Loughborough University

24MPP565

Advanced Processing of Materials

Semester 2 2024/25 | In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Answer **ALL THREE** questions

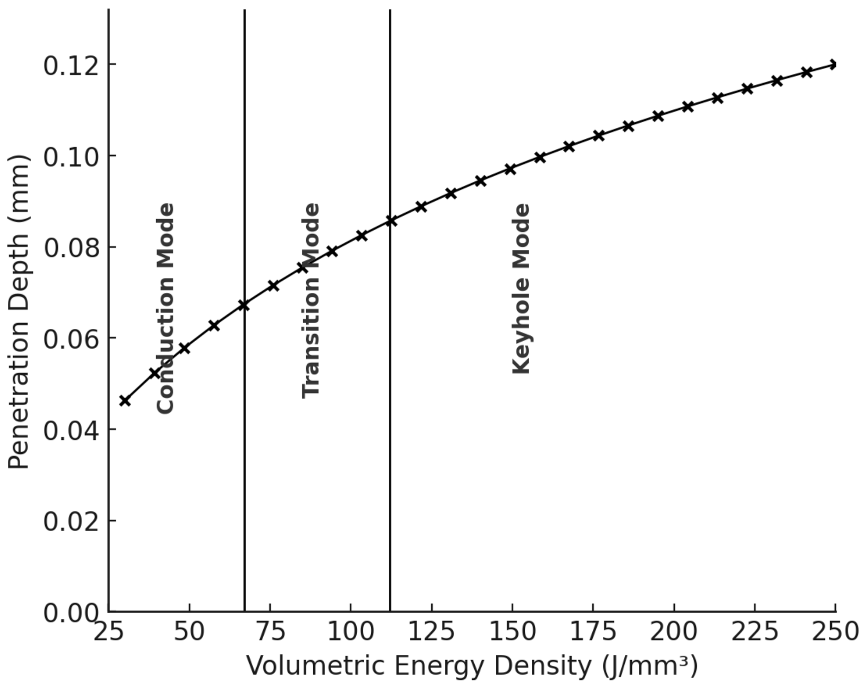
1. Laser-based powder bed fusion (LPBF) is used to process stainless steel powder with a particle size distribution of 5 – 100 μm and a mean diameter of 35.80 μm. The layer thickness is maintained at 40 μm, to account for the average powder size.

   The volumetric energy density (VED) is calculated using Equation 1, and the process parameters are listed in Table 1:

$$\text{VED}=\frac{P}{v\times h\times t} \qquad \text{[Equation 1]}$$

Table 1 Process Parameters:

Laser Powers (W):	200, 250, 400
Scanning Speeds (mm/s):	650, 750, 850, 950, 1050, 1150, 1250, 1350
Hatching Space (μm):	90
Layer Thickness (μm):	40
Spot Size (μm):	100



(a)

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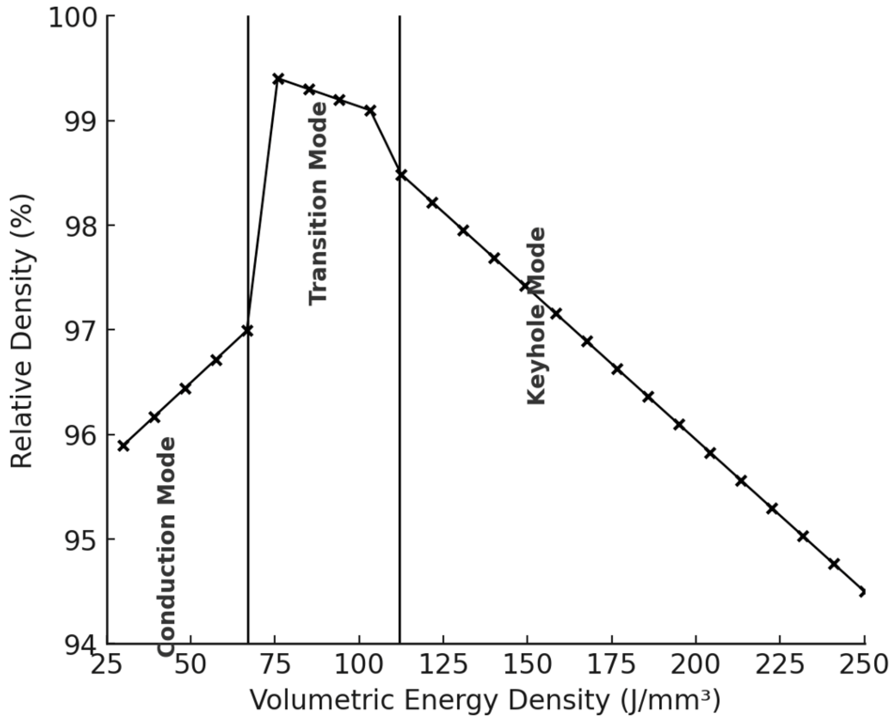
Q1 Continued/…



(b)

Figure 1 (a) penetration depth as a function of volumetric energy density for LPBF of stainless steel. (b) Relative density vs VED of LPBF fabricated stainless steel.

(a) For each set of process parameters below, calculate the VED and use the provided graph (Figure 1) and Table 1 to determine the melt mode. Give your answer for VED to two decimal places.

(i) Laser power of 200 W, and a scanning speed of 1350 mm/s. [2 marks]

(ii) Laser power of 400 W, and a scanning speed of 750 mm/s [2 marks]

(iii) Explain different defects formed when VED is at the low end of the conduction mode compared to when it is at the high end of the keyhole mode. [4 marks]

(b) Using the provided Relative Density vs. Volumetric Energy Density graph as shown in Figure 1 (b) and the process parameters given in Table 1, recommend an optimised combination of laser power and scanning speed that maintains high density in the part produced using LPBF of stainless steel and justify your choice. [4 marks]

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Q1 Continued/…

(c) A part which includes three holes of diameter 11 mm, 25 mm and 6 mm respectively is shown in Figure 1 (c). This part is to be manufactured using Selective Laser Melting (SLM) additive manufacturing on a 200 mm × 200 mm base plate. Considering the three build orientation options illustrated (Cases 1, 2 and 3), discuss the advantages and limitations of the build orientations by considering any four factors. [8 marks]

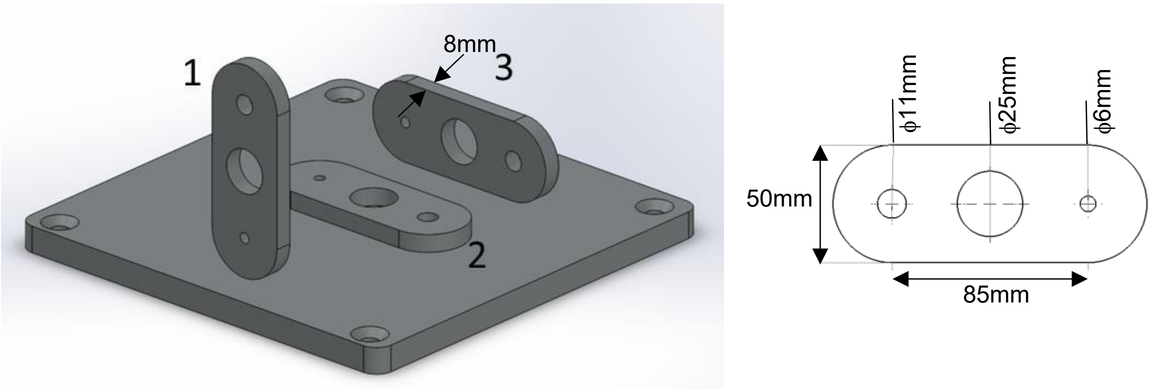

Figure 1 (c) Three different build orientations and dimension of the part.

2. (a) State and explain the advantages of using single-crystal Ni-based superalloy turbine blades compared to turbine blades with equiaxed or directionally solidified structures.

[6 marks]

(b) Describe how grain growth is controlled to produce a single-crystal turbine blade.

[4 marks]

(c) Al-4Cu (wt.%) is a heat treatable aluminium alloy. As a result of the ageing process, the strength of the alloy changes over time. Sketch a graph that plots the strength of the alloy as a function of ageing time, explaining the shape of the curve. [4 marks]

(i) In the underaged condition, the strength increment, $\Delta\tau$, of an aluminium alloy due to precipitates of radius, r, can be described using the following equation:

$$\Delta\tau = 4.1G\varepsilon^{1.5}\left(\frac{rV_f}{b}\right)^{0.5} \quad \text{[Equation 2]}$$

where G is the shear modulus, ε is a precipitate/matrix misfit strain, r is the precipitate radius, V_f is the volume fraction of precipitates and *b* is the magnitude of the Burgers vector. In the overaged condition, the strength increment can be described using the following equation:

$$\Delta\tau = \frac{Gb}{\lambda} \quad \text{[Equation 3]}$$

Where λ is the precipitate spacing.

$$\lambda^2 = \left(\frac{2\pi r^2}{3V_f}\right) \quad \text{[Equation 3]}$$

Calculate the precipitate radius at peak strength and the strength increment of the alloy at the peak radius. Give your answers to two decimal places.

Use the following data for calculation: ε = 0.012, V_f = 0.03, G = 28 GPa and b = 0.28 nm. [6 marks]

3. (a) $BaTiO_3$ electroceramics are often produced using a cold sintering processing step.

   (i) Describe the role of the transient solution which is formed between grains during cold sintering. [3 marks]

   (ii) Explain why pressure needs to be applied during cold sintering. [2 marks]

   (iii) Explain why post-annealing is often carried out after cold sintering to enhance the properties of the final $BaTiO_3$ electroceramic. [5 marks]

   (b) Two densified ceramic samples have the same composition of $BaTiO_3$, but with different average grain sizes (20 μm and 1 μm respectively). Sketch the polarisation versus electric field hysteresis (*P*-*E*) loops at room temperature for BOTH samples. Justify the difference in ferroelectric behaviours if any. [5 marks]

   (c) A cylindrical shaft for an aerospace component is machined from a Ti-6Al-4V billet. The billet is a solid cylinder with a diameter of 0.8 m and a height of 0.4 m. The final part is a hollow cylindrical shaft with an outer diameter of 0.66 m, a wall thickness of 15 mm, and the same height (0.4 m).

   (i) Calculate the *buy-to-fly* ratio, where the density of Ti-6Al-4V is 4430 kg/m³. Give your answer to two decimal places. [2 marks]

   (ii) If the Material Removal Rate (MRR) is 16 mm³/s and the specific cutting energy is 3.9 Ws/mm³, calculate the total electrical energy in kWh required to machine the part. Give your answer to two decimal places. [3 marks]

   Use the following equation and data for calculation:

   $$\text{Power} = \text{MRR} \times k \qquad \text{[Equation 4]}$$

   1 Ws = 1 J ; 1 kWh = 3.6×10^6 J

END OF PAPER

Dr Y Y Tse