FACULTY OF APPLIED SCIENCE AND ENGINEERING

MMS 411 H1: MATERIALS IN MANUFACTURING

FINAL EXAMINATION: 23rd APRIL 2001

EXAMINER: Dr. T.H. NORTH

EXAMINATION TYPE: A

ANSWER ALL QUESTIONS

(All questions are not of equal value)

Question 1

i) Figure 1 shows the relation between the work of adhesion and the interfacial free energy $\gamma_{M/C}$. Carefully explain why:
   a) the observed adhesive strength of Ni/Al_2O_3 joints is much less than that of Fe-15Cr/Al_2O_3 joints
   b) no quantitative values are given for the observed strength of the metal/ceramic joints (poor, fair, good and excellent are used)?

[8 marks]

ii) Indicate and explain the governing relations when Al_2O_3 is wetted using a Cu-Ag eutectic liquid braze for the following situations:
   a) when the Cu-Ag liquid does not contain any reactive constituents
   b) when Ti is added to the Cu-Ag braze and reaction occurs wholly within the ceramic substrate and the rate of spreading of the droplet exceeds the rate of growth of the reaction product at the solid-liquid interface
   c) when Ti is added and chemical reaction occurs wholly within the liquid phase

[6 marks]

iii) When Ti is added to a Cu-Ag eutectic braze during Al_2O_3 bonding and the chemical reaction occurs wholly within the liquid phase, the contact angle is 8°. The free energy change per unit area when the chemical reaction occurs wholly within the liquid phase is –900 mJ/m^2. Also, the free energy change per unit area is –1800 mJ/m^2 when the chemical reaction occurs wholly within the ceramic substrate. The surface tension of the reactive brazing material is

2100 mJ/m^2 and the bonding temperature is 1250 K. Calculate the contact angle resulting when the chemical reaction occurs wholly within the ceramic substrate and the rate of spreading of the droplet exceeds the rate of growth of the reaction product at the solid-liquid interface.

[6 marks]

Question 2.

i) The size of an unwetted flaw is determined by the following relation:

$$a = a_o \left[1 - \frac{A_{sl}}{\gamma_{sv}} \right]^2$$

where, a is the unwetted flaw dimension, a_o is the unwetted flaw dimension when A_{sl} is zero, A_{sl} is the spreading coefficient and γ_{sv} is the surface energy o the solid-vapor interface
Deduce the relation between the fracture strength of completed joints and the surface energy terms (γ_{sv}, γ_{lv} and γ_{sl}).
Sketch the relationships between joint fracture strength, the work of adhesion and the critical surface tension value of the liquid when a) a single adherend is bonded using a range of adhesives, b) when a single adhesive is used to bond a range of adherends.

[9 marks]

ii) The surface of aluminum base material is abraded with the objective of varying the γ_{sv} value (see the Table below). If the aluminum test samples are bonded using a PVA-VA adhesive having a γ_{lv} value of 30 mN/m, which is of the aluminum sections will produce the highest joint strength values? Carefully explain the underlying reasons for your selection.

Substrate Code	γ_{sv} (mJ/m^2)
Aluminum A	25
Aluminum B	52
Aluminum C	46
Aluminum D	19
Aluminum E	35
Aluminum F	39
Aluminum G	29

[8 marks]

iii) Describe the laboratory test used by aerospace companies to determine the effectiveness of different aluminium alloy surface treatments in limiting crack extension with time in polymer/metal joints. Explain a) why this type of test is required and why it is not needed in when aluminum test sections are bonded using laser welding b) how the information produced in this laboratory test is applied in *actual application* situations

[9 marks]

Question 3.

i) Titanium components are being TLP-bonded using a 30 μm thick nickel interlayer. Using the accompanying Ti-Ni binary equilibrium diagram (Figure 2) describe:

a) the metallurgical processes that occur as the bonding operation progresses when the TLP-bonding operation is carried out at 950 °C and at 1200 °C

b) the final products formed at room temperature in completed joints (when the bonding temperatures are 950 °C and 1200 °C)

Indicate which bonding temperature (950 °C or 1200 °C) you would recommend for this particular joining operation. Why?

[9 marks]

ii) Figure 3 shows the relation between the relative amount of eutectic and the holding time at the bonding temperature a) during conventional TLP-bonding using a 30 μm thick Ni-B interlayer, b) during wide-gap brazing when a mixture of powdered Ni-base superalloy material and a Ni-B interlayer are introduced prior to bonding. Explain a) why the bonding operation is completed so much faster during wide-gap brazing and b) why the grain orientations are so different in joints quenched to room temperature part way through each bonding operation

[8 marks]

iii) The mechanical properties produced during TLP-bonding of Ni-based superalloy material using a Ni-B interlayer are much better than those produced a) by fusion welding, b) using soldering when a layer of eutectic material is retained at the joint interface following the joining operation. In each case explain why superior joint tensile strength, fracture toughness and creep rupture strength properties are produced in TLP-bonded joints.

[10 marks]

Question 4.

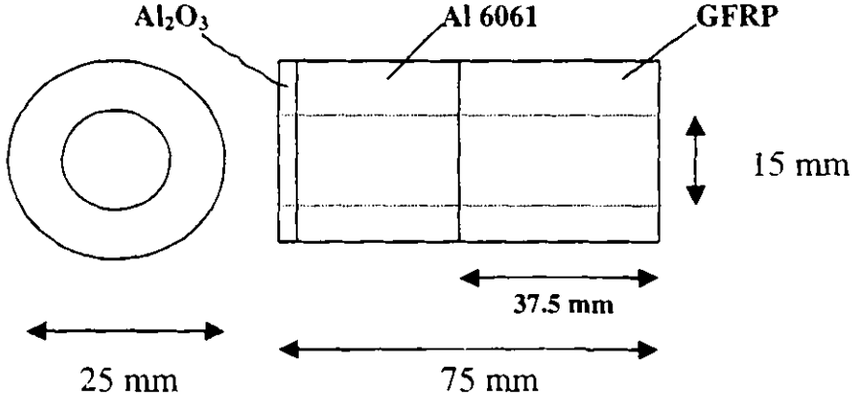
You have been asked by your company to recommend processing routes for the manufacture of a tubular component that will be used in a helicopter engine. The component is made using three base materials, namely, Al_2O_3, Al 6061-T6 aluminum alloy and GFRP. In the final assembly, the Al 6061-T6 section is faced with a 1 mm thick Al_2O_3 layer (see the design below). Al 6061-T6 aluminum, GFRP and alumina have the following properties:

Al 6061-T6	melting point (580 °C), hardness (1200 MPa), density (2.8 Mg/m^3)
GFRP	hardness (320 MPa), density (1.3 Mg/m^3)
Alumina	melting point (2930 °C), hardness (3900 MPa), density (3.9 Mg/m^3)

The tolerance on the critical dimensions is ±0.5 mm and the surface roughness is 3.5 μm.

i) Indicate the processing routes that you would recommend for each component and the problems that you might expect when they are applied.

ii) Recommend techniques that you would use to assemble the three sections together prior to dispatch to the client



[20 marks]

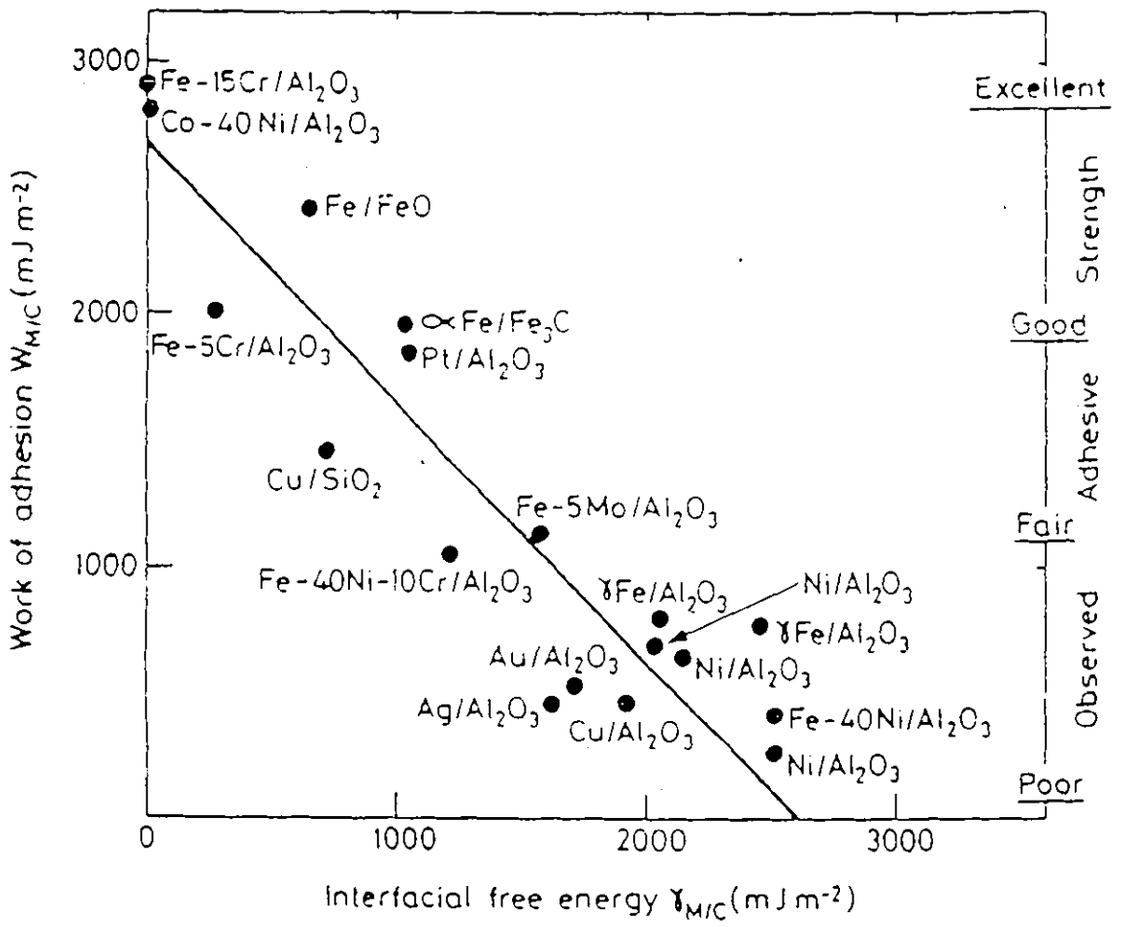


Figure 1

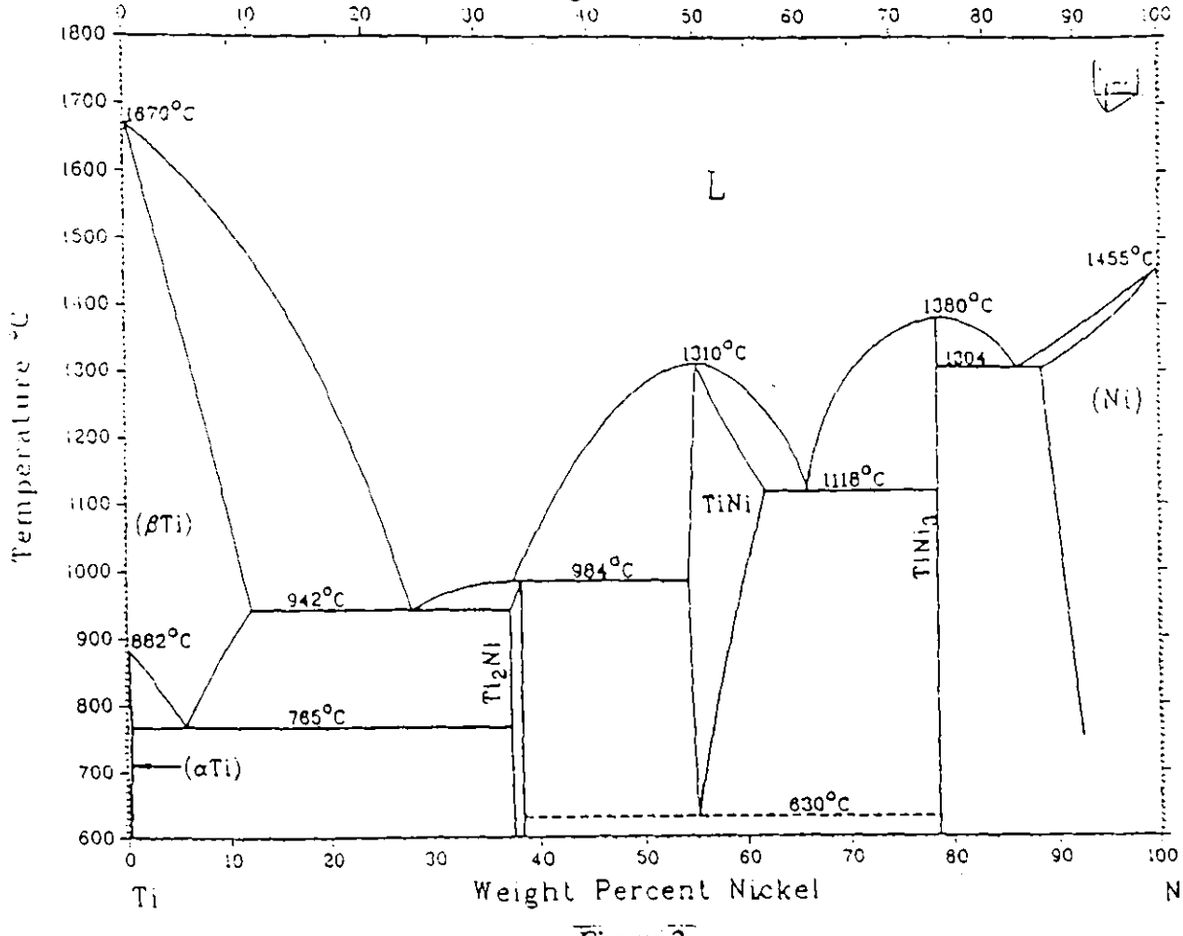


Figure 2

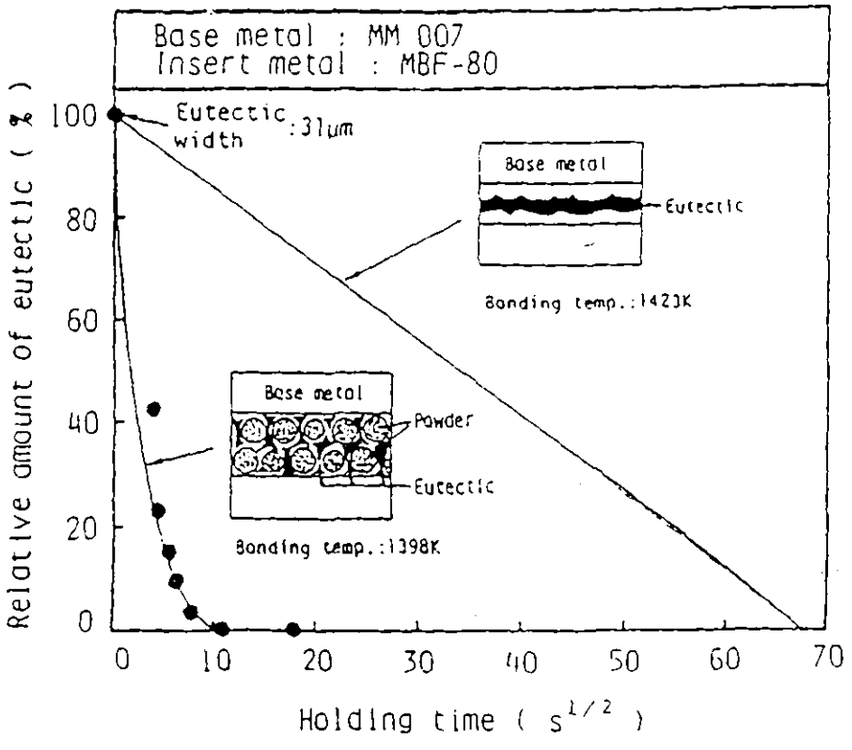
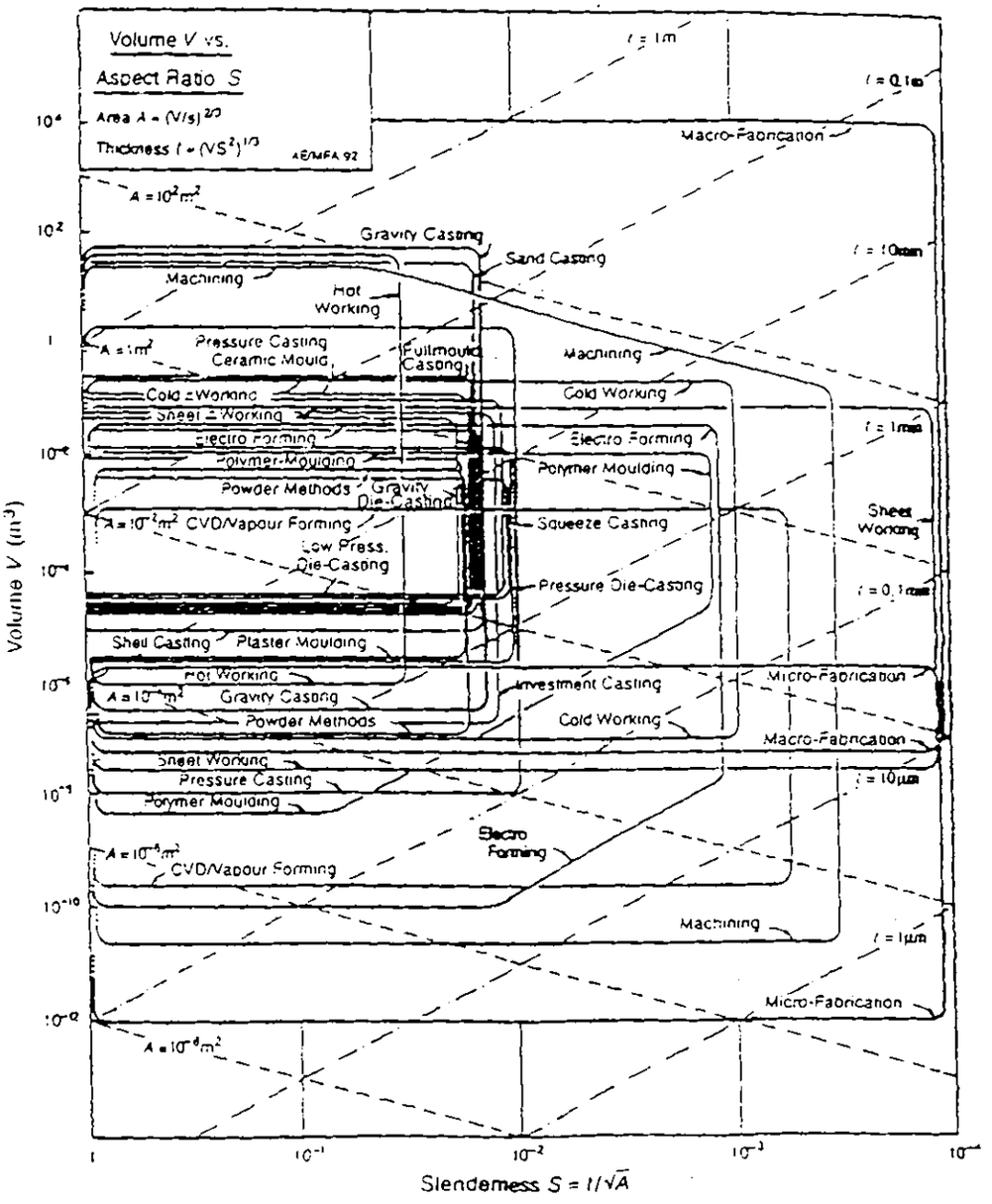
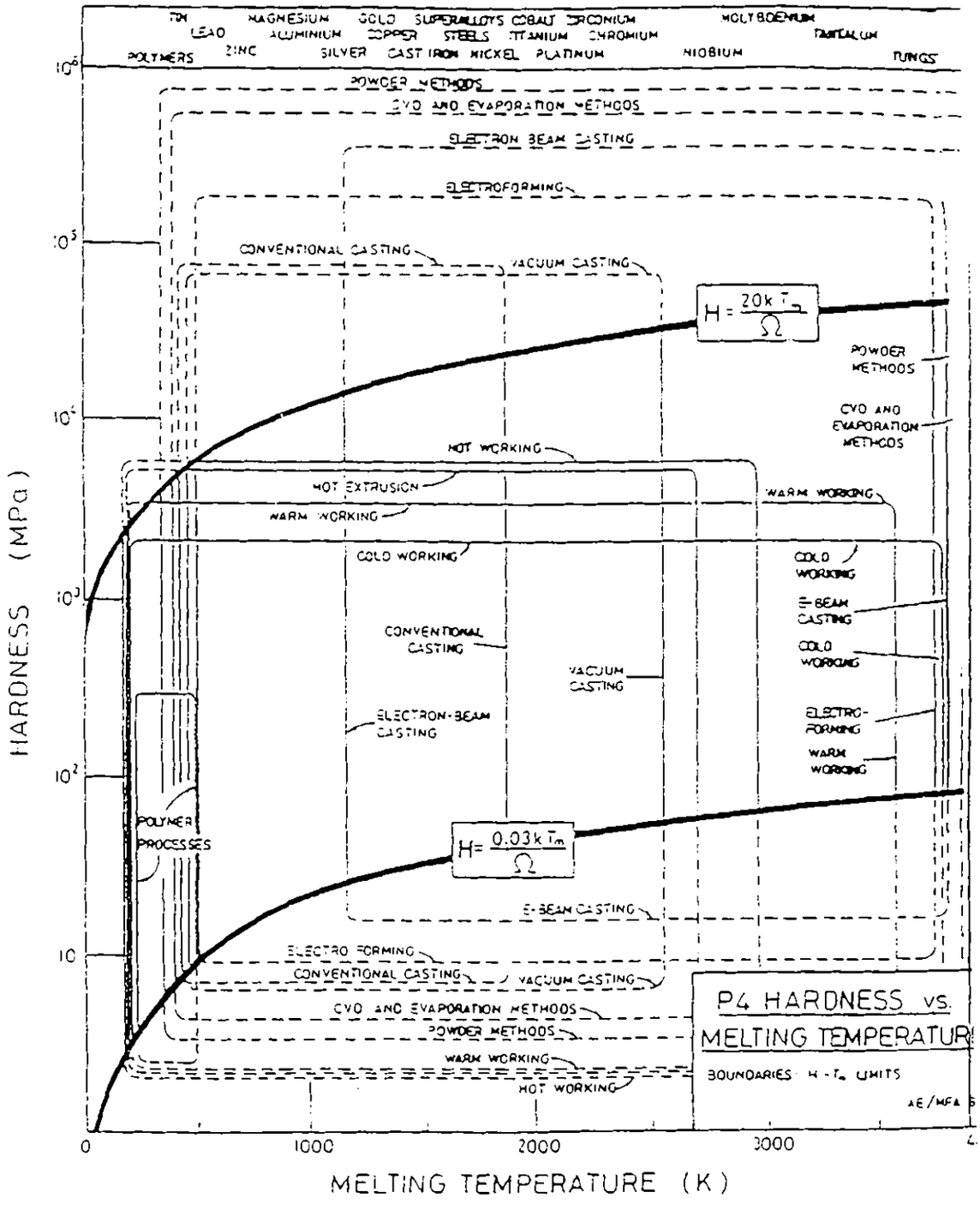
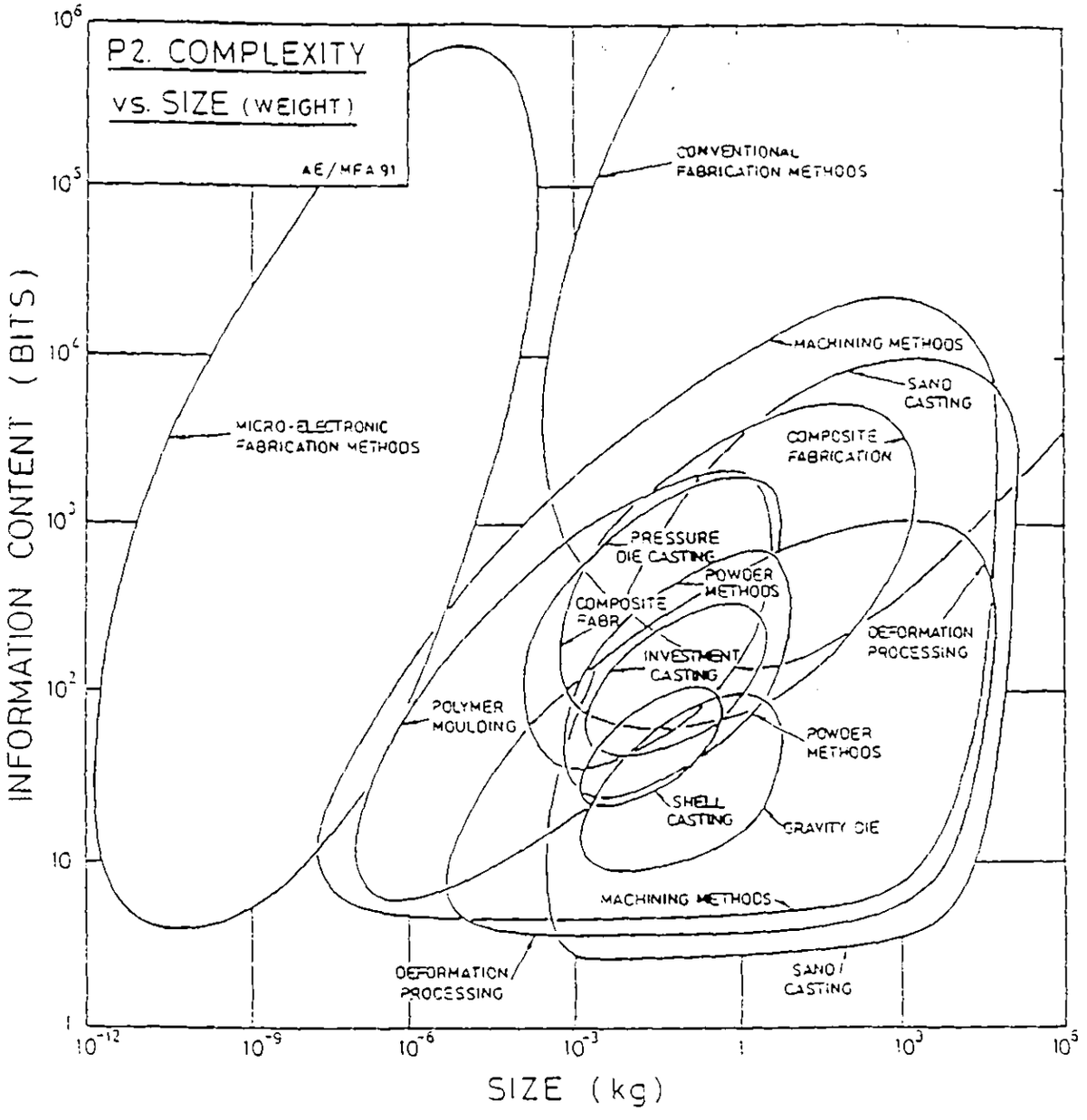
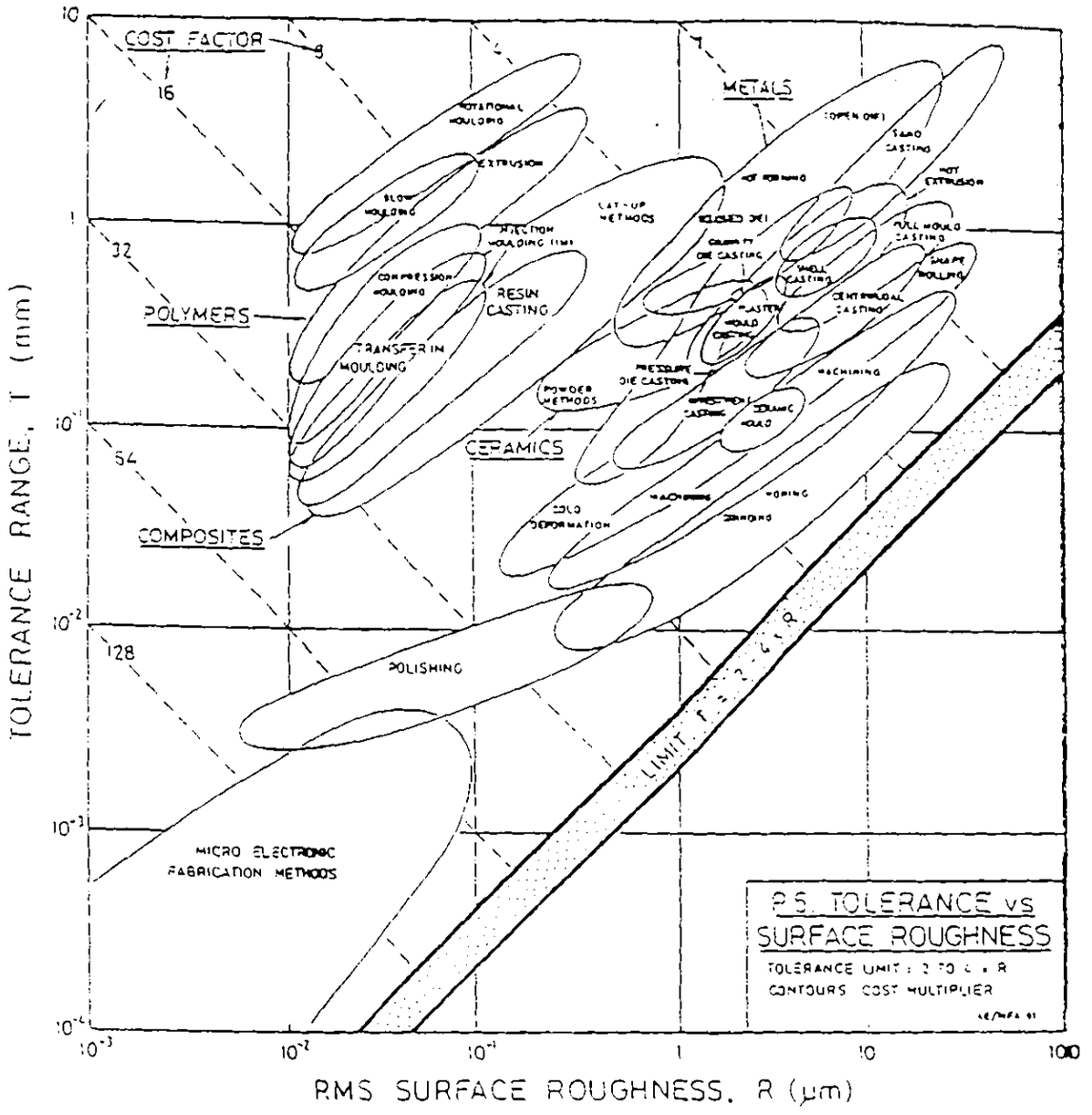

Base metal : MM 007
Insert metal : MBF-80
Eutectic width :31μm
Base metal
Eutectic
Bonding temp.:1423K
Base metal
Powder
Eutectic
Bonding temp.:1398K
Relative amount of eutectic (%)
100
80
60
40
20
0
0
10
20
30
40
50
60
70
Holding time (s^1/2)

Figure 3


Volume V vs.
Aspect Ratio S
Area A = (V/s)^2/3
Thickness t = (VS^2)^1/3
AE/MFA 92
Volume V (m^3)
Slenderness S = t/√A
Macro-Fabrication
Micro-Fabrication
Gravity Casting
Sand Casting
Machining
Hot Working
Pressure Casting
Ceramic Mould
Full mould Casting
Cold Working
Sheet Working
Electro Forming
Polymer Moulding
Powder Methods
Gravity Die-Casting
CVD/Vapour Forming
Low Press. Die-Casting
Squeeze Casting
Pressure Die-Casting
Shell Casting
Plaster Moulding
Investment Casting


TIN
MAGNESIUM
GOLD
SUPERALLOYS
COBALT
ZIRCONIUM
MOLYBDENUM
LEAD
ALUMINIUM
COPPER
STEELS
TITANIUM
CHROMIUM
TANTALUM
POLYMERS
ZINC
SILVER
CAST IRON
NICKEL
PLATINUM
NIOBIUM
TUNGS
POWDER METHODS
CVD AND EVAPORATION METHODS
ELECTRON BEAM CASTING
ELECTROFORMING
CONVENTIONAL CASTING
VACUUM CASTING
$H = \frac{20k\,T_m}{\Omega}$
POWDER METHODS
CVD AND EVAPORATION METHODS
HOT WORKING
HOT EXTRUSION
WARM WORKING
COLD WORKING
E-BEAM CASTING
CONVENTIONAL CASTING
VACUUM CASTING
ELECTRON-BEAM CASTING
ELECTRO-FORMING
POLYMER PROCESSES
$H = \frac{0.03k\,T_m}{\Omega}$
E-BEAM CASTING
ELECTRO FORMING
CONVENTIONAL CASTING
VACUUM CASTING
CVD AND EVAPORATION METHODS
POWDER METHODS
WARM WORKING
HOT WORKING
P4 HARDNESS vs. MELTING TEMPERATURE
BOUNDARIES H - T_m LIMITS
AE/MFA
HARDNESS (MPa)
10^5
10^4
10^3
10^2
10
0
1000
2000
3000
MELTING TEMPERATURE (K)


P2. COMPLEXITY
vs. SIZE (WEIGHT)
AE/MFA 91
INFORMATION CONTENT (BITS)
SIZE (kg)
CONVENTIONAL FABRICATION METHODS
MICRO-ELECTRONIC FABRICATION METHODS
MACHINING METHODS
SAND CASTING
COMPOSITE FABRICATION
PRESSURE DIE CASTING
POWDER METHODS
COMPOSITE FABR
INVESTMENT CASTING
DEFORMATION PROCESSING
POLYMER MOULDING
POWDER METHODS
SHELL CASTING
GRAVITY DIE
MACHINING METHODS
DEFORMATION PROCESSING
SAND CASTING


COST FACTOR
8
16
32
64
128
METALS
POLYMERS
COMPOSITES
CERAMICS
RESIN CASTING
TRANSFER IN MOULDING
POLISHING
MICRO ELECTRONIC FABRICATION METHODS
LIMIT
P.S. TOLERANCE vs SURFACE ROUGHNESS
TOLERANCE RANGE, T (mm)
RMS SURFACE ROUGHNESS, R (μm)