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*Exámenes resueltos 2012-2016*

**2° Materiales Aeroespaciales I**

**Grado en Ingeniería Aeroespacial**

**Escuela Politécnica Superior**
**Universidad Carlos III de Madrid**




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Universidad Carlos III de Madrid

EXAM

January 2014

**Aerospace Materials I (2nd Year)**

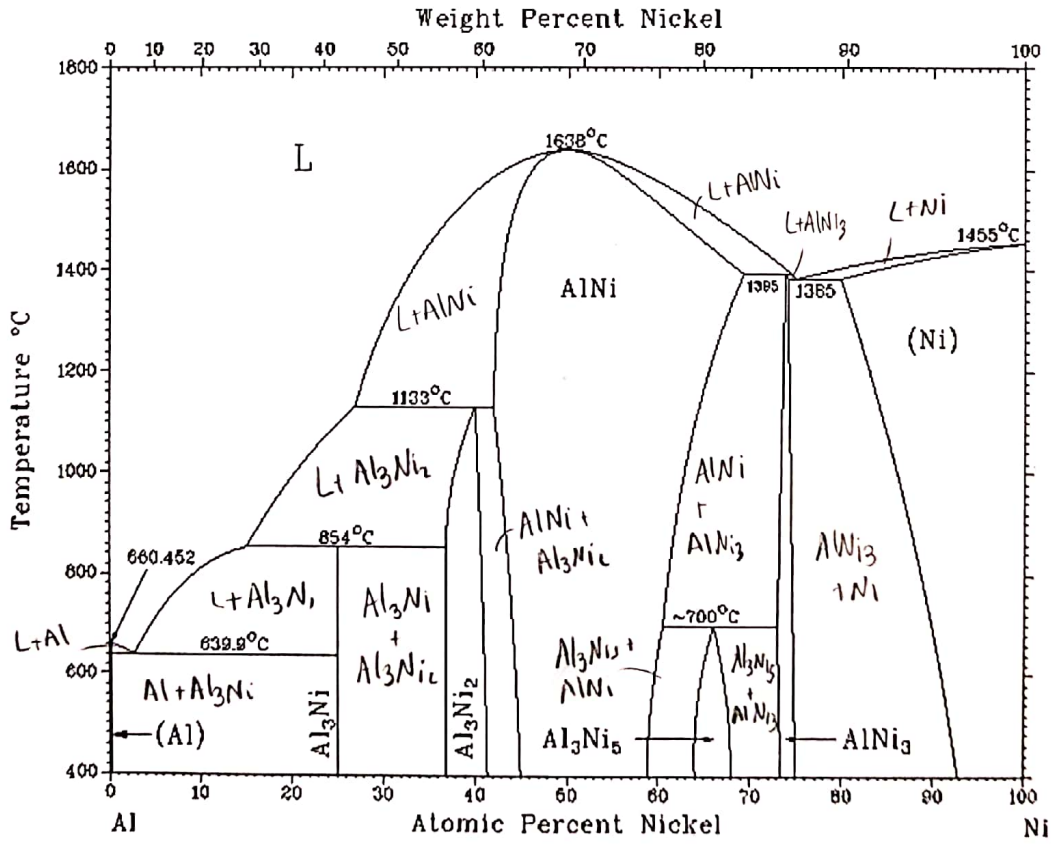
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**Surname:** **Name:** **Group:**

**Information:**

- Read the questions carefully before answering. Use the space given for answering each question.
- You have 2h 30min to complete the exam.
- The marks assigned to each of the questions are given at the beginning of the question.
- To pass the exam you need a minimum mark of 4 over 10.

1. **(2 marks)** Use the following Al-Ni phase diagram to answer the questions.
   a) Determine the invariant reactions that take place at the following temperatures: 639.9ºC, 700ºC, 1133ºC, 1385ºC. For each reaction state its name, temperature and composition (in at% of Ni) of all phases involved in the reaction.
   b) For an alloy that has a 10 at% of Ni draw in the square provided a schematic sketch of the microstructure that would be observed at a temperature of 638ºC.
   c) For an alloy that has a 10 at% Ni indicate the quantity and composition of the phases present and the quantity of the microconstituents present at a temperature of 638ºC.
   d) Indicate which intermetallic compounds have congruent and incongruent melting.
   e) What is the maximum solubility of Al in Nickel and at what temperature is it observed.

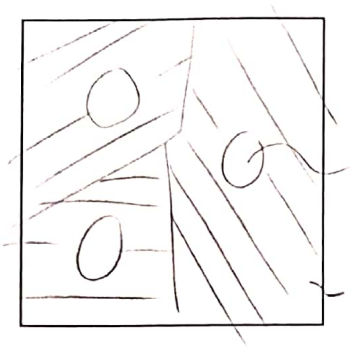



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b)



638°C

$Al_3Ni'$

eutectic ($Al_3Ni + Al$)

a) 639.9°C : Eutectic : L(3%at Ni) → Al (0%at Ni) + $Al_3Ni$ (25%at Ni)

700°C : Peritectoid : AlNi (60%at Ni) + $AlNi_3$ (73%at Ni) → $Al_3Ni_5$ (65%at Ni)

1133°C : Peritectic : AlNi (43%at Ni) + L (26%at Ni) → $Al_3Ni_2$ (40%at Ni)

1385°C : Eutectic : L (77%at Ni) → $AlNi_3$ (75%at Ni) + Ni (80%at Ni)

c) $C_0$ = 10%at Ni , T = 638°C

- phases: Al and $Al_3Ni$

$C_{Al}$ = 0%at Ni  $W_{Al} = \frac{25-10}{25-0} = 0.6$

$C_{Al_3Ni}$ = 25%at Ni  $W_{Al_3Ni} = 0.4$ ⊗

- microconstituents: $Al_3Ni'$ and eutectic (Al + $Al_3Ni$)

$C_{Al_3Ni'}$ = 25% Ni  $W_{Al_3Ni'} = \frac{10-3}{25-3} = 0.32$

$C_E$ = 3%at Ni  $W_E = 0.68$ ⊗

$W_{Al_3Ni,E} = W_{Al_3Ni,T} - W_{Al_3Ni'} = 0.4 - 0.32 = 0.08$

$W_{Al,E} = W_{Al,T} = 0.6$

$W_{Al_3Ni,E} + W_{Al,E} = W_E$
$0.08 + 0.6 = 0.68$ ✓

d) Congruent : AlNi

Incongruent : $Al_3Ni$, $Al_3Ni_2$, $Al_3Ni_5$, $AlNi_3$

e) Max solubility of Al in Ni : 82%at Ni → 18%at Al at 1385°C

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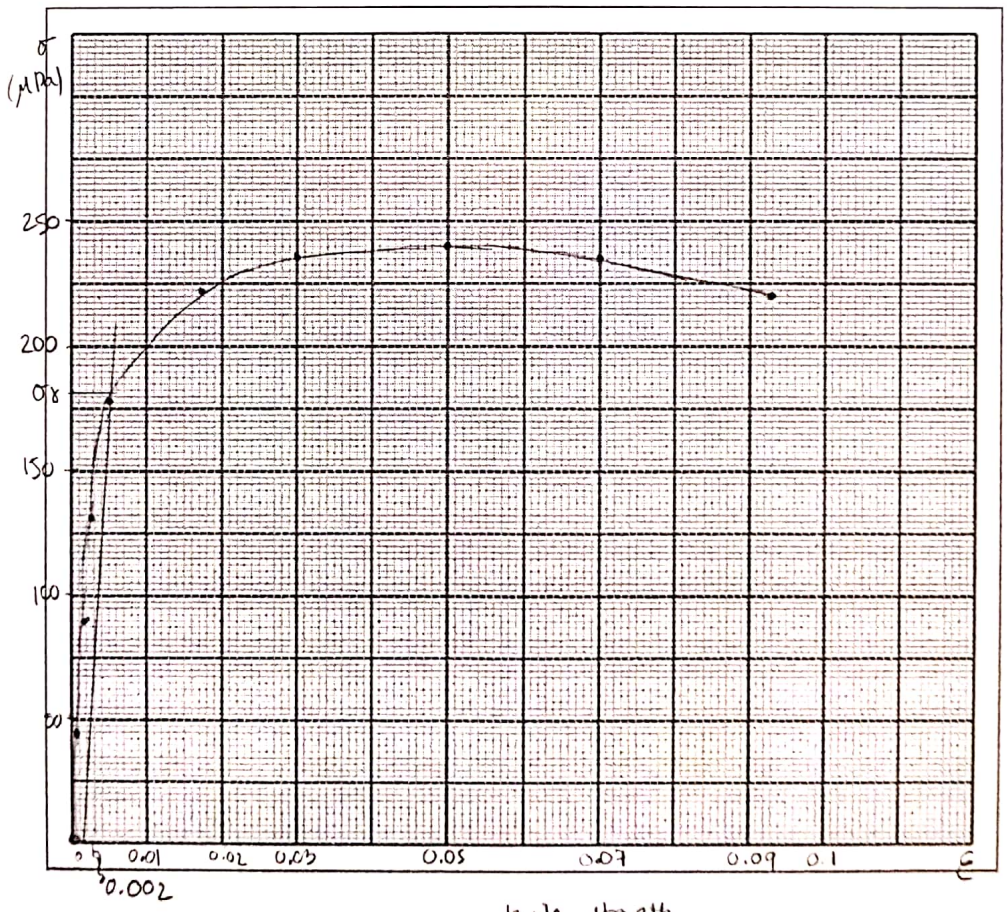
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2. **(2 marks)** The following data were collected from a 12 mm diameter test specimen of magnesium ($l_o$= 30.00 mm). After fracture, the gage length is 32.61 mm and the diameter is 11.74 mm. Poisson's ratio for Mg is 0.29.
   a) Plot the engineering stress-strain curve. Determine the yield strength and the tensile strength.
   b) Calculate the modulus of elasticity and the modulus of resilience.
   c) Calculate the % elongation and the % reduction in area.
   d) Determine the engineering stress at fracture and the real stress at fracture. Calculate the real stress and the real strain for an engineering stress 176.8 MPa.
   e) Calculate the change in diameter when a tensile load of 10000 N is applied to this test specimen.

| Load (N) | Gage Length (mm) | Stress (MPa) | Strain (mm/mm) |
|---|---|---|---|
| 0 | 0000 | 0 | 0.0 |
| 5000 | 0.0296 | 44.2 | 0.000987 |
| 10000 | 0.0592 | 88.4 | 0.001973 |
| 15000 | 0.0888 | 132.6 | 0.00296 |
| 20000 | 0.15 | 176.8 | 0.005 |
| 25000 | 0.51 | 221.0 | 0.017 |
| 26500 | 0.90 | 234.3 | 0.030 |
| 27000 | 1.50 (max. load) | 238.7 | 0.050 |
| 26500 | 2.10 | 234.3 | 0.070 |
| 25000 | 2.79 (fracture) | 221.0 | 0.093 |




a) From graph, $\sigma_y$ = 186 MPa  $\sigma_{max}$ = 238.7 MPa (tensile strength)

b) $\sigma = E\varepsilon \rightarrow E = \frac{\sigma}{\varepsilon} = \frac{132.6}{0.00296} = 44800\ MPa = 44.8\ GPa$

$U_r = \frac{1}{2}\frac{\sigma_y^2}{E} = \frac{1}{2}\frac{186^2}{44100} = 0.386\ MPa$

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El **mejor proyector**
relación calidad/precio
Los recomendados de amazon y WUOLAH



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c) % elongation $= \frac{32.61 - 30}{30} \times 100 = 8.7\%$ ($l_f$, $l_0$)

% RA $= \frac{\frac{\pi}{4}h^2 - \frac{\pi}{4}11.74^2}{\frac{\pi}{4}12^2} \times 100 = 4.3\%$ ($A_0$, $A_f$)

d) At fracture, $\sigma_{nf} = 221\,MPa$ (table)

necking: $\sigma_r = \frac{F}{A_r} = \frac{25000}{\frac{\pi}{4}(11.74 \cdot 10^{-3})^2} \cdot 10^{-6} = 230\,MPa$

At $\sigma_{ng} = 176.8\,MPa$ → below $\sigma_{max}$ → no necking

$\sigma_r = \sigma_{ng}(1 + \varepsilon_{ng}) = 176.8(1 + \underbrace{0.005}_{table}) = 177.624\,MPa$

$\varepsilon_r = \ln(1 + \varepsilon_{ng}) = \ln(1 + 0.005) = 0.004987$

e) $\nu = \frac{-\frac{\Delta\phi}{\phi_0}}{\frac{\Delta l}{l_0}}$ → $\Delta\phi = -\nu\frac{\Delta l}{l_0}\phi_0 = -0.29 \cdot 0.001973 \cdot 12\,mm = -6.866 \cdot 10^{-3}\,mm$

↳ $F = 10000N \rightarrow \varepsilon = 0.001973$

$\Delta\phi = \phi_f - \phi_0 \rightarrow \phi_f = 12 - 6.866 \cdot 10^{-3} = 11.993\,mm$

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3. **(1 mark)**
   a) What is the primary role of the matrix and the fibers, respectively, in a fiber reinforced composite?
   b) What is the most common fiber product used in aeronautical technology for the fabrication of laminate structures? Describe briefly how it is manufactured.

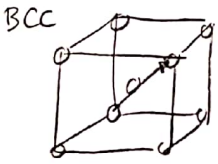
a) The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. The fibers provide strength by carrying most of the load. The matrix forms the shape of the component; transfers load into and out of the fibers, separates the fibres to prevent failure of adyacent fibers if one fails, protects the fibre from the environment (degradation), keeps fibre orientation and provides ductility and toughness.

b) Prepegs are the most common fiber form in aeronautical technology. Prepegs are resin-impregnated fiber forms (tape or fabric), that deliver a consistent fiber/resin combination and ensure complete wetout. They are manufacture by impregnating fibers with a controlled amount of resin (thermoset or thermoplastic), using the solvent, hot-melt or powder-impregnation technologies:

1) Continuous fibers are aligned and subjected to surface treatment 2) Fibers are coated by dipping in resin/solvent bath and a series of rollers ensure the correct amount of resin is impregnated 3) Tape is dried to evaporate the solvent and partially cured over cylinder 4) The tape is protected by a baking paper and stored.

4. **(1 mark)** What is the family of close packed directions for BCC and FCC structures respectively? How many octahedral and tetrahedral interstitial sites exist in the FCC structure? Determine de density of aluminum, which has and FCC structure, given that the interaplanar distance for planes (111) is 0.234 nm

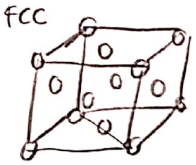
DATA: M(Al)=26.98 g/mol ; $N_A$=6.022 x $10^{23}$ $mol^{-1}$




Closed pack directions:

[111]

[110]




In compact structure (like FCC)

n = 4 atoms

n° tetrahedral interstitials = 2n = 8

n° octahedral " = n = 4

$$FCC \rightarrow d_{111} = \frac{a}{\sqrt{1^2+1^2+1^2}} = 0.234 \rightarrow a = 0.405\,nm$$

$$\rho = \frac{nM}{N_A V_c} = \frac{4 \cdot 26.98}{6.022 \cdot 10^{23} \cdot (0.405 \cdot 10^{-7}\,cm)^3} = 2.697\,g/mol$$

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④ Hot isostatic pressing: simultaneous compaction and shaping and sintering of ceramic particles by pressure uniformly applied to all directions

Sintering: the process in which fine particles of ceramic material become chemically bonded together at a temperature high enough for atomic diffusion to occur between particles

**5. (1 mark)**

a) What are some common properties to most ceramic materials? What two main factors affect the packing of ions in ionic solids?

b) Describe briefly the basic steps in dry-pressing methods for producing such ceramic materials as technical ceramic compounds and structural refractories.

a) • High hardness • Limited electrical and thermal conductivity • Brittle
• High Young's Modulus and high melting point (strong bonds (covalent and/or ionic))
• Low thermal shock resistance (stability at high temperature)
• Resistance to oxidation/corrosion (Chemical stability)

The factors that affect the packing of ions are the relative size of ions (define the coordination index) and their charge, in order to maintain electroneutrality

b) The basic process steps are: (i) mix ceramic powder (ii) compaction/pressing (iii) sintering. The most important processes are:

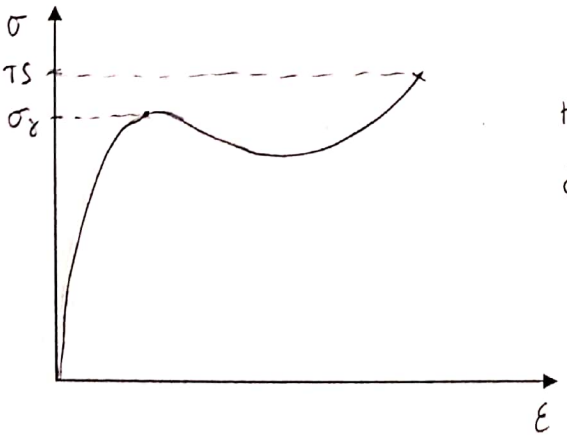
Dry pressing followed by sintering: simultaneous uniaxial compaction and shaping of ceramic particles in a die (followed by sintering)

Cold isostatic pressing followed by sintering: Simultaneous compaction and shaping of ceramic particles by pressure applied uniformly in all directions (followed by sintering) ⊛

**6. (1 mark)** Polymers

Draw a characteristic stress-strain curve for a typical semi-crystalline polymer in the axis provided. Label the yield and tensile strengths on your curve. Does plastic deformation start in the crystalline or amorphous regions of a semicrystalline polymer? How does the amount of crystallinity affect the mechanical properties and the melting temperature of a polymer? Explain briefly.

→ Polymers I slide 32




Plastic deformation starts in the amorphous regions of the polymer. with the elongation of amorphous tie chains. Then there is the tilting of lamellar chain folds, followed by separation of crystalline block segments. Finally, there is orientation of the block segments and tie chains with tensile axis.

Crystallinity increases the strength by increasing intermolecular bonding. Also partially crystalline polymers exhibit a melting temperature (amorphous polymers exhibit only a glass transition temperature). Melting temperature increases with increasing amount of crystallinity due to increasing intermolecular bonding.

ductility (?) → Tulara sidjan

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7. **(1 mark)** Consider the following diffusion couples: (i) C in FCC Iron (ii) C in BCC Iron (iii) Fe in FCC Iron and (iv) Fe in BCC Iron.
   a) What will be the diffusion mechanism in each case?
   b) Where does C diffuse faster in FCC Iron or in BCC Iron? Explain your answer briefly.
   c) Will the activation energy for C diffusion in FCC Iron be higher or lower than that for Fe diffusion in iron?

a) i) and ii) interstitial diffusion ; iii) and iv) vacancy diffusion

b) C diffuses faster in BCC Iron because it is a more open structure than FEC ( PF(FCC) > PF(BCC) )

c) Lower . C diffuses by interstitial diffusion and Fe by vacancy diffusion. There are more intestial sites available than vacancies, making interstitial diffusion easier than vacancy diffusion. This is reflected in the lower activation energy for C diff. in Fe when compared to Fe diff. in Fe

8. **(1 mark)**
a) Explain what type of semiconductors are (i) silicon doped with 1ppm Boron and (ii) silicon doped with 1ppm Indium. Assuming that they are both at the same temperature, which semiconductor will have higher conductivity? Explain. (Boron- column III A of the periodic table; Indium- column III A of the periodic table; B ion size < In ion size).
b) Calculate the electrical conductivity of silicon doped with $4.5 \times 10^{21}$ Boron atoms/$m^3$ assuming complete dopant ionization.

(DATA: $\mu_e$=0.135 $m^2V^{-1}s^{-1}$; $\mu_h$= 0.048 $m^2V^{-1}s^{-1}$; $q_e$=-1.6022x$10^{-19}$C)

| p-type | B Al Ga In Te | n-type | P As Sb Bi |
|---|---|---|---|
| ↓ size | | ↓ size | |
| ↑ σ | | ↑ σ | |
| holes | | e⁻ | |

a) i) Boron doped: extrinsic p-type semiconductor with acceptor level
ii) Indium doped: extrinsic p-type semiconductor with acceptor level

The smaller the doping ion the stronger the attraction of the valence e⁻ by the nucleus. Therefore in the band theory, this means that for p-type semiconductors, the smaller the doping ion the higher the attraction of the acceptor level, which would reduce Ea and therefore increase conductivity

↓ size → ↑ σ ⇒ $\sigma_{B\text{-doped}} > \sigma_{In\text{-doped}}$ since size B < size In

b) $\sigma = n|q_e|\mu_h = 4.5 \cdot 10^{21} \frac{atoms}{m^3} \cdot 1.6 \cdot 10^{-19} A \cdot s \cdot 0.048 \, m^2V^{-1}s^{-1} = 35 \, \Omega^{-1}m^{-1}$

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