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

Spring Semester 2006
Professor R. Gronsky
MSE 121

Name (*Please Print*)

Final Examination

Instructions

Please print your name above and initial all pages in case they are separated.

Solutions must be written neatly and concisely in the spaces provided.

This is an open-book exam.

Guidelines

Be aware of multi-part problems; answer, and label your answers to, all questions posed.

Show all of your work for partial credit, as appropriate.

There are five (5) problems worth 60 points each.

Problem 1: Solidification Processing

The equilibrium phase diagram of the binary Ni-Ti system reveals a very deep eutectic at T_E = 943°C relative to the melting temperatures of elemental Ni (T_M = 1455°C) and elemental Ti (T_M = 1672°C), with a nearby peritectic at 985°C. Consequently Ni-Ti system presents some challenges to the processing engineer attempting to produce a shape casting for service in elevated temperature applications.

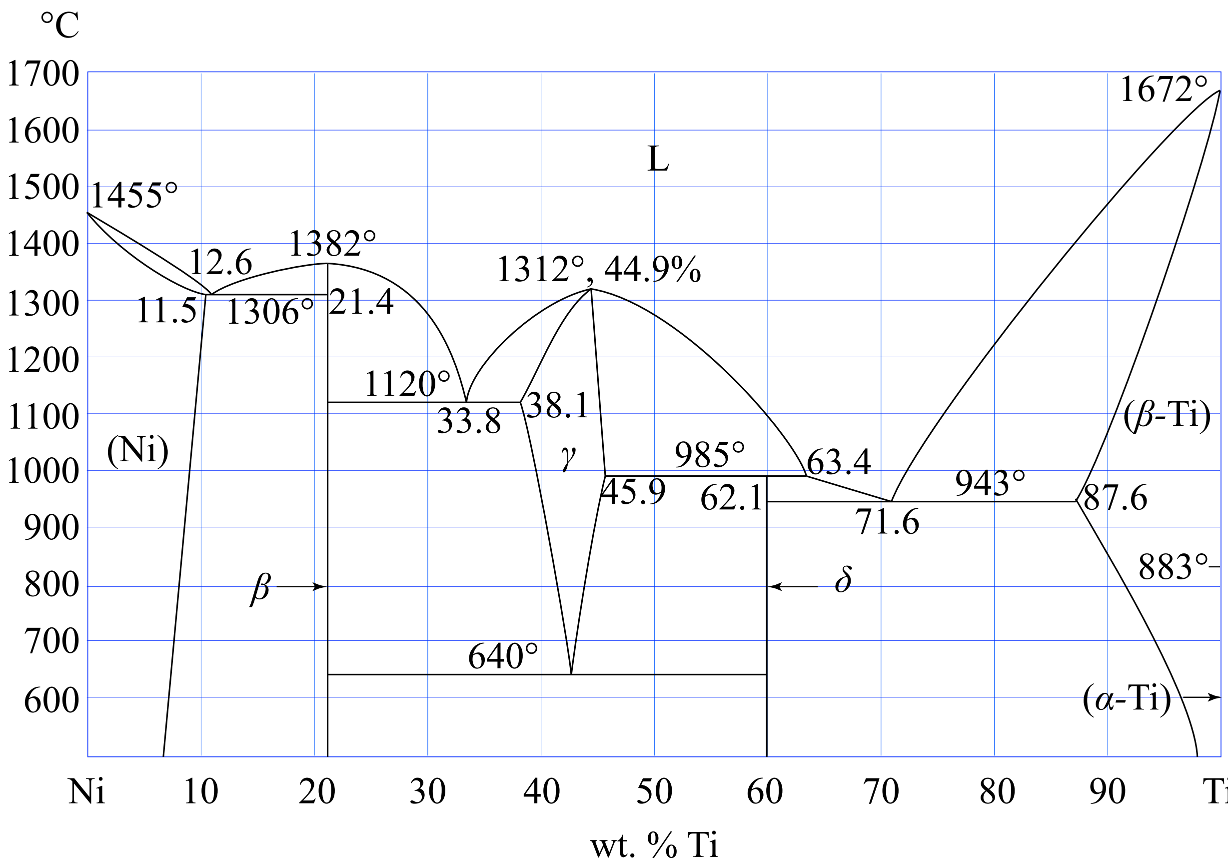


Figure 1-1 The Equilibrium Nickel-Titanium Phase Diagram, from the *Metals Handbook*, Volume **8**, 8th Edition, American Society for Metals, Metals Park, Ohio, (1973), p. 326.

Notes: The equilibrium β phase is stoichiometric Ni_3Ti, with an ordered hexagonal crystal structure having *Strukturbericht* designation $D0_{24}$. The equilibrium γ phase has NiTi stoichiometry and a $B2$ (CsCl-type) structure, while the equilibrium δ phase is $NiTi_2$, with the $E9_3$ structure, described by a face-centered cubic Bravais lattice and 112 atoms per unit cell, belonging to the $Fd3m$ space group. Equiatomic NiTi (pure γ phase) can be processed to exhibit "shape-memory" behavior. It is sometimes called by the trademarked name Nitinol™.

Problem 1(a)

20 points

Describe the equilibrium solidification process for a Ni-50 wt.% Ti alloy, beginning with liquid at 1300°C, and cooling to room temperature. Sketch and label representative micrographs in the frames below, showing the evolution of the microstructure throughout the cooling process at each of the temperatures indicated at bottom right of the figures. Clearly label and describe the microconstitutents and their morphologies in the space at right.

T = 1100°C

T = 700°C

T = 25°C

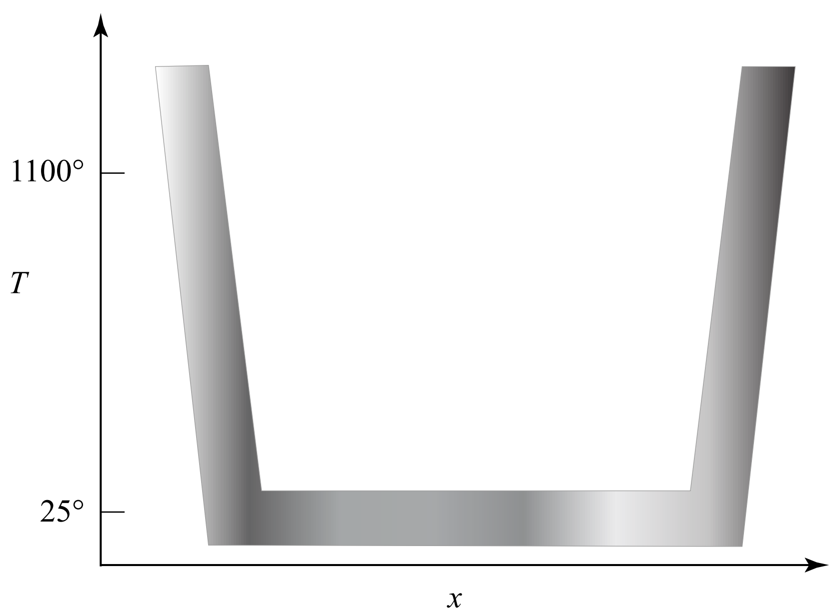
Problem 1(b)
20 points

Recall that the heat flux through the mold of a casting is given by the well-known partial differential equation

$$\vec{J} = -k_m \frac{\partial T}{\partial x}$$

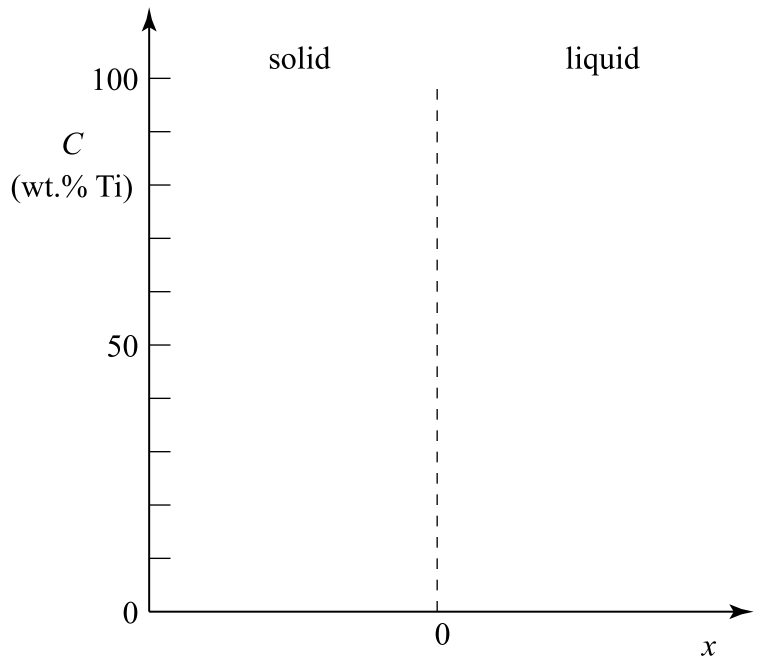
where k_m is the thermal conductivity of the mold.

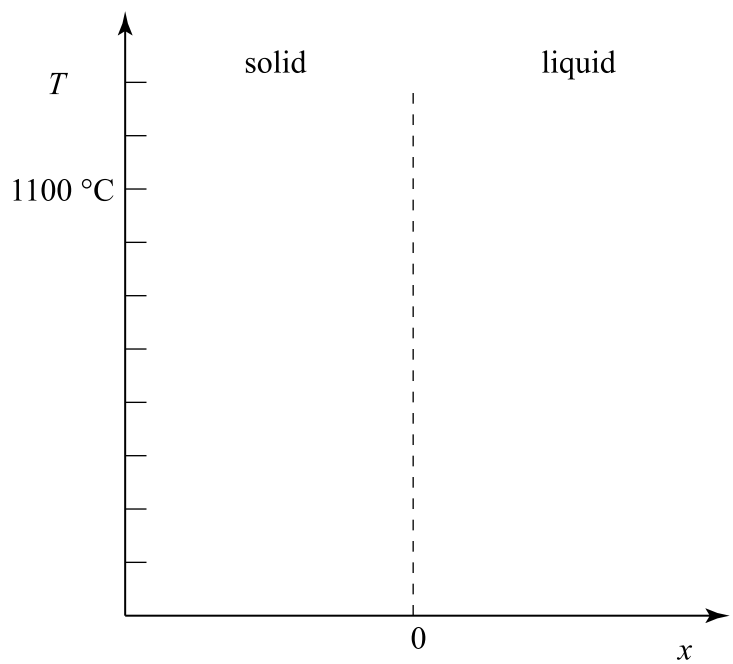
In the space below, sketch a cross-section through an open-top mold of a Ni-50 wt.% Ti alloy casting, identifying the location of both the solid phase(s) and the liquid phase when the alloy reaches 1100°C. Let x be the spatial parameter through the mold and casting as shown below. Now plot directly on your sketch the temperature profile across the mold, solid phase(s) and liquid phase during an actual (non-equilibrium) solidification reaction.



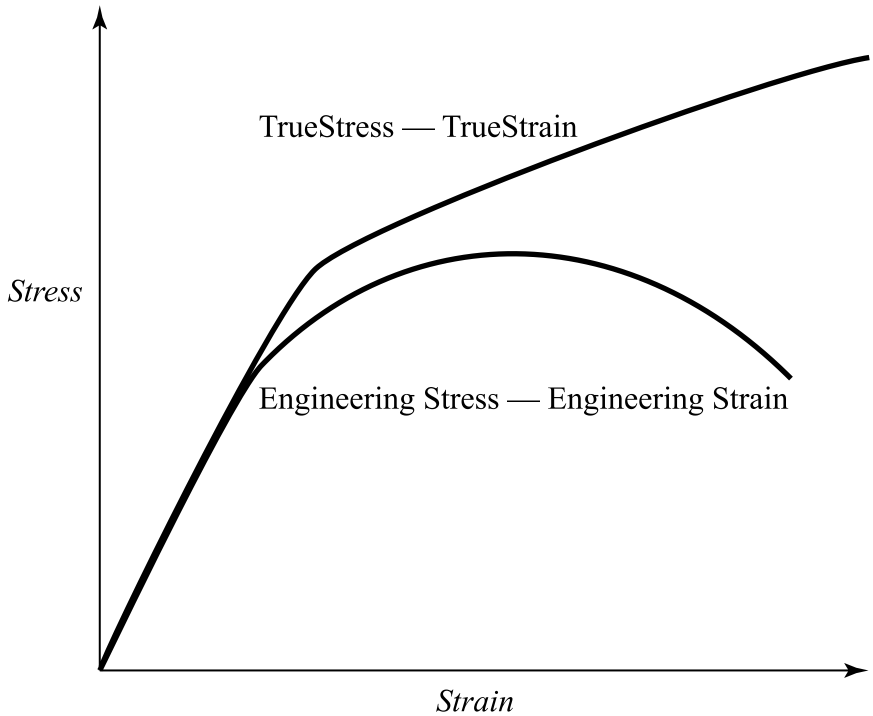
Problem 1(c)
20 points

For this same (Ni-50 wt.% Ti) alloy, construct composition vs distance plots across the solid-liquid interface corresponding to an alloy at 1100°C in order to illustrate the phenomenon of constitutional supercooling. Explain your constructions in detail and clearly label the supercooled region. Is there a "mushy zone" associated with this solidification event shown on your drawing above? Why or why not? Is constitutional supercooling evident in your sketch from part (b) above? Explain.





Problem 2: Deformation Processing



Problem 2(a)
20 points

The elastic behavior of metallic alloys is described by Hooke's Law

$$\sigma = Ee$$

while the plastic behavior is described by the Holloman Equation

$$\sigma_t = K\varepsilon^n \text{ .}$$

Explain in detail the differences between these two expressions. What are the variables, and how are they determined? Do both of these expressions relate to deformation processing? Why or why not?

Problem 2 (b)
20 points

The bulk deformation processes are generally classified into four categories: forging, extrusion, drawing, and rolling. Briefly describe and differentiate each of these processes.

Forging --

Extrusion --

Drawing --

Rolling --

Why is it that final flow stress is used to calculate the load applied during forging, but a mean flow stress is used to calculate the load during extrusion, drawing, and rolling? Be specific.

Problem 2(c)
20 points

Sheet forming processes are widely used throughout the metals processing industries, yet exact mathematical solutions exist for only the simplest of sheet forming operations. One reason for this problem is plastic anisotropy. During sheet forming, the strains along the width of the sheet compared to the strains through the thickness of the sheet determine the plastic anisotropic ratio (r).

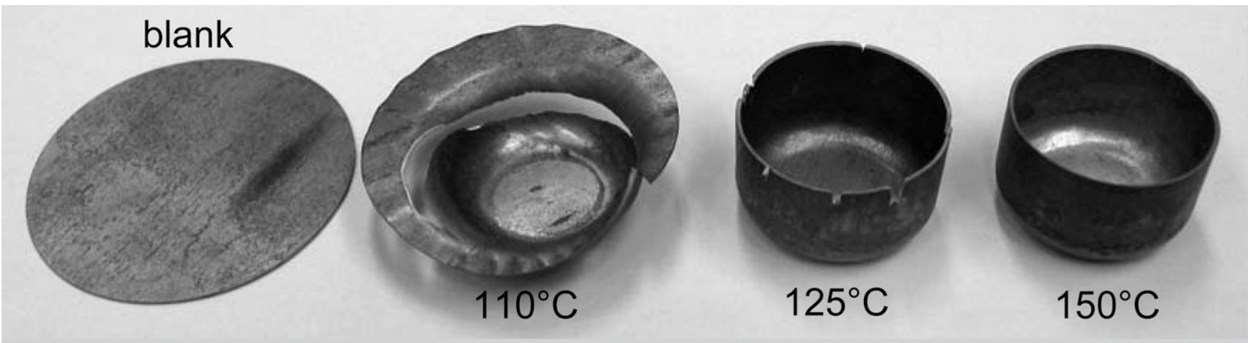
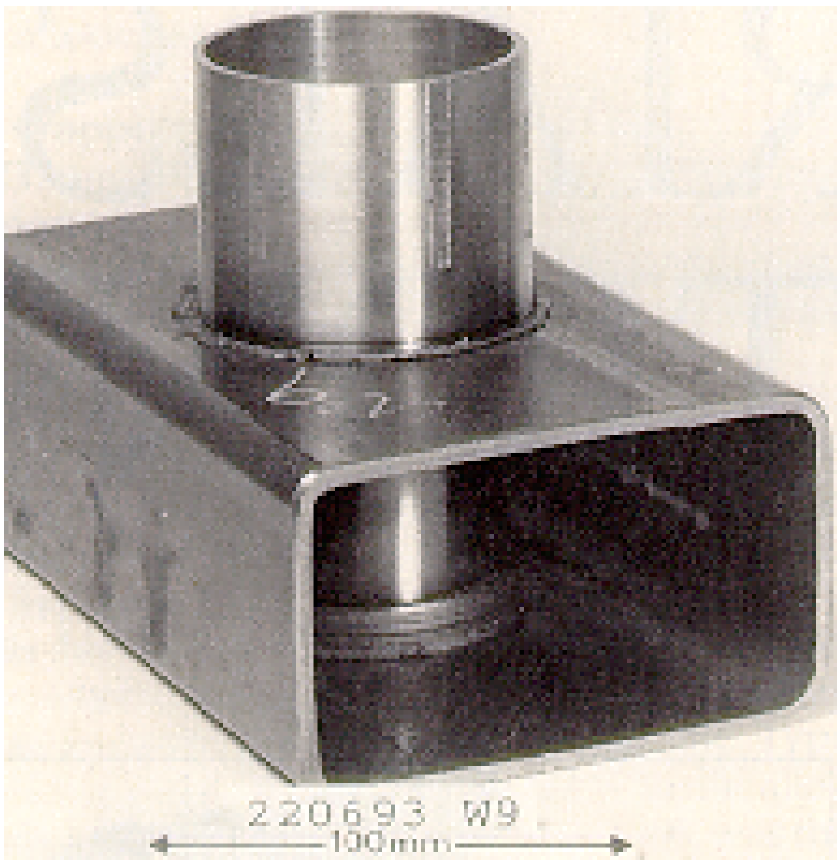


Figure 2-1 Results of deep drawing a Mg-3 wt.% Al 1 wt.% Zn alloy as a function of temperature. From S.R. Agnew, J.W. Senn, and J.A. Horton, *Journal of Metals*, May 2006, p. 62.

Magnesium alloys are especially prone to difficulties during sheet forming operations at room temperature, but their formability at moderately elevated temperatures can be vastly improved, as evident in Figure 2-1. Explain, citing the effect of r.

Problem 3: Metals Joining Processes

The major metals joining methods include soldering, brazing, and welding. Welding comes in two sub categories: fusion welding and solid state welding. Solid state welding includes pressure welding and friction-stir welding.



Problem 3(a)
20 points

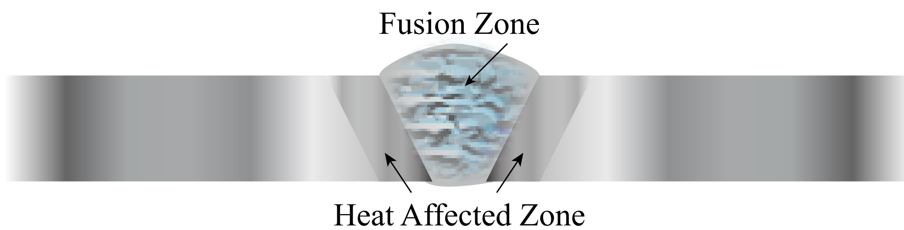
In all electric arc welding processes, some provision must be made to protect the weld zone from the surrounding atmosphere, in order to avoid rapid oxidation. Explain how this is done for two different methods: manual shielded metal arc (SMA) welding with heavy coated electrodes and metal inert gas (MIG) arc welding. Be specific.

SMA --

MIG --

Problem 3 (b)
20 points

This schematic of a butt weld in a type 304 (18% Cr, 8% Ni) stainless steel workpiece indicates the relative locations of the fusion zone and heat affected zone with reference to the base alloy.



Explain the meaning of the heat affected zone, citing specifically the changes in microstructure that distinguishes it from the fusion zone and the base alloy. Be specific for this case of a stainless steel.

Problem 3(c)

20 points

Alloys of aluminum can be soldered, and one of the most popular solders for this application has a composition of 91% Sn and 9% Al, with a liquidus / solidus very near to 200°C. Rationalize this composition, citing both the definition of soldering and susceptibility to galvanic corrosion. Why for example is microelectronic solder (63 Sn – 37 Pb) not used?

Noble (cathodic)	Platinum
	18-8 Stainless Steel
	Nickel
	Silver solder
	Bronze
	Copper
	Brass
	Tin
	Lead
	Lead-Tin solder
	Cast iron
	Steel
	2024 aluminum alloy
	Cadmium
	Commercially pure aluminum
Active (anodic)	Zinc

Table 3-1 The Galvanic Series in Seawater, from Fontana, M.G. and Greene, N.D., *Corrosion Engineering*, John Wiley & Sons, New York (1978).

Problem 4: Shape Forming

Industrial deformation processes are generally divided into two categories, bulk forming, which affects the entire volume of the workpiece, and sheet forming, which is much more localized, generally to a change in sheet thickness.

Problem 4(a)
20 points

During forming operations, lubricants are often used to protect surfaces from wear, to protect surfaces from environmental attack, and to extract heat. Compare and contrast hydrodynamic lubrication with boundary lubrication in meeting these goals.

Hydrodynamic --

Boundary --

Problem 4(b)

20 points

During powder metallurgical processing, the plastic response of metal powders results in good green compact strength. An important consequence of this plastic behavior is an increase in density, which can be approximated using the following expression.

$$D_y = \left(\frac{1 - D_0}{1.3\sigma_f} + D_0^3\right)^{\frac{1}{3}}$$

where D_y is the density induced by yielding, D_0 is the degree of densification (ratio of uncompacted powder density to compacted powder density), and σ_f is the flow stress at the pressing temperature.

Would you expect this parameter (D_y) to be greater as a result of hot isostatic pressing (HIP) or cold isostatic pressing (CIP)? Explain. Note that D_y is not the same as the density of the final sintered product.

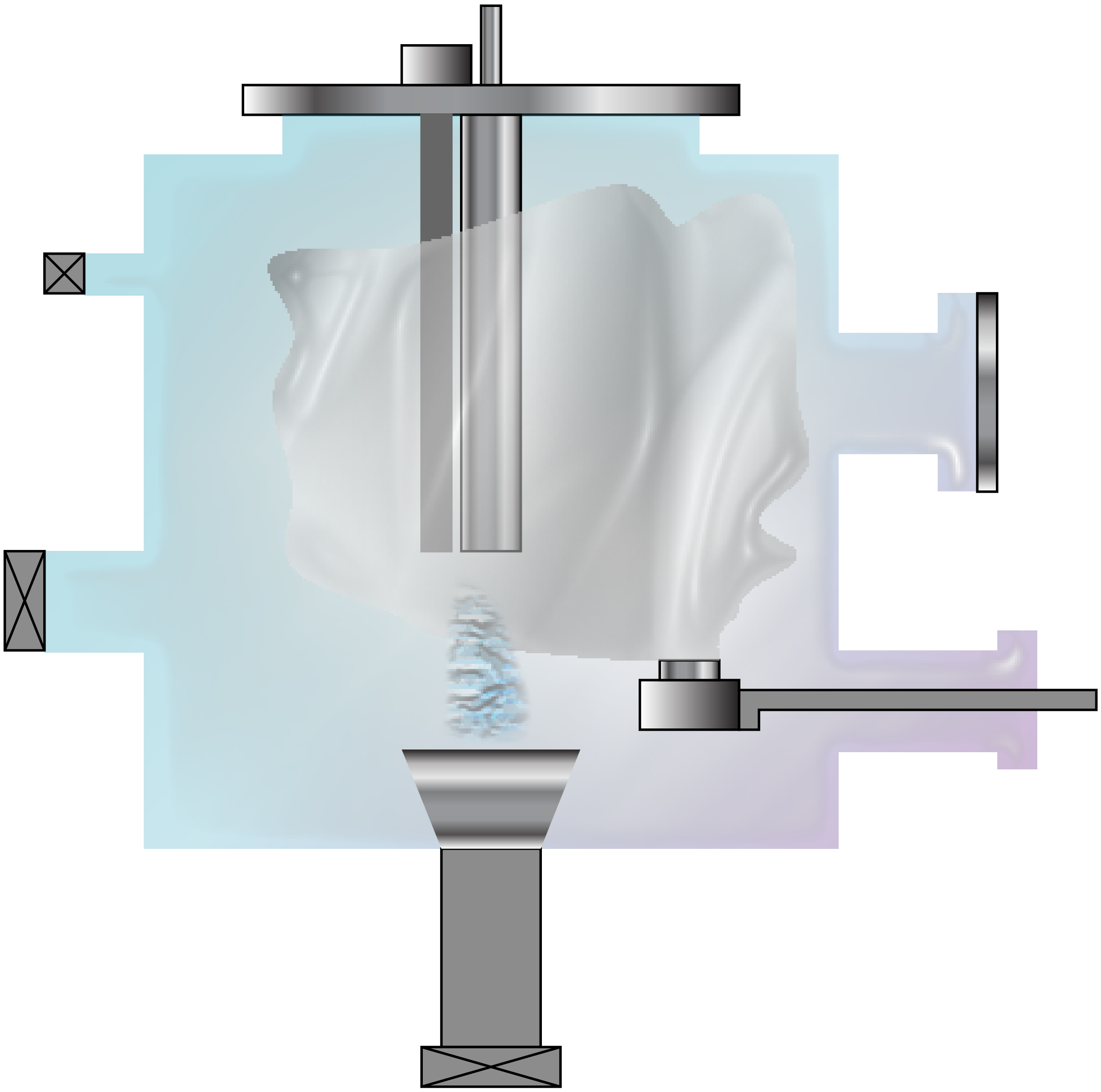
Problem 4 (c)

20 points

Machinability is a poorly defined term that is often used in engineering practice. Several attempts at indexing machinability have been made over the years, and one of the most popular is called the "machinability rating." The benchmark for this rating is AISI 1112 steel, with a machinability rating of 1.0. By comparison, the machinability rating is 0.25 for type 304 stainless steel, 1.0 for 7075-T6 Al alloy, and 5.0 to 10.0 for Mg alloys.

Rationalize these numbers. How would you explain these differences, citing reasons relating to the microstructure of each alloy system. Remember that steel and aluminum alloys are cubic, magnesium and zinc are hexagonal. Steels can have a wide range of microstructural variations from martensitic to pearlitic. Al alloys in the 7000 series can be precipitation-hardened.

Problem 5: Thin Films and Surface Treatments



Problem 5(a)
20 points

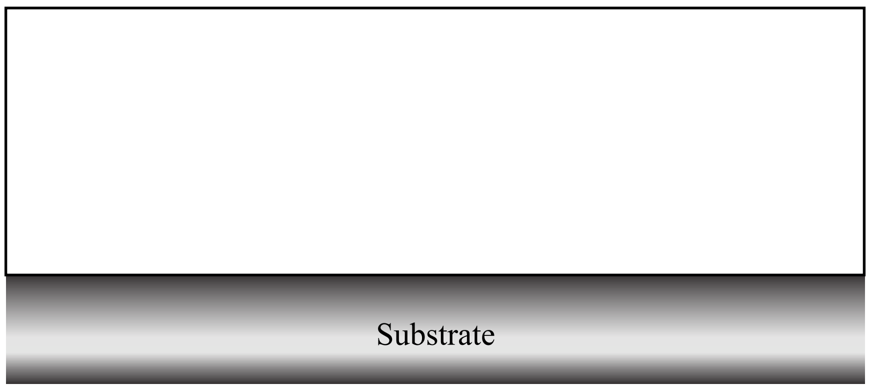
Recall that the diffusional flux across an interface plane is given by Fick's First Law,

$$J = -D\frac{\partial C}{\partial x}$$

where D is the diffusivity and C is the concentration of the diffusion species. Explain how a low carbon steel can be made more wear resistant by carburizing the surface. How is this carburization procedure performed, and how can the carburized case depth (the depth of penetration of the carbon atoms) be determined?

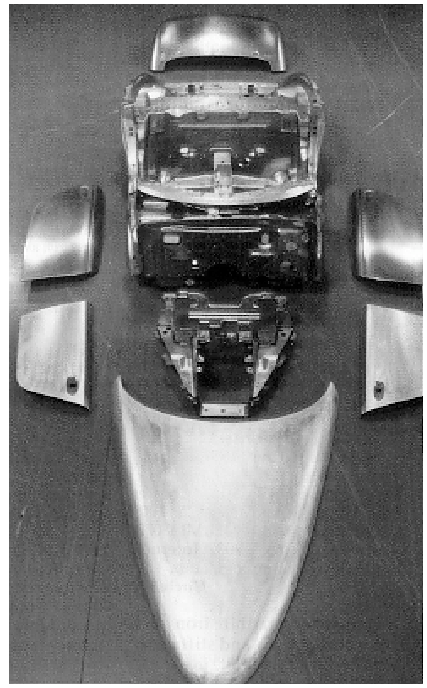
Problem 5(b)
20 points

During the deposition of thin metallic alloy films by sputtering, the film is found to possess a columnar microstructure. Sketch a cross section showing the substrate and sputtered film with columnar morphology.



Explain the origin of this morphology. Be specific, citing how the sputtering process is implicated.

Problem 5(c)
20 points



The final heat treatment given to the Plymouth Prowler is the "paint baking" cycle of 2 hours at 150°C, which not only dries the low VOC paint, but also imparts higher "dent resistance" to the aluminum sheet stock comprising the skin.

The composition of the Alcoa™ Aluminum Alloy X6022 skin is: 1% Si, 0.1% Fe, 0.05% Cu, 0.05% Mn, 0.5% Mg, 0.1% Cr, 0.25% Zn, 0.15% Ti, balance Al.

Explain this result. Why is such a gentle heat treatment so effective in improving the mechanical properties of the base alloy. Be specific.

Results:

THIRTY-SIX (36) STUDENTS TOOK THIS EXAM IN THE SPRING SEMESTER OF 2006, WITH THE FOLLOWING OUTCOME:

POSSIBLE POINTS = 300
HIGH = 282
MEAN = 242
LOW = 114
SIGMA = 34