Name: ………………...

Prename: …………………

You will have 60 minutes to solve the following 4 questions (in real exam up to 9 for 120min).

All necessary additional information, where the software would be needed, is given in the Appendix.

1. Derive Materials Indices

Show that the best material choice for a cantilever beam of given length *L* and with a given section (*t* x *t*) that will deflect least under its own self-weight is that with the largest value of $M = E/\rho$, where ρ is the density.

Start by listing the function, the objective and the constraints. You will need the equations for the deflection of a cantilever beam with a square cross-section *t* x *t*. The deflection of a beam under a distributed load *f* per unit length:

$$\delta = \frac{1}{8}\frac{fL^4}{EI}$$

where *I* is given in the table on the next page. For a self-loaded beam $f = \rho A g$ where ρ is the density of the material of the beam, *A* its cross-sectional area and *g* the acceleration due to gravity.

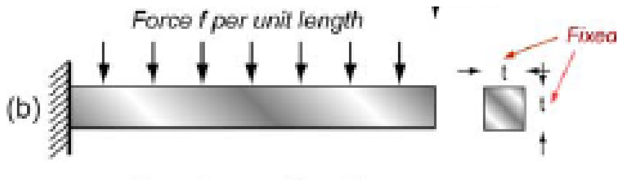


Figure 1

Function	
Constraints	
Objective	
Free variables	

Function	• *Self-loaded cantilever beam*
Constraints	• *Length L specified* • *Section t x t specified*
Objective	• *Minimize the deflection, δ*
Free variables	• *Choice of material only*

The beam carries a distributed load, f per unit length, where

$$f = \rho \; g \; t^2$$

where ρ is the density of the beam material and g is the acceleration due to gravity and $I=t^4/12$ from the table. Such a load produces a deflection

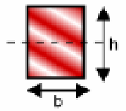
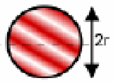
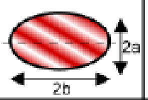
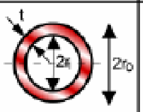
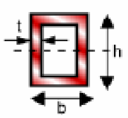
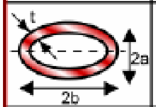
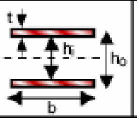
$$\delta = \frac{3}{2}\frac{fL^4}{Et^4} = \frac{3}{2}\frac{gL^4}{t^2}\left(\frac{\rho}{E}\right)$$

(the objective function). As before, t and L are given. The deflection is minimized by maximizing

$$M = E/\rho$$

Comments: ………………………………………………………………………………………………………
……
……
……

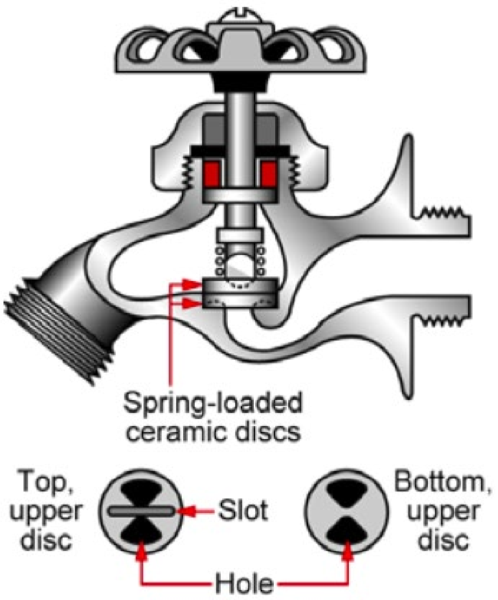
2. Moments of sections.

Section shape	Area A m	Moment I m⁴	Moment K m⁴	Moment Z m⁴	Moment Q m⁴	Moment Z p m⁴
	bh	$\frac{bh^3}{12}$	$\frac{bh^3}{3}(1-0.58\frac{b}{h})$ (h > b)	$\frac{bh^2}{6}$	$\frac{b^2h^2}{(3h+1.8b)}$ (h > b)	$\frac{bh^2}{4}$
	$\frac{\sqrt{3}}{4}a^2$	$\frac{a^4}{32\sqrt{3}}$	$\frac{\sqrt{3}a^4}{80}$	$\frac{a^3}{32}$	$\frac{a^3}{20}$	$\frac{3a^3}{64}$
	πr^2	$\frac{\pi}{4}r^4$	$\frac{\pi}{2}r^4$	$\frac{\pi}{4}r^3$	$\frac{\pi}{2}r^3$	$\frac{\pi}{3}r^3$
	πab	$\frac{\pi}{4}a^3b$	$\frac{\pi a^3b^3}{(a^2+b^2)}$	$\frac{\pi}{4}a^2b$	$\frac{\pi}{2}a^2b$ (a < b)	$\frac{\pi}{3}a^2b$
	$\pi(r_o^2-r_i^2)$ $\approx 2\pi rt$	$\frac{\pi}{4}(r_o^4-r_i^4)$ $\approx \pi r^3 t$	$\frac{\pi}{2}(r_o^4-r_i^4)$ $\approx 2\pi r^3 t$	$\frac{\pi}{4r_o}(r_o^4-r_i^4)$ $\approx \pi r^2 t$	$\frac{\pi}{2r_o}(r_o^4-r_i^4)$ $\approx 2pr^2 t$	$\frac{\pi}{3}(r_o^3-r_i^3)$ $\approx \pi r^2 t$
	$2t(h+b)$ $(h,b >> t)$	$\frac{1}{6}h^3t(1+3\frac{b}{h})$	$\frac{2tb^2h^2}{(h+b)}(1-\frac{t}{h})^4$	$\frac{1}{3}h^2t(1+3\frac{b}{h})$	$2tbh(1-\frac{t}{h})^2$	$bht(1+\frac{h}{2b})$
	$\pi(a+b)t$ $(a,b >> t)$	$\frac{\pi}{4}a^3t(1+\frac{3b}{a})$	$\frac{4\pi(ab)^{5/2}t}{(a^2+b^2)}$	$\frac{\pi}{4}a^2t(1+\frac{3b}{a})$	$2\pi t(a^3b)^{1/2}$ (b>a)	$\pi abt(2+\frac{a}{b})$
	$b(h_o-h_i)$ $\approx 2bt$ $(h,b >> t)$	$\frac{b}{12}(h_o^3-h_i^3)$ $\approx \frac{1}{2}bth_o^2$	--	$\frac{b}{6h_o}(h_o^3-h_i^3)$ $\approx bth_o$	--	$\frac{b}{4}(h_o^2-h_i^2)$ $\approx bth_o$
	$2t(h+b)$ $(h,b >> t)$	$\frac{1}{6}h^3t(1+3\frac{b}{h})$	$\frac{2}{3}bt^3(1+4\frac{h}{b})$	$\frac{1}{3}h^2t(1+3\frac{b}{h})$	$\frac{2}{3}bt^2(1+4\frac{h}{b})$	$bht(1+\frac{h}{2b})$
	$2t(h+b)$ $(h,b >> t)$	$\frac{t}{6}(h^3+4bt^2)$	$\frac{t^3}{3}(8b+h)$	$\frac{t}{3h}(h^3+4bt^2)$	$\frac{t^2}{3}(8b+h)$	$\frac{th^2}{2}\{1+\frac{2t(b-2t)}{h^2}\}$

2. Ceramic valves for taps.

Taps drip because the rubber washer is worn or the brass seat is pitted by corrosion, or both. Ceramics wear well, and they have excellent corrosion resistance in both pure and salt water. Many household taps now use ceramic valves.

The sketch shows how they work. A ceramic valve consists of two disks mounted one above the other, spring-loaded so that their faces are in contact. Each disk has a diameter of 20 mm, a thickness of 3 mm and weighs about 10 grams. In order to seal well, the mating surfaces of the two disks must be flat and smooth, requiring high levels of precision and surface finish; typical tolerance < 0.02 mm and surface roughness < 0.1 μm. The outer face of each has a slot that registers it, and allows the upper disc to be rotated through 90° (1/4 turn). In the "off" position the holes in the upper disc are blanked off by the solid part of the lower one; in the "on" position the holes are aligned. A production run of 10^5 – 10^6 is envisaged.



2.1 Please list all functions and constraints:

Function: a) Shape a ceramic valve

Constraints: b) Material class: Technical ceramic

c) Shape class: Prismatic

d) Mass: 0.01kg

e) Minimum section: 3mm

f) Tolerance : 0.02mm

g) Surface roughness : 0.1µm

h) Planned batch size: 10^5 -10^6

Free variables: Choice of process

2.2 Write down the typical evaluation steps and comment them.

………

General requirements → Concept → Embodiment → Detail study

………

or………

………

Evaluate: Function/Objectives → Constraints → Free variables

………

………

2.3 Please find appropriate production processes of such valves under the constraints mentioned above? (please **mark your choices in the tables and graphs** in the Appendix):

………

………

- Powder methods (e.g. Pressing and Sintering) and/or
- injection molding

………

………

………

………

………

………

Comments: ……………………………………………………………………………………………

………

All requirements fulfilled beside **Tolerance** and **Roughness:**

→ a separate **grinding** and/or **polishing** operation is required !

………

3. Materials Processing Technologies

3.1 Name at least 3 thermal treatment (annealing) processing methods for metal alloys. Explain for 2 Examples with a few sentences qualitatively the time and temperature processing conditions and the resulting microstructure

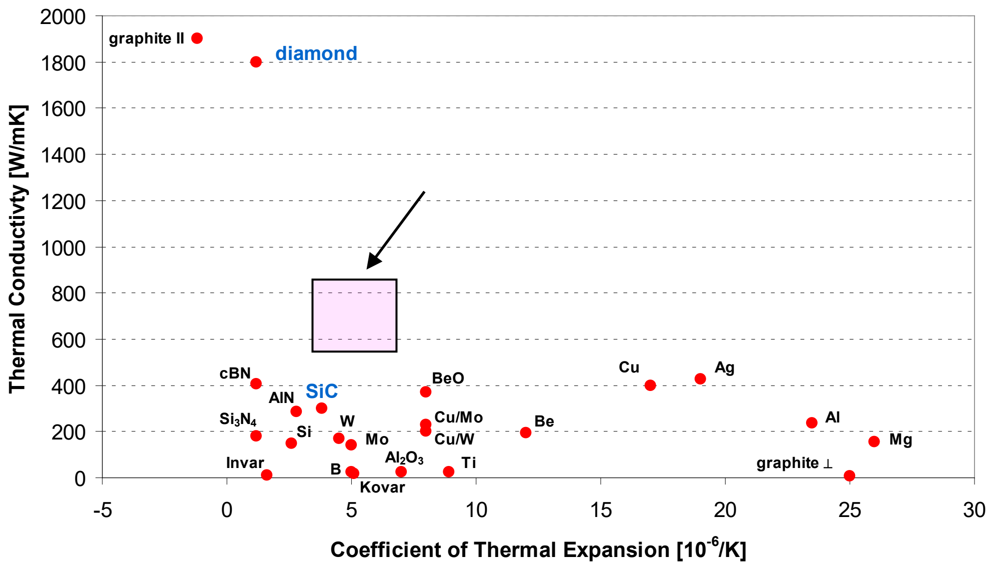
Annealing methods: Stress relief, Spherodize, Process Anneal, Full Anneal, Normalize, Quenching, Tempering of Martensite, precipiation hardening. We heat to annealing temperature and cool slowly (full aneal for instance) or quench (Martensite formation).

Normalize: Deform steel with large grains. Heat treat to allow for recrystallisation, and formation of smaller grains.
Precipitation hardening: heat to solutionise, quench to retain solid solution and and then reheat to nucleate small particles.

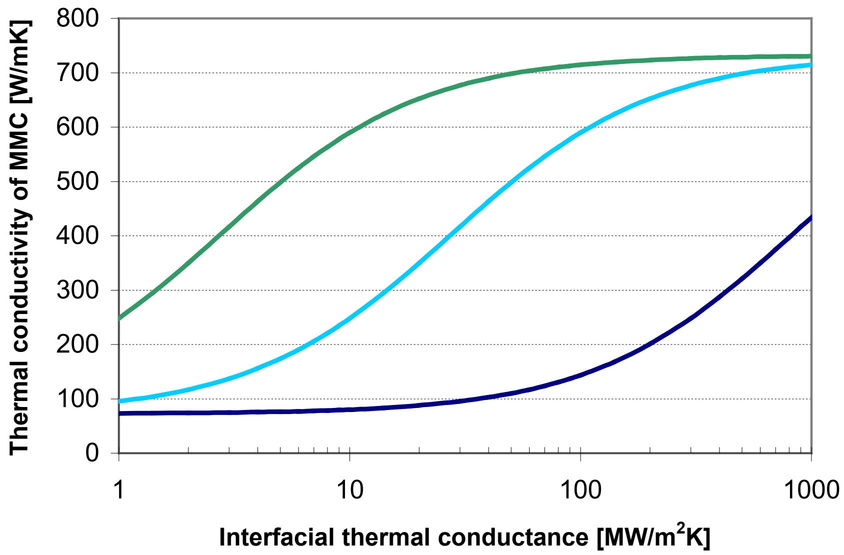
3.2 Describe the surface engineering process "PVD – Physical Vapour Deposition". Compare PVD to "Thermal Spraying" in terms of typical substrate temperatures during deposition and coating thickness.

Evaporation or sputtering of target and transfer of sputtered material in vacuum to the substrate where the film forms. PVD forms coatings with thickness of several microns whereas Thermal Spraying forms coatings with hundreds of microns thickness. PVD operate near room temperature up to 500°C whereas thermal spraying can reach up to 800°C.

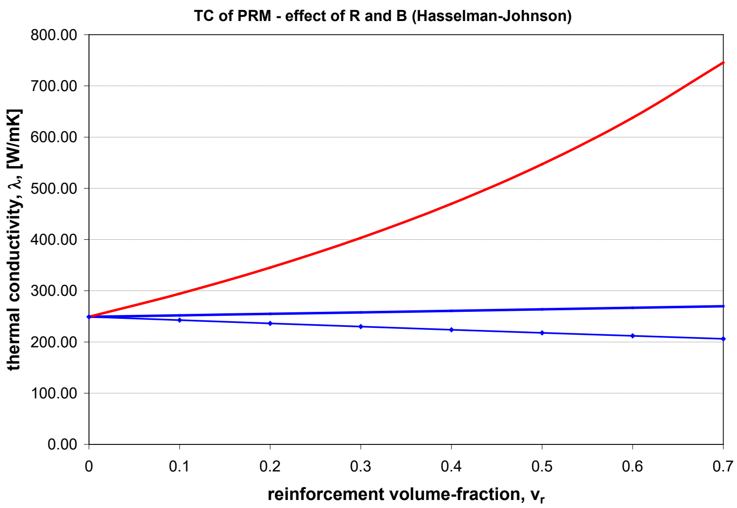
4. Hi power electronics requires the use of high thermal conductivity heat sinks. Targeted properties are about 600-800 W/(mK), and thermal expansion close to that of silicon chips (4-7ppm/K).



Info 1: thermal conductivity *vs* coefficient of thermal expansion.



Info 2: effect of the particle size on the effective thermal conductivity. 2, 60 and 600 microns diamonds in aluminium.



Matrix	Reinforcment	Particle size	Interfacial thermal conductance
Al	SiC	50 µm	8·1 W/m2·K
Al	Diamond	50 µm	8·1 W/m2·K
Al	SiC	6.4µm	8·1 W/m2·K

Info 3: effect of reinforcement volume fraction on the thermal conductivity of the composite

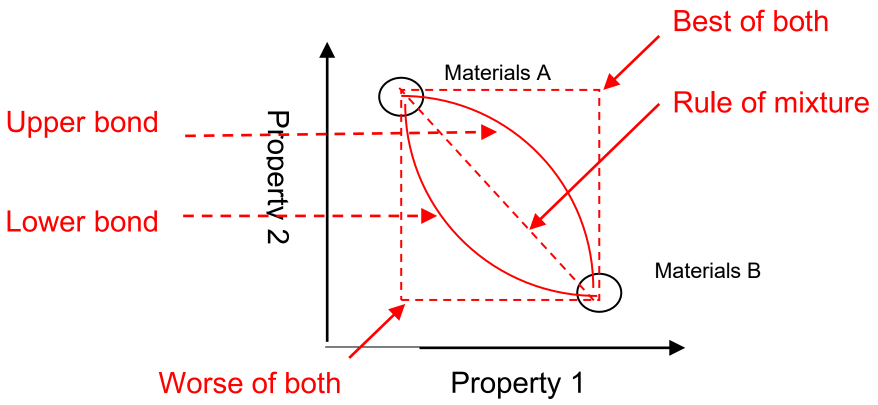
4.1 Explain the materials selection process to access the desired properties. Motivates the selection of the matrix and the reinforcement; discuss the thermal expansion coefficient issue; the thermal conductivity, for isotropic- or anisotropic composite; the volume fraction, the particle size and the influence of processing on the interfacial reaction (use and graphically complete info graphiques.1-3, if needed for your explanation)

1) select the configuration (isotropic particle reinforced composite)
2) select a metal with closest thermal conductivity from targeted 600W/mK; Cu, Al, Ag. Consider its too high thermal expansion
3) select material 2 (reinforcement) for its high thermal conductivity meeting the requirement but as having a too small coefficient of thermal expansion (diamond)
4) consider the expected mixing law for these particular properties, and the associated upper and lower bonds
5) adjust the relative fraction to enter the targeted square (info1)
6) select the particle size a) as large as possible to limit the total extend of the interface between the metal and the particles but b) reasonably small to allow machining (<100micron particle)
7) select the processing (squeeze casting of gas pressure infiltration) to obtain a high thermal interface conductance (->TC), and a mechanical load transfer(->CTE)
8) estimate the effective thermal conductivity by using the Hasselman-Johnson relation by assuming thermal interface conductance associated to the dedicated process.
9) Etc…

4.2 Name and briefly describe the additional material selection variables associated with the design of composites.

- **Components**: choice of materials to be combined
- **Configuration**: shape and connectivity of the components
- **Relative volume**: volume fraction of each component
- **Scale**: length-scale of the structural unit
- **Connectivity:** bend and stretch-dominated lattice structures

4.3. When combining two materials what can be expected from the properties? Give some examples and illustrate them on the graphic bellow



Example: Density follows the rule of mixture, zinc plated steel shows a best of both case (high strength, high corrosion resistance) etc…

Figure 4.4: shematic scatterplot representation of two properties

4.4. The electrical conductivity of a electrical insulating polymer have to be increased by addition of a metallic phase. Gives a materials selection strategy to obtain a high electrical conductivity while keeping the metallic volume fraction as low as possible

Starting from the given polymer, select an excellent electrical conductor (for ex Cu Au Ag), select the shape of the metallic phase. While using particles require a volume fraction close to 40% to reach electric percolation, using long fibers can significantly reduce the percolation threashold which is depending on the square root of the ratio of the fiber length by the fiber diameter.

Appendix:

Table 1: Process – Materials Matrix

	Process	Metals, ferrous	Metals, non-ferrous	Ceramics	Glasses	Elastomers	Thermoplastics	Thermosets	Polymer foams	Composites
Shaping	Sand casting	●	●							
	Die casting	●	●							
	Investment casting	●	●							
	Low pressure casting		●							
	Forging	●	●							
	Extrusion		●							
	Sheet forming	●	●							
	Powder methods	●	●	●						
	Electro-machining	●	●	●						
	Conventional machining	●	●	●	●	●	●	●	●	
	Injection molding		●	●	●	●	●	●	●	
	Blow molding				●		●			
	Compression molding				●	●	●	●		
	Rotational molding					●	●	●	●	
	Thermo-forming					●	●	●		
	Polymer casting					●	●	●	●	
	Resin-transfer molding						●	●	●	●
	Filament winding									●
	Lay-up methods									●
	Vacuum bag									●
Joining	Adhesives	●	●	●	●	●	●	●	●	●
	Welding, metals	●	●							
	Welding, polymers					●	●	●	●	
	Fasteners	●	●	●	●	●	●	●	●	●
Finishing	Precision machining	●	●				●	●		●
	Grinding	●	●	●	●					●
	Lapping	●	●	●	●					●
	Polishing	●	●	●	●		●	●		●

Table 2: Process – Shape Matrix

Group	Process	Circular prismatic	Non-circular prismatic	Flat sheet	Dished sheet	3-D solid	3-D hollow
Metal shaping	Sand casting	●	●			●	●
Metal shaping	Die casting	●	●			●	●
Metal shaping	Investment casting	●	●			●	●
Metal shaping	Low pressure casting	●	●			●	●
Metal shaping	Forging	●	●			●	
Metal shaping	Extrusion	●	●				
Metal shaping	Sheet forming	●	●	●	●		
Metal shaping / Ceramic shaping	Powder methods	●	●			●	●
Metal shaping / Ceramic shaping	Electro-machining	●	●	●		●	●
Metal shaping / Ceramic shaping / Polymer shaping	Conventional machining	●	●	●	●	●	●
Metal shaping / Ceramic shaping / Polymer shaping	Injection molding	●	●			●	●
Polymer shaping	Blow molding				●		●
Polymer shaping	Compression molding			●	●	●	
Polymer shaping	Rotational molding				●		●
Polymer shaping	Thermo-forming				●		
Polymer shaping	Polymer casting	●	●			●	●
Polymer shaping / Composite shaping	Resin-transfer molding	●	●	●	●	●	●
Composite shaping	Filament winding	●	●		●		●
Composite shaping	Lay-up methods			●	●	●	
Composite shaping	Vacuum bag			●	●		

Table 3: Process – Mass Range Matrix:

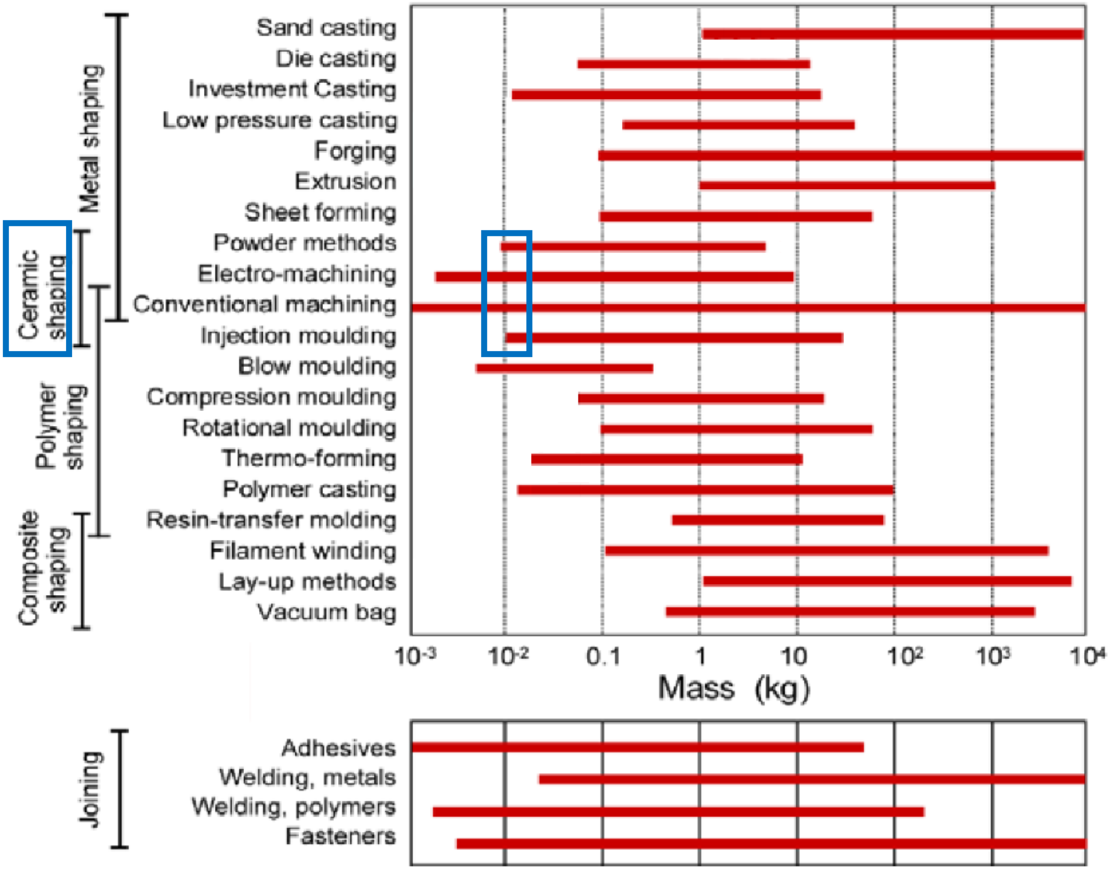


Table 4: Process – Section Thickness Matrix:

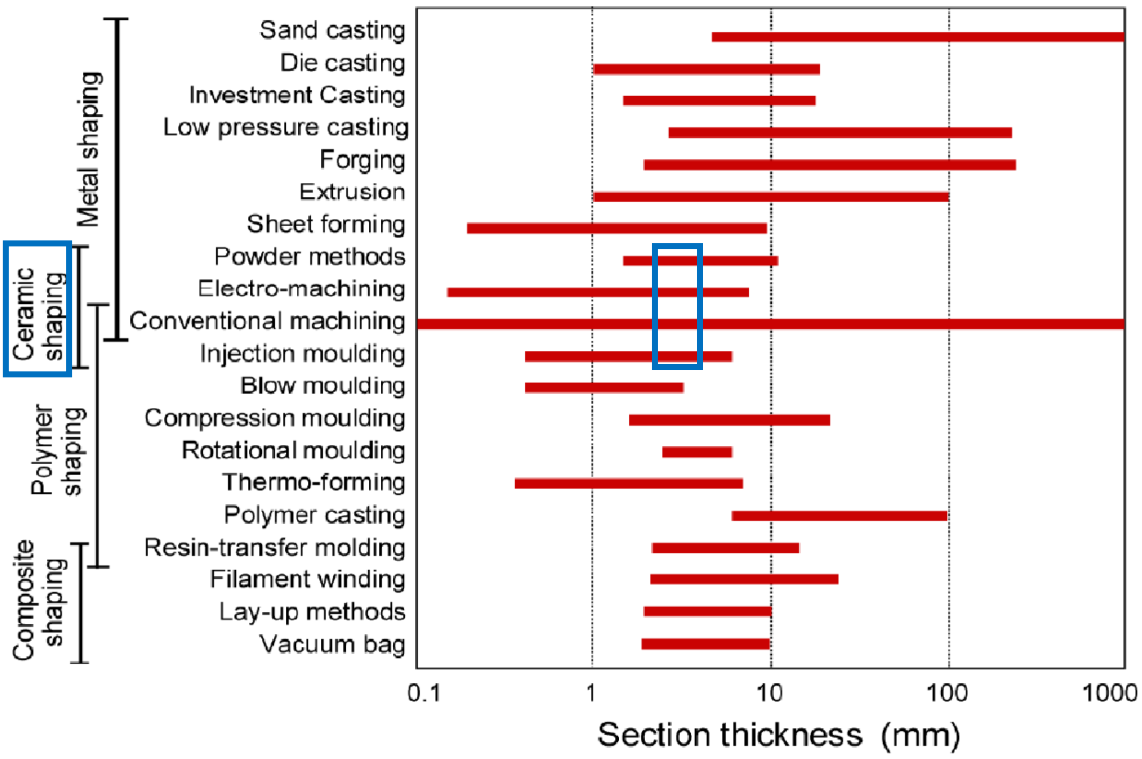


Table 5: Process – Tolerances Matrix:

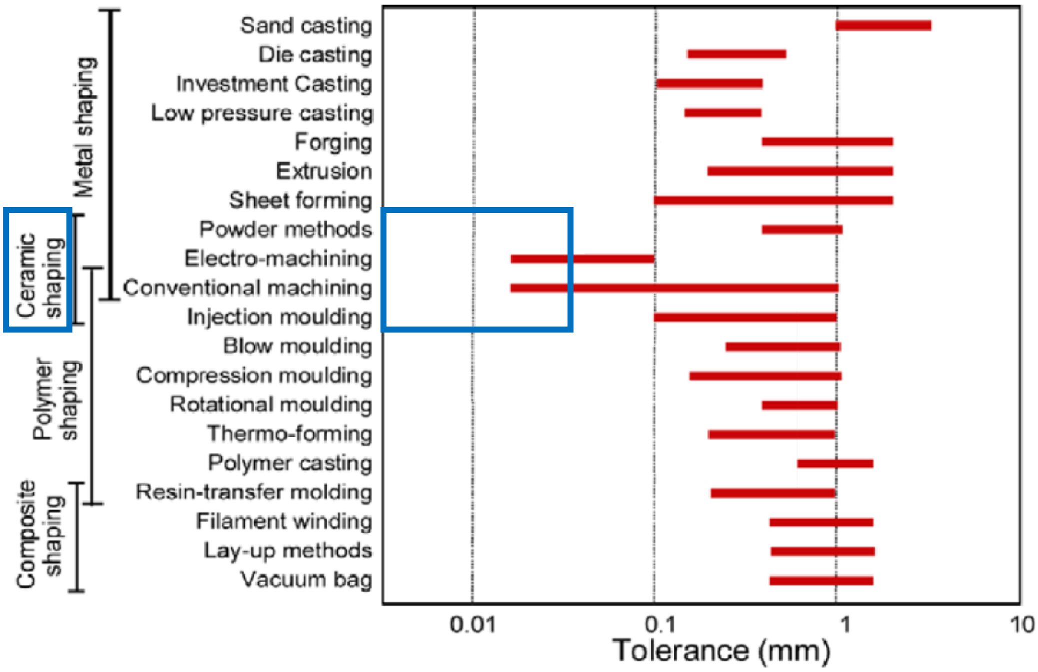


Table 6: Process - Roughness Matrix:

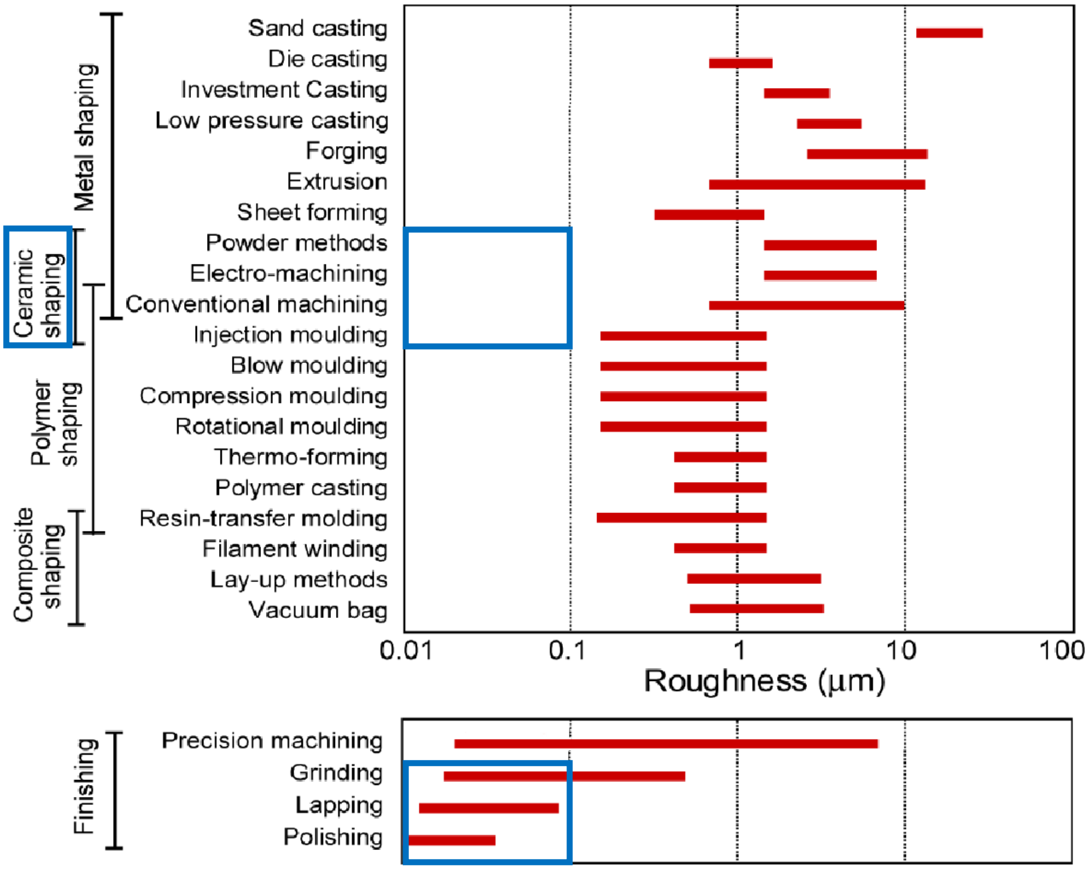


Table 7: Process – Economic Batch-Size: