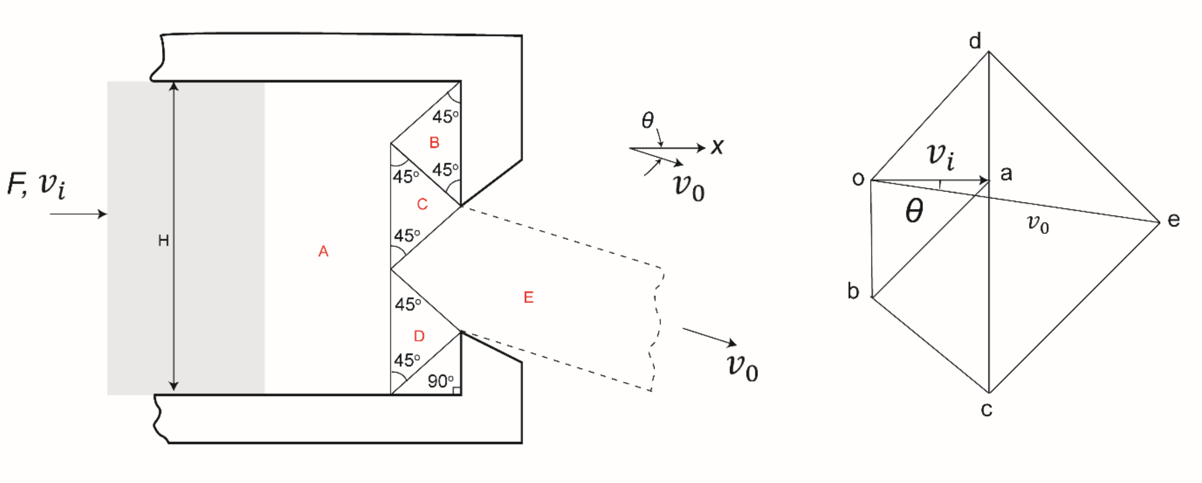
1(a) (i)



$$tan\theta = \frac{0.5\ v_0}{2.5v_0} = 0.2$$
$$\theta \sim 11^o$$

(ii)

Interface	Length	Velocity	Internal power per unit depth
ab	$\sqrt{2}H/5$	$\sqrt{2}v_i$	$2kHv_i/5$
bc	$\sqrt{2}H/5$	$\sqrt{2}v_i$	$2kHv_i/5$
ce	$\sqrt{2}H/5$	$3v_i/\sqrt{2}$	$kHv_i/5$
de	$\sqrt{2}H/5$	$3v_i/\sqrt{2}$	$3kHv_i/5$
ac	$2H/5$	$2v_i$	$4kHv_i/5$
ad	$2H/5$	v_i	$4kHv_i/5$

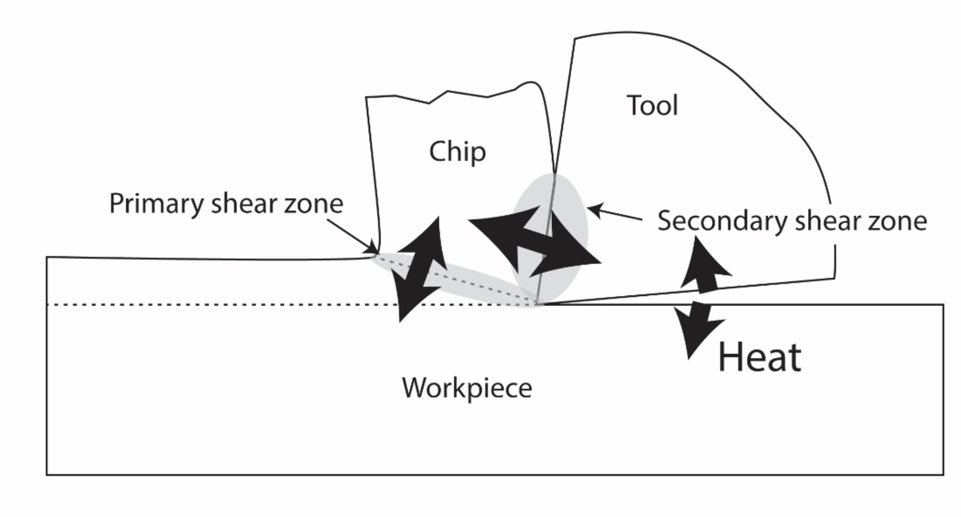
Total $16kHv_i/5$

External power per unit depth = Fv_i
Internal power per unit depth = $16\ kHv_i/5$
Equate external and internal power:
$Fv_i = 16\ kHv_i/5 \ => F = 16\ kH/5$

(b) (i) The assumptions are:

1. All the plastic work is dissipated as heat.
2. Adiabatic heating.
3. Temperature rise is dominated by heat from the primary shear zone.

(ii)

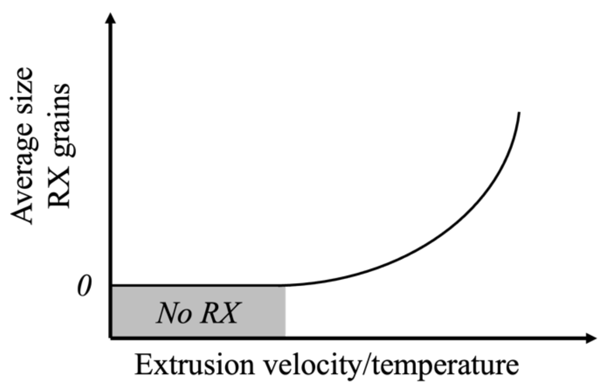


In machining processes, the temperature rise is a critical aspect due to the intense plastic deformation and friction involved. The temperature rise occurs primarily in two key zones:

1. **Primary shear zone**: Where the bulk of plastic deformation occurs as the material is sheared to form the chip.
2. **Secondary shear zone**: Where frictional heating occurs due to the sliding of the chip on the rake face of the cutting tool.

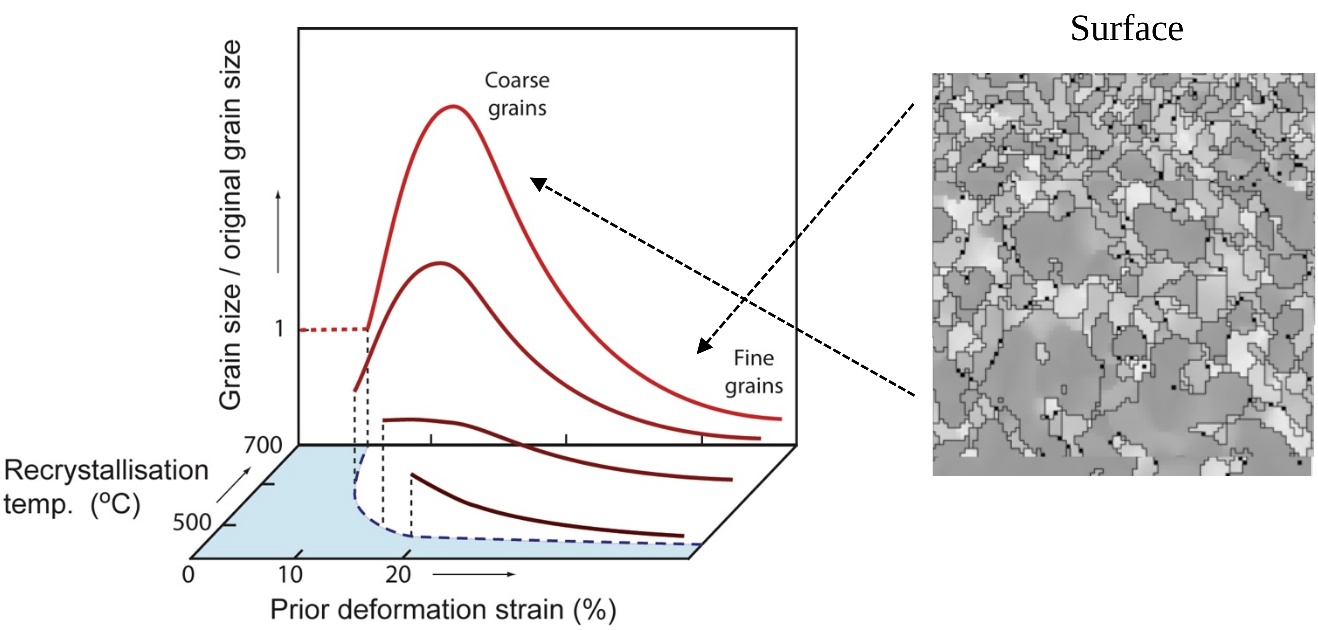
(iii) The intensity of heat is generally higher at the tool-chip interface (Secondary shear zone) compared to the primary zone. As a result, the secondary shear zone is larger and have higher peak temperatures than the average values calculated.

(c) (i) Since plastic strain does not vary with extrusion velocity, the average grain size of recrystallised grains increases exponentially with temperature (following an Arrhenius law). Below a certain velocity, the temperature is too low to promote recrystallisation. As the velocity/temperature increases, more and more recrystallised grains nucleate and grow.



smaller average grain size (locally). See the relationship between strain and grain size in RX

(ii) Because the strain induced in the material is non-uniform and maximum at the contact surface with the die. This may result in a higher nucleation rate of RX grains and thus a as well as schematic microstructure below.



2 (i) To solve this problem, it is simpler to break down the dumbbell geometry into three cylinders (2 for the ends and 1 for the handle).
The total volume of the entire dumbbell is going to be the sum of the volumes of these three parts, while its total area is going to be the sum of the areas of these three parts minus 4 times the area of the handle face (where the handle is joint to the two ends).
We can also compute the total volume and area of the ½ dumbbell design by halfing the volume of the entire dumbbell and by taking ½ the total area of the dumbbell plus 1 time the area of the handle face.

The numerical values of these quantities are reported in the following table:

	cylinder	**rod**	**dumbbell**	**1/2 dumbbell**
Area [cm^2]	589.048623	276.460154	1404.29192	702.1459581
Volume [cm^3]	883.572934	251.327412	2018.47328	1009.23664

Hereafter we calculate the volme/area ratio and apply Chvorinov’s rule to compute the solidification time, t_s, for all these parts:

	cylinder	**rod**	**dumbbell**	**1/2 dumbbell**
V/A	1.5	0.90909091	1.43736018	1.437360179
Solidification time [min]	32.4	11.9008264	29.7504617	29.75046169

The difference in solidification time between the entire dumbbell and ½ dumbbell is negligible.

(ii)
The reason why there is no difference in solidification time is that the V/A ratio difference between the entire dumbbell and the ½ dumbbell is minimal since the handle contributes very little to it. It is also noteworthy that in this calculation we assume the 2 ends in the dumbbell design to start solidify at the same time. So, taking one out of the mould will not shorten the casting process.

(iii)
It follows from (ii) that the re-design brings little to no advantage in terms of productivity. It may allow producing smaller moulds, but the savings in terms of cost are minimal assuming that the mould has must be prepared manually (e.g., using sand casting). On the other hand, the additional welding step required to make dumbbells from ½ dumbbells is going to add to the production cost and time. Thus, the redesign is actually detrimental to productivity and cost.

(iv)
Casting in the orientation shown in Figure 2B is better than the alternative orienatation (upside down) since the section that will take longer to solidify is closer to the top of the mould (and thus to the risers). Flipping the orientation of the casting may result in a choked metal flow and the formation of shrinking defects in the buler part of the design.

(v)
No. Cast iron will not form martensite or other brittle phases as a result of the fast cooling during welding. Moreover, even if it did, it would probably not be an issue given that dumbbells are not used in structural applications and thus must not carry loads.

3 (a) (i) Residual stresses in gears are introduced during manufacturing processes like machining, grinding, or heat treatment, and can cause failure in service. These stresses may lead to surface cracking, distortion, or stress corrosion cracking, especially when combined with external loads during operation.
<u>Mitigation:</u> Shot peening or laser peening to introduce beneficial compressive residual stresses.

(ii) “Liberty Ships” failed due to brittle fracture exacerbated by the cold temperatures. The materials used, such as low-quality welded steel, had poor strength at low temperatures, causing cracks to propagate rapidly under stress.
<u>Mitigation:</u> Use of low-carbon or alloy steels with high toughness and ductility at low temperatures (e.g., steels with improved Charpy impact test results).

(iii) Cyclic loading, especially in rolling contact, can lead to fatigue failure due to repeated stress cycles (example: railway tracks). Over time, this causes surface cracks, pitting, or spalling, reducing the component’s life.
<u>Mitigation:</u> Use coatings to reduce wear and periodically inspect to replace worn components.

(iv) Sodium lubricants in nuclear reactors can pose issues such as chemical reactivity, particularly with water or air, and lead to material degradation (e.g., embrittlement or corrosion).
<u>Mitigation</u>: Explore less reactive/corrosive coolant alternatives in reactor designs.

(b) (i) **Short-Fiber Composites** are the ideal choice for the EV dashboard support structure:

- They meet the mechanical load and vibration requirements for the application.
- Their manufacturing processes (e.g., injection moulding) are well-suited to creating the complex geometries needed for mounting points.
- They are cost-effective, aligning with the automotive industry’s emphasis on economical large-scale production.

(ii) **Vehicle’s chassis support is a critical structural component**, making **Long-Fiber Composites** the most suitable material selection due to their superior mechanical properties. These composites can handle high loads and provide the necessary structural support.

4 (a) **Design consolidation**: less joints and thus a reduced number of possible failure points in the part. **Weight reduction**: LPBF allows to optimise the geometry of structural components (using for instance topology optimisation tools) for maximum strength-to-weigth ratio.

(b) (i) DED allows to produce partswithout support structures. This is an advantage since support structures are “wasted” material and requireinvolved post-processing to be removed.

(ii) They typically yield poorer surface finish, which is going to be problematic for structural application since surface asperities may act as stress concentrators and initiate fatigue cracks.

(iii) DED does not require a powder bed. Therefore, the heat input from melting and solidification of metal can only be transferred through the already built sections of the part into the build platform. This results into lower cooling rates compared to LPBF, wherein the powder bed acts as heat sink throughout the entire manufacturing process. Itw also leads to thermal build ups during manufacturing which may induce differential cooling and thus different phase transformations throughout the build. This phenomenon causes scatter in mechanical properties, making the certification of DED-built parts more challenging.

(c) (i) From welding, we would expect to see the formation of martensite because of the very rapid cooling rates that characterise these additive manufacturing processes. However, as more and more layers of material are deposited/consolidated on top of this initial microstructure, we would expect it to transform to a more equilibrated microstructure through tempering.

(ii) However, it is challenging to estimate the final microstructure of parts produced by laser-based additive manufacture because it depends on the cyclic thermal treatments induced by the scanning laser, the path of the laser itself, as well as the geometry of the part.