OLLSCOIL NA hÉIREANN, CORCAIGH
THE NATIONAL UNIVERSITY OF IRELAND, CORK

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

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B.E. DEGREE (ELECTRICAL)

ME4002 - PRODUCTION ENGINEERING

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Answer **three** questions from **EACH** section

Approved calculators are permitted

TIME ALLOWED
3 hours

SECTION A: MATERIALS PROCESSING & DESIGN FOR MANUFACTURE

1. (a) A valve control wheel to be cast from a eutectic alloy consists of a central cylindrical hub, four cylindrical spokes and an annular rim, as shown below in Figure 1. Using Chvorinov's modulus technique, predict the solidification sequence of the wheel. (All dimensions are in cm, diagram not to scale).

   (b) A design engineer has suggested that by reducing the thickness *t* of the annular rim from 5 cm to 3 cm will enable the wheel to be cast using a single feeder located at point *A* covering one surface of the hub. Show that this is not possible, stating clearly the criteria for one primitive to feed another.

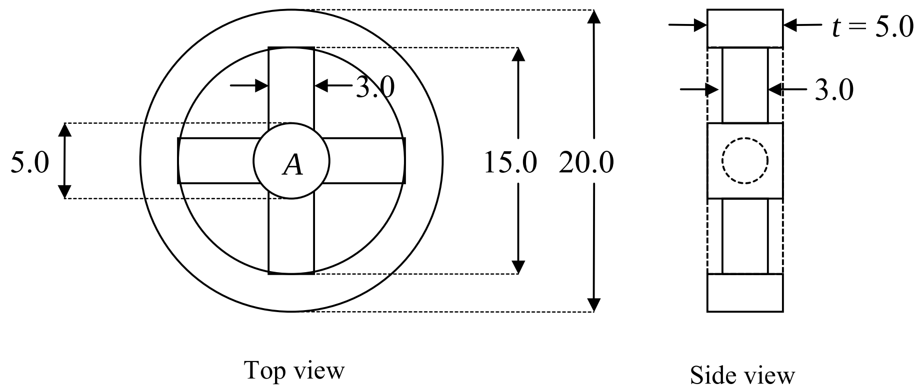

Figure 1: Valve control wheel for Question 1.

2. (a) Explain what is mean by 'die kick', how it may be avoided in die design, and why it is important to use a minimum number of die pieces in a forging process. Explain why it is difficult to forge very thin sections, and explain the role of 'flash lands'.

   (b) Using the sizing chart shown overleaf in Figure 3, estimate the minimum size forging hammer that must be used to manufacture the component shown below in Figure 2 by hot forging from a medium carbon steel, with the forging direction normal to the shaded surface. Indicate on a sketch of the component where draft angles and radiusing will be necessary. (All dimensions are in mm, diagram not to scale).

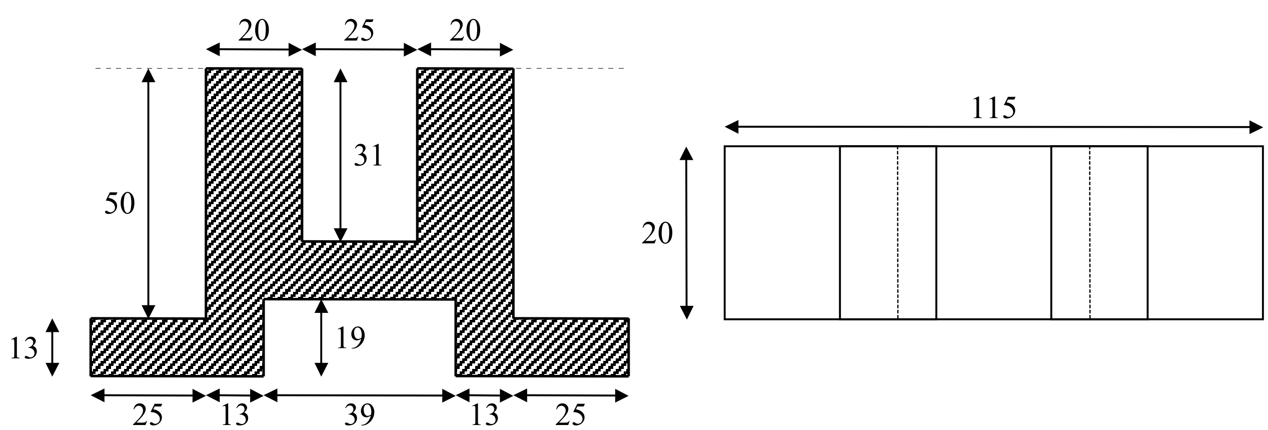

Figure 2: Component for Question 2.

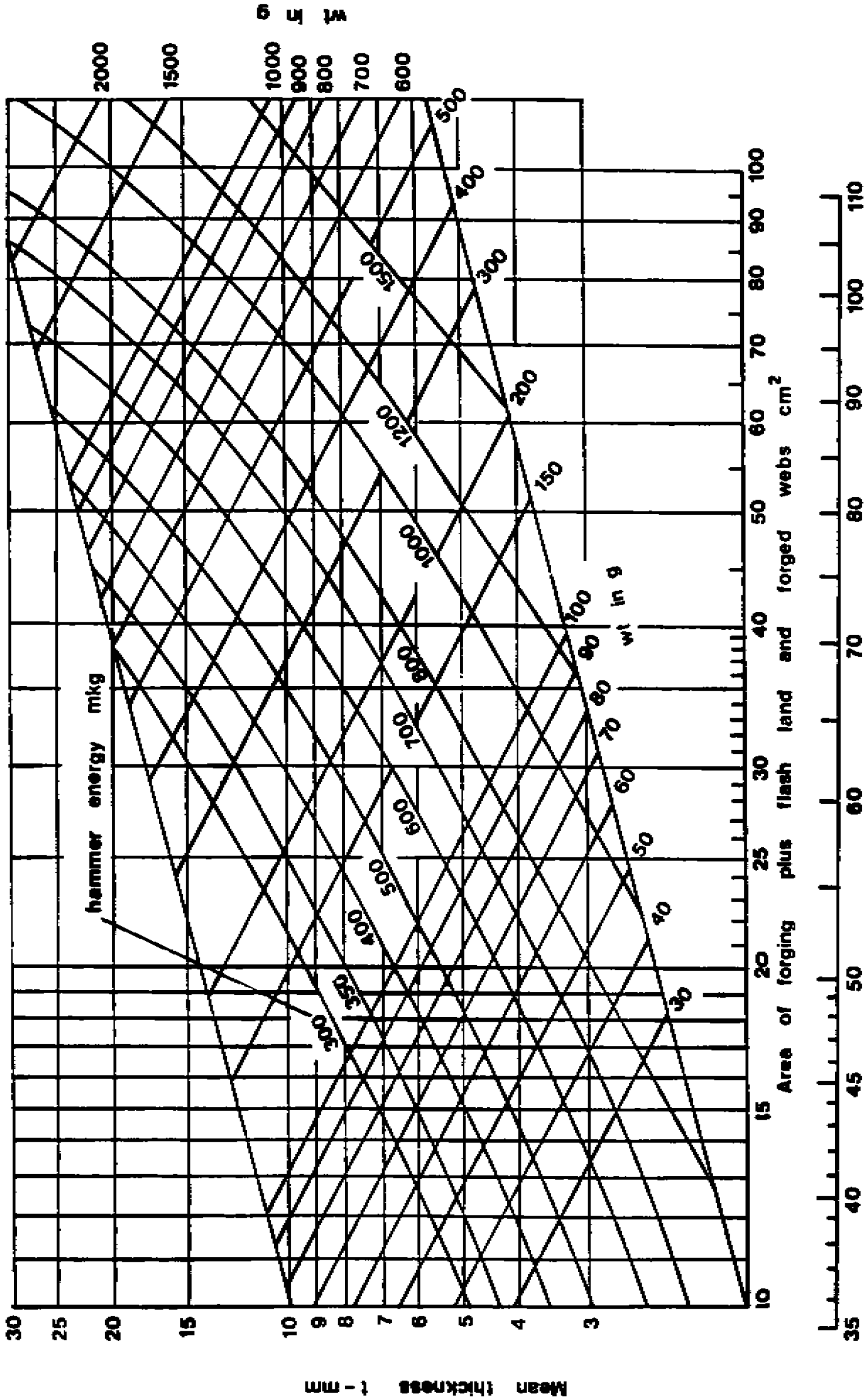

Figure 3: Hammer sizing chart for Question 2.

3. (a) Describe the main differences between thermosetting and thermoplastic polymers, giving a suitable example of each. Explain in detail why different forming processes and extruder barrels are required for each material.

   (b) Using diagrams where necessary, describe manufacturing processes suitable for making the following components from a thermoplastic polymer:

   (i) a 2 litre mineral water bottle
   (ii) packaging for a chocolate Easter egg
   (iii) a domestic bath

4. Explain in detail the reasons for shrinkage and distortion when arc-welding butt joints, and explain how they may be reduced by careful joint design. Describe pre- and post- welding techniques that may be used to prevent or remove distortion in the final welded assembly. Give the advantages and disadvantages of each technique, and use diagrams where appropriate to illustrate your answers.

SECTION B: NON-DESTRUCTIVE TESTING

5. Explain the general principles involved in eddy current testing and describe TWO applications in which eddy current evaluation techniques would be an appropriate choice of material characterisation method. For each application, outline:
    - the advantages of eddy current testing as opposed to other NDT techniques;
    - the characteristics of the material that the test is intended to reveal;
    - the limitations of eddy current testing in respect of sensitivity to the specified characteristics;
    - the cross-sensitivity of eddy current techniques to other material or geometrical factors, and how this sensitivity can be reduced.

6. For each NDT requirement given below, describe a suitable method of achieving the stated objective. Give a brief outline of the underlying theory and outline any precautions to be taken to ensure consistent, reproducible results. State any advantages or limitations of the particular methods chosen, supporting your answers with quantitative arguments wherever possible.
    (a) detecting surface-breaking cracks 1μm or more wide in ceramic insulators used on overhead electricity pylons.
    (b) detecting delaminations in composite panels, consisting of five layers of 1 mm thick polymer sheet, bonded together with adhesive. The technique should be capable of determining which of the layers have delaminated.
    (c) detecting sub-surface hairline cracks of 0.2 mm long or more in steel shafts.

7. (a) Describe the four main scattering mechanisms which may occur as X-rays or γ-rays pass through a material. Explain how the scattered radiation may degrade the quality of a radiographic image, and hence define the term "build up factor".

    (b) Describe in detail the principles of operation of the following, using diagrams where appropriate:
    (i) X-ray tube
    (ii) Image intensifier tube
    (iii) Microchannel plate

8. A chemical engineering company proposes to use large cylindrical aluminium reaction vessels for a mildly corrosive, high temperature, high pressure process. Safety considerations will force the company to inspect the vessels periodically using non-destructive testing procedures to monitor the presence of any flaws. Inspection can be carried out while the vessels are not in service, but no direct access to the inner walls will be possible. Potentially hazardous types of flaw that could be generated are thought to include surface breaking cracks (on both exterior and interior surfaces), internal cracks with orientations ranging from radial to transverse (i.e. perpendicular and parallel to the surface respectively), extended regions of micro-porosity, and localised thinning of the vessel walls over areas greater than a few cm^2. Defects with sizes down to 1 mm should be detectable, as should any reduction in wall thickness of more than 5 mm. The nominal wall thickness of the reaction vessel is 30 mm.

   Outline suitable methodology based on ultrasonic NDT techniques for carrying out the required inspection. By using appropriate numerical data as the basis for quantitative reasoning, specify the type of probe(s), the operating frequency or frequencies, the mode(s) of wave propagation and the wave incidence angle(s) to be used. Sketch diagrams showing possible probe geometries for each of the flaws mentioned, and give diagrams showing the expected idealised received signals that would characterise the flaw in each case.

(End)

PROPERTIES OF TYPICAL ENGINEERING MATERIALS

Material	Alloy constituents	0.1% proof (yield) stress	Young's modulus	Density	Specific heat capacity	Coefficient of linear thermal expansion	Thermal conduct-ivity	Electrical resistivity (per cube)	Relative cost	Notes
METALS AND ALLOYS	% by mass	σ_y (MPa)	E (GPa)	$\rho \times 10^3$ ($kg{\cdot}m^{-3}$)	c (10^3 $J{\cdot}kg^{-1}{\cdot}K^{-1}$)	α ($10^{-6}{\cdot}K^{-1}$)	λ ($W{\cdot}m^{-1}{\cdot}K^{-1}$)	ρ_e ($\Omega{\cdot}m$)	(k£·m^{-3})	
CAST IRON grey	3.5C	100-250	100-150	7.0-7.4	0.52	11	50	700×10^{-9}	0.8	
malleable	2.5C	250-500	170	7.3	0.52	11	40	340×10^{-9}	1.0	
STEEL mild	0.06-0.25C	250-500	210	7.9	0.45	11	50	120×10^{-9}	1.2	
medium carbon	0.25-0.6C	250-700	210	7.9	0.45	11	50	230×10^{-9}	1.5	
alloy	Ni Cr Mo	700-1000	215	7.9	0.45	11	30	300×10^{-9}	2	
stainless	0.2C 16Cr	500-1000	215	7.8	0.5	10	25	720×10^{-9}	4-7	Martensitic
	0.1C 18Cr 8Ni	200-800	215	7.8	0.5	16	16	740×10^{-9}	4-7	Austenitic
MAGNESIUM alloy	8Al 0.5Zn	150-250	40	1.8	1.0	25	100	600×10^{-9}	7	
ALUMINIUM pure		30-140	70	2.7	0.88	27	240	36×10^{-9}	2.2	
alloy	4Cu 1Mg	125-400	70	2.8	0.9	27	180	38×10^{-9}	3.4	"Duralumin"
TITANIUM alloy	4Al 4Mn	1000	110	4.5	0.5	9	17 (1)	500×10^{-9} (1)	80	(1) Pure metal
ZINC alloy	4Al 1Cu	250	108	7	0.4	30	100	700×10^{-9}	3.2	"Mazak"
NICKEL alloy	Cr Co	100-800	190	8.5	0.4	13	15	1200×10^{-9}	30	"Inconel"/"Nimonic"
COPPER pure		50-300	130	8.9	0.38	17	400	17×10^{-9}	8	
bronze	7.5 Sn	150-750	100	8.9	0.38	18	60	140×10^{-9}	20	
brass	30-40 Zn	150-500	100	8.5	0.37	18-23	130	65×10^{-9}	9	

THERMOPLASTIC POLYMERS	Ultimate tensile stress (MPa)								
Polyethylene PE	5-25	0.1-1.0	0.9-0.95	2.3	100-200	0.4	$>10^{14}$	0.6	
Polypropylene PP (g)	25-35	1-1.5	0.9		110-170	0.2	$>10^{14}$	0.7	
Polyvinyl chloride PVC	60	2.5	1.4	1-2	50	0.15	$>10^{14}$	1	
Polytetrafluoroethylene PTFE	15-40	4-6	2.2	1	100-200	0.25	$>10^{17}$	22	"Fluon"/"Teflon"
Polystyrene PS	50	1-3	1.1	1.3	60-80	0.15	$>10^{11}$	0.7	
Polymethylmethacrylate PMMA	50-70	3	1.2	1.5	50-90	0.2	$>10^{12}$	1.6	"Perspex"
Polyamide (nylon) PA (g)	50-90	1-3	1.1	1.6	80-150	0.22	$>10^{10}$	2.5	
Polyacetal (Polyoxymethylene) POM	65	3	1.4	1.4	30-35	0.25	$>10^{11}$	2.0	"Kematal"
Acrylonitrile-butadiene styrene ABS	20-40	2	1-1.1		60-100		$>10^{15}$	1.2	
Polyethylene terephthalate PET (g)	70-170 (1)	2.3	1.3	1.3	20 (1)		$>10^{19}$	2.2	"Melinex"/"Mylar" (1) Oriented film
Polycarbonate PC (g)	60-70	2.8	1.2		70	0.15	10^{16}	2.4	
THERMOSETTING POLYMERS									
Epoxy and polyester: 'GRP', 'DMC', 'SMC'	90-130	20-30	1.5-2.0	1.7	15-30	0.2-0.4	$>10^{16}$	1.7	'Glass fibre reinforced plastics'
Phenol, urea, melamine- formaldehyde (g)	30-50	5-8	1.4-2.0	1.7	30-45	0.2	$>10^{12}$	1.1-2.4	

(g) With glass fibre filler, UTS and E increased by x2 to x3, density by +0.2

Note: Polymers exhibit creep at room temperature. The given values for σ and E are for short-term loading only.

RUBBERS					Max usable temp. (°C)				
Natural (polyisoprene)	20		0.9-1.2	1.9-1.4	85	0.13-0.16	10^6-10^{16}	0.5	Soft →Hard
Polyurethane	25	0.001 to	1.1		85			3.0	
Neoprene (polychloroprene)	20	1.0 as	1.2		95			2.0	
Nitrile	15	required	1		115			1.0	
Fluorocarbon	15		1.8		290			35.0	

WOOD pine	20-100	15 (1) 1 (2)	0.5	2.8	3-5 (1) 35-60 (2)	0.15	10^{10} (dry)	0.4	(1)along grain (2)across grain
GLASS crown	30-90	70	2.5	0.7	8.5	1	$>10^9$	1.0	
CONCRETE	15-70(1)	15-40	2-2.5	0.8-1.2	10-20	1.5-2.5	10^2-10^9	0.25	(1) compressive (cube)

FLUIDS	Viscosity	Bulk Modulus			Coefficient of volumetric expansion			Relative cost	
	η (10^{-3} Pa·s)	k (Pa)			β (10^{-3} K^{-1})			(£·m^{-3})	
WATER pure	1 (1)	2.2×10^9	1	4.19	0.2	0.67	5×10^3	0.2	(1) tap water at 20°C
sea	1		1.03	3.9			1		
OIL engine (10W50)	300 (1) 20 (2)	1.7×10^9	0.9	2	1	0.15	$>10^{10}$	400	(1)at 20°C (2)at 100°C
AIR at 20°C, 10^5 Pa	0.02	10^5	1.2×10^{-3}	1	3.7	0.032	→∞		
HYDROGEN at 20°C, 10^5 Pa	0.009	10^5	0.084×10^{-3}	14	3.7	0.14	→∞	2	

ACOUSTIC PROPERTIES*	Density ($kg{\cdot}m^{-3}$)	Longitudinal velocity ($m{\cdot}s^{-1}$)	Shear velocity ($m{\cdot}s^{-1}$)
ALUMINIUM ("Duralumin")	2790	6320	3130
BRASS (70Cu 30Zn)	8640	4700	2100
COPPER	8930	5010	2270
IRON (Cast)	7220	4600	2600
LEAD	11200	200	700
MAGNESIUM	1738	5800	3000
NICKEL	8840	5600	3000
STEEL mild	7800	5900	3200
STEEL stainless	7890	5790	3100
TITANIUM	4510	6100	3100
TUNGSTEN	19400	5200	2900
ZINC	7000	4200	2400
AIR (@20°C and 1 atm)	1.2×10^{-3}	344	-
OIL	880	1700	-
WATER (@20°C)	1000	1480	-

ACOUSTIC PROPERTIES*	Density ($kg{\cdot}m^{-3}$)	Longitudinal velocity ($m{\cdot}s^{-1}$)	Shear velocity ($m{\cdot}s^{-1}$)
CARBON (Pressed graphite)	1800	2400	
EPOXY RESIN	1100	2440	
GLASS	2240	5100	2800
NYLON	1120	2600	1100
PERSPEX (PMMA)	1180	2700	1300
POLYETHYLENE	900	1950	540
POLYPROPYLENE	880	2660	
RUBBER (Neoprene)	1310	1600	
SILICON NITRIDE	3270	11000	6250
WOOD pine	450	3500	

PIEZOELECTRIC MATERIALS			Piezoelectric pressure ($V{\cdot}m{\cdot}N^{-1}$)
LITHIUM NIOBATE	4700	7080	0.37
LEAD-ZIRCONATE-TITANATE (PZT)	7500	4440	0.24
PVDF	1800	2300	0.23
QUARTZ	2650	5750	0.58

*Shear velocity may be approximated to one half of the longitudinal velocity. All values shown vary with exact material composition. Many materials exhibit significant anisotropy.