontinuities of unstable crack growth (Figure 3.7, type II). These discontinuities are called 'pop in' since they produce the audible popping sound.

With such a variety of behavior, a consistent definition of the load at fracture P_Q is needed. Figure 3.7 illustrates this. A line is drawn from the origin with a slope (m_5) equal to 95% of the slope (m_t) of the initial linear portion of the P-v curve. The load at fracture is then taken as the maximum load supported by the sample in advance of the point where OB intersects the P-v curve. Obviously you need to think about, and quantify the uncertanty in getting P_Q as this may be a major factor in your stress intensity uncertainty.

DETERMINING THE STRESS INTENSITY AT FRACTURE K_Q

The relationship between the stress intensity and the load applied to the sample is not a simple one since it depends on the form of the stress field far from the crack where the shape of the sample and its precise loading conditions are important. To consider these it is necessary to perform a finite element computation, using the theory of elasticity, of the stress field in the sample. Such a computation has already been performed for the compact specimen geometry used in the present experiment. The following function is a curve fit to the results of this computation

$$K_Q = \left(\frac{P_Q}{t\sqrt{w}}\right)(0.866 + 4.64\alpha - 13.32\alpha^2 + 14.72\alpha^3 - 5.6\alpha^4)^* \left[\frac{2+\alpha}{(1-\alpha)^{1.5}}\right] \qquad (3.2)$$

where $\alpha = a_i/w$ and a_i is the total crack length. Note that this is an empirical form of Equation 3.1 with x replaced by w and the stress replaced by P_Q/tw.

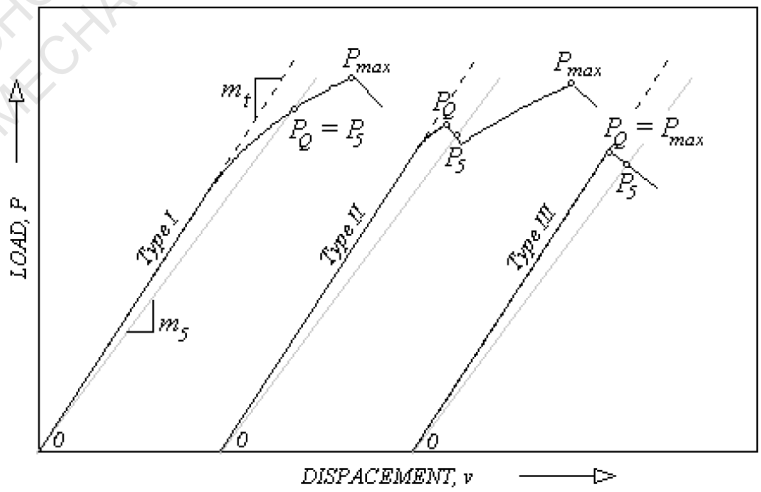


Figure 3.7: Three types of load displacement behavior and the identification of the critical load (ASTM E 399. Type I - tearing (plane stress fracture). Type II - mixed. Type III - cleavage (plane strain fracture)

DETERMINE PLANE STRESS OR PLANE STRAIN

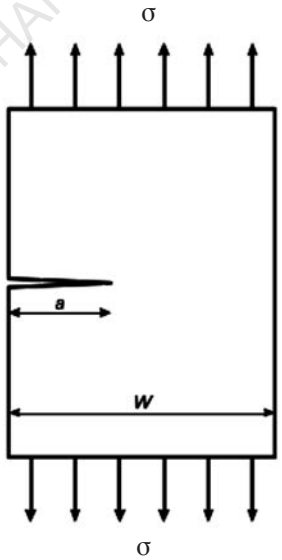
The relationships listed on the data sheet are from ASTM E 399, and are used to determine whether the sample was in plane stress or plane strain. Specifically, if both conditions (on K_Q and P_Q) are met then the sample was in plane strain, otherwise, it was in plane stress. Note that σ_o is the yield strength of the sample material (276 MPa), h, t and w are the sample dimensions. See if the answers you get agree with your own judgments based upon how the sample failed.

DETERMINE THE PLASTIC ZONE SIZE

The relationships listed on the data sheet are from ASTM E 399 and are used to determine the size of the plastic zone. As noted above, the plastic zone must be small compared to the sample size used to generate Equation 3.2 to be valid. How do the results you get here compare with your impressions of the dimpling during the test? If valid, interpret your value of K_Q as K_C or K_{IC}.

RESULTS

1. Plot the load versus displacement curve for each specimen (i.e. 4 graphs). Make sure the graphs are clearly labelled.
2. Calculate K_{IC} as outlined in the data on the specimens tested. Which of the tests performed (if any) were valid for obtaining K_{IC}? What is this value or can you make a reasonable estimate from the given data?
3. Would you say that 6061-T6 is a tough alloy? Compare your results to published values for other widely available aluminum alloys.
4. Discuss the form of the fracture surfaces revealed and whether they are consistent with the P-v behaviour in each case and with the plane stress or plane strain determination.
5. Consider a plate with an edge crack (see figure below). The plate thickness is such that a plane strain condition is present. Given W = 1000 mm and the stress intensity factor $K_I = C\sigma\sqrt{\pi a}$ where C = 1.12.



Material	Yield Strength, σ_{ys} [N/mm^2]	Tensile Strength, σ_{uts} [N/mm^2]	K_{Ic} [N/mm$^{3/2}$]
Steel 4340	1470	1820	1500
Maraging Steel	1730	1850	2900
Aluminum 7075-T6	500	560	1040

a) Does fracture occur at a stress $\sigma = \frac{2}{3}\,\sigma_{ys}$ and a crack length a = 1 mm?

b) What is the critical defect size at a stress $\sigma = \frac{2}{3}\,\sigma_{ys}$?

REFERENCES

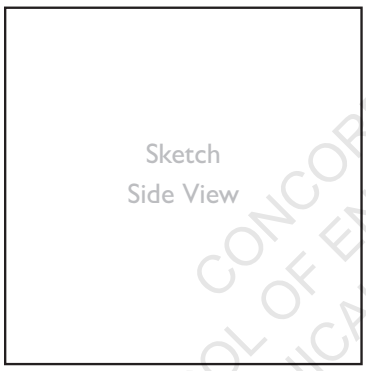
- Callister Jr., W.D., Materials Science and Engineering An Introduction, 6th Edition, John Wiley & Sons, 2003, pp 201-203.
- Devenport, W.J., Laboratory Course Notes, Department of Aerospace and Ocean Engineering, Virginia Polytechnic Institute and State University, 1996.

DATA SHEET
EXPERIMENT 3: FRACTURE TOUGHNESS TESTING OF ALUMINUM

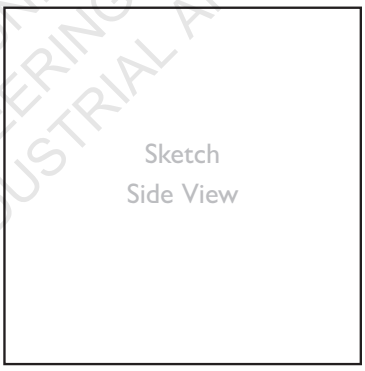
6061-T6 Aluminum	1 inch specimen	1.5 inch specimen	1.5 inch specimen (fatigued)	2 inch specimen (fatigued)

MATERIAL PROPERTIES, INITIAL SAMPLE DIMENSIONS

Yield Strength σ_o [MPa]				
Specimen half-height h [mm]				
Specimen width measured to hole centers w [mm]				
Specimen thickness t [mm]				
Total Crack length a_i [mm]				

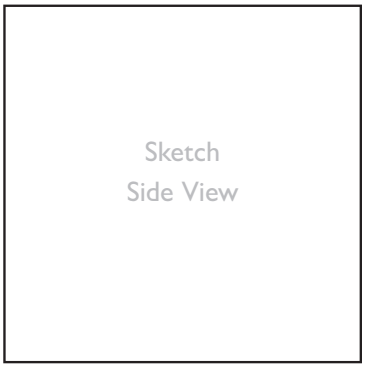


1 inch specimen



1.5 inch specimen

1.5 inch specimen (fatigued)



2 inch specimen (fatigued)

6061-T6 Aluminum	1 inch specimen	1.5 inch specimen	1.5 inch specimen (fatigued)	2 inch specimen (fatigued)

DETERMINING LOAD AT FRACTURE

Initial slope of elastic deformation line m_t				
$m_5 = 95\% \, m_t$				
Load P_5 at intersection of load displacement curve and line of slope m_5 drawn from origin [N]				
Maximum load P_{max} [N]				
P_Q (chosen according to Figure 3.7) [N]				

DETERMINING STRESS INTENSITY AT FRACTURE

Non-dimensional crack length $\alpha = a_i/w$				
Stress intensity at fracture K_Q (Equation 3.2) [MPa-$m^{1/2}$]				

DETERMINING PLANE STRESS OR PLAIN STRAIN

$2.5(K_Q/\sigma_O)^2$ [m]				
Is $2.5(K_Q/\sigma_O)^2$ less than t, a_i, $(w - a_i)$ and h?				
P_{max}/P_Q				
Is P_{max}/P_Q less than 1.1?				
Plane stress or Plane strain?				

6061-T6 Aluminum	1 inch specimen	1.5 inch specimen	1.5 inch specimen (fatigued)	2 inch specimen (fatigued)

DETERMINING PLASTIC ZONE SIZE

FOR PLANE STRAIN COMPUTE…				
Plastic zone size $r_O = (K_Q/\sigma_O)^2/3\pi$ [m]				
For strain fracture Toughness $K_{IC} = K_Q$ [MPa–$m^{1/2}$]				
FOR PLANE STRESS COMPUTE…				
Valid? (i.e. - Is $4r_O$ less than a_i, $(w - a_i)$ and h?)				
If valid, what is $K_c = K_Q$? [MPa–$m^{1/2}$]				

EXPERIMENT

4

HEAT TREATMENT, HARDNESS AND IMPACT TESTING OF STEELS

INTRODUCTION

Various types of heat treatment processes are used to change the following properties or conditions of some materials, for example:

- Improve the toughness
- Increase the hardness
- Increase the ductility
- Improve the machinability
- Refine the grain structure
- Remove the residual stresses
- Improve the wear resistance

The following are the general reasons for heat treatment:

- **Hardening** : Steels can be heat treated to high hardness and strength levels. The reasons for doing this are obvious. Structural components subjected to high operating stress need the high strength of a hardened structure. Similarly, tools such as dies, knives, cutting devices, and forming devices need a hardened structure to resist wear and deformation.
- **Tempering** : As-quenched hardened steels are so brittle that even slight impacts may cause fracture. Tempering is a heat treatment that reduces the brittleness of steel without significantly lowering its hardness and strength. All hardened steels must be tempered before use.
- **Softening a Hardened Structure** : Hardening is reversible. If a hardened tool needs to be remachined, it may be softened by heat treatment to return it to its machinable condition. Most steels weld better in their soft state than in their hardened state; softening may be used to aid weldability.
- **Recrystallization** : If a metal is cold worked, grains or crystals deform, become elongated, and in doing so harden and strengthen a metal. There is a limiting amount of cold work that a particular metal can be subjected to. In rolling of steel into thin sheets, you can only reduce the cross-sectional area so much before it gets too hard to roll. At this point it would be desirable to return the grains to their original shape. Heat treatment can accomplish this. The transformation of coldworked grains to an undistorted shape is called recrystallization. Very large coarse grains can also be refined by recrystallization. This type of heat treatment is essential if a steel is to be subjected to severe cold working in rolling, drawing, etc.
- **Stress Relief** : One of the most frequent reasons for heat treatment is to remove internal stress from a metal that has been subjected to cold working or welding. Stress relieving is a heat treatment used to remove internal strains without significantly lowering the strength. It is used where close dimensional control is needed on weldments, forgings, castings, etc.
- **Hot-Working Operations** : Most metal shapes produced by steel mills are at least rough shaped at elevated temperatures. Heat treating is required to bring the rough metal shapes to the proper temperature for hot-forming operations. Forging, hot rolling, roll welding, and the like are all performed at temperatures of sufficient magnitude as to prevent the formation of distorted grains that will harden the metals. Hot-working operations require dynamic recrystallization which is achieved by working at the proper hot-work temperatures.

- Diffusion of Alloying Elements : One of the criteria for hardening steel is that it has sufficient carbon content. Low carbon steels can be hardened, at least on the surface, by heat treating at an elevated temperature in an atmosphere containing an alloying element that will diffuse into the steel and allow surface hardening on quenching. Carbon is frequently diffused into the surface of soft steels for surface hardening. Using this same principle, elements such as chromium, boron, nitrogen, and silicon can be diffused in the surface of steel for special purposes.

As stated above, heat treatments can be used for a variety of reasons. Annealing treatments are generally used to soften a metal either after a cold working process or prior to a machining stage. Annealing of steels involves heating to specified temperature (depending on carbon composition) holding and then cooling slowly. For many non-ferrous metals, slow cooling is not always required. Spherodizing is a particular form of annealing used in higher carbon steels to produce a microstructure of Fe_3C spheroids in a ferrite matrix which is considerably softer and hence easier to machine than the same steel in the normalized or quenched and tempered state.

Normalizing of steels is similar to annealing except that cooling is slightly faster being performed in air (on the bench) as opposed to in the furnace. The microstructure in annealed and normalized steels will generally be a mixture of ferrite, pearlite and cementite depending on carbon content, with finer pearlite (and hence stronger material) being produced for normalized material. These are diffusion transformations requiring time.

In steels (and rarely in some other materials) it is possible to produce some meta-stable phases such as martensite by a diffusionless transformation brought on by a fast change in temperature called quenching. The martensite produced in steels is very hard and very brittle. This makes for good wear resistance but poor impact resistance. Tempering is carried out to reduce the brittleness without a large drop in strength and hardness. The ability to form this martensite depends on the carbon content of the steel (more carbon – more martensite is possible, the temperatures used the alloying elements in the steel and the severity of the quench. This is known as the hardenability of the steel. Ideally one would prefer to be able to handle large samples all the way through. This requires a high hardenability. This is produced by alloying.

MATERIAL

- 1018 steel
- 4130 Steel
- O-1 tool steel

The samples are machined 2.5 long x 0.4375 width x 0.4375 depth (all in inches) with a 0.085 inch deep 45° V-groove cut (Notch) across one face at the centre of the specimen length (see Experiment 2 - Figure 2.5).

APPARATUS

All specimens are heat treated in a Lindberg/Blue M Split Hinge Tube Furnace (see Figure 4.1) using an independent digital temperature control module. Temperatures can reach 1200°C. The process tube (3 inch diameter) is made out of quartz, fitted on to the tube adapters located on both ends of the furnace. Argon gas is flushed through the quartz tube to prevent any oxidation of the steel.

Figure 4.1 Lindberg/Blue M Split Hinge Tube Furnace.

Hardness tests are performed using the Rockwell Hardness testers from Wilson Instruments as illustrated in Figure 4.2. This tester operates by measuring the differential depth of a permanent deformation caused by the application and removal of differential loads. Various penetrator and load combinations are used to adapt to materials of varying hardness and thickness. The penetrators include a cone-shaped diamond and hard steel balls 0.0625 inch to 0.5 inch diameter. The standard Rockwell test uses a minor load of 10 kg to seat the penetrator firmly in the surface of the specimen. Then the depth gage is zeroed and the major load is applied then removed. While the minor load still acts, the depth of penetration is measured on a dial calibrated in Rockwell hardness numbers. Major loads for the standard Rockwell test are 60, 100, and 150 kg.

Figure 4.2: Rockwell Hardness Tester by Wilson Instruments

The Charpy impact test is done on the Tinius-Olsen Charpy/Izod Impact Machine. See Experiment 2 for more information on this machine.

PROCEDURE

Each lab section will test 2 samples of 1018 steel, 2 samples of 4130 steel and 2 samples of O-1 tool steel of various heat treatments (see Table 4.1).

Table 4.1: Heat Treatments

WEEK 2 (FIRST WEEK OF THE EXPERIMENT)

Steel	Lab TJ -X	Lab XR -X	Lab XP-X	Lab TL -X	Lab XJ-X	Lab XN -X	Lab TP -X	Lab XL -X	Lab TR -X	Lab TN -X
1018	Q&T 205°C	Q&T 315°C	Q&T 540°C	Q&T 425°C	As Received	Q&T 540°C	As Received	Q&T 205°C	Q&T 315°C	Q&T 425°C
1018	Q&T 705°C	Q&T 760°C	Quench	Q&T 650°C	Air Cool	Quench	Air Cool	Q&T 705°C	Q&T 760°C	Q&T 650°C
4130	Q&T 205°C	Q&T 315°C	Q&T 540°C	Q&T 425°C	As Received	Q&T 540°C	As Received	Q&T 205°C	Q&T 315°C	Q&T 425°C
4130	Q&T 705°C	Q&T 760°C	Quench	Q&T 650°C	Air Cool	Quench	Air Cool	Q&T 705°C	Q&T 760°C	Q&T 650°C
O-1	Q&T 205°C	Q&T 315°C	Q&T 540°C	Q&T 425°C	As Received	Q&T 540°C	As Received	Q&T 205°C	Q&T 315°C	Q&T 425°C
O-1	Q&T 705°C	Q&T 760°C	Quench	Q&T 650°C	Air Cool	Quench	Air Cool	Q&T 705°C	Q&T 760°C	Q&T 650°C

WEEK 1 (SECOND WEEK OF THE EXPERIMENT)

Steel	Lab TI -X	Lab XQ -X	Lab XO-X	Lab TK-X	Lab XI -X	Lab XM -X	Lab TO -X	Lab XK -X	Lab TQ -X	Lab TM -X
1018	Q&T 540°C	As Received	Q&T 425°C	Q&T 540°C	Q&T 205°C	Q&T 315°C	Q&T 425°C	Q&T 205°C	As Received	Q&T 315°C
1018	Quench	Air Cool	Q&T 650°C	Quench	Q&T 705°C	Q&T 760°C	Q&T 650°C	Q&T 705°C	Air Cool	Q&T 760°C
4130	Q&T 540°C	As Received	Q&T 425°C	Q&T 540°C	Q&T 205°C	Q&T 315°C	Q&T 425°C	Q&T 205°C	As Received	Q&T 315°C
4130	Quench	Air Cool	Q&T 650°C	Quench	Q&T 705°C	Q&T 760°C	Q&T 650°C	Q&T 705°C	Air Cool	Q&T 760°C
O-1	Q&T 540°C	As Received	Q&T 425°C	Q&T 540°C	Q&T 205°C	Q&T 315°C	Q&T 425°C	Q&T 205°C	As Received	Q&T 315°C
O-1	Quench	Air Cool	Q&T 650°C	Quench	Q&T 705°C	Q&T 760°C	Q&T 650°C	Q&T 705°C	Air Cool	Q&T 760°C

HEAT TREATMENT

A demonstration on quenching a sample is performed by the lab technician. Other samples with differing quenching and tempering conditions have been prepared already. Samples are inserted into the tube furnace (preheated to 900°C). This is the austenitizing temperature. Let the argon gas flow slowly. It will minimize the formation of an oxide film that you would later need to remove in order to obtain accurate hardness readings. Wait 2 hours for the samples to acquire furnace temperature, then quench in water (or oil), or let air cool. Stand clear when the lab technician is removing the samples from the furnace. Hold the samples at the tempering temperature for 2 hours. Quench in water.

HARDNESS

Use the Rockwell hardness testers on each sample by taking the average of at least 3 readings. A range of hardness will be encountered throughout this experiment so you may need to switch scales. Use the Rockwell C scale (150 kg) for hardened material in conjunction with the Rockwell B scale and 0.0625 inch ball penetrator (100 kg) for softer states. Refer to the chart posted in the lab above the Rockwell testers for conversions and the applicable range of each scale. The B and C scales are most often quoted in the literature along with Brinell hardness so these readings may be helpful to compare your results to expected values. Follow the steps below to get a proper Rockwell reading (refer to Figure 4.4):

1. Select the correct combination of weights (being at the rear of the machine) and penetrators for the hardness scale you wish to use. A data plate mounted on the machine gives this information along with instructions regarding use of the black or red dial numbers.
2. Make certain the crank (4) is in its forward position, nearest to you.
3. Place the sample on the anvil, in position for test.
4. Slowly turn the wheel spokes (1) clockwise. This raises the anvil and sample toward the penetrator tip. After contact is gently made, continue raising sample until small pointer (5) is about in line with the small black dot and the large pointer (6) is within the coloured sector (7). The minor load has now been applied to the sample.
5. After step (d), the large pointer (6) on the dial is nearly vertical. Now, turn the knurled collar (2) until the SET line on the dial scale is in line with and under the large pointer (6).
6. Depress the trip lever (3). This triggers the mechanism that applies the major load. The crank (4) will automatically move away from you.
7. After the crank (4) has come to rest, gently pull the crank back toward you as far as it will go. If this is done abruptly, a false reading will be obtained due to jarring.
8. Record the scale reading of the large pointer (6). The black scale is read for the diamond penetrator (such as Rockwell C), and the red scale is read for the ball penetrators (such as for a Rockwell B test).
9. Remove the minor load by lowering the anvil (turn wheel (1) counter clockwise).

IMPACT TESTING

For safety reasons, impact tests on the Instron impact machine is performed by the lab technician. Record the impact energy in ft-lb$_f$ on the data sheet for the 6 samples. Forward the data to the lab instructor. Gather the broken halves and label them as a set. Study the fracture surface of all the specimens tested and sketch them, neatly differentiating between the ductile and brittle fracture areas.

RESULTS

A complete set of data (i.e. all heat treatments) is available after the first week Friday labs are finished in order to calculate the results. The lab instructor will e-mail one week's worth of raw data to one team member in each lab group.

1. Using the cumulative results, plot values of hardness versus impact energy for all materials
2. Comment on the transition in fracture energy in relation to the visible fracture surfaces and results of the hardness tests for all the materials. Include the fracture sketches of all specimens.
3. Plot a graph showing hardness versus tempering temperature for all steels. Comment on the graph.
4. Plot a graph showing impact energy and tempering temperature for all steels. Comment on the graph.
5. Supposing one was to make a cold chisel from O-1 tool steel, recommend a heat-treatment process. What hardness and toughness combination are you aiming for? Is O-1 the best choice for this application? If not, discuss what else might you select?
6. Select from the list below the one metal or alloy that is best suited for each of the following applications. Justify your selection.

   (Plain Carbon Steel, Brass, Gray Cast Iron, Platinum, Stainless Steel, Titanium Alloy, Magnesium, Zinc, Tool Steel, Aluminum, Tungsten)

   a) Internal combustion engine block
   b) Condensing heat exchanger for steam
   c) Jet engine turbofan blades
   d) Drill bit

REFERENCES

- Callister Jr., W.D., *Materials Science and Engineering An Introduction*, 6th Edition, John Wiley & Sons, 2003, pp 360–370.
- Askeland, D.R, *The Science and Engineering of Materials*, 3rd Edition, PWS Publishing Company, 1994, pp 152–155.

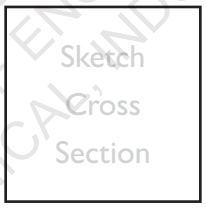
DATA SHEET
EXPERIMENT 4: HEAT TEATMENT, HARDNESS AND IMPACT TESTING OF STEELS

1018 STEEL

Specimen #	Heat Treatment	Rockwell Hardness	Charpy Impact Energy [ft-lb$_f$]
0	As-Receive		
1	Air-Cool		
2	Quench		
3	Q&T 205°C		
4	Q&T 315°C		
5	Q&T 425°C		
6	Q&T 540°C		
7	Q&T 650°C		
8	Q&T 705°C		
9	Q&T 760°C		

As-Receive

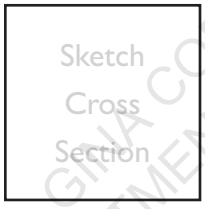
Air-Cool



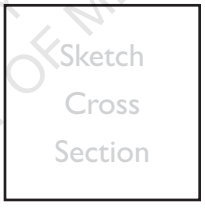
Quench

Q&T 205°C

Q&T 315°C



Q&T 425°C



Q&T 540°C

Q&T 650°C

Q&T 705°C

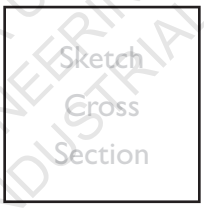
Q&T 760°C

4130 STEEL

Specimen #	Heat Treatment	Rockwell Hardness	Charpy Impact Energy [ft-lb$_f$]
10	As-Receive		
11	Air-Cool		
12	Quench		
13	Q&T 205°C		
14	Q&T 315°C		
15	Q&T 425°C		
16	Q&T 540°C		
17	Q&T 650°C		
18	Q&T 705°C		
19	Q&T 760°C		

As-Receive

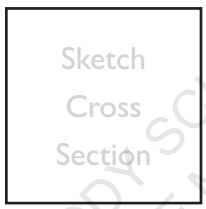
Air-Cool



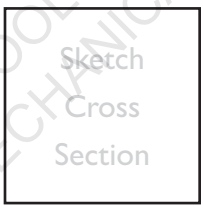
Quench

Q&T 205°C

Q&T 315°C



Q&T 425°C



Q&T 540°C

Q&T 650°C

Q&T 705°C

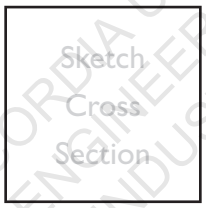
Q&T 760°C

O-1 TOOL STEEL

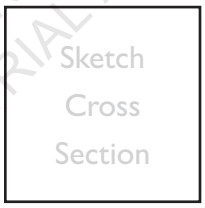
Specimen #	Heat Treatment	Rockwell Hardness	Charpy Impact Energy [ft-lb$_f$]
20	As-Receive		
21	Air-Cool		
22	Quench		
23	Q&T 205°C		
24	Q&T 315°C		
25	Q&T 425°C		
26	Q&T 540°C		
27	Q&T 650°C		
28	Q&T 705°C		
29	Q&T 760°C		

As-Receive

Air-Cool



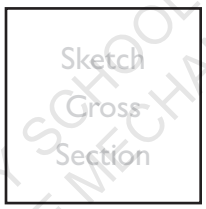
Quench



Q&T 205°C

Q&T 315°C

Q&T 425°C



Q&T 540°C

Q&T 650°C

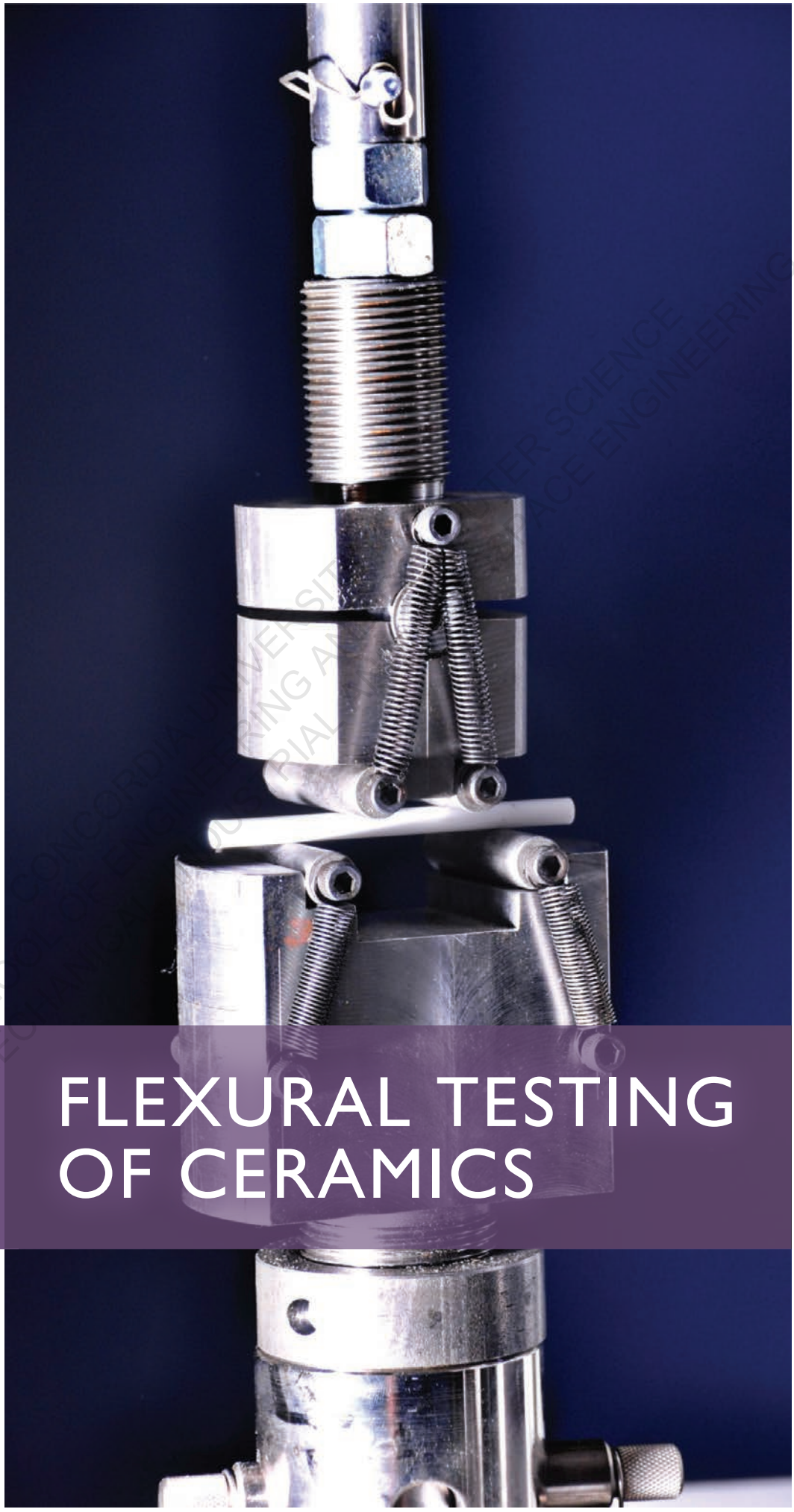
Q&T 705°C

Q&T 760°C

EXPERIMENT

5

FLEXURAL TESTING OF CERAMICS



INTRODUCTION

Mechanical strength is generally defined as the ability of materials to withstand loads without being fractured. Usually strength is thought of in terms of tensile strength and ceramics, generally being brittle, are often erroneously considered as being weak. Ceramics have very good mechanical properties when in compression (e.g. concrete) however not all loading of ceramics is compressional. The strength of a ceramic is usually measured in bending, i.e. flexural strength or modulus of rupture (MOR), mainly because of the simple specimen geometry and the inherent difficulties of tensile testing ceramics. However, there are drawbacks to flexural testing.

Another important mechanical property of ceramics is their high hardness. This property is exploited in applications such as abrasives, (SiC and Al_20_3) cutting tools (sialons, diamond) and more recently wear resistant ceramics (Si_3N_4, Al_20_3) used for bearings, seals and other mechanical engineering applications where high wear rates of conventional materials are encountered.

THEORY

There are two standard flexural test methods: (1) 3-point Flexure Test and (2) 4-point Flexure Test. In this experiment, the 4-point flexure test is performed.

4-POINT FLEXURE TEST

In this test the loading force is applied by means of two loading pins with a distance between them equal to a half of the distance between the supporting pins shown in Figure 5.1.

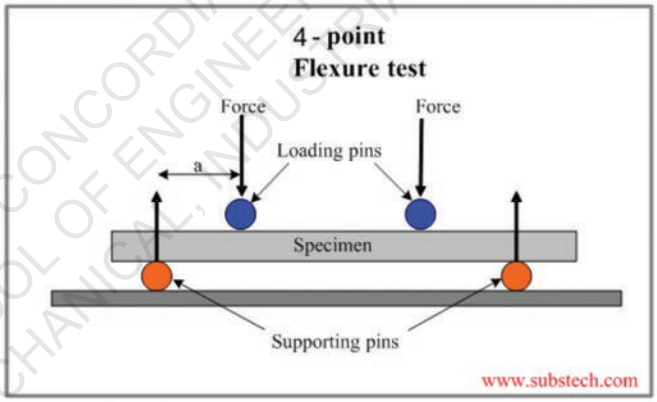


Figure 5.1: 4-point flexure test

FLEXURAL STRENGTH CALCULATION

As a result of the loading, the specimen bends, causing formation of a tensile stress in its convex side and compression stress in the concave side. The cross head speed in a flexural test is normally within the range 0.1 to 10 mm/min. Speeds of 1 mm/min or 2.54 mm/min are mostly used in the tests. The Flexural strength stress is calculated from the load value at fracture. Flexural strength or modulus of rupture (MOR) is the tensile stress of the extreme fibre of a specimen at its failure in the flexure test. Flexural strength in 4-point test of round specimen is calculated by the formula:

$$MOR = \frac{16Fa}{\pi D^3} = \frac{2Fa}{\pi r^3} \qquad (5.1)$$

where F is the total force applied to the specimen by two loading pins; r is the specimen section radius; a is the distance between the supporting and loading pins (= 10 mm); and D is the section diameter of a round specimen.

WEIBULL STATISTICS FOR FAILURE STRENGTH ANALYSIS

Tensile properties of ceramics depend so critically on the size and geometry of each flaw, there is considerable scatter in the values for strength determined from a tensile, bending or fatigue test. Ceramic parts produced from identical materials by identical methods can fail at very different applied loads. In order to design structural parts using ceramics, the probability that a flaw is present that will cause failure to occur at any given stress must be known. The Weibull distribution and Weibull modulus provide a statistical approach to designing with ceramics.

For ductile materials, the distribution of strength (yield or tensile) tends to be very narrow and close to a Gaussian distribution. However, the strength of ceramics and glasses varies considerably (i.e. testing a large number of identical samples of glass or alumina ceramic will show a wide scatter owing to changes in distribution of flaw sizes. The strength of brittle materials is not Gaussian; it is better described by a Weibull distribution shown in Figure 5.2(a). At low stresses, a small fraction of samples contain flaws large enough to cause fracture; most fail at intermediate applied stress and a few contain only small flaws and do not fail until large stresses are applied. A very narrow distribution is preferred.

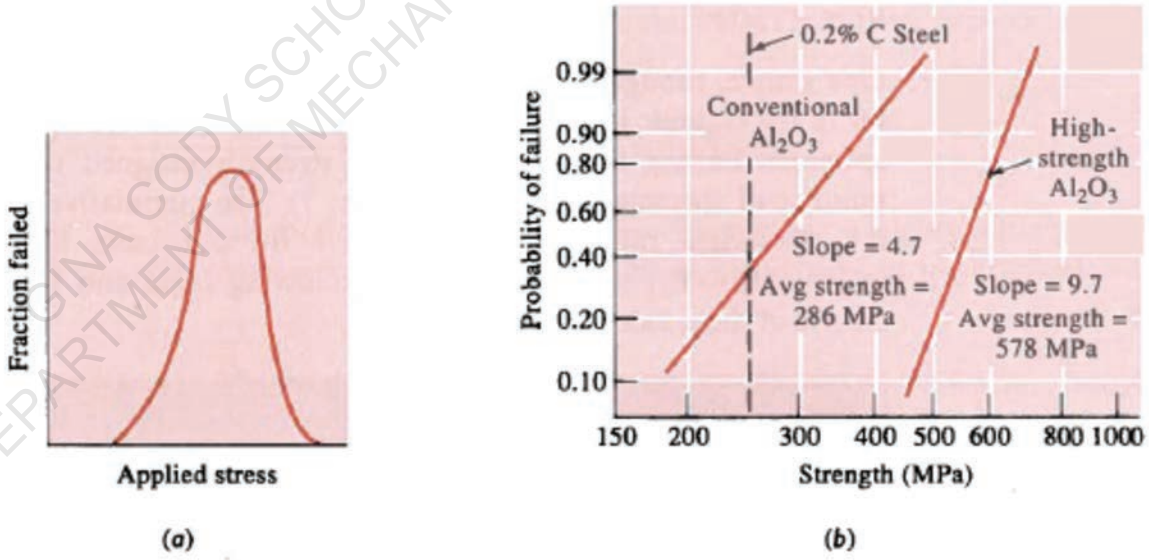


Figure 5.2: (a) Weibull distribution; (b) Cumulative plot on log-log scale

The probability of failure can be related to the failure stress by

$$\ln\left[\ln\left(\frac{1}{1-P}\right)\right] = m \bullet \ln(MOR) \tag{5.2}$$

where P is the cumulative probability of failure and m is the Weibull modulus. The probability of failure is shown in a cumulative manner in Figure 5.2(b) for Al_2O_3 prepared by two different processes. When the applied stress is high, there is a very high probability that any sample will fail. As the stress decreases so does the probability of failure. The Weibull modulus m is the slope of the cumulative probability curve. For critical design, the value of m should be large; a high slope represents a ceramic with a narrow range of flaw sizes.

One simple method for determining the behaviour of the ceramic is to assign a numerical rank to the specimens with the specimen having the lowest fracture strength assigned the value of 1. The total number of specimens is n. The cumulative probability P is then the numerical rank divided by n + 1. Then, plot ln {ln [1/(1-P)]] versus ln (MOR).

MATERIAL

- Borosilicate Clear Rod (Glass) – 5 mm diameter

The material is cut to 60 mm lengths to be tested in a four-point bending test.

PROCEDURE

CAUTION: When using hydrofluoric acid (HF), safety glasses, lab coat and safety gloves must be worn. Wash gloves before removing and wash hands afterwards. When breaking glass and rods wear safety glasses and use plexiglass screen.

1. Take 5 of the glass bars and place CAREFULLY in the plastic beaker/holder. Pour sufficient dilute 5% HF acid from marked bottle to cover bars completely and leave for 20 minutes.
2. Using 4-point testing rig, break 5 as-received glass bars noting breaking load. Use constant loading rate for all experiments.
3. Using 4-point testing rig, break 5 glass bars that have been lightly abraded with SiC paper (120 grit).
4. Using 4-point testing rig, break 5 glass bars that have been polished with 5 micron diamond paste.
5. After 20 minutes, carefully remove etched glass rods ensuring that they do not rub against anything (except plastic holder).
6. Wash rods thoroughly, leaving to rinse for 5 minutes. Rinse in alcohol and air dry. Without touching the length of the bar (only ends) place in the 4-point jig and test.
7. Record the fracture loads on the data sheet.

RESULTS

1. Using spreadsheet software, calculate the modulus of rupture in [MPa] for each set of bars.
2. Plot the Weibull distribution to obtain the Weibull modulus for each set of bars.
3. Describe the effect of flaws on the mechanical strength of ceramics.
4. Explain any differences when the glass rods are abraded with SiC paper and polished with diamond paste.
5. How do different methods of strength measurement, i.e. tensile testing, 3 point and 4 point bend testing influence the measured strength of ceramics and why? Discuss the advantages and disadvantages of each test method.
6. Besides chemical etching, how else can the tensile strength of ceramics and glasses be increased?
7. Seven silicon carbide specimens were tested and the following fracture strengths were obtained: 23 MPa, 49 MPa, 34 MPa, 30 MPa, 55 MPa, 43 MPa and 40 MPa. Estimate the Weibull modulus for the data and discuss the reliability of the ceramic.

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- Callister Jr., W.D., *Materials Science and Engineering An Introduction*, 6th Edition, John Wiley & Sons, 2003, pp 410–414.
- Davidge, R.W., *Mechanical Behaviour of Ceramics*, Cambridge University Press, 1980.
- Askeland, D.R, *The Science and Engineering of Materials,* 3rd Edition, PWS Publishing Company, 1994, pp 433–439.

DATA SHEET
EXPERIMENT 5: FLEXURAL TESTING OF CERAMICS

BOROSILICATE CLEAR ROD (GLASS) – AS RECEIVED

Sample Number	Fracture Load [N]
1	
2	
3	
4	
5	

BOROSILICATE CLEAR ROD (GLASS) SANDED WITH SiC PAPER

Sample Number	Fracture Load [N]
1	
2	
3	
4	
5	

BOROSILICATE CLEAR ROD (GLASS) POLISHED WITH DIAMOND PASTE

Sample Number	Fracture Load [N]
1	
2	
3	
4	
5	

BOROSILICATE CLEAR ROD (GLASS) ETCHED IN HF

Sample Number	Fracture Load [N]
1	
2	
3	
4	
5	

EXPERIMENT

6

MATERIAL SELECTION USING CES SOFTWARE

INTRODUCTION

The Cambridge Engineering Selector (CES) is a computer system contains programs for selection, manufacturing processes and shaping of materials. The use of selection charts and selection criteria is discussed in lectures, and this knowledge is assumed. This lab aims at showing how the CES software can be used to create any materials selection chart as an aid to materials selection in the design process.

CES contains a large database of materials and their properties. Charts are created using specified axes (e.g. density, strength, modulus or user-defined functions etc.), where materials can be plotted as a bar or bubble for the range of their properties. A performance index can be plotted to select those materials which optimize performance (such as mass, cost, corrosion resistance etc.). Additional stages can be added to refine the selection. The output can be transferred to a Microsoft Word document for your final report. You can save your work in a project file, which stores the current status of your session. Also, you can copy and paste the graphs and the results from CES into a Word document.

The Generic database contains information on a broad range of materials (e.g. aluminum alloys, steels, polymers, ceramics.). More refined information is available in other databases (e.g. the light alloys database contains data for individual alloy compositions and heat treatments). The generic database is usually used at the start of a design study and is suitable for all the design exercises in this lab.

DEPARTMENT OF MECHANCIAL, INDUSTRIAL AND AEROSPACE ENGINEERING

MECH 321

PROPERTIES & FAILURE OF MATERIALS

EXPERIMENT 6

MATERIAL SELECTION USING CES SOFTWARE

Student Name *ID#*

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Lab Section: _____

OBJECTIVE

Address the design process of a solid circular cantilever beam from the perspective of materials selection; that is, for some application, selecting a material having a desirable or optimum property or combination of properties using the CES software.

INTRODUCTION

For this portion of the design process, you will establish criteria for selection of stiff-light and strong-light materials for this cantilever beam. It will be assumed that the force and length of the beam are specified, whereas the radius may be varied.

A cylindrical cantilever beam is subjected to a force, F, as indicated in Figure 6.1. The beam-end deflection δ is:

$$\delta = \frac{FL^3}{3EI} \tag{6.1}$$

where L, E and I are the length, modulus of elasticity and moment of inertia of the beam, respectively.

Here, I is moment of inertia, which for a solid cylinder is:

$$I = \frac{1}{4}\pi r^4 \tag{6.2}$$

The stress imposed on the unfixed end σ is:

$$\sigma = \frac{FLr}{I} \tag{6.3}$$

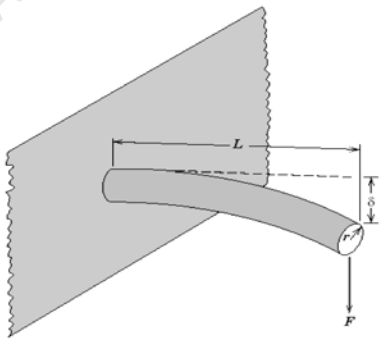

Figure 6.1: Cylindrical cantilever beam

STIFF-LIGHT

Develop an expression for the mass of material required in terms of force, deflection, length, density and modulus of elasticity of the material. Consider the mass, m, of any given quantity of material is just the product of its density (ρ) and volume ($\pi r^2 L$). Group the material properties of density and modulus of elasticity as one set in your solution.

STRONG-LIGHT

Develop an expression for the mass of material required in terms of force, length, density and strength of the material. Consider the mass, m, of any given quantity of material is just the product of its density (ρ) and volume ($\pi r^2 L$). Group the material properties of density and strength as one set in your solution.

The best materials to be used for a stiff-light and strong-light beam are those having low $\rho/\sqrt{E}$ and $\rho/\sigma^{2/3}$, respectively. In terms of material suitability, it is sometimes preferable to work with what is termed a performance index, P, which is just the reciprocal of these ratios; that is,

$$P = \frac{\sqrt{E}}{\rho}$$

$$P = \frac{\sigma^{2/3}}{\rho}$$

In this context, we want to utilize a material having a large performance index.

RESULTS

To examine the performance indices of a variety of materials, use the material selection charts or CES software. These are plots of the values of material property versus those of another property. Both axes are scaled logarithmically. Taking the logarithm of the performance indices equations above will yield a family of straight and parallel lines all having a finite slope. Each line in the family corresponds to different performance index.

Using the CES software, create the following stages,

- Select those metal alloys with stiffness performance indices greater than 3.0 (in SI units). Plot Young's Modulus (Y-Axis) versus Density (X-Axis).
- Select those metal alloys having strength performance indices greater than 18.0 (in SI units). Plot Elastic Limit (Y-Axis) versus Density (X-Axis).
- Plot None (Y-Axis) versus Price (X-Axis).

DISCUSSION

Which material would you select if stiffness, strength, price or other factors are to be considered relative to this application? Justify your choice. Use page 48 to write your discussion.

REFERENCES

- Ashby, M., Materials Selection in Mechanical Design, 3rd edition, Burlington, Massachusetts: Butterworth-Heinemann, 1999.

DISCUSSION

Faculty of Engineering and Computer Science
Expectations of Originality

This form sets out the requirements for originality for work submitted by students in the Faculty of Engineering and Computer Science. Submissions such as assignments, lab reports, project reports, computer programs and take-home exams must conform to the requirements stated on this form and to the Academic Code of Conduct. The course outline may stipulate additional requirements for the course.

1. Your submissions must be your own original work. Group submissions must be the original work of the students in the group.
2. Direct quotations must not exceed 5% of the content of a report, must be enclosed in quotation marks, and must be attributed to the source by a numerical reference citation[1]. Note that engineering reports rarely contain direct quotations.
3. Material paraphrased or taken from a source must be attributed to the source by a numerical reference citation.
4. Text that is inserted from a web site must be enclosed in quotation marks and attributed to the web site by numerical reference citation.
5. Drawings, diagrams, photos, maps or other visual material taken from a source must be attributed to that source by a numerical reference citation.
6. No part of any assignment, lab report or project report submitted for this course can be submitted for any other course.
7. In preparing your submissions, the work of other past or present students cannot be consulted, used, copied, paraphrased or relied upon in any manner whatsoever.
8. Your submissions must consist entirely of your own or your group's ideas, observations, calculations, information and conclusions, except for statements attributed to sources by numerical citation.
9. Your submissions cannot be edited or revised by any other student.
10. For lab reports, the data must be obtained from your own or your lab group's experimental work.
11. For software, the code must be composed by you or by the group submitting the work, except for code that is attributed to its sources by numerical reference.

You must write one of the following statements on each piece of work that you submit:
For individual work: **"I certify that this submission is my original work and meets the Faculty's Expectations of Originality",** with your signature, I.D. #, and the date.
For group work: **"We certify that this submission is the original work of members of the group and meets the Faculty's Expectations of Originality",** with the signatures and I.D. #s of all the team members and the date.

A signed copy of this form must be submitted to the instructor at the beginning of the semester in each course.

I certify that I have read the requirements set out on this form, and that I am aware of these requirements. I certify that all the work I will submit for this course will comply with these requirements and with additional requirements stated in the course outline.

Course Number: _____ Instructor: _____
Name: _____ I.D. # _____
Signature: _____ Date: _____

[1] Rules for reference citation can be found in "Form and Style" by Patrich MacDonagh and Jack Bordan, fourth edition, May, 2000, available at http://www.encs.concordia.ca/scs/Forms/Form&Style.pdf.
Approved by the ENCS Faculty Council February 10, 2012

NOTES

NOTES

IN CASE OF EMERGENCY REMAIN CALM

AND FOLLOW THESE INSTRUCTIONS

Fire/Evacuation

Fire:

- If you see smoke or fire activate the nearest fire alarm.

Evacuation:

- Stay calm; do not rush or panic
- Safely stop your work,
- Gather your personal belongings; coat, purse, etc...
- Close and lock your door and windows.
- Use stairs only; do not use elevators or escalators,
- Once outside, move away from the building.
- Do not re-enter the building until instructed to do so by Security.

Shelter In Place

Communication:

- Shelter-in-Place will be announced by intercom P.A. voice communication, text messaging,
- Fire alarms will not be sounded.

Procedures:

- Lock classroom, office and lab doors if possible, remain quiet and do not enter the hallway,
- Should the fire alarm sound, DO NOT evacuate the building unless:
  1. *You have first hand knowledge that there is a fire in the building*,
  2. *You are in imminent danger, or*
  3. *You have been advised by Security or Police to evacuate the building.*
- Crouch down in the areas that are out of sight from doors and windows,
- Anyone in the hallways are to seek shelter in the nearest classroom,
- Anyone outdoors on campus should immediately take cover,
- If safe you can call 514-848-(8800) for more information on the situation.

Suspicious Person/Package

Suspicious Person:

- Do not physically confront the person,
- Do not let anyone into a locked building/office,
- Call Security @ 514-848-(3717),
- Provide as much information as possible about the person and his or her direction of travel.

Suspicious Package:

- Do not touch or disturb object,
- Call Security @ 514-848-(3717),
- Notify your Supervisor.

Hazardous Materials

- If an emergency develops or if anyone is in danger, call 514-848-(3717)
- Move awa from the site of the hazard to a safe location,
- Follow instructions of Emergency Personnel,
- Alert others to stay clear of the area,
- Notify Emergency Personnel if you have been exposed to the hazard or have information about the release

Medical Emergencies

- In the event of a serious or life threatening injury or illness;
- From a safe location; call Security immediately at 514-848-(3717),
- Ensure your personal security before attempting first-aid,
- Provide the victim appropriate first-aid & comforting,
- Do not give the victim anything to drink or eat.

**If the injury is the result of a fall or significant trauma: Do not move the victim unless absolutely necessary.*

Power Failure

- Remain calm and move cautiously to a lighted area,
- Do not evacuate unless asked to by Emergency Personnel
- Do not use candles
- For loacalized outages, contact Security at 514-848-(3717)

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