Materials Behavior Qualifying Examination

SYLLABUS

Exam Content: (will be based on material covered in the following courses)

ME 330, Engineering Materials
ME 430, Failure Mechanisms in Engineering Materials
ME 431, Failure Analysis of Mechanical Components

Exam Topics:

1. Covered in ME 330:
   - Metals, Polymers, Ceramics, Composites
   - Elasticity - Stiffness
   - Plasticity
   - Monotonic Deformation – Static Strength
   - Cyclic Deformation
   - Fatigue
   - Creep
   - Fracture Mechanics
   - Strength of Materials
   - Oxidation and Wear

2. Covered in ME 430:
   - Crystal Elasticity
   - Crystal Plasticity
   - Yielding
   - Strengthening of Metals
   - Hall-Petch
   - Fracture Toughness

Reference Textbooks:


QUALIFYING EXAMINATION
FOR
Materials Behavior

Department of Mechanical and Industrial Engineering
University of Illinois at Urbana-Champaign

Wednesday, August _____
9:00 AM – 12:00 PM

IMPORTANT EXAMINATION INFORMATION

1. Identify your examination and work with your University Identification Number (UIN, I-Card number in blue beginning with 65) on each page. DO NOT ENTER YOUR NAME ANYWHERE IN THE EXAMINATION.

2. Choose 3 out of the 4 problems.

3. Each problem counts 10 points.

4. Start each problem in a new examination booklet and write on only the right-hand side (front side) of each sheet.

5. Hand in this problem package with your exam booklets.
Problem 1.

i) Sketch a dislocation loop in the form of a circle and specify the Burgers vector of the loop (parallel to the plane of the loop). Based on your choice of Burgers vector, please denote the portions of the loop that are edge and those that are screw. Would you expect dislocation loops generally to be circular in shape? If not, show how the circular loop you have drawn will change its shape. Please discuss and explain your answers. (There are no external stresses acting on the loop).

ii) Consider the crystal shown in the figure under the action of an applied shear stress \( \tau \). Calculate the work done per unit thickness \( h \) by the applied shear stress \( \tau \) if a dislocation is displaced in its slip plane by an amount \( x \). Calculate the corresponding plastic shear strain produced in terms of the dislocation density and any other parameters you may require.

iii) Assuming annealed crystal, calculate the plastic shear strain for an average dislocation displacement of 0.5mm. Please use typical values for the magnitudes of the Burgers vector and dislocation density.
Problem 2

Part I. Briefly define the following concepts:

a) Modes I, II and III
b) Crack-tip singularity
c) Stress intensity factor
d) Strain energy release rate $G$
e) Fracture toughness $K_{IC}$

Part 2: Solve the following problem:

A specimen of 4340 steel alloy with a plane strain fracture toughness of 54.8 MPa (m)$^{1/2}$ is exposed to a stress of 1030 MPa. Will this specimen experience fracture if it is known that the largest surface crack is 0.5 mm long? Why or why not? Assume that the parameter $Y$ has a value of 1.0.
**Problem.**

i) a) Two researchers have simultaneously and independently studied the activation energy for creep of an alloy whose melting point temperature is $T_m = 1000 \, ^\circ\text{K}$. Both used the Arrhenius-type equation

$$
\dot{\epsilon} = Ae^{-\Delta H/RT}
$$

(2)

to plot their data, where $\dot{\epsilon}$ is the steady state (minimum) creep rate, $T$ is the absolute temperature, $\Delta H$ is the activation energy for the creep process, $R$ is the ideal gas constant, and $A$ is a pre-exponential parameter. When their data are plotted in a semilog paper ($\log \dot{\epsilon}$ vs. $1/T$) their results were different. Investigator I concluded for his/her work that one activation energy was controlling the creep behavior of the material. Investigator II, on the other hand, concluded that creep in the alloy was very complex since the activation energy was not constant throughout his/her test range. Which investigator is correct or are they both correct? Please explain your answer thoroughly.

![Graph showing log \( \dot{\epsilon} \) vs. \( 1/T \), with curves denoted Investigator I and Investigator II.]

b) Please describe how each investigator might have determined the activation energies.

ii) Self diffusion in alpha iron is much faster than self diffusion in gamma iron. Under a given applied stress, which creep rate is larger at the transition temperature: in alpha iron or in gamma iron? Note that the transition temperature is greater than half of the melting point temperature.
Problem 4

The basis for crystal plasticity models is shown in Figure below. The picture depicts an fcc single crystal. Explain how many slip systems are active in fcc? What is a Schmid factor? And if multiple systems are active how would you calculate the overall strain rate in the crystal?

Basis for Crystal Plasticity Models

\[ \dot{\gamma}^s = \dot{\gamma}_0 \left( \frac{\tau^s}{\tau^c} \right)^N \]

\( \dot{\gamma}_0 \) = Reference Shear Rate
N = Inverse Rate Sensitivity
s = slip or twin system
\( \tau^c \) = Shear Flow Resistance

fcc case

![Diagram of fcc crystal with slip systems and (111) planes]