ME 354 Mechanics of Materials Laboratory
Overview and Summary

Prerequisites

- ENGR 170 "Introduction to Materials Science"
- ENGR 220 "Mechanics of Materials"

General Description

Mechanics of Materials Laboratory (5 Credits)
Study of the properties, behavior and performance of engineering materials including stress-strain relations, strength, deformation, fracture, creep, and cyclic fatigue.

Introduction to experimental techniques common to structural engineering, interpretation of experimental data, comparison of measurements to numerical/analytical predictions, and formal, engineering report writing.

Three 1-hr lectures/week + One 1-hr recitation/week
+ One 3-hr laboratory/week

Laboratory exercises

1) Measurement, Significant Figures, And Statistics

2) Strains, Deflections And Beam Bending

3) Curved Beams

4) Mechanical Properties and Performance of Materials
- Tension
- Hardness
- Torsion
- Charpy V-Notch Impact

5) Stress Concentrations

6) Fracture

7) Fatigue (Time-Dependent Failure)

8) Creep (Time-Dependent Deformation)

9) Structures

10) Compression and Buckling

ME 354, MECHANICS OF MATERIALS LABORATORY

MEASUREMENT, SIGNIFICANT FIGURES, AND STATISTICS

PURPOSE

The purpose of this exercise is familiarize you with measurements, significant figures, and statistics.

ASPECTS OF MECHANICS OF MATERIALS

Measurements, inherent error, discrepancy, magnitude and units, direct measurements, Indirect measurements, accuracy, precision

Absolute error, relative error and percentage error

$$err_a = X_t - X_m \qquad \text{(absolute)}$$

$$err_r = \frac{X_t - X_m}{X_m} = \frac{err_a}{X_m} \qquad \text{(relative)}$$

$$\%err = 100\left(\frac{X_t - X_m}{X_m}\right) = 100\ err_r \qquad \text{(percentage)}$$

where X_t is the true value and X_m is the measured value

Significant figures and statistics

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n} \qquad \text{(sample mean)}$$

$$\hat{\sigma}_s = \sqrt{\frac{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}{n-1}} \qquad \text{(sample standard deviation)}$$

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STRAINS, DEFLECTIONS AND BEAM BENDING LABORATORY

PURPOSE

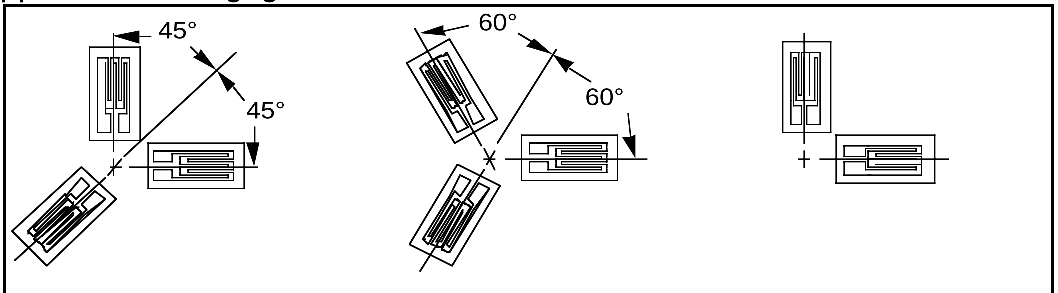
The purpose of this exercise is a) to familiarize the user with strain gages and associated instrumentation, b) to measure deflections and compare these to predicted deflections, and c) to verify certain aspects of stress-strain relations and simple beam theory.

ASPECTS OF MECHANICS OF MATERIALS

1) Strain transformations

$$\varepsilon_\theta = \varepsilon_x \cos^2\theta + \varepsilon_y \sin^2\theta + \gamma_{xy}\cos\theta\sin\theta$$

applied to strain gages



a) Rectangular Rosette b) Delta Rosette c) Biaxiial Strain Gage

Rectangular

$$\varepsilon_x = \varepsilon_{0^\circ}$$

$$\varepsilon_y = \varepsilon_{90^\circ}$$

$$\gamma_{xy} = 2\varepsilon_{45^\circ} - (\varepsilon_{0^\circ} + \varepsilon_{90^\circ})$$

Delta

$$\varepsilon_x = \varepsilon_{0^\circ}$$

$$\varepsilon_y = \frac{1}{3}\left[2(\varepsilon_{60^\circ} + \varepsilon_{120^\circ}) - \varepsilon_{0^\circ}\right]$$

$$\gamma_{xy} = \frac{2\sqrt{3}}{3}\left[\varepsilon_{60^\circ} - \varepsilon_{120^\circ}\right]$$

2) Constitutive relations

Stress

$$\{\sigma\} = [C]\{\varepsilon\}$$

$$\sigma_x = \frac{E}{(1+\nu)}\varepsilon_x + \frac{\nu E}{(1+\nu)(1-2\nu)}(\varepsilon_x + \varepsilon_y + \varepsilon_z)$$

$$\sigma_y = \frac{E}{(1+\nu)}\varepsilon_y + \frac{\nu E}{(1+\nu)(1-2\nu)}(\varepsilon_x + \varepsilon_y + \varepsilon_z)$$

$$\sigma_z = \frac{E}{(1+\nu)}\varepsilon_z + \frac{\nu E}{(1+\nu)(1-2\nu)}(\varepsilon_x + \varepsilon_y + \varepsilon_z)$$

$$\tau_{xy} = G\gamma_{xy}$$

$$\tau_{yz} = G\gamma_{yz}$$

$$\tau_{xz} = G\gamma_{xz}$$

Strain

$$\{\varepsilon\} = [S]\{\sigma\}$$

$$\varepsilon_x = \frac{1}{E}\left[\sigma_x - \nu(\sigma_y + \sigma_z)\right]$$

$$\varepsilon_y = \frac{1}{E}\left[\sigma_y - \nu(\sigma_x + \sigma_z)\right]$$

$$\varepsilon_z = \frac{1}{E}\left[\sigma_z - \nu(\sigma_x + \sigma_y)\right]$$

$$\gamma_{xy} = \frac{1}{G}\tau_{xy}$$

$$\gamma_{yz} = \frac{1}{G}\tau_{yz}$$

$$\gamma_{xz} = \frac{1}{G}\tau_{xz}$$

3) Beams in bending (Analytical and Numerical)

$$\sigma = -\frac{My}{I} \text{ and } \sigma_{max} = \frac{Mc}{I}$$

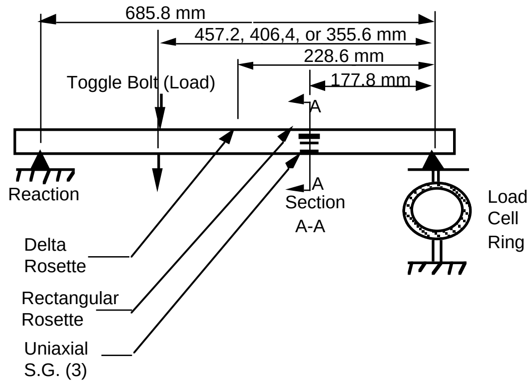


FIGURE 1 - Overall view of Test Specimen Geometry and Setup

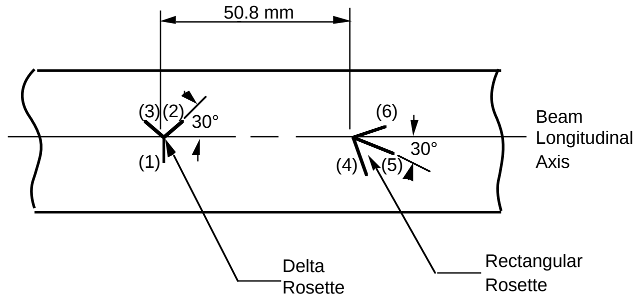
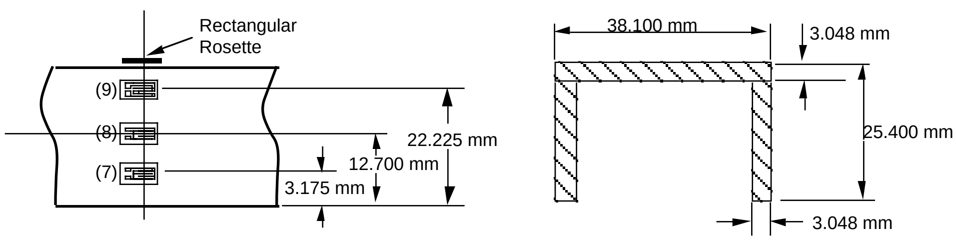


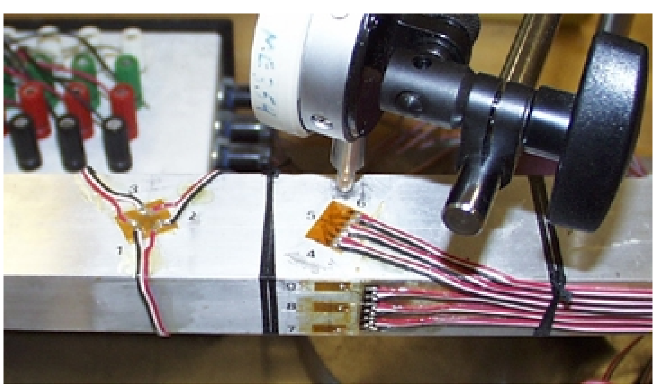
FIGURE 2 - Top View of Specimen Geometry Showing Orientations of 3-Element Strain Gage Rosettes. Note: Strain Gage Channel Numbers are Shown in Parentheses.



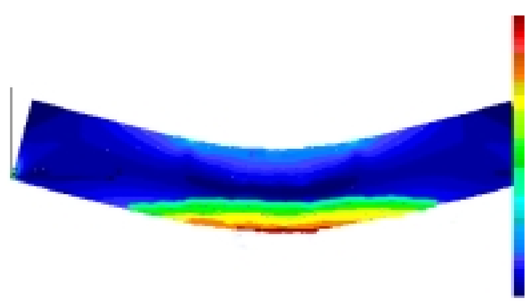
a) Side View of Uniaxial Strain Gage Locations.

b) Cross Section of Beam

FIGURE 3 - Strain Gage Locations and Cross Sectional Dimensions of the Beam. Note: Strain Gage Channel Numbers are Shown in Parentheses.



Actual Experimental Setup



Finite Element Analysis

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STRESSES IN STRAIGHT AND CURVED BEAMS

PURPOSE

The purpose of this exercise is to the study the limitations of conventional beam bending relations applied to curved beams and to use photo elasticity to determine the actual stresses in a curved beam for comparison to analytical and numerical solutions.

ASPECTS OF MECHANICS OF MATERIALS

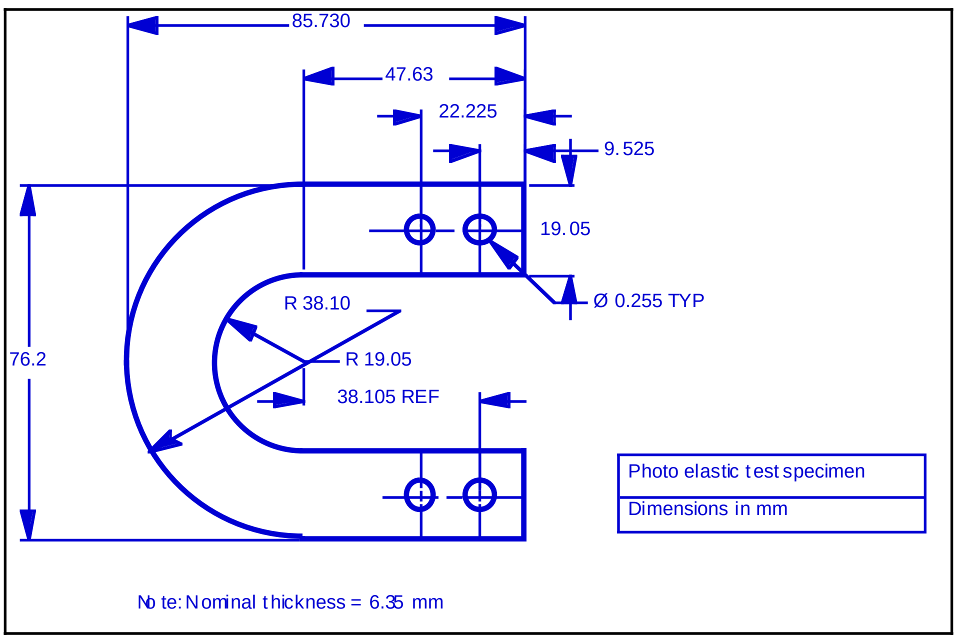
1) Nonlinear strain distribution and therefore nonlinear stress distribution in curved beams in bending

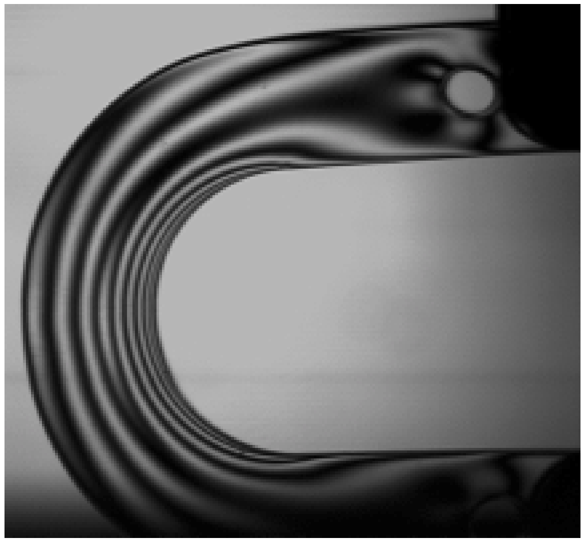
$$\varepsilon_x = -\left(\frac{R_o \varepsilon_o}{r}\right)\frac{y}{h_t}$$

$$\sigma_x = -\left(\frac{R_o \sigma_o}{r}\right)\frac{y}{h_t} = -\frac{My}{(y+\rho)A\bar{y}}$$

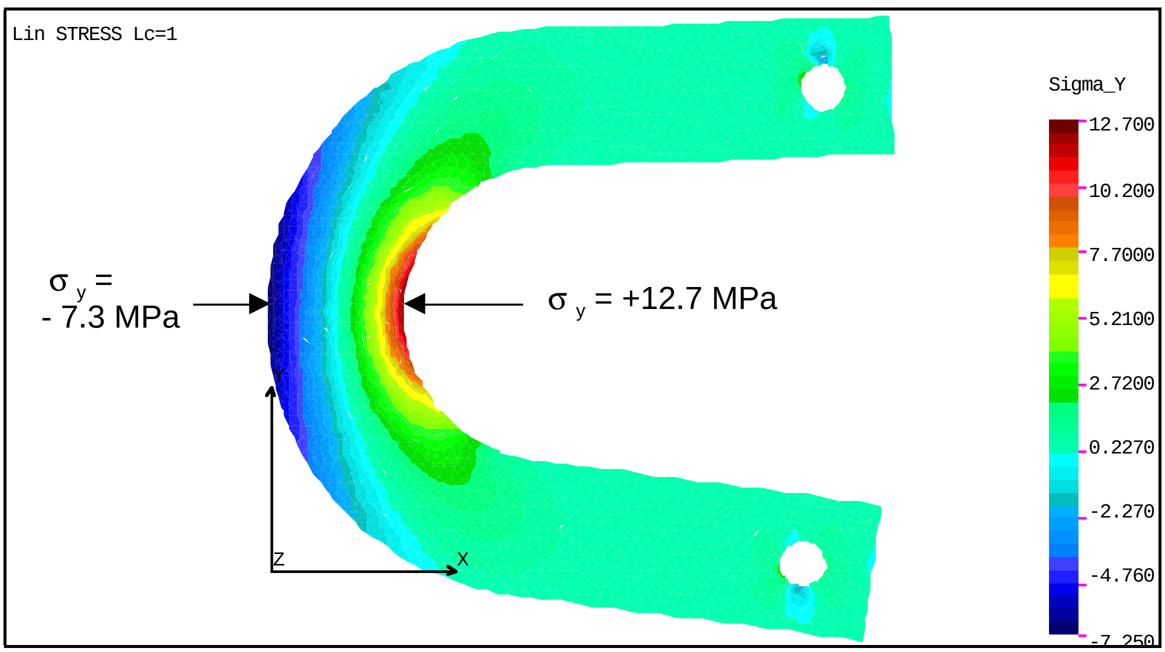
2) Photoelasticity, birefringence and the stress optic law

$$(\sigma_1 - \sigma_2) = f\,\frac{\bar{N}}{t}$$





3) Finite element analysis consistent with analytical and empirical results



ME 354, MECHANICS OF MATERIALS LABORATORY

MECHANICAL PROPERTIES AND PERFORMANCE OF MATERIALS: TENSILE TESTING

PURPOSE

The purpose of this exercise is to obtain a number of experimental results important for the characterization of the mechanical behavior of materials. The tensile test is a fundamental mechanical test for material properties which are used in engineering design, analysis of structures, and materials development.

MECHANICAL PROPERTIES AND PERFORMANCE OF MATERIALS: HARDNESS TESTING

PURPOSE

The purpose of this exercise is to obtain a number of experimental results important for the characterization of the mechanical behavior of materials. The hardness test is a mechanical test for material properties which are used in engineering design, analysis of structures, and materials development.

MECHANICAL PROPERTIES AND PERFORMANCE OF MATERIALS: TORSION TESTING

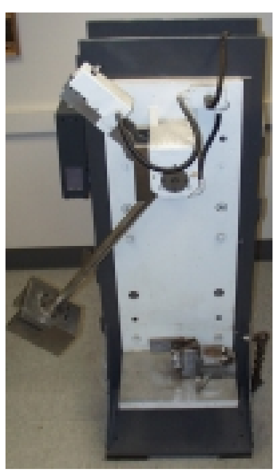
PURPOSE

The purpose of this exercise is to obtain a number of experimental results important for the characterization of materials. In particular, the results from the torsion test will be compared to the results of the engineering tensile test for a particular alloy using the effective stress-effective strain concept.

MECHANICAL PROPERTIES AND PERFORMANCE OF MATERIALS: CHARPY V-NOTCH IMPACT

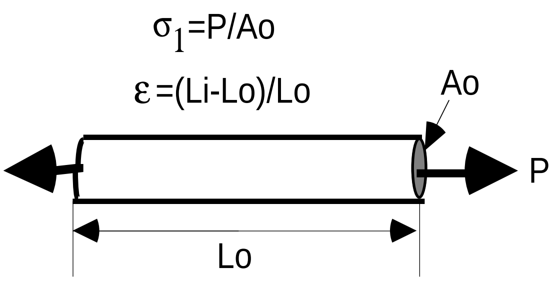
PURPOSE

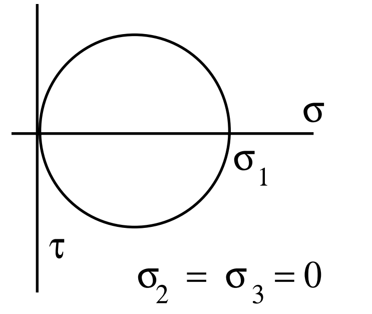
The purpose of this exercise is to obtain a number of experimental results important for the characterization of the mechanical behavior of materials. The Charpy V-notch impact is a mechanical test for determining qualitative results for material properties and performance which are useful in engineering design, analysis of structures, and materials development.



ASPECTS OF MECHANICS OF MATERIALS

1) Uniform, uniaxial stress state used to extract material properties in elastic and plastic ranges (tension)





Mohr's Circle for Uniaxial Tension

2) Localized deformation evaluation resistance to penetration and allows empirical correlation to tensile strengths (hardness).

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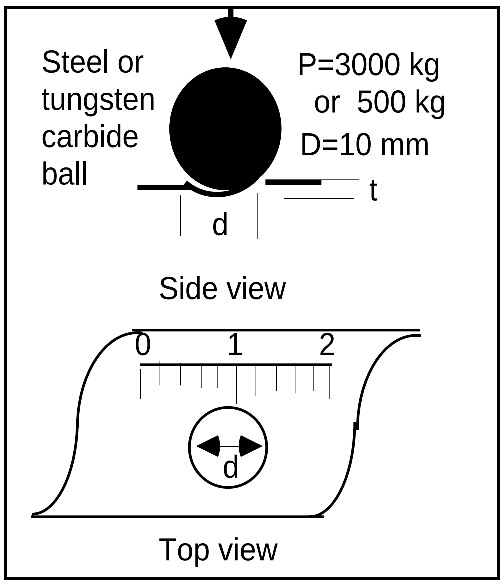
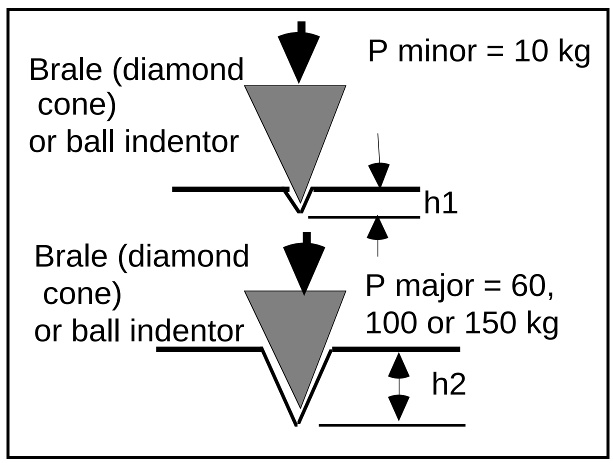


Rockwell



Rockwell Scale (X =)	Indentor	Pmajor (kg)
B	1/16" ball	100
C	Brale (diamond)	150

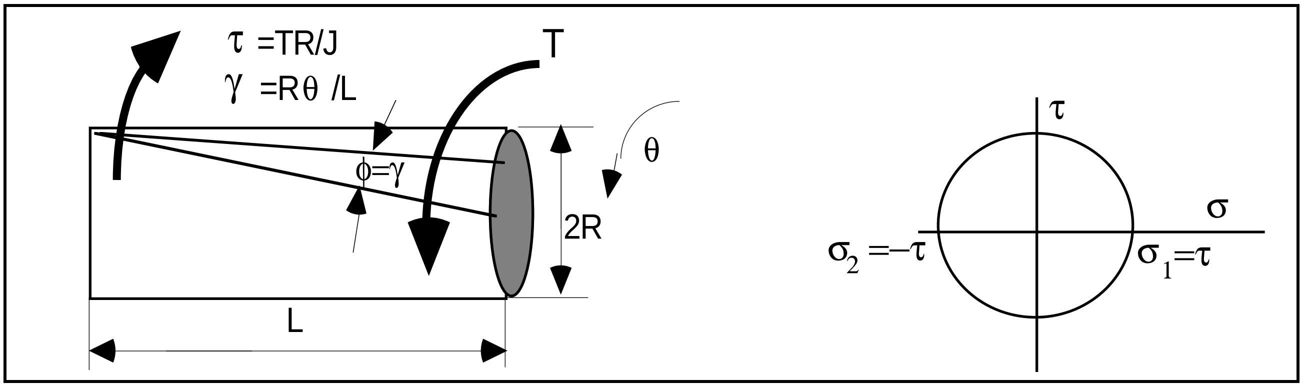
$$BHN = HB = \frac{P}{\pi D t} = \frac{2P}{\pi D\left[D - \sqrt{\left(D^2 - d^2\right)}\right]}$$

$$HRX = R_X = M - \frac{\left(h_2 - h_1\right)}{0.002}$$

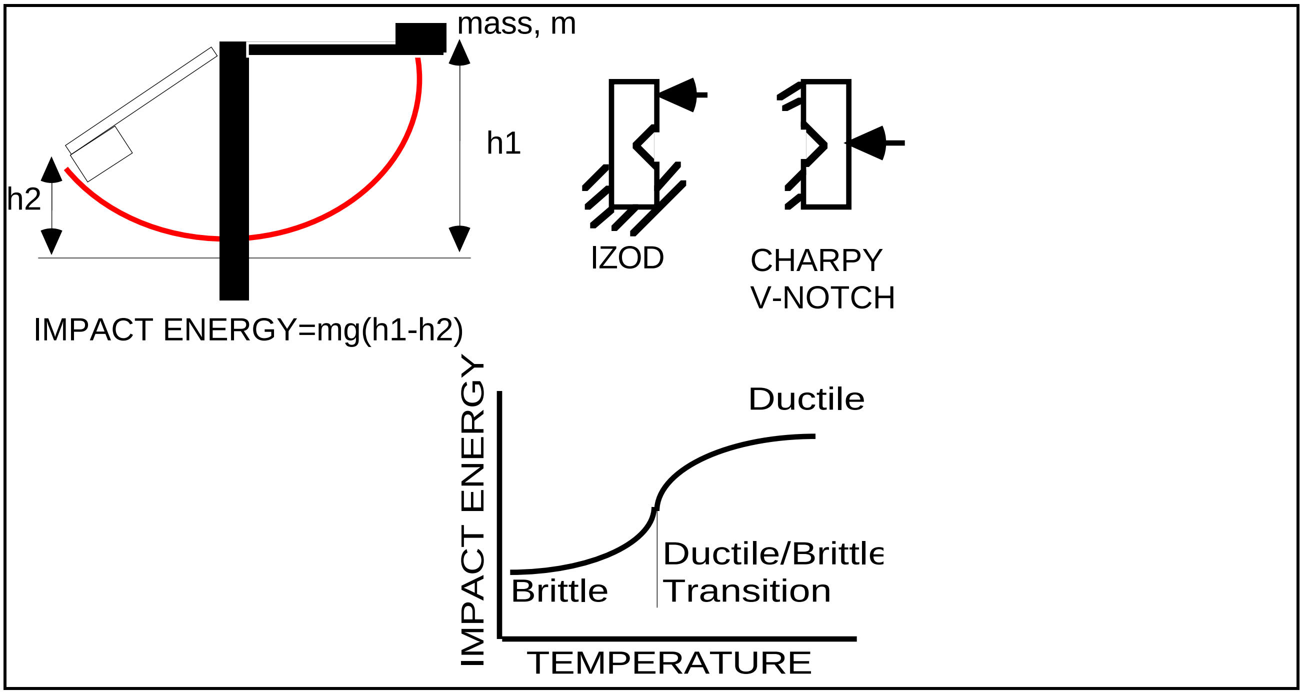
M = 100 for C scale

M = 130 for B scale

3) Non uniform plastic stress state can be analyzed using results from the uniform stress state of the tension test and effective stress-strain relations for plasticity (torsion)



4) Environmental and geometrical effects such as temperature, notches, and loading rate can cause materials to behave much differently than they may in tension tests (impact).



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STRESS CONCENTRATIONS

PURPOSE

The purpose of this exercise is to the study the effects of geometric discontinuities on the stress states in structures and to use photo elasticity to determine the stress concentration factor in a simple structure.

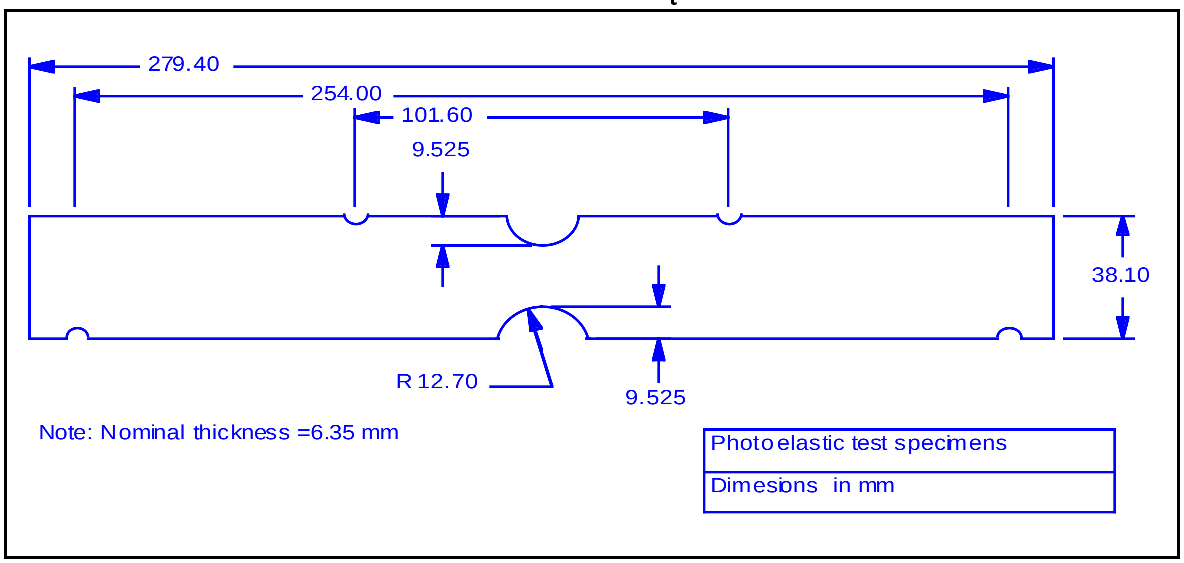
ASPECTS OF MECHANICS OF MATERIALS

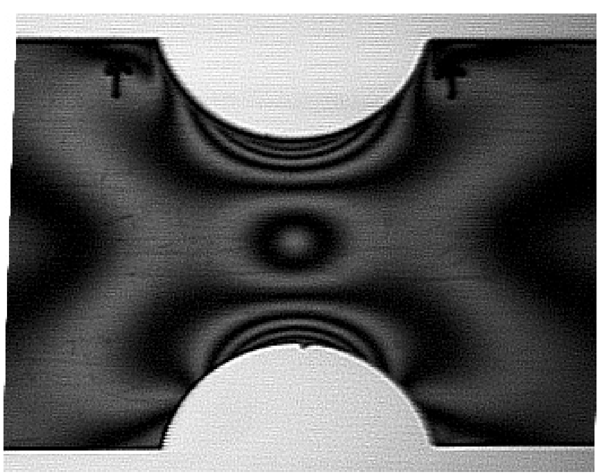
1) Stress concentration factors due to stress raisers in components

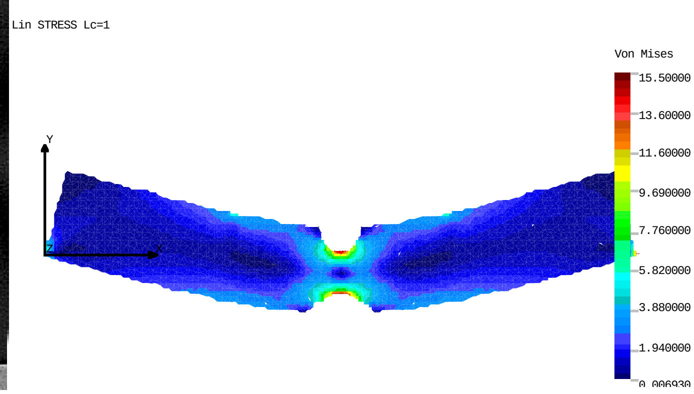
$$k_t = \frac{\sigma_{local}}{\sigma_{remote}}$$

2) Photoelasticity, birefringence and the stress optic law

$$(\sigma_1 - \sigma_2) = f\,\frac{\overline{N}}{t}$$







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FRACTURE

PURPOSE

The purpose of this exercise is to study the effects of cracks in decreasing the load-carrying ability of structures and to determine the plane strain critical stress intensity factor, K_{Ic}, for single-edge notched specimens.

ASPECTS OF MECHANICS OF MATERIALS

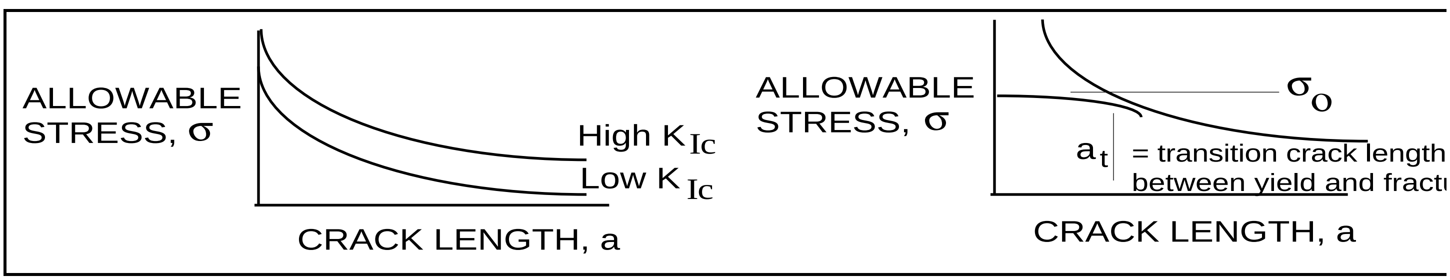
1) Stress intensity factor

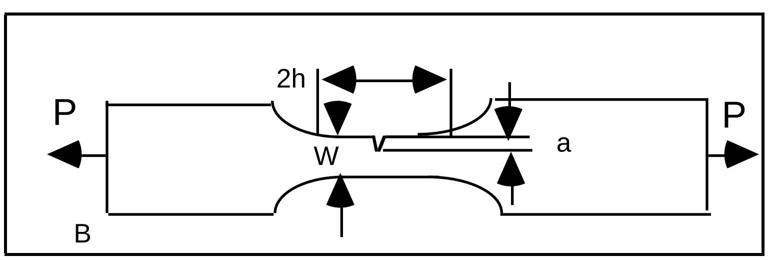
$$K_I = F(\alpha)\sigma\sqrt{\pi a}$$

Fractures if $K_I = K_{Ic}$

2) Fracture toughness and the reduction of the load-carrying capability of structures because of cracks

$$\sigma = \frac{K_{Ic}}{F(\alpha)\sqrt{\pi a}}$$





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COMPRESSION AND BUCKLING

PURPOSE

The purpose of this exercise is to study the effects of end conditions, column length, and material properties on compressive behaviour and buckling in columns.

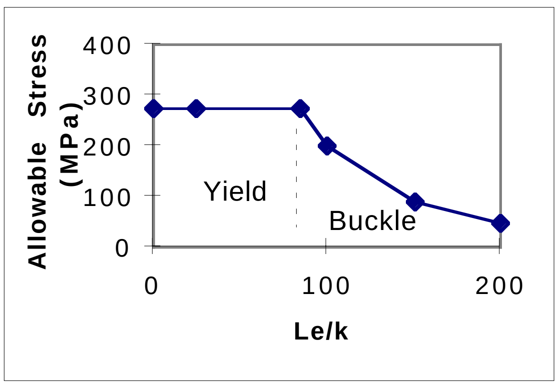
ASPECTS OF MECHANICS OF MATERIALS

1) Geometric instability of buckling in compression

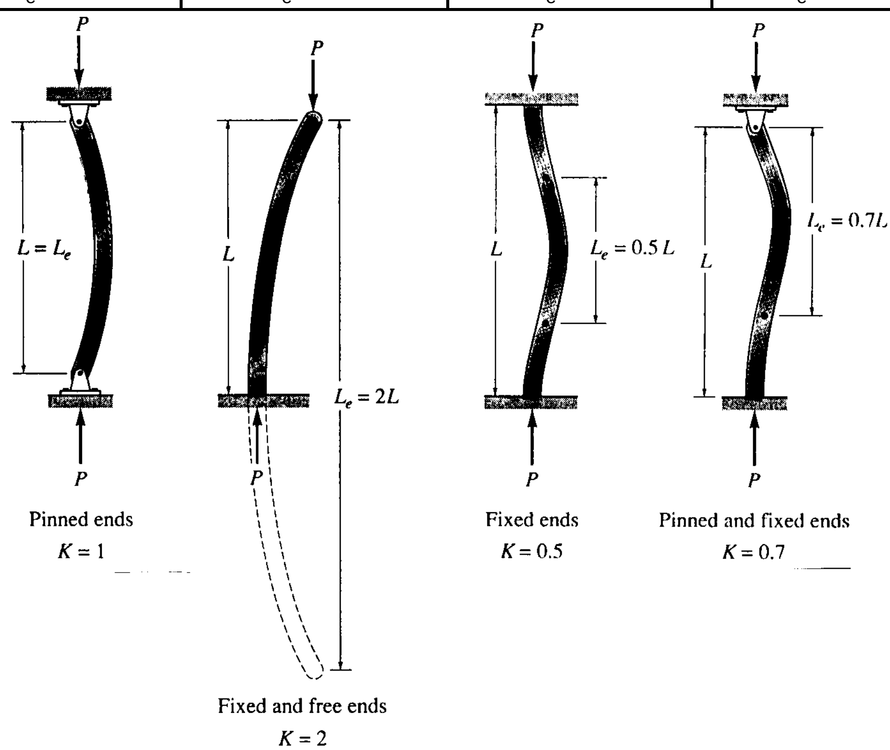
$$\sigma = \sigma_{cr} = \frac{\pi^2 E}{(L_e / k)^2}$$

2) Material yielding in compression

$$\sigma = \sigma_o$$



Pinned/Pinned	Fixed/Free	Fixed/Fixed	Pinned/Fixed
$L_e = L$	$L_e = 2L$	$L_e = L/2$	$L_e = 0.7\ L$



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FATIGUE

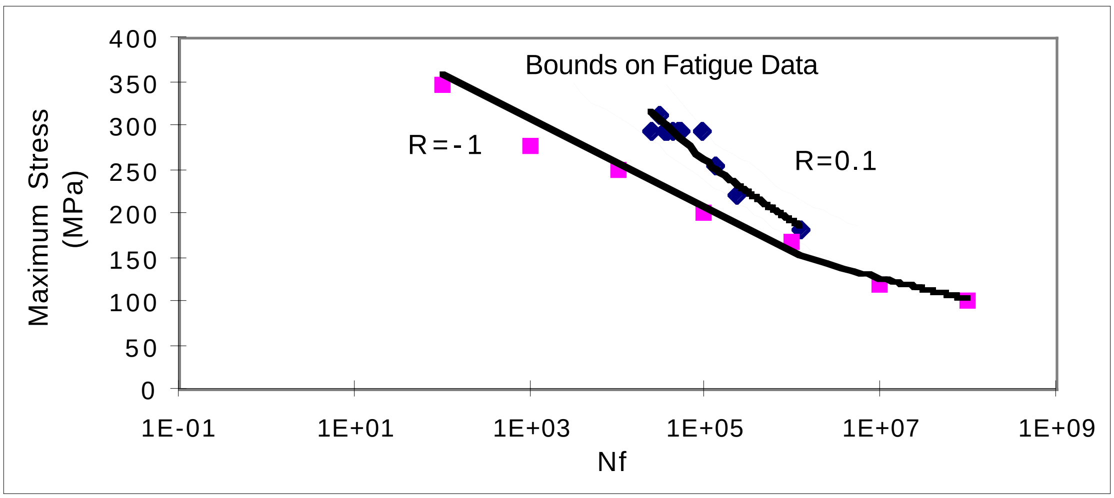
PURPOSE

The purpose of this exercise is to determine the effect of cyclic loads on the long-term behaviour of structures and to determine the fatigue lives (N_f) as functions of uniaxial tensile stress for an aluminum alloy. Axial fatigue tests are used to obtain the fatigue strength of materials where the strains are predominately elastic both upon initial loading and throughout the test.

ASPECTS OF MECHANICS OF MATERIALS

1) S-N curves and the effects of stress ratio, surface finish and maximum stress on time-dependent failure due to fluctuating loads.

2) Variability in fatigue data



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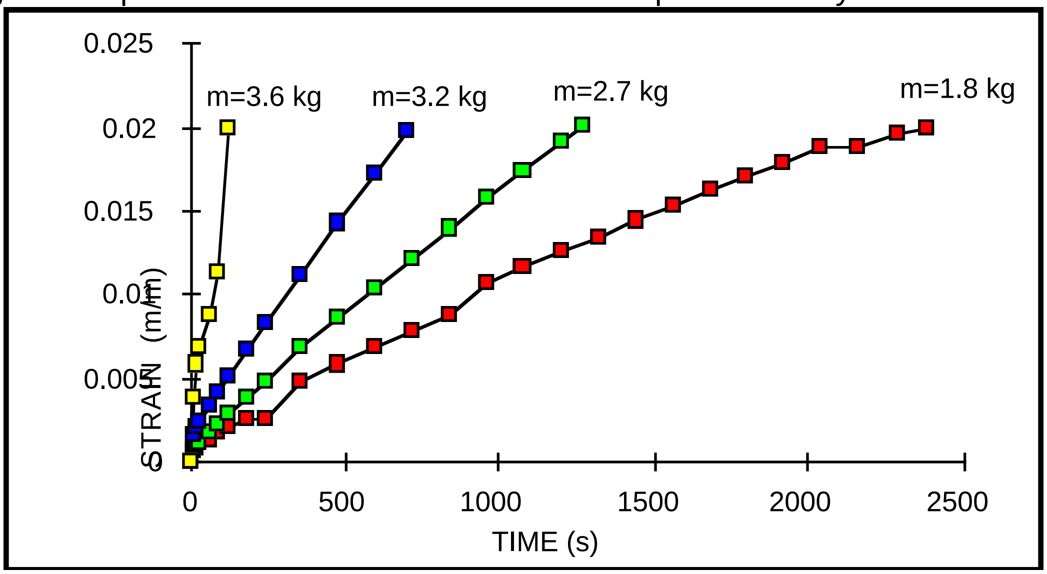
CREEP

PURPOSE

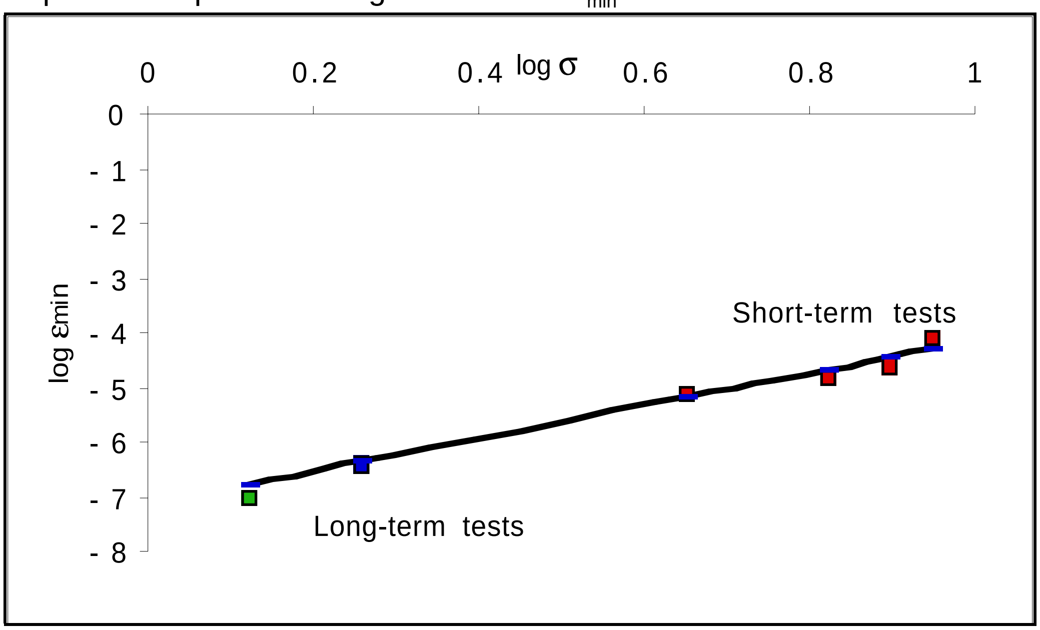
The purpose of this exercise is study the effect of loading on the time-dependent deformation (i.e., creep) and to characterize the room temperature creep behaviour of a soft alloy under various loads. Specifically, short-term creep tests will be used to identify constants in the $\dot{\varepsilon}_{min} = A\sigma^n$ relation. Predictions using these constants will be compared to results measured from long-term creep tests of this same alloy.

ASPECTS OF MECHANICS OF MATERIALS

1) Strain-curves and the effect of applied stress on the time-dependent deformation at a homologous temperature of about 0.5 for this low-temperature alloy



2) Predicting long-term creep behaviour with test results that have creep times much less than the required creep times using the relation $\dot{\varepsilon}_{min} = A\sigma^n$



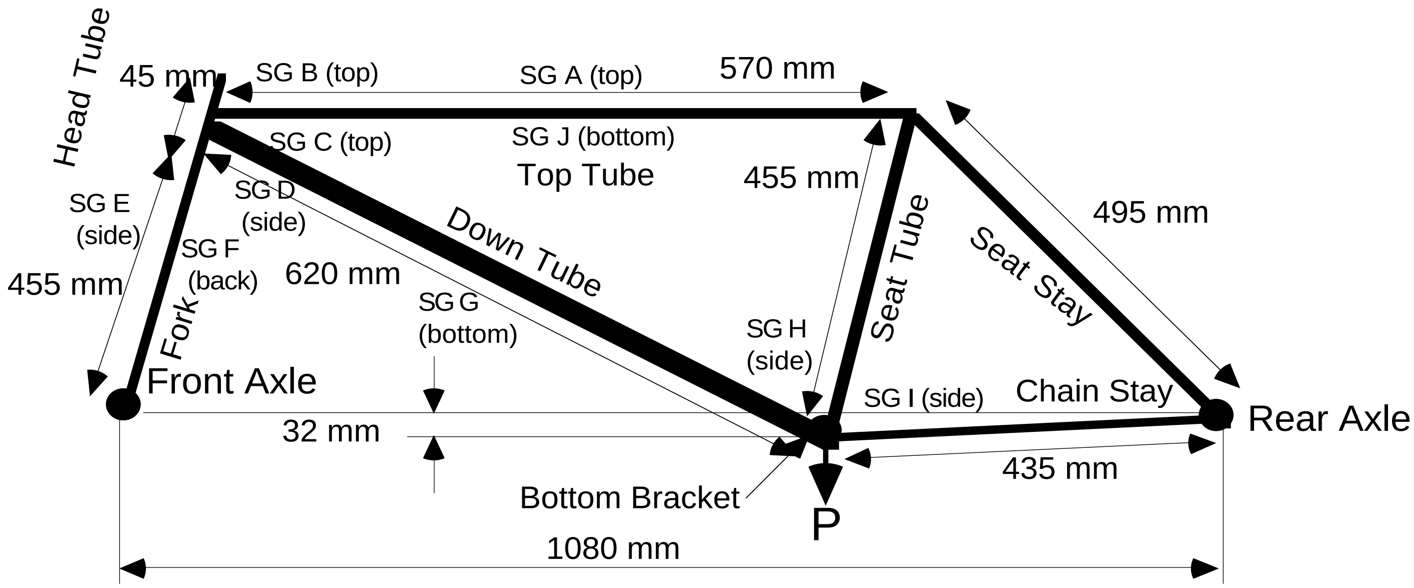
ME 354, MECHANICS OF MATERIALS LABORATORY
STRUCTURES

PURPOSE

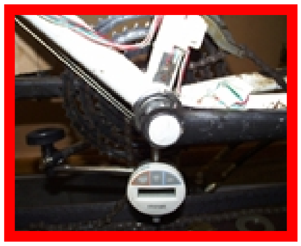
The purpose of this exercise is to the study the effects of various assumptions in analyzing the stresses and loads in an engineering structure.

<u>ASPECTS OF MECHANICS OF MATERIALS</u>

1) Analyzing a complex engineering structure (bicycle frame) using an assumed simple truss analysis



2) Experimentally-measured strains together with stresses calculated from constitutive relations used to evaluate actual stress distributions and loads for comparison to those determined in the truss analysis.



3) Application of a simple interpretation of a virtual work technique to analyze a complex structure

$$\Delta = \sum \frac{N_U N_L L}{EA}$$

4) Use of a finite element analysis (FEA) model to allow analysis of complex structures without the need to oversimplify