SOLUTIONS

UNIVERSITY OF CALIFORNIA
College of Engineering
Department of Materials Science & Engineering

Professor R. Gronsky

Fall Semester 2014

Engineering 45

Midterm 01

This is a 50 minute examination with 4 equally weighted problems.

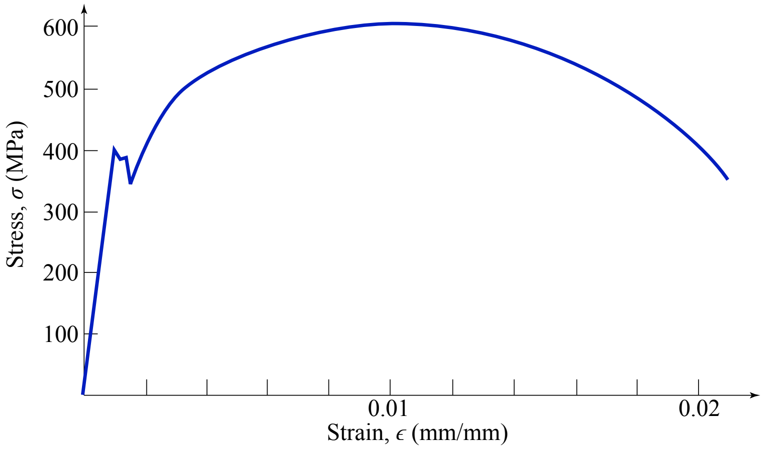
Instructions

WAIT! Do not open these pages until “START” is announced.

While you are waiting please
PRINT your name clearly and legibly at the top of this page,
SILENCE your mobile phones and other electronic devices,
STORE all belongings under your seat and out of sight, and
NOTE the following rules.

ONLY writing instruments / eraser / straightedge are allowed.
Calculators are NOT allowed.
Questions during the exam are NOT allowed.
You ARE held to your Honor Code!

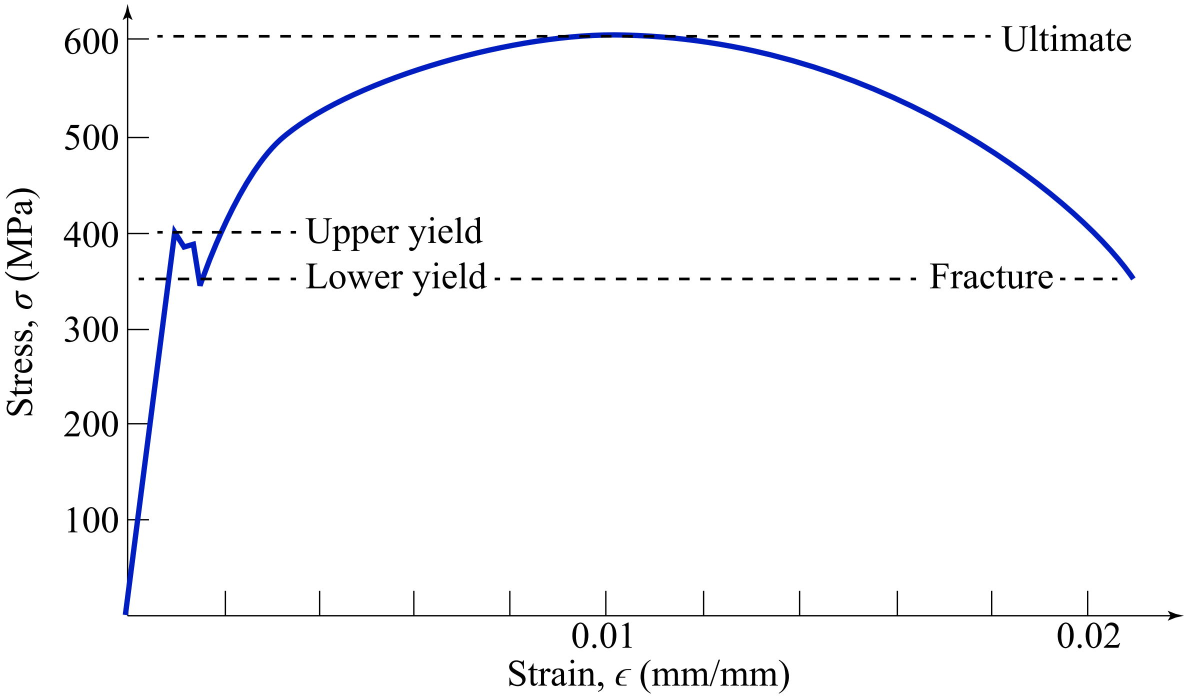
Problem (1)



The media consults you for your engineering expertise about the steel used in the construction of the new Strawberry Creek Bridge, for which the stress-strain curve shown here is provided. The reporter's opening question, motivated by a concern for earthquakes, is a simple one: "How strong is it?" What do you say?

Answer (1)

"There are three (3) answers to your astute question, because strength can be defined in three different ways. Fortunately because of the data provided to us in the stress-strain curve, we can specify all three, and those are the yield strength, the ultimate strength, and the fracture strength. Allow me to explain…



Answer (1) continued

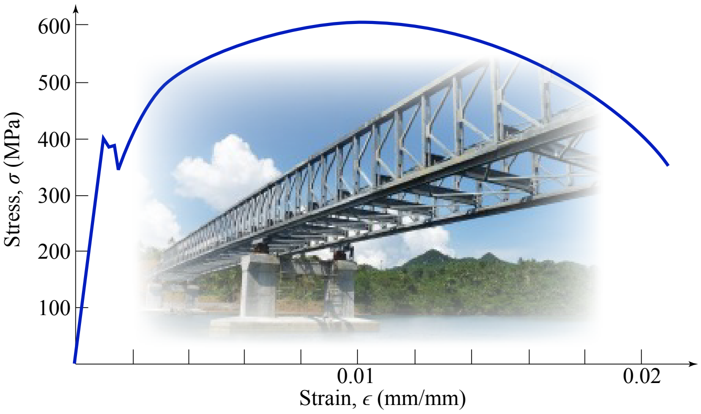
Yield Strength is defined as the value of stress causing a material to deform permanently. Most materials have some elasticity, exhibited by recoverable deformation as a part "snaps back" when load is removed, but if the load is large enough, the part will 'yield' to that load and deform beyond its elastic limit, causing a permanent shape change. Determining the yield strength of a material requires that it be subjected to increasing load in a systematic way, and measuring the extent of deformation induced by that load, watching for the onset of permanent deformation. Data from such studies is gathered and presented as stress (load divided by cross-sectional area) *vs*. strain (change in length per unit length) to eliminate any geometrical dependence. That is what you see in the plot provided. The yield strength is then identified by the transition from linear to non-linear behavior at small values of strain. In the plot this transition is very clear, marked by a downturn with serrations before a smooth curving arc is established at higher loads. This behavior is typical of steel, causing engineers to define both an 'upper yield,' at 400 MPa, and a 'lower yield,' at 350 MPa, the latter being set by the minimum value just before the smooth curve is established. Consequently it can said that the Strawberry Creek Bridge will yield to stresses in the range of 350 to 400 MPa.

Ultimate Strength is defined as the maximum stress carried by a material. Most often it is called the 'ultimate tensile strength,' which is based upon a uniaxial tensile test. The loading condition is not specified in this case, so we can just call it 'ultimate.' Once again our plot is very clear in its depiction of a maximum in the stress-strain curve, which occurs at a stress of 600 PMa. Therefore it can be said that the Strawberry Creek Bridge will stand up to stresses as high as 600 MPa. To be clear, the bridge will be permanently deformed under this stress, which could cause other problems, but the steel components will survive.

And finally, there is **Fracture Strength**, the stress that causes complete failure of the bridge at the end of its load-bearing life. This stress is read at the end of the curve, corresponding to a value of 350 MPa, and is the result of cumulative damage to the steel induced by having borne up to 600 MPa earlier in its lifetime, with continued loading beyond that. Provided all of its fasteners remain intact (sometimes a very big assumption), the steel in the Strawberry Creek Bridge can therefore be expected to survive an earthquake inducing stresses not exceeding 350 MPa in a single event. It will be up to municipal authorities and traffic control to ensure safety (number of vehicles on the bridge at any one time) under these constraints.

Hello? Ms. Reporter? Are you still there…?"

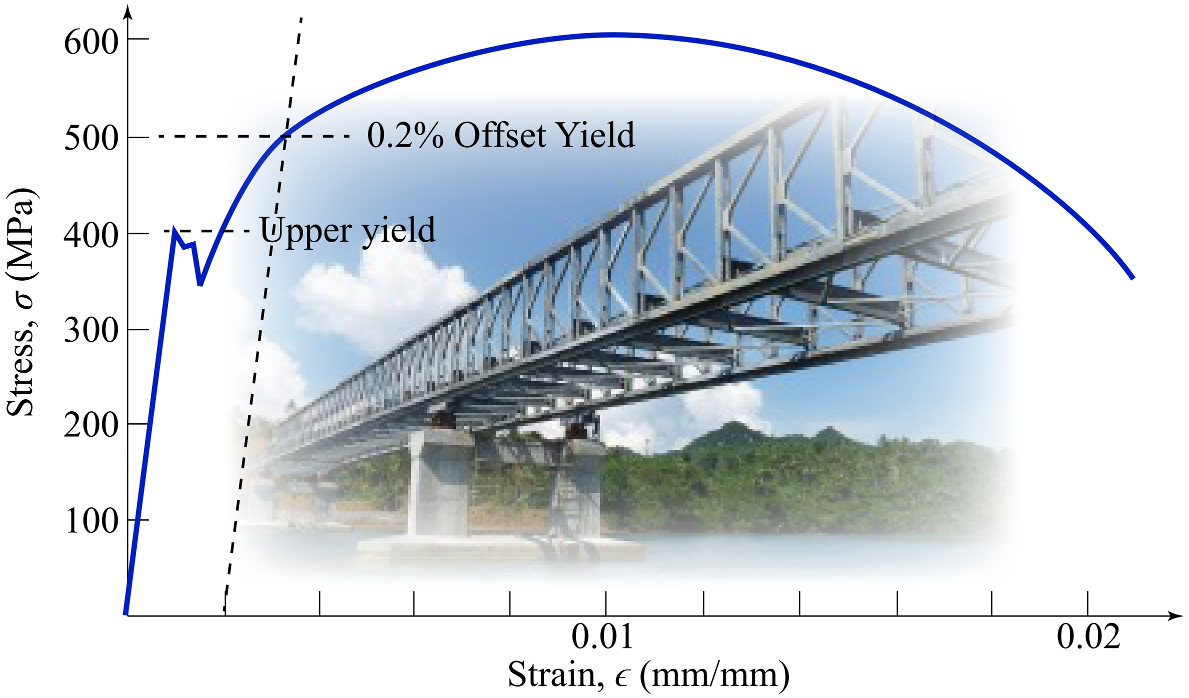
Problem (2)



During a televised news conference on the day the Strawberry Creek Bridge opened, a representative of the bridge builder, Crooked Creek Construction Company, stood before a poster incorporating the same stress-strain plot, and proclaimed: "We chose the toughest possible steel for this project. It is 100 MPa stronger than anything used before, as the 0.2% offset method demonstrates." None in attendance are able to interpret this claim, but a reporter recognizes you as an engineer, and passes the microphone to you for an explanation. What do you say?

Answer (2)

"Please allow me to approach this beautiful poster so I can illustrate the claim being made by our representative here, who, with all due respect, is patently wrong."



Answer (2) continued

The ‘0.2% Offset Method’ is specified by the American Society for Testing of Materials as a way to determine yield strength when the transition from linear to non-linear behavior at small values of strain is not sharply defined. It is executed by locating 0.2% or 0.002 on the strain axis, then constructing a line parallel to the initial linear portion of the curve, and noting where it intersects the curve. That intersection established the ‘yield stress’ by the 0.2% offset method. Here you can see that the value is 500 MPa. But there is no reason to use the 0.2% offset method in this case because the transition from linear to non-linear behavior is so clear, as is usually the case for construction-grade steels.

On the plot shown here, the transition occurs at a value of 400 MPa (known as the ‘upper yield point’). So, our representative’s claim that this steel is ‘100 MPa stronger than anything used before’ is true because, by this inappropriate definition, it is even 100 MPa stronger than ITSELF!!

But there is another error looming here: our representative’s original statement about choosing the ‘toughest possible steel for this project.’ Toughness is an attribute describing the ability of a material to absorb energy during deformation. It is not measured in units of ‘strength,” because strength alone is not an indication of toughness. Ductility also matters, with high strength and high ductility yielding the toughest materials for energy-absorbing applications, such as during seismic events. It doesn’t surprise me that our representative, who clearly doesn’t understand ‘strength’ would also have a poor understanding of ‘toughness.’ But perhaps our representative has something to say in his defense…

By the way Mr. Representative, is that a Stanford tie you’re wearing?”

Problem (3)

Anyone interested in "metallic bonding" might consult Wikipedia < http://en.wikipedia.org/wiki/Metallic_bonding > for enlightenment. Here are the opening two sentences.

> "Metallic bonding occurs as a result of electromagnetism and describes the electrostatic attractive force that occurs between conduction electrons (in the form of an electron cloud of delocalized electrons) and positively charged metal ions. It may be described as the sharing of free electrons among a lattice of positively charged ions (cations)."

What do you say?

Answer (3)

"Call the Wiki Police!"

The accepted model of metallic bonding is a state of cohesion induced by long-range sharing of outer shell electrons across many atoms. These bonding electrons comprise a "sea" or "cloud" of negative charge within which the atomic nuclei are sustained in a bound configuration. Consequently metallic bonds are non-directional, giving metals their observed ductility. In a quantum-mechanical description, the wavefunctions attributed to the bonding electrons in a metal are said to be "delocalized," spread across many atoms, to stand in contrast with the covalent bond, where the bonding electrons are sharply "localized" between bonded atoms. This makes covalent bonds much more directional; the direction of orbital overlap determining the orientation(s) of the bond. Finally, the ionic bond is the only bond formed between ions. Positively-charged cations are bonded to negatively-charged anions by an electrostatic (Coulombic) interaction, which makes ionic bonds non-directional too.

Now to the errors in Wikipedia…

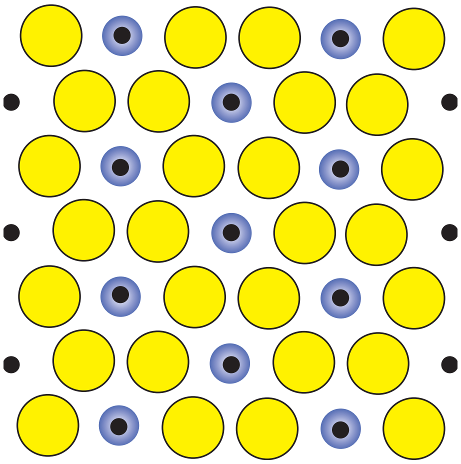
"Metallic bonding occurs as a result of electromagnetism" is WRONG because there are no magnetic interactions involved in such a bond.

"Electrostatic attractive force that occurs between conduction electrons (in the form of an electron cloud of delocalized electrons) and positively charged metal ions" is WRONG because there are no ionic species in metals.

"Sharing of free electrons among a lattice of positively charged ions (cations)" is WRONG because again there are no cations in a metal, and because metallic bonds exist whether or not atoms sit in their assigned lattice locations. This is why metallic bonding survives extensive plastic deformation.

Problem (4)

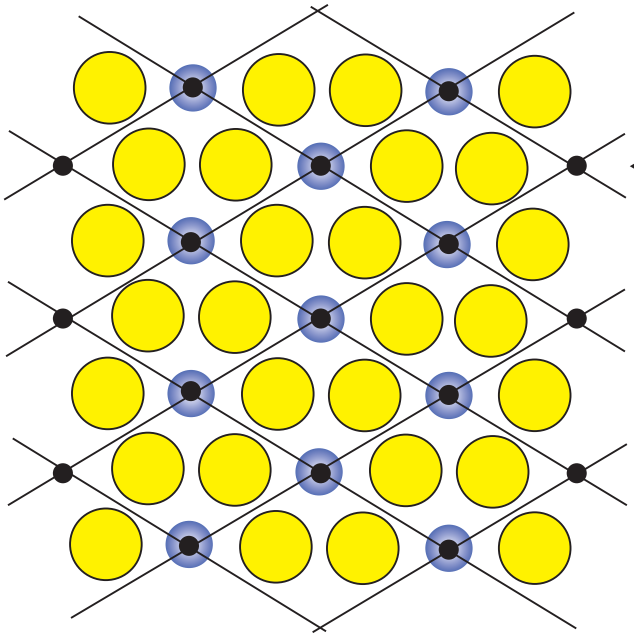
Consider the following two different assignments (option [**a**] and option [**b**]) of a "lattice" shown by large dots (●) to define the projected ion positions in a crystal structure comprised of a divalent cation and a monovalent anion. For both cases, specify the appropriate "motif" corresponding to the choice of lattice, sketch a primitive unit cell, and specify the contents of your chosen primitive cell to assess which option is the correct assignment. Explain your choice.

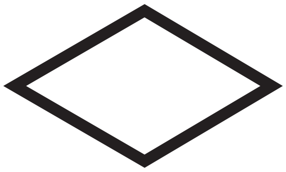


Option [**a**]

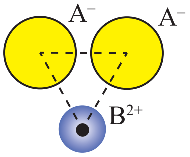
Answer (4)

For option [**a**], the divalent cation is labeled here as B^{2+}, and the monovalent anion as A^-, distributed as they appear in the motif associated with each and every point (•) of the lattice. The primitive unit cell is identified, and its tiling pattern is shown to indicate how it fills space with no gaps and no overlaps. Each unit cell contains one cation and two anions, preserving charge neutrality, as is required of a proper unit cell.



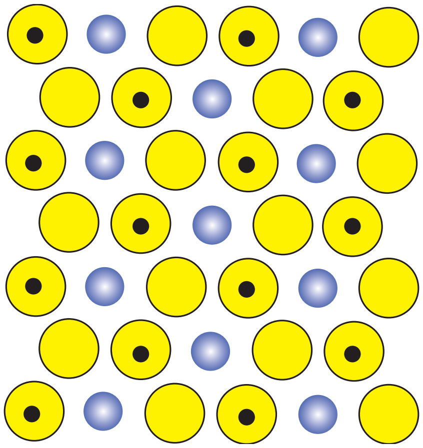


Primitive Unit Cell



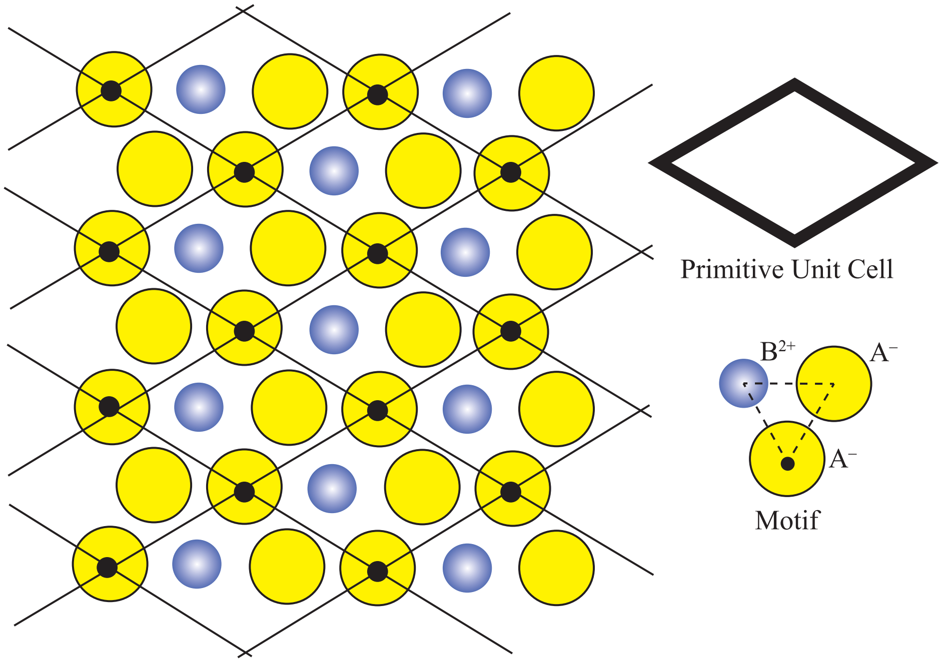
Motif

Answer (4) continued



Option [**b**]

For option [**b**], the divalent cation is again labeled as B^{2+}, and the monovalent anion as A^-, distributed as they appear in the motif associated with each and every point (•) of the lattice. The primitive unit cell is identified, and its tiling pattern is shown to indicate how it fills space with no gaps and no overlaps. Each unit cell contains one cation and two anions, preserving charge neutrality, as is required of a proper unit cell.



Regarding the "correct" assignment, BOTH are correct. Despite the translation of the lattice from option [**a**] to option [**b**], a new motif assigned to each lattice point restores the chemical balance for this ionic compound, which would be written as A_2B.