Manufacturing processes and cost modeling

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Learning objectives for this lecture unit

Ansys software mentioned	• Ansys Granta EduPack™, a teaching software for materials education

Intended Learning Outcomes	
Knowledge and Understanding	Understanding of the cost model included in Ansys Granta EduPack software
Skills and Abilities	Ability to use a simple cost model to guide manufacturing process choice
Values and Attitudes	Appreciation of how costs influence the choice of material and processes

Resources

- Text: ***"Materials: engineering, science, processing and design"*** 4th edition by M.F. Ashby, H.R. Shercliff and D. Cebon, Butterworth Heinemann, Oxford, 2019, Chapters 1-2
- Text: ***"Materials Selection in Mechanical Design",*** 5th edition by M.F. Ashby, Butterworth Heinemann, Oxford, 2016, Chapters 1-2
- Texts: ***Callister, Budinski, Askeland and others*** – recommended reading in records
- Ansys Granta EduPack software

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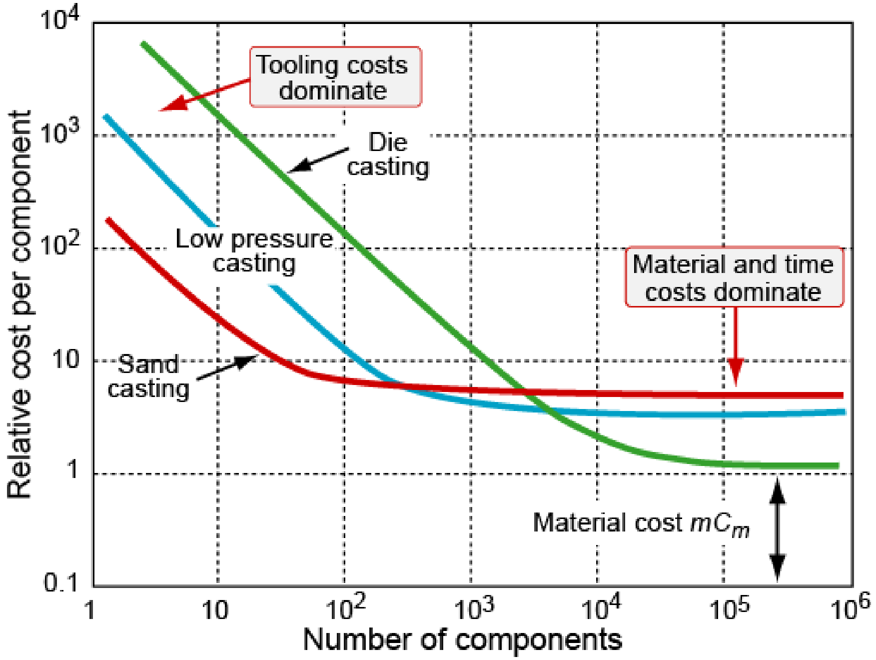
Outline of lecture unit



- ProcessUniverse and its organization
- Shaping, Joining and Surface treatment
- Price, cost and value
- Cost information in Ansys Granta EduPack software
- Inputs to a cost model for selection
- The model and its implementation
- Additive manufacturing
- Part cost estimator

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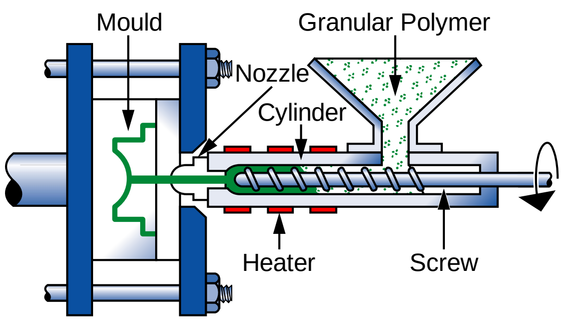
Organizing info: manufacturing processes

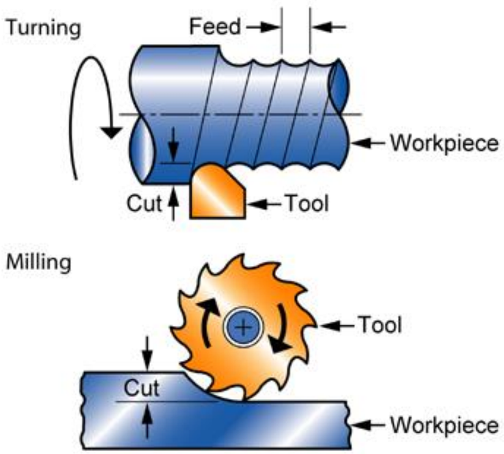
Primary shaping



Injection moulding

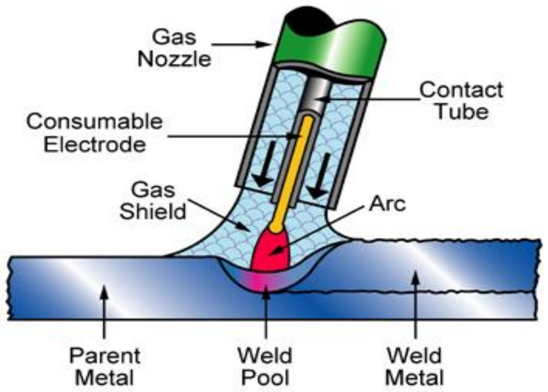
No.8-CMYK-5/01

Secondary shaping



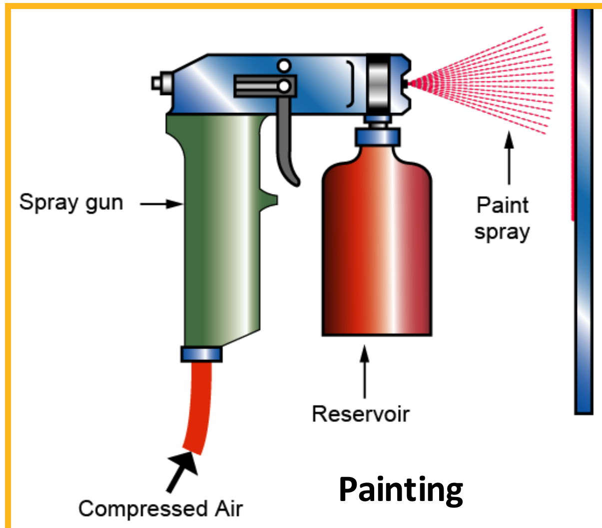
Machining

Joining



Welding

Surface treating



Painting

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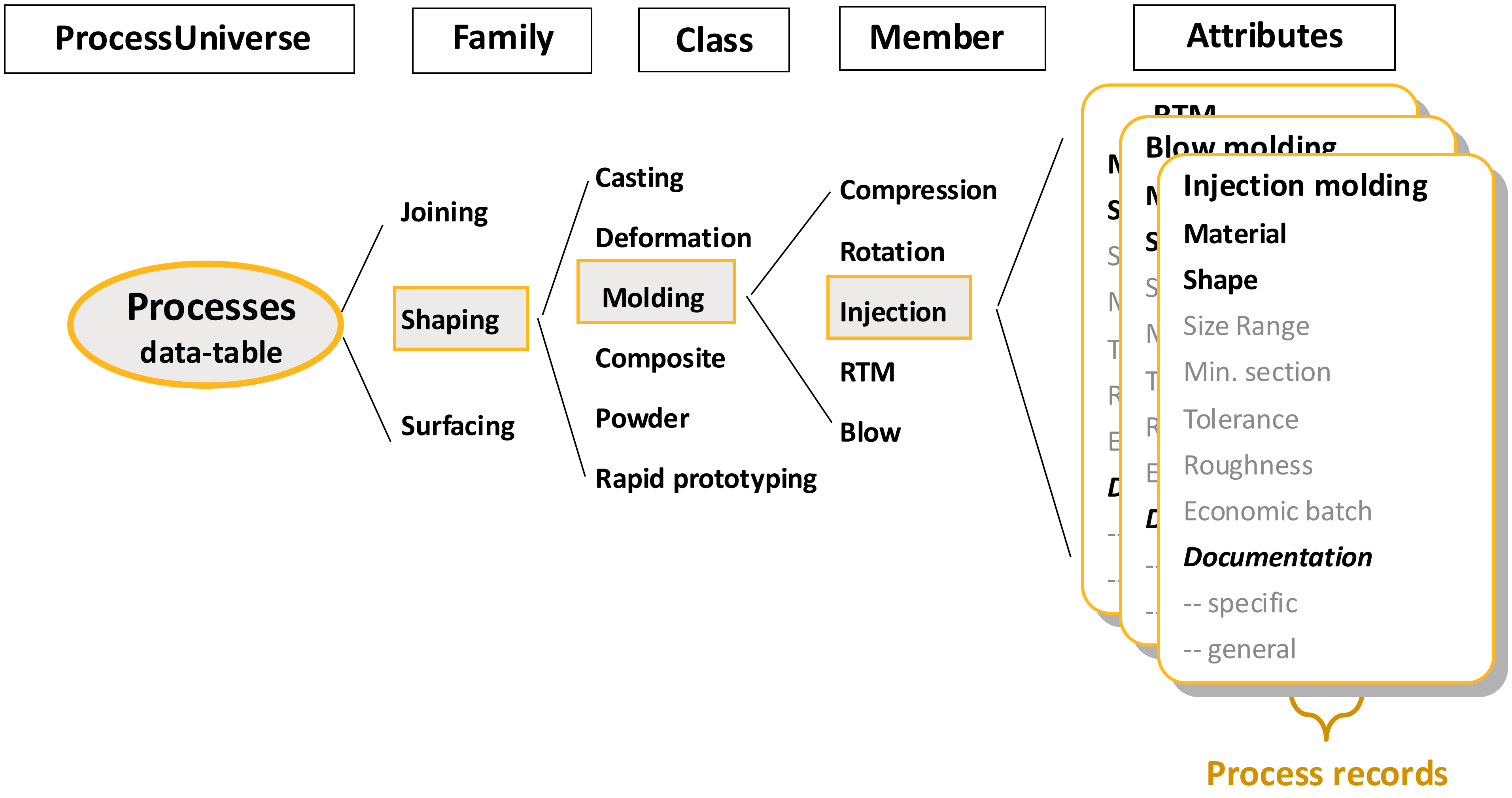
Organizing information: the PROCESS TREE



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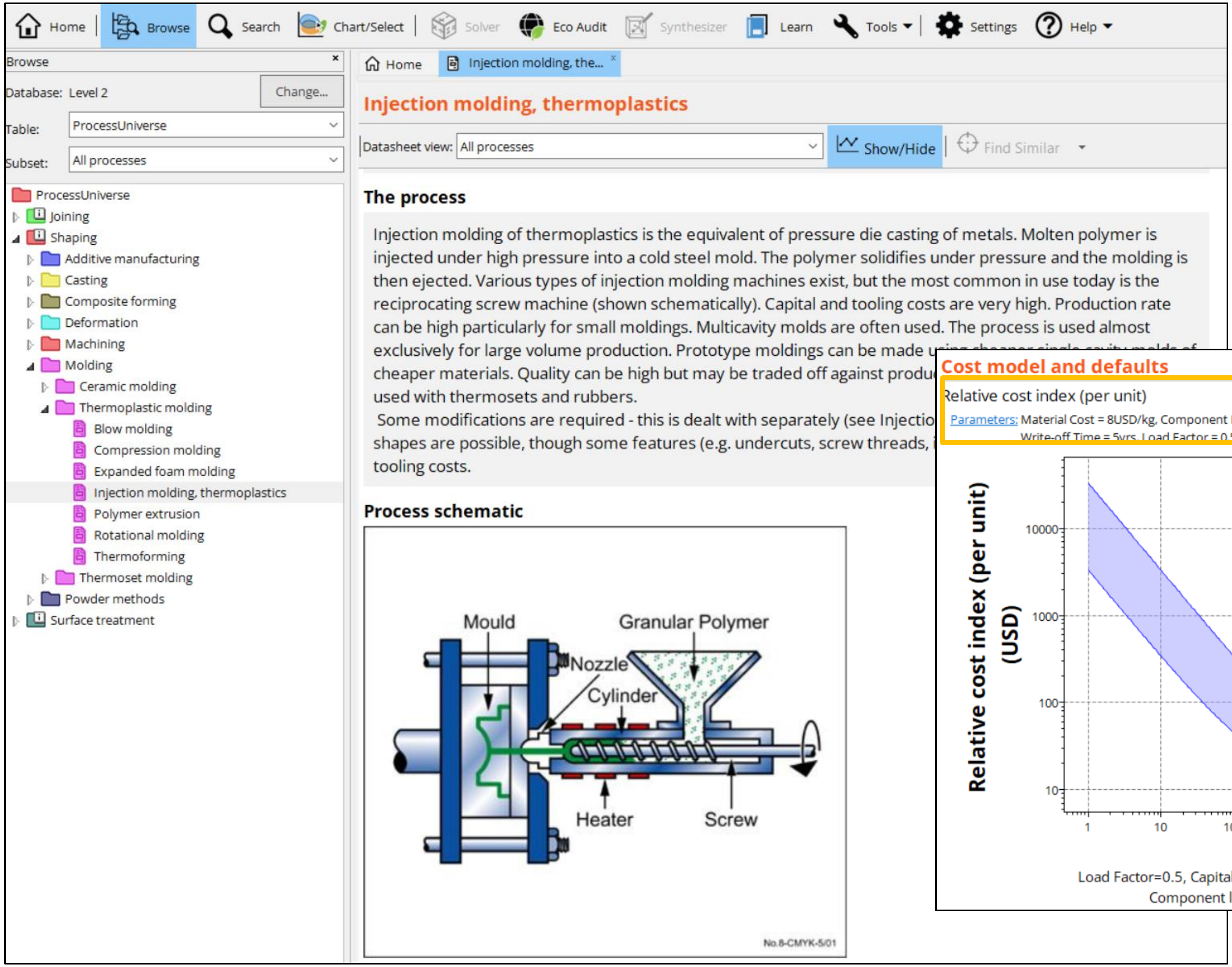
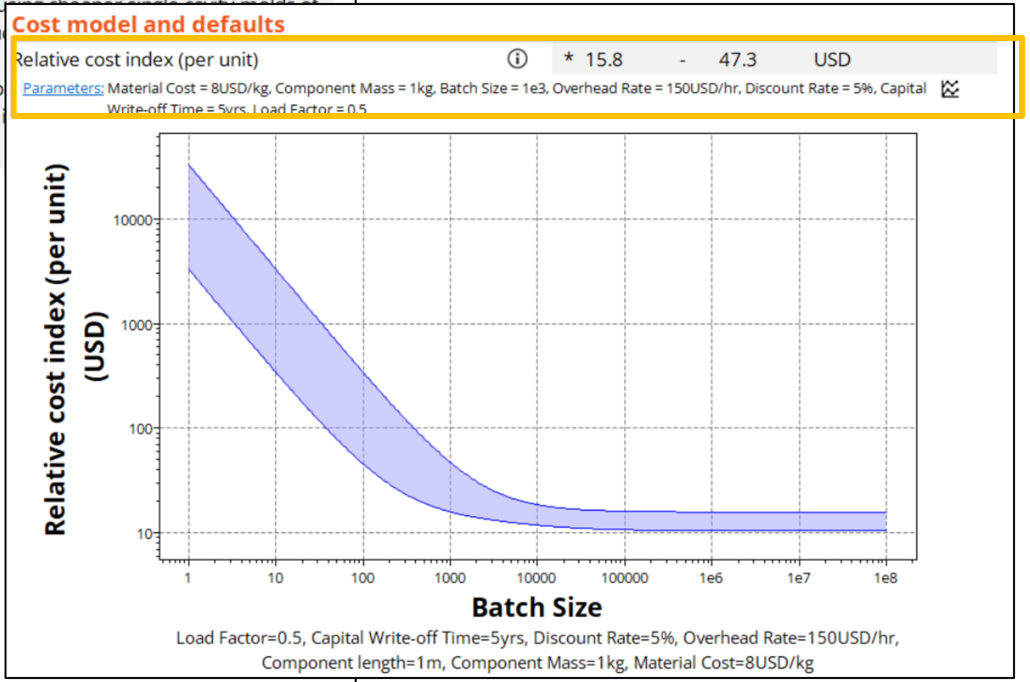
Finding information in the Ansys Granta EduPack Software



The cost model is implemented for selected shaping records



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A shaping datasheet*

Injection molding, thermoplastics

Material compatibility					
Polymers - thermoplastics	ⓘ	✓			
Shape					
Circular prismatic	ⓘ	✓			
Non-circular prismatic	ⓘ	✓			
Solid 3-D	ⓘ	✓			
Hollow 3-D	ⓘ	✓			
Economic compatibility					
Relative tooling cost	ⓘ	very high			
Relative equipment cost	ⓘ	high			
Labor intensity	ⓘ	low			
Economic batch size (units)	ⓘ	1e4	-	1e6	
Physical and quality attributes					
Mass range	ⓘ	0.001	-	25	kg
Range of section thickness	ⓘ	0.4	-	6.3	mm
Tolerance	ⓘ	0.07	-	1	mm
Roughness	ⓘ	0.2	-	1.6	µm
Surface roughness (A=v. smooth)	ⓘ	A			

Links to materials

Key constraints in choosing a shaping process

Excerpts from *Ansys Granta EduPack software* Level 2

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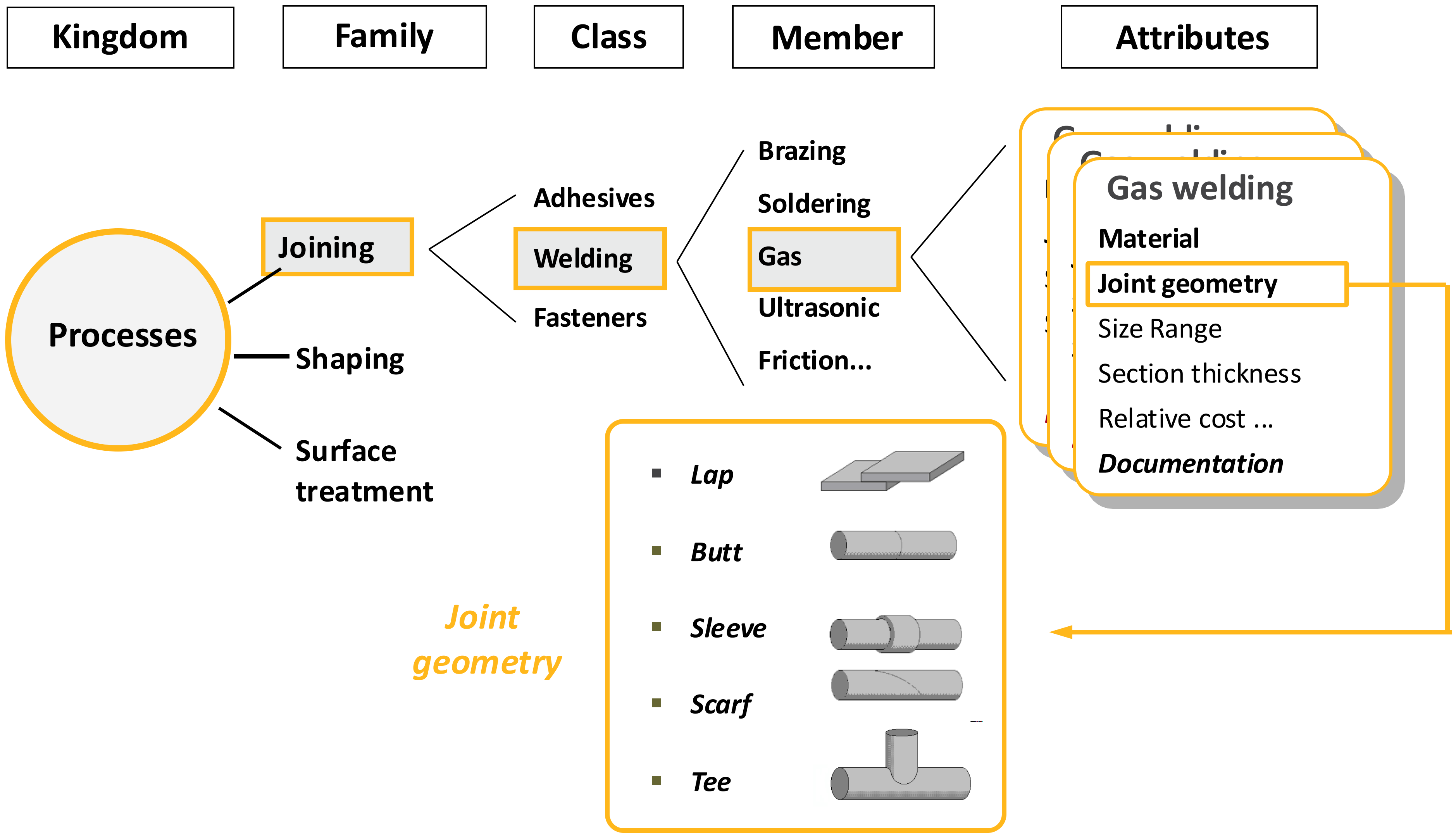
Data organization: joining processes



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A joining datasheet*

Gas tungsten arc (TIG)

Datasheet view: All processes | Show/Hide | Find Similar

Joining > Thermal welding > Metals > High temperature >

Description

Image

Image caption

(1) Hotwire TIG © TWI Ltd at flickr (2) TIG welding © TWI Ltd at flickr

The process

Tungsten inert-gas (TIG) welding is a heavy-duty welding process (others are MMA and MIG) is the cleanest and most precise, but also the most expensive. In one regard it is very like MIG welding: an arc is struck between a non-consumable tungsten electrode and the work piece, shielded by inert gas (argon, helium, carbon dioxide) to protect the molten metal from contamination. But, in this case, the tungsten electrode is not consumed because of its extremely high melting temperature. Filler material is supplied separately as wire or rod. TIG welding works well with thin sheet and can be used manually, but is easily automated. Both penetration and deposition rates are much less than those of MIG welding, but precise control of the weld is easier.

Process schematic

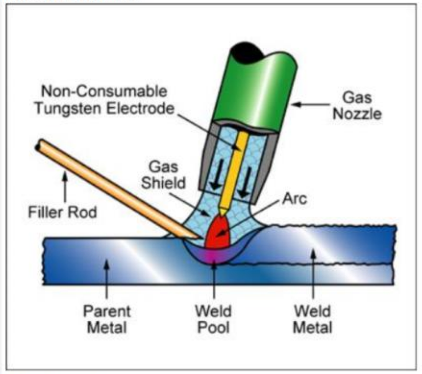

Figure caption

Tungsten - inert gas welding

Material compatibility					
Metals - ferrous	ⓘ	✓			
Metals - non-ferrous	ⓘ	✓			
Function compatibility					
Electrically conductive	ⓘ	✓			
Thermally conductive	ⓘ	✓			
Watertight/airtight	ⓘ	✓			
Demountable	ⓘ	✗			
Joint geometry compatibility					
Lap	ⓘ	✓			
Butt	ⓘ	✓			
Sleeve	ⓘ	✓			
Scarf	ⓘ	✓			
Tee	ⓘ	✓			
Load compatibility					
Tension	ⓘ	✓			
Compression	ⓘ	✓			
Shear	ⓘ	✓			
Bending	ⓘ	✓			
Torsion	ⓘ	✓			
Peeling	ⓘ	✓			
Economic compatibility					
Relative tooling cost	ⓘ	low			
Relative equipment cost	ⓘ	medium			
Labor intensity	ⓘ	low			
Physical and quality attributes					
Mass range	ⓘ	870	-	2.25e3	kg
Range of section thickness	ⓘ	0.7	-	8	mm
Unequal thicknesses	ⓘ	✓			
Processing temperature	ⓘ	597	-	1.98e3	°C

Links to materials

Key constraints in choosing a joining process

*Excerpts from *Ansys Granta EduPack software* Level 2

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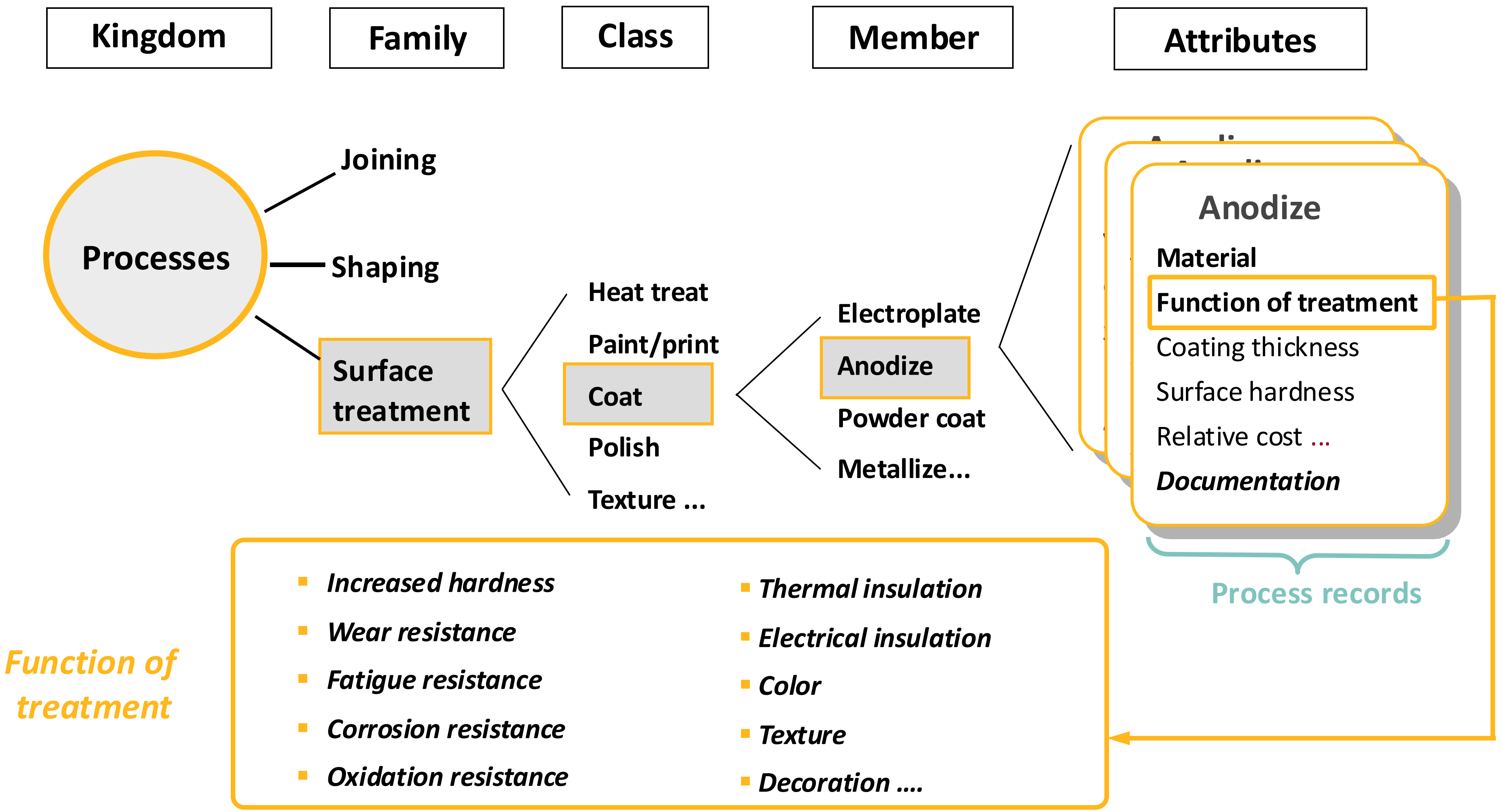
Data organization: surface treatment



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A surface-treatment datasheet*

Induction and flame hardening

Datasheet view: All processes | Show/Hide | Find Similar

Surface treatment > Heat treatments >

Description

Image

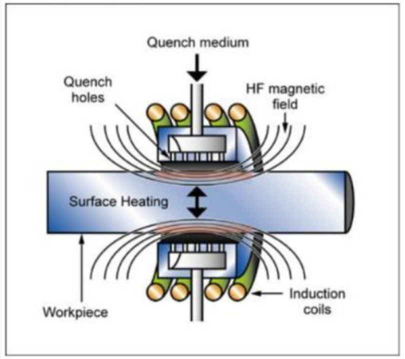
Image caption

(1) A flame hardened metal part © Metal Technology Co. Ltd. (2) A timing sprocket for an engine that has been heat treated to a specific hardness, and then flame hardened at only the surface of the teeth © Zaereth at Wikimedia Commons (CC BY 4.0)

The process

Induction hardening allows the surface of carbon steels to be hardened with minimum distortion or oxidation. A high frequency (up to 50kHz) electromagnetic field induces eddy-currents in the surface of the work-piece; these currents heat the surface into the austenitic phase-region, from which it is rapidly cooled from a gas or liquid jet, giving a martensitic surface layer. The depth of hardening depends on the frequency of the electromagnetic field. In flame hardening, heat is applied instead by means of one or more high-temperature gas burners, followed, as before, by rapid cooling. Both processes are versatile and can be applied to work pieces that cannot readily be furnace treated or case hardened in the normal way. Induction and flame hardening allow selective hardening of particular areas of the work piece. Both give a surface layer with a hardness that is lower than that of diffusion-based processes like carburizing and nitriding, but the depth is greater. The hardened surface layer carries internal stresses that can lead to micro cracking if the process conditions are incorrect.

Process schematic



Material compatibility		
Metals - ferrous	ⓘ	✓
Function of treatment		
Hardness	ⓘ	✓
Wear resistance	ⓘ	✓
Fatigue resistance	ⓘ	✓
Friction control	ⓘ	✓
Economic compatibility		
Relative tooling cost	ⓘ	low
Relative equipment cost	ⓘ	medium
Labor intensity	ⓘ	low
Physical and quality attributes		
Surface roughness (A=v. smooth)	ⓘ	A
Curved surface coverage	ⓘ	Very good
Coating thickness	ⓘ	300 - 3e3 µm
Surface hardness	ⓘ	420 - 720 HV
Processing temperature	ⓘ	454 - 521 °C
Process characteristics		
Discrete	ⓘ	✓

Links to materials

Key constraints in choosing a joining process

*Excerpts from *Ansys Granta EduPack software* Level 2

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Cost, price and value

- **Cost** = what it actually costs to make the part or product
- **Price** = the sum you sell it for
- **Value** = the worth the consumer puts on the product

The real requirement is

Cost < Price < Value

C < P < V

To maximize profit, P - C
we seek to minimize C

"Not worth the price" **means P > V**

"Good value for money" means **P < V**

The cost of producing a component of or product is made up of

- the **material cost**
- the **cost of manufacture**

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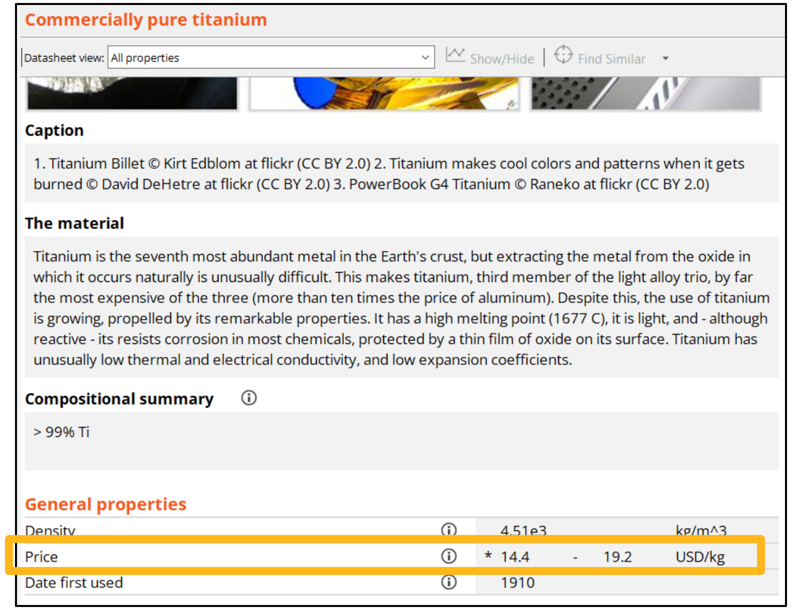
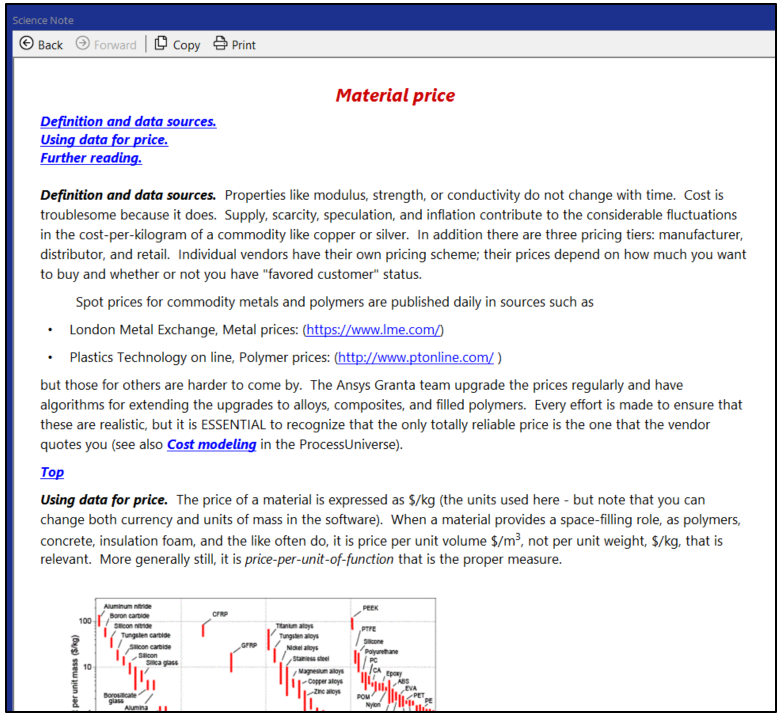
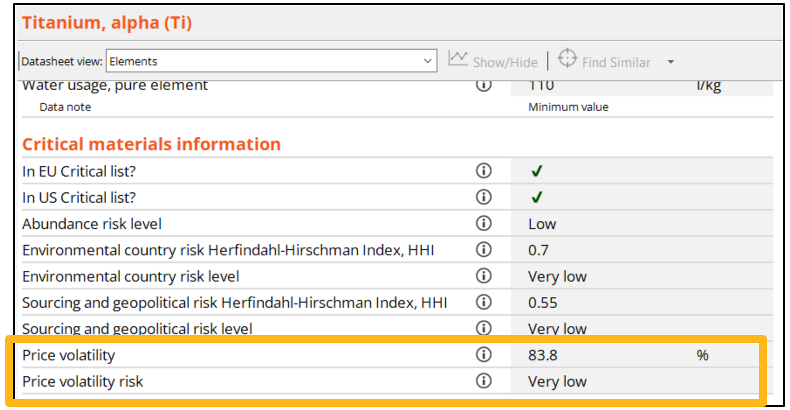
The material cost



Material prices are updated once per year...



Science Note highlights price/cost issues



The Elements database reflects price volatility

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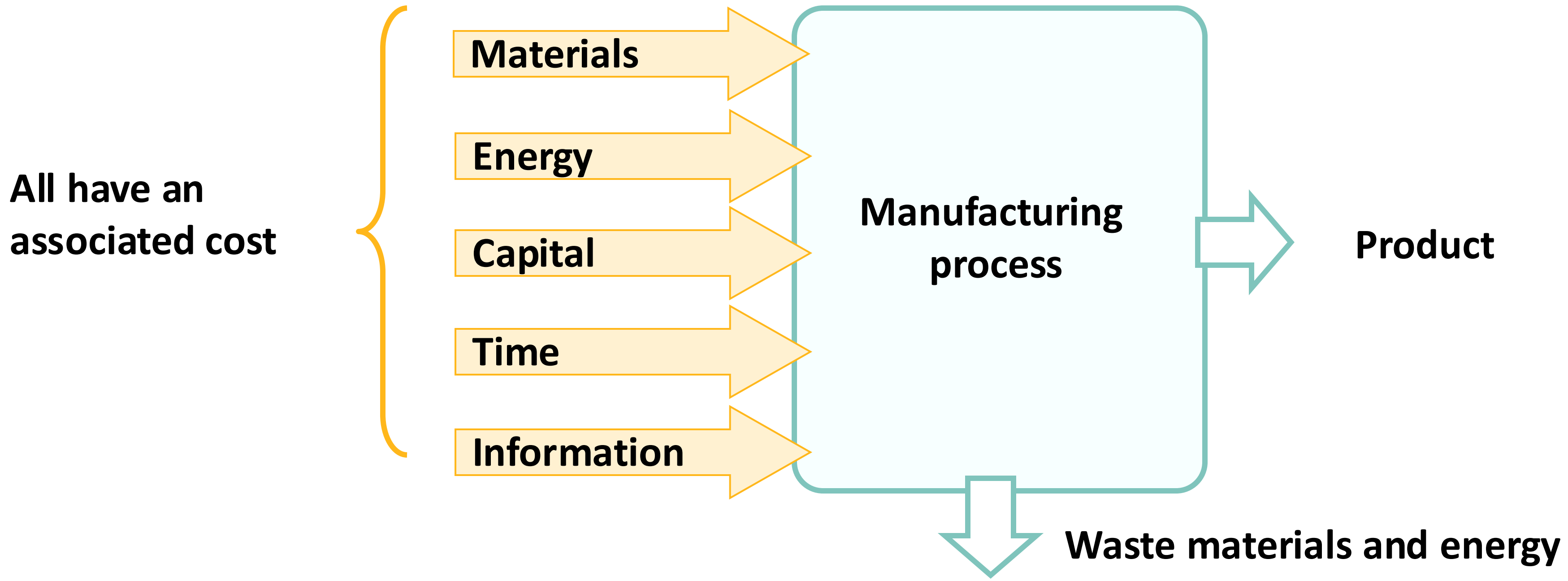
Estimating cost

When alternative material-process combinations meet the constraints, it is logical to rank them by **cost**

- **Cost estimate for competitive bidding** -- *absolute* cost is wanted, to $\pm$ 5%
- **Cost estimate for ranking** -- a *relative* cost is OK – but need generality

Generic inputs to any manufacturing process:



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Inputs to a generic cost estimator

Generic = can be applied to any process

Resource	Symbol	Unit
Materials including consumables	C_m	$/kg
Capital cost of equipment cost of tooling	C_t C_c	$ $
Time overhead rate (including labor)	C_{oh}	$/hr
Energy cost of energy	C_e	$/hr
Information R&D or royalties	C_i	$/year

Lump into overhead rate C_{oh}

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The cost per unit of output

materials, tools, capital, overhead

$$C = \left[\frac{m \cdot C_m}{1-f}\right] + \left[\frac{C_t}{n}\right] + \frac{1}{\dot{n}}\left[\frac{C_c}{L \cdot t_{wo}}\right](1+d)^{t_{wo}} + \frac{\dot{C}_{oh}}{\dot{n}}$$

f = fraction lost

Characteristics of the process

Cost of equipment	C_c
Cost of tooling	C_t
Production rate	$\dot{n}$

The database has approximate value-ranges for these

Site-specific, user defined parameters

Batch size	n
Mass of component	m
Capital write-off time	t_{wo}
Load factor	L
Discount rate	d
Overhead rate	$\dot{C}_{oh}$

These are entered by the user via a dialog box

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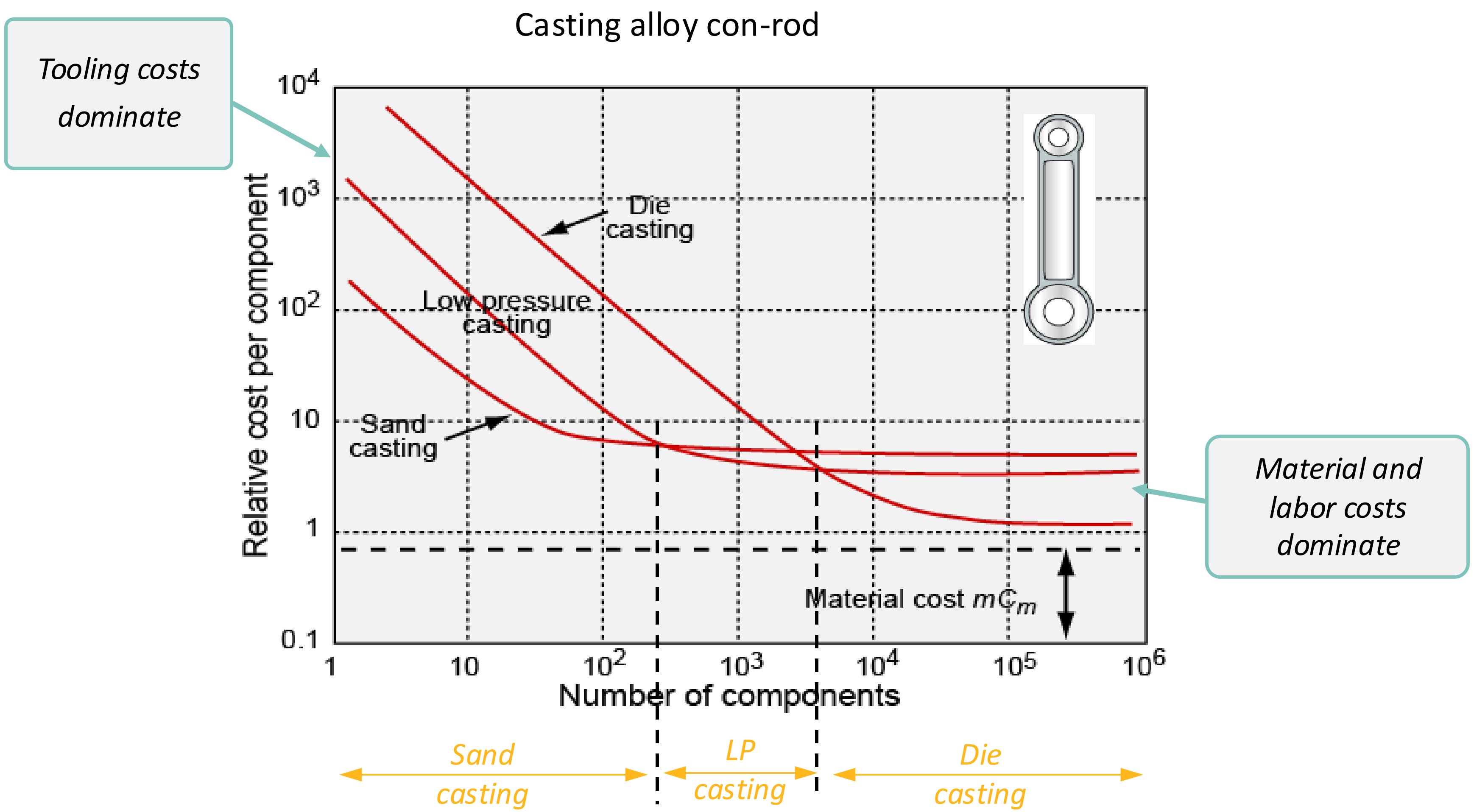
Features of a cost model



- **Identify most economic process**
- **Dependence on overhead rate etc.**

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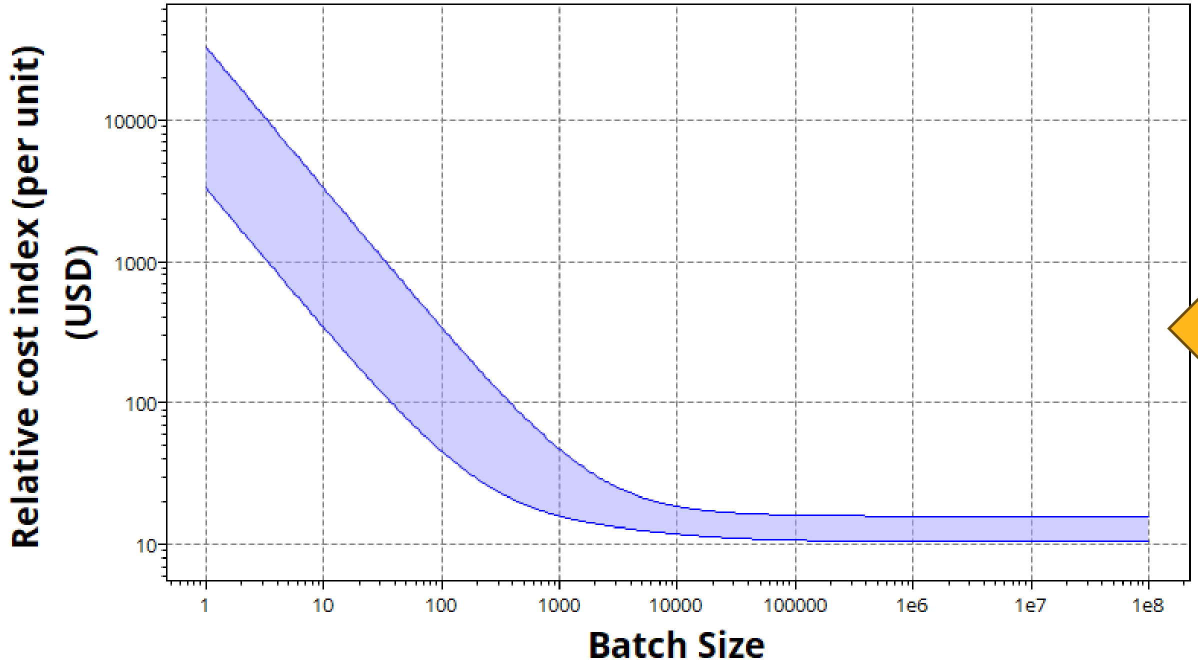
Cost model in Ansys Granta EduPack software Levels 2 and 3

Cost modeling

Relative cost index (per unit) 15.8-47.3 USD

Parameters: Material Cost = 8USD/kg, Component Mass = 1kg, Batch Size = 1e3, Overhead Rate = 150USD/hr, Discount Rate= 5%, Capital Write-off Time = 5yrs, Load Factor = 0.5



Name	Limits	Value
Capital Write-off Time (yrs)	1-25	5
Component Mass (kg)	0.001-10000	1
Component Length (m)	0.01-100	1
Discount Rate (%)	0-100	5
Load Factor	0.1-1	0.5
Material Cost (USD/kg)	0.1-10000	8
Overhead Rate (USD/hr)	1-500	150

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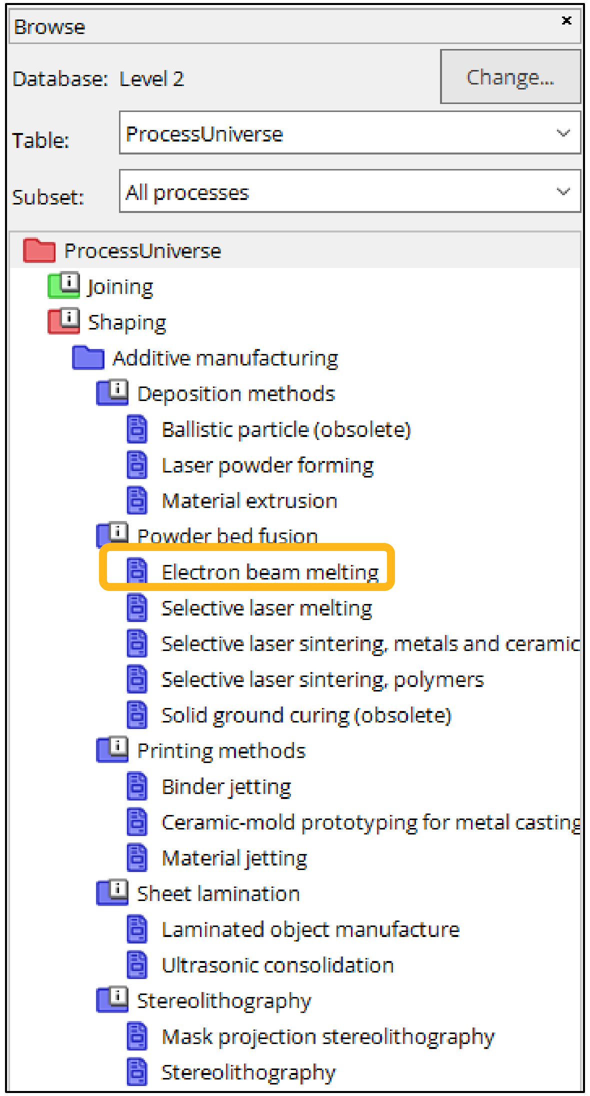
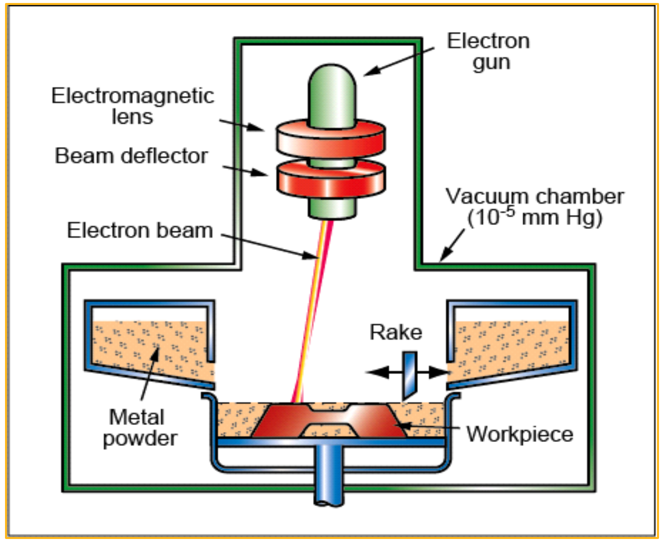
15 additive manufacturing processes



e-beam melting



ELECTRON BEAM MELTING (EBM) is a powder bed fusion technique similar to SLM. In this process a high-energy electron beam is scanned across a thin layer of metallic powder, causing local melting and resolidification. A thin layer of powder is then spread on top by a wiper or milling head and the process repeated until the object is complete. To maintain a steady-state uniform temperature throughout the build, the substrate is heated before laying the powder bed. Operating at an elevated temperature results in a grain pattern more similar to cast microstructures. As with other additive manufacturing processes, a CAD solid model of the part is used to create the code to guide the electron beam.

This process is also known as in-situ shelling.

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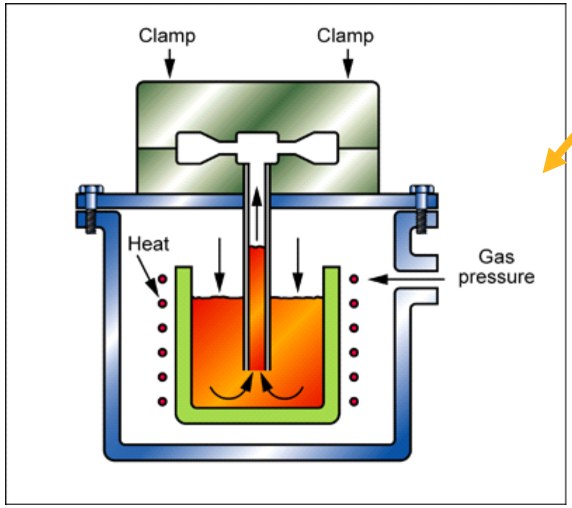
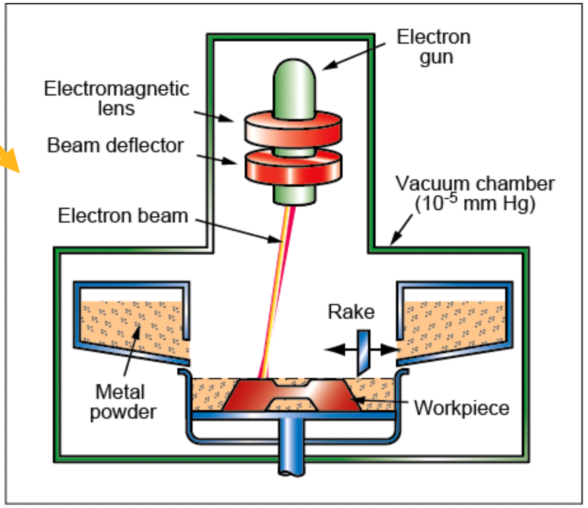
Comparison of manufacturing processes

Traditional vs Additive

Low pressure die



e-beam melting



In LOW PRESSURE DIE CASTING, molten metal is displaced upwards into a die by low pressure gas. The die cavity is filled slowly upwards which minimizes entrained air and gives high soundness. Such castings have better metallurgical integrity than conventional die castings, and they can be heat-treated. The process has most of the benefits of die casting without the disadvantages. The dies are made from cast iron which is comparatively cheap and easy to machine. Tool steel inserts may be used for high production runs of complex castings. Tooling costs are about half those for pressure die casting. The process is only suitable for low melting point alloys (Tm < 950 C). Shapes are of average complexity and undercuts are possible but expensive.

ELECTRON BEAM MELTING (EBM) is a powder bed fusion technique similar to SLM. In this process a high-energy electron beam is scanned across a thin layer of metallic powder, causing local melting and resolidification. A thin layer of powder is then spread on top by a wiper or milling head and the process repeated until the object is complete. To maintain a steady-state uniform temperature throughout the build, the substrate is heated before laying the powder bed. Operating at an elevated temperature results in a grain pattern more similar to cast microstructures. As with other additive manufacturing processes, a CAD solid model of the part is used to create the code to guide the electron beam.

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Comparison of manufacturing processes

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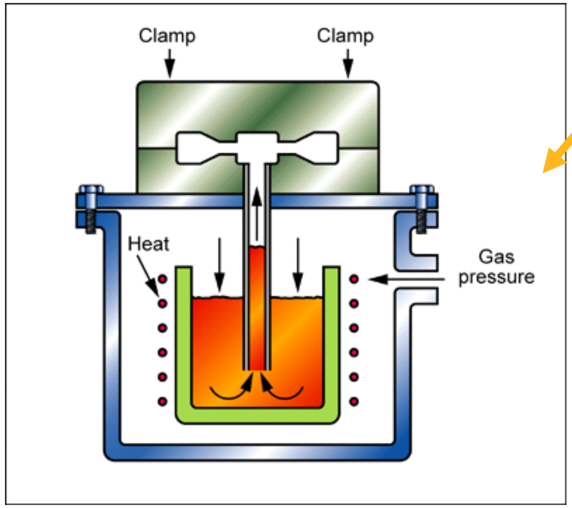
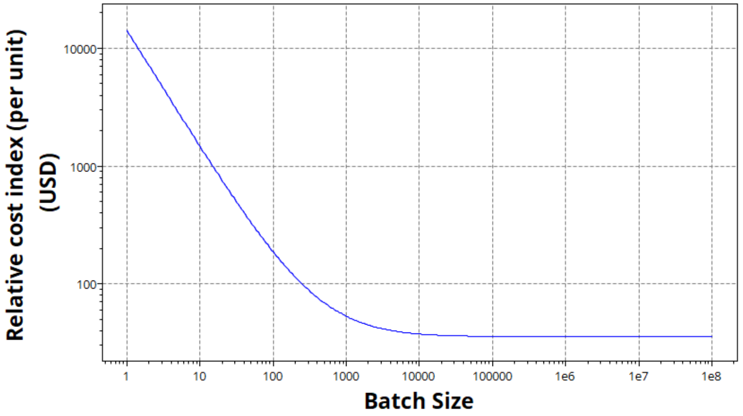
Low pressure die



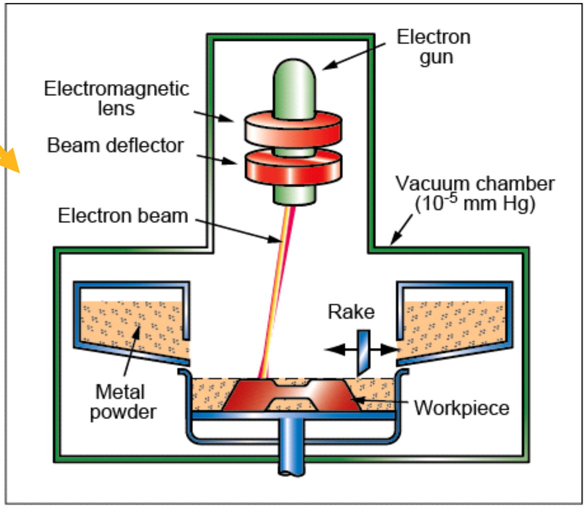
Cost model and defaults

Relative cost index (per unit) 53 USD

Parameters: Material Cost = 8USD/kg, Component Mass = 1kg, Batch Size = 1e3, Overhead Rate = 150USD/hr, Discount Rate = 5%, Capital Write-off Time = 5yrs, Load Factor = 0.5



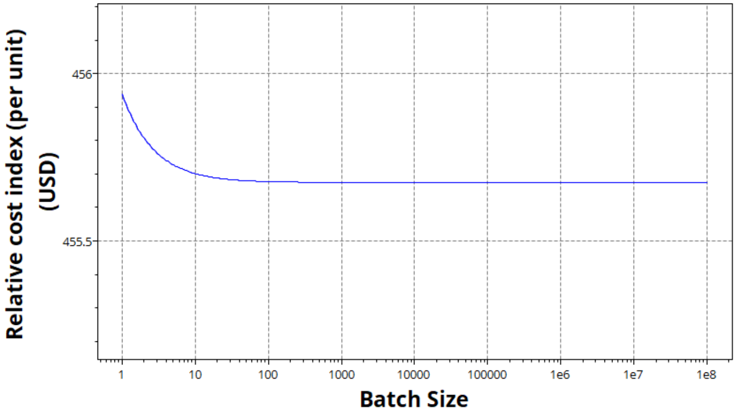
e-beam melting



Cost model and defaults

Relative cost index (per unit) 456 USD

Parameters: Material Cost = 8USD/kg, Component Mass = 1kg, Batch Size = 1e3, Overhead Rate = 150USD/hr, Discount Rate = 5%, Capital Write-off Time = 5yrs, Load Factor = 0.5



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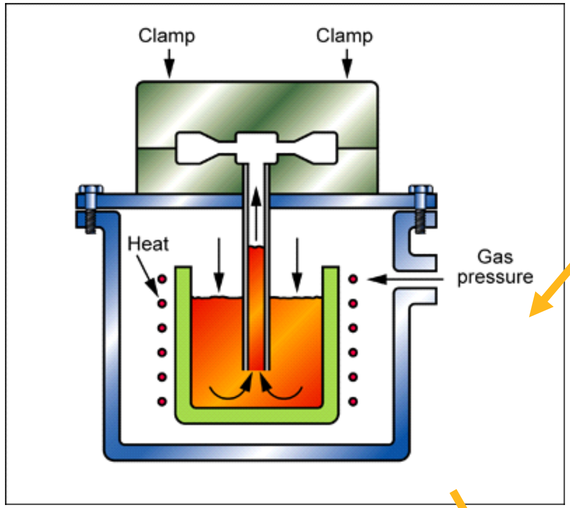
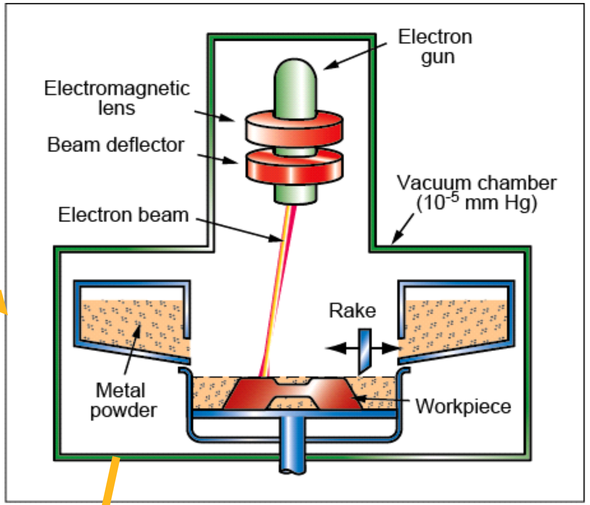
Comparison of manufacturing processes

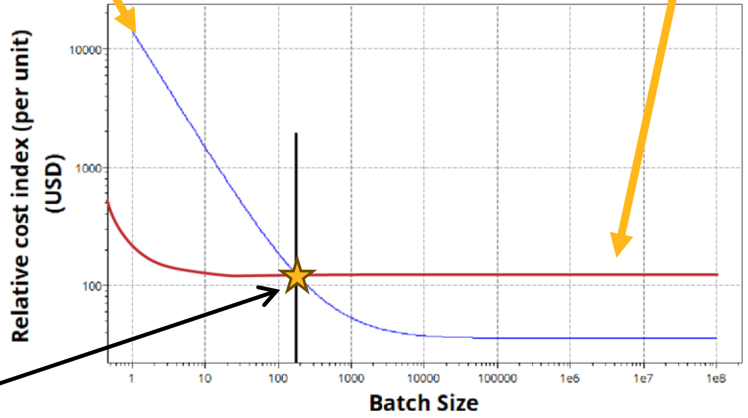
Low pressure die



Traditional
vs Additive

e-beam melting





Cross-over point: ~200 parts

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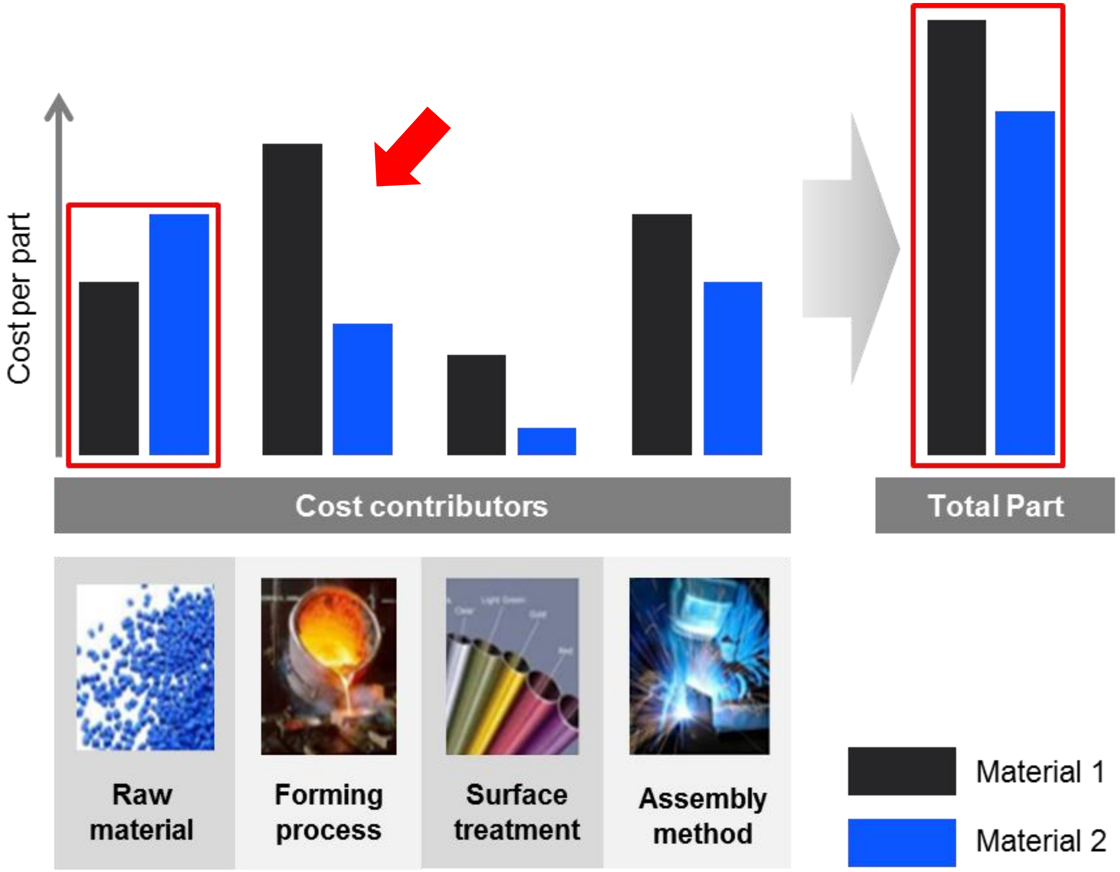
Synthesizer model for part cost



PP-20% mineral filled door panel
15% saving in vehicle weight but what about cost?

- Quickly estimate the **cost to manufacture a component**
- **Compare different classes** of materials and processing routes

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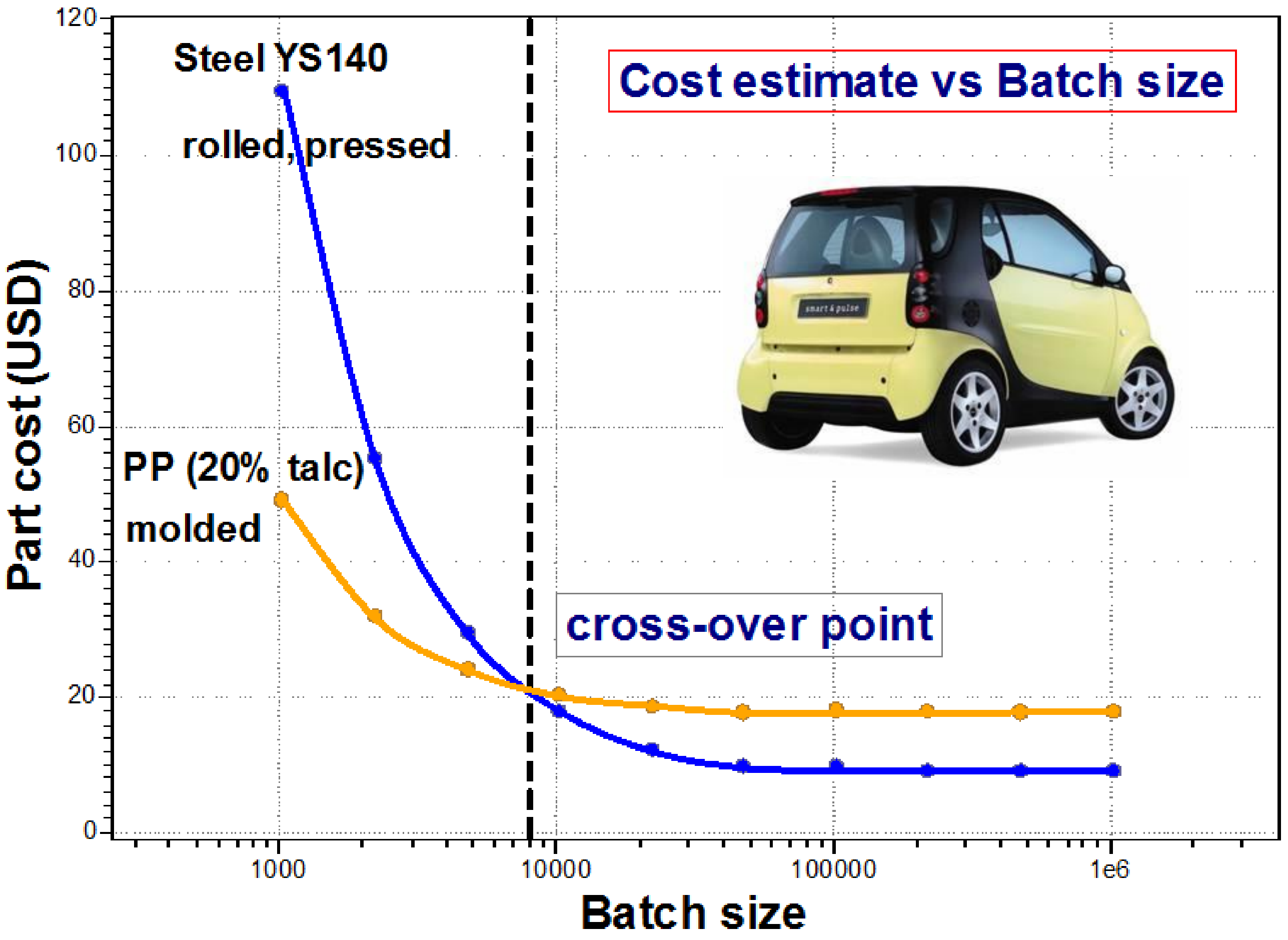
Part cost comparison: Door panel



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Summary

- Processes can be organised into a tree structure containing records for structured data and supporting information, **Links** connect processes to materials
- Select on primary constraints
  - **Shaping:** *material, shape and batch size*
  - **Joining:** *material(s) and joint geometry*
  - **Surface treatment**: *material and function of treatment*
- Simple cost model introduces the basic features of process costs adequate for ranking
- The cost of a product consists of material cost and manufacturing cost
- Additive manufacturing has the same unit cost for all batch sizes
- The part cost estimator in the Synthesizer tool can be used to estimate manufacturing costs for different options

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