Engineering Tripos Part IIA - 2016 - Paper 3C1 - Solutions

Q1 (a) Casting processes:

(i) Sand casting:

- The mould consists of sand with a small amount of resin binder packed around a re-usable pattern. This results in relatively poor dimensional accuracy and surface finish.
- The thin sections in the nozzle design would be vulnerable to sand particle defects and loss of dimensional accuracy due to erosion of the mould. This would be a limitation given the 2 mm minimum thickness for this component.

Pressure die casting

- Permanent, metallic dies result in a better surface finish and tolerance compared to sand casting.
- The applied pressure would give better results for the thinner sections in the nozzle design.

Both processes:

- The changes in cross-sectional thickness in the component would make it vulnerable to shrinkage defects.

[5 marks]

(ii) Sand casting

- May be susceptible to fluidity defects, such as misruns or cold shuts, which would affect the mechanical properties of the part. This would be a particular problem in the thinner sections.
- A suitable alloy would be needed with high fluidity – for example eutectic composition – which will also impact on properties.

Pressure die casting

- Would be susceptible to porosity, as a result of turbulence. This would negatively affect properties.
- The applied pressure may give more flexibility over the choice of alloy composition, as fluidity will be less of a concern.

[4 marks]

(iii) Sand casting

- Low material and equipment costs, but high labour costs, which could be a disadvantage depending on batch size and required production rates.

Pressure die casting

- Much higher equipment and setup costs, which mean a large economic batch size.
- The melting point of the Al alloy will affect the choice of material for the dies, to avoid excessive distortion and wear.

[3 marks]

(b) Machining a wrought alloy extrusion:

(i) - Improved dimensional accuracy and surface finish.
- Fewer defects, greater repeatability.
- Better mechanical properties of wrought alloys versus cast.

[3 marks]

(ii) - Billet will be preheated, to reduce the flow stress of the material and the extrusion forces.
- Friction and plastic deformation will result in a temperature rise during extrusion.
- Temperatures and times should be sufficient to complete the solution heat treatment
- Temperatures should not exceed the melting temperature, as this will affect the surface finish of the extrusion, which may impact on downstream processes.

[3 marks]

(iii) - Temperature rises as a result of inadequate cooling during drilling out of the central hole may have caused the material to locally over-age.
- Quench sensitivity: the extrusion has a large diameter, so it is possible that equilibrium precipitation occurred near the centre-line on quenching, which would reduce the capacity for age hardening.

[2 marks]

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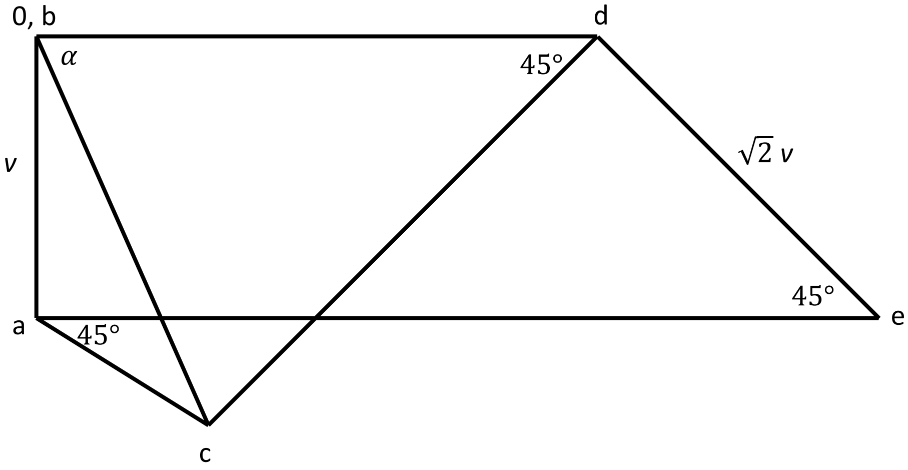
Q2 (a) (i) Velocity diagram



[5 marks]

(ii) Geometry: $\sin\alpha = \frac{3}{\sqrt{10}}$, $\cos\alpha = \frac{1}{\sqrt{10}}$

Relative velocities:

$v_{bc}\cos\alpha = \frac{v_{ac}}{\sqrt{2}}$, $v_{bc}\sin\alpha = v + \frac{v_{ac}}{\sqrt{2}}$ $\quad \therefore v_{bc} = \frac{\sqrt{10}}{2}v$, $v_{ac} = \frac{\sqrt{2}}{2}v$

$\frac{v_{cd}}{\sqrt{2}} = v + \frac{v_{ac}}{\sqrt{2}} = \frac{3}{2}v \quad \therefore v_{cd} = \frac{3\sqrt{2}}{2}v$

$v_{de} = \sqrt{2}v$

$v_{0d} = v_{bc}\cos\alpha + \frac{v_{cd}}{\sqrt{2}} = \frac{v}{2} + \frac{3v}{2} = 2v$

$v_{ae} = \frac{v_{ac}}{\sqrt{2}} + \frac{v_{cd}}{\sqrt{2}} + v = \frac{v}{2} + \frac{3v}{2} + v = 3v$

Work done (half model):

Interface	Length	Sliding velocity	Power
BC	$\sqrt{10}W$	$\sqrt{10}v/2$	$5kWLv$
AC	$\mathbf{2\sqrt{2}W}$	$\mathbf{\sqrt{2}v/2}$	$\mathbf{2kWLv}$
CD	$\sqrt{2}W$	$3\sqrt{2}v/2$	$3kWLv$
0D	**2W**	$\mathbf{2v}$	$\mathbf{4kWLv}$
DE	$\sqrt{2}W$	$\sqrt{2}v$	$2kWLv$
AE	$\mathbf{W}$	$\mathbf{3v}$	$\mathbf{3kWLv}$
			Total = $19kWLv$

Work balance: $\frac{F}{2}v = 19kWLv$, $F = 38kWL$

[8 marks]

(iii) Contribution of friction shown in bold above: 9/19 = 47% of total power

[2 marks]

(b) (i) The critical location is that which cools the most slowly, which is likely to be somewhere on the symmetry axis of the forging. A bar of diameter $D_e = 3W$ is slightly larger than a circle inscribed within the bar on the symmetry line. This is reasonable, given that the material at the edges (e.g. blocks D and E) will slow the cooling rate.

[2 marks]

(ii) $D_e = 3 \times 20$ mm = 60 mm . From the CCT: phases are approximately 50% ferrite, 50% bainite. Surface hardness can be read from the left hand axis: 430 HV .

[3 marks]

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Q3 (a) (i) Surface treatments:

- Paint: Physical barrier, protecting the surface from contact with moisture and oxygen, preventing wet corrosion. Prevents oxidation at high temperatures.
- Shot peening: Surface plastic deformation, resulting in a residual compressive stress. Will extend fatigue life, by delaying crack initiation. The work hardening will also increase abrasion resistance.
- Laser hardening: Rapid heating and cooling results in transformation hardening. This will increase the abrasion resistance of the surface.
- Galvanisation: Zinc coating will corrode preferentially to the steal substrate, providing protection against wet corrosion.

[8 marks]

(ii) Problems:

- Paint: May degrade at high temperatures. Could be damaged by abrasive dust, limiting effectiveness. Could crack under cyclic straining.
- Shot peening: Local work hardening could increase the susceptibility to wet corrosion.
- Laser hardening: No protection against wet corrosion. If surface ductility is reduced, could be susceptible to the initiation of fatigue cracks.
- Galvanisation: High temperatures could melt the zinc, risking liquid metal embrittlement.

[4 marks]

(b) Replacement material:

(i) Manufacturing route:

- Stainless steel: extrusion or drawing
- Nylon: extrusion, possibly injection moulding
- Silicon nitride: powder processing (sintering)

[3 marks]

(ii) Suitability:

- Stainless steel: High strength alloy, will resist fatigue crack initiation and abrasion. Suitable for high temperature environment. Corrosion resistant.
- Nylon: Unsuitable for these operating temperatures. Also, the moist environment would lead to water absorption and dimensional changes. Low hardness would make it susceptible to abrasion.
- Silicon nitride: Suitable for a high temperature environment, hard and wear resistant. But low toughness. May be vulnerable to strains induced by variations in thermal expansion. Would be very expensive to manufacture, compared to the other options.

[5 marks]

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Q4 (a) Semi-crystalline thermoplastic polymer:

(i) Shape:

- A tubular section would require thick walls to maintain adequate stiffness, which would lead to issues with shrinkage. A solid cross-section would reduce the complexity of the dies, but would lead to further shrinkage problems.
- If the tubular section is long, then fluidity issues would need to be considered, to ensure adequate mould filling. Might be vulnerable to weld line defects.
- Variations in section thickness would need to be avoided, particularly at the mounting brackets. This would lead to sink marks, affecting quality.

[3 marks]

(ii) Process variables:

- Injection pressure: a higher pressure would help to compensation for shrinkage in thick sections.
- Hold-on time: keeping the component under pressure for longer would again counteract the effects of shrinkage.
- Mould temperature: A high enough temperature is needed to ensure low melt viscosity, good mould filling and avoidance of defects at weld lines. But a high mould temperature also reduces cooling rates, increases the degree of crystallinity and increases shrinkage.

[4 marks]

(iii) Polymer molecular structure:

- Chain length and side groups affect molecular mobility and therefore ability to crystallise: more complex molecules means slower crystallisation.
- Slower crystallisation means lower percentage crystallinity in the component. This means less shrinkage, but also a lower elastic modulus.
- Molecular structure may also affect the viscosity of the molten polymer, which could affect mould filling and related defects.

[3 marks]

(b) Additives:

- Filler particles could be added to increase the elastic modulus, allowing section thicknesses to be reduced, and hence benefiting shrinkage problems.
- Fire retardants could be added, to improve the safety of the polymer components for public transport applications.
- Anti-ageing additives could be used to prevent UV degradation, and extend lifespan.
- Disadvantages: additional cost, need to understand impact on processing parameters (changes to viscosity etc), affects the ability to recycle the material.

[4 marks]

(c) (i) There would be difficulties with shaping, if the whole assembly were manufactured from CFRP. The tubular section can be economically manufactured using e.g. filament winding. But the mounting brackets would require more expensive and labour intensive processes, such as hand layup. Fibre discontinuities at the tube-bracket interface would also be vulnerable mechanically, requiring extra reinforcement and therefore weight.

[2 marks]

(ii) Joining processes:

- Hot-plate welding: Relies on hot plastic deformation, so unsuitable for this material combination. The epoxy matrix won't soften significantly on heating.
- Riveting: Suitable for this material combination. Relatively inexpensive. But will introduce stress concentrations in the composite component, damaging fibres and interfaces, potentially reducing the component lifespan.
- Adhesive bonding: The most suitable option. Compatible with this material combination. Will not damage the composite.

[4 marks]

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