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

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

SUMMER EXAMINATIONS, 2004

B.E. DEGREE (ELECTRICAL)

PRODUCTION ENGINEERING
ME4002

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Time allowed**:** 3 hours

Answer *three* questions from *BOTH* sections

All questions carry equal marks

The use of a Casio fx570w or fx570ms calculator is permitted

The use of mathematics tables is permitted

SECTION A: MATERIALS PROCESSING AND DESIGN FOR MANUFACTURE

1. The component shown in Figure 1 is to be cast in a eutectic alloy, and consists of a rectangular upper plate with an 18.0mm diameter through hole, connected via two 8.0mm diameter cylindrical pillars and a rectangular block to a flat base plate with a 22.0mm square cut-out. Using Chvorinov's modulus technique, and clearly stating any feeding criteria, calculate the solidification sequence of the component and show that the entire casting can be fed from a single feeder placed covering the shaded surface *A,* and calculate the minimum height of the required feeder. All dimensions are in cm. (Diagrams are not drawn to scale.)

[20 *marks*]

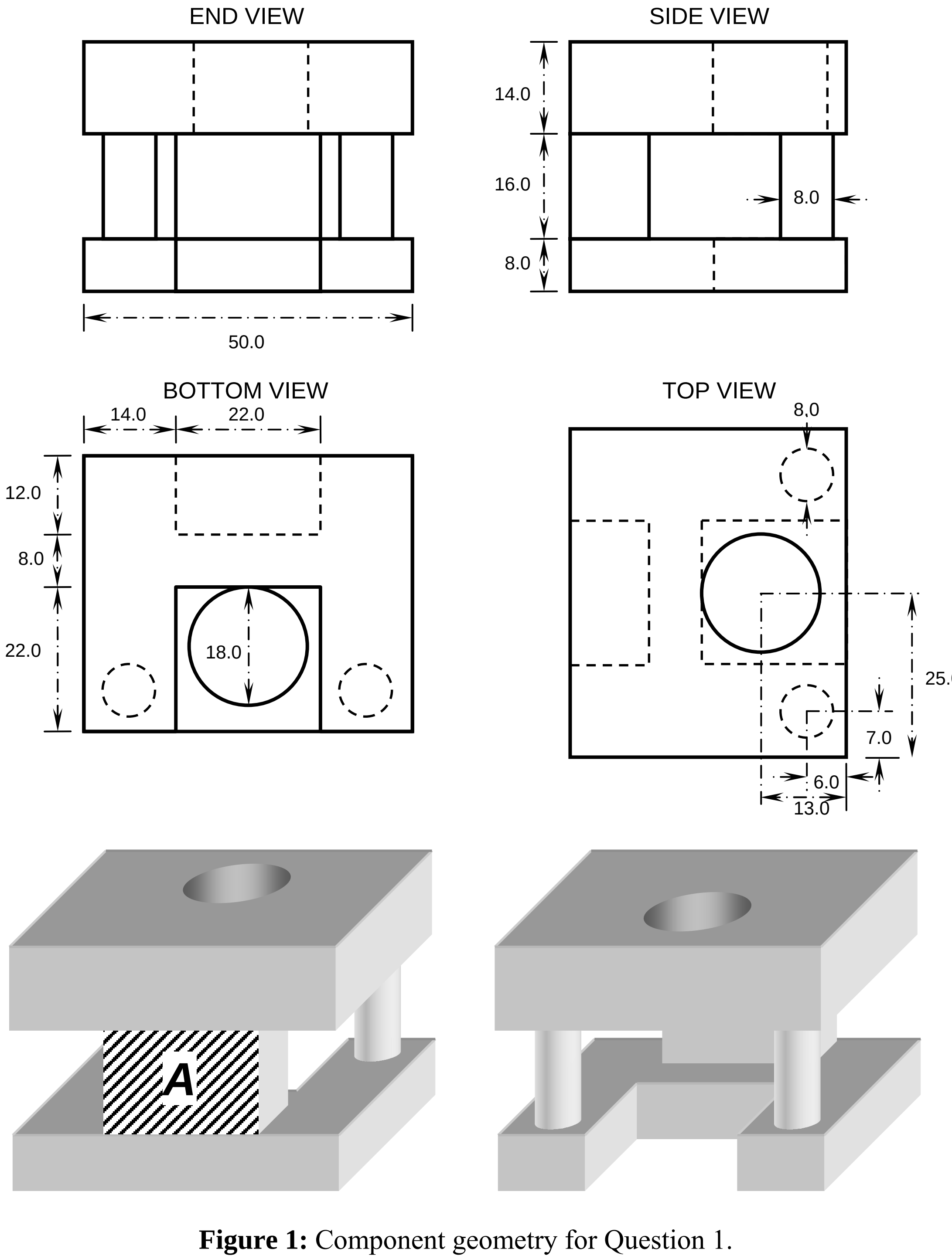

Figure 1: Component geometry for Question 1.

2. The prototype component shown below in Figure 2 is to be manufactured in a high shrinkage polymer by injection moulding. The component consists of a 60x40x32mm box containing two 5mm thick partitions, four identical hollow cylindrical bosses, two 5x8mm through-holes in the vertical sides along section *C-C*, and two end-slots 5x2x24mm along section *B-B* as shown. Criticise the design and suggest improvements, using sketches where appropriate to illustrate your answers. All dimensions are in mm. (Diagrams are not to scale.)

[*20 marks*]

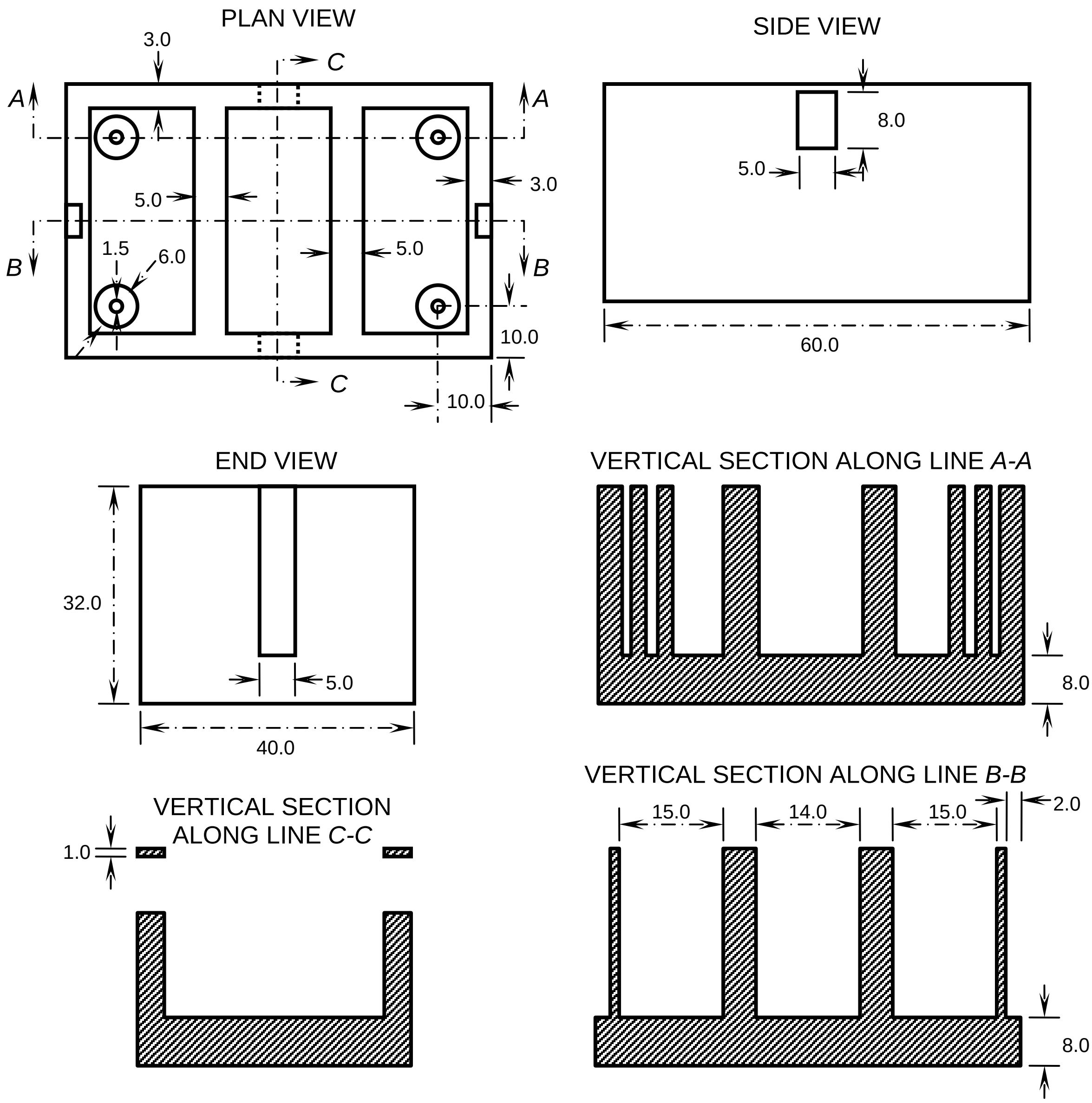

Figure 2: Component geometry for Question 2

3. (a) Explain in detail what is meant by springback in sheet metal forming, and describe three ways in which it may be eliminated.

[*8 marks*]

(b) The bracket shown below in Figure 3 is to be manufactured from 3.0mm thick brass sheet, with four 110° bends as shown, produced by a sequence of punching, notching and wiping operations. The outer two bends have a radius of 8.0mm, the inner two bends have a radius of 5.0mm. (Diagram is not drawn to scale).

Calculate the following:

(i) the total length *L* of the starting blank and the location *y* of the central two holes. If $R < 2t$, $K_{BA} = 0.33$; If $R \geq 2t$, $K_{BA} = 0.5$

(ii) the hole clearance and the actual diameters of the punches and dies required, given an allowance *a* of 6%

(iii) the wiping tool angle, assuming a springback of 5%

[*12 marks*]

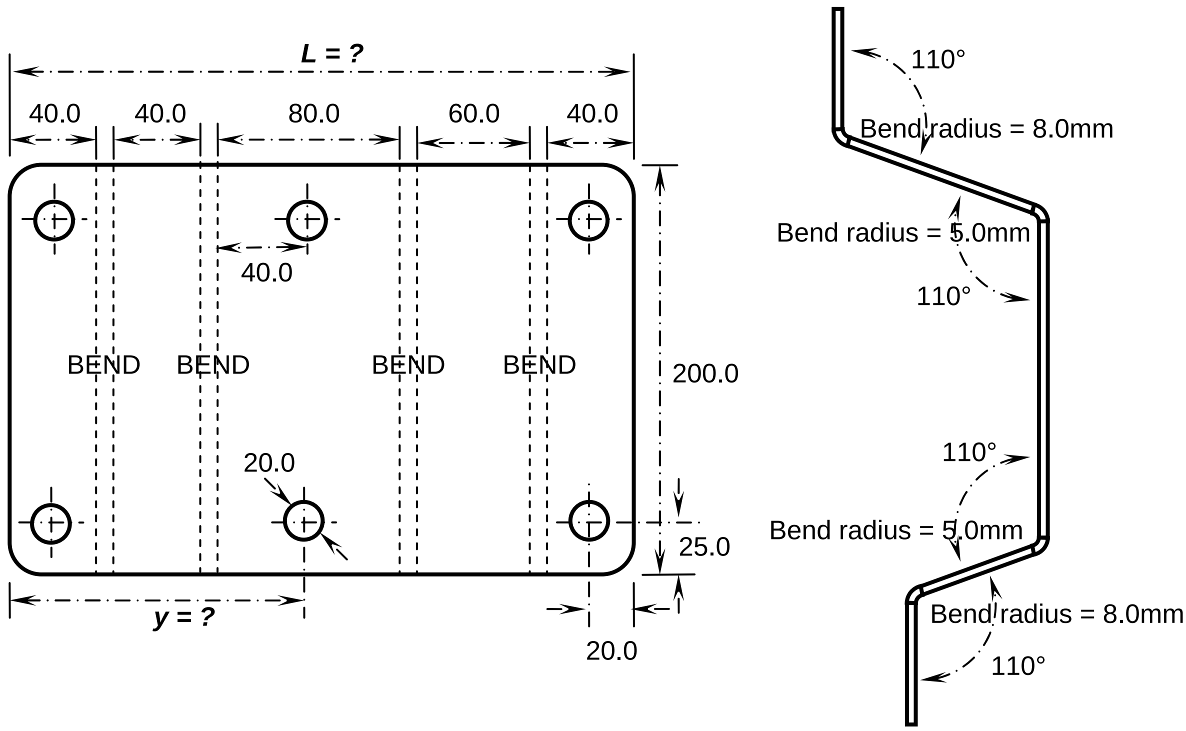

Figure 3: Component geometry for Question 3.

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.

[*20 marks*]

(End of Section A)

SECTION B: NON-DESTRUCTIVE TESTING

5. Every summer, an oil-fired power station must shut down one of its four boilers for two weeks so that the equipment may be inspected for defects. Of particular concern are the two tube bundles in the condenser. Both bundles consist of 4,000 individual stainless steel tubes that pass through holes in support plates at each end and at 2m intervals along their length. The tubes have an outer diameter of 30mm, a nominal wall thickness of 4mm, and are 10m long. Only access to the inside of each tube at either end is possible. The tubes are susceptible to internal and external corrosion that gradually thins the tube wall over the middle 6m of the tube, external radial cracks near the tube supports, and internal and external longitudinal cracks anywhere along the tube length. All leaking tubes and any tubes that are deemed likely to fail before the next annual shutdown must be blanked off before the condenser is put back in service. Critical defects are cracks more than 30% deep, and wall thinning of more than 50%. If more than 40% of the tubes in a bundle are defective, the entire bundle must be replaced. Describe how the tube bundles could be inspected using eddy current testing, using sketches where appropriate. Answers should include details of the principles of eddy current techniques and the apparatus applicable to the given scenario, critical parameters, any precautions required to ensure detection of the defects outlined above, and any advantages and disadvantages of the proposed methods.

[*20 marks*]

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 sketches as appropriate and qualitative arguments where possible.

(a) Detect all surface-breaking cracks wider than 1μm in ceramic insulators used on overhead electricity pylons.

[*6 marks*]

(b) Accurately determine the depth of surface-breaking cracks more than 2mm deep in an aluminium storage vessel with walls 20mm thick. The locations of the defects are known, having been determined previously by ultrasonic inspection.

[*7 marks*]

(c) Monitor the propagation of known cracks in a steel railway viaduct that has been in service for over 50 years.

[*7 marks*]

7. A company wishes to use ultrasound to inspect steel for internal shrinkage cavities and inclusions as it emerges from a continuous casting process. The steel section will be moving at speeds of up to 2 m/min and will be at a temperature of between 800°C and 1100°C. Describe a suitable non-contact ultrasonic NDT system based on laser generation of ultrasound, and detection of ultrasound by EMATs. The system should use both longitudinal and shear waves. Answers should include details of the generation and detection principles, any precautions required to ensure consistent and reliable results, and advantages and disadvantages of the proposed inspection technique.

[*20 marks*]

8. The component shown below in Figure 4 is manufactured from 3 pieces of mild steel by an automated precision welding process. The two flanges are welded circumferentially inside and outside to the ends of a section of rolled tube that has a longitudinal weld running its entire length. The overall length of the component is 500mm; all other dimensions may be estimated. Outline the basic principles and methods that would be required to locate surface-breaking and sub-surface cracks in all the welded joints in the component by magnetic particle inspection (MPI). Answers should include the advantages and disadvantages of using MPI for this application, any special considerations to ensure reliable and consistent detection of the described defects, and ways of improving the sensitivity of the technique. (Diagram not drawn to scale).

[*20 marks*]

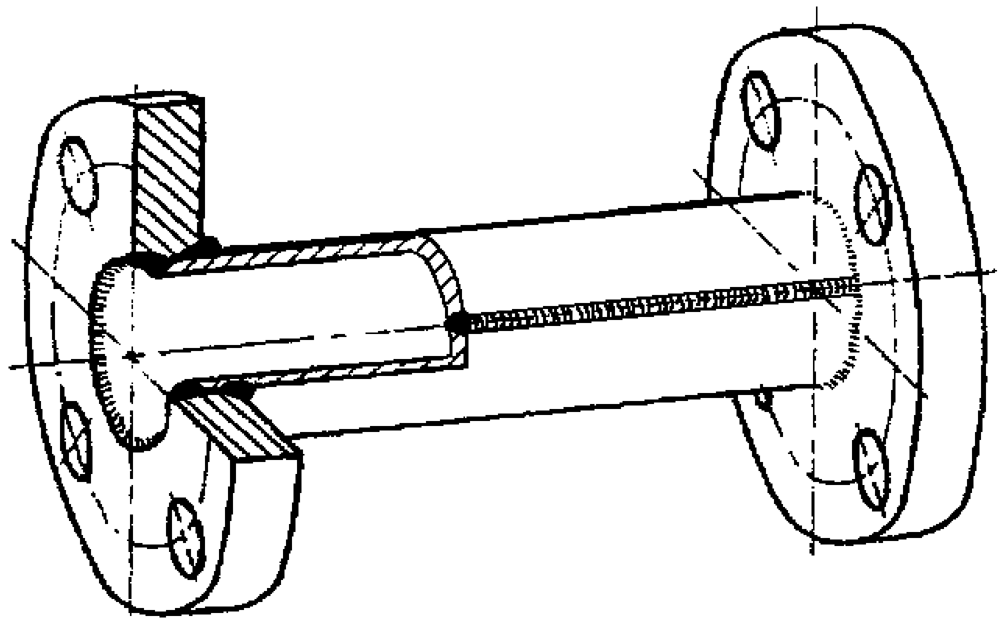

Figure 4: Component assembly for Question 8.

(End of Section B)

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	
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 ($\Omega{\cdot}m$)	($k€{\cdot}m^{-3}$)	Notes
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 ($10^{-3}\ K^{-1}$)			($€{\cdot}m^{-3}$)	
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.