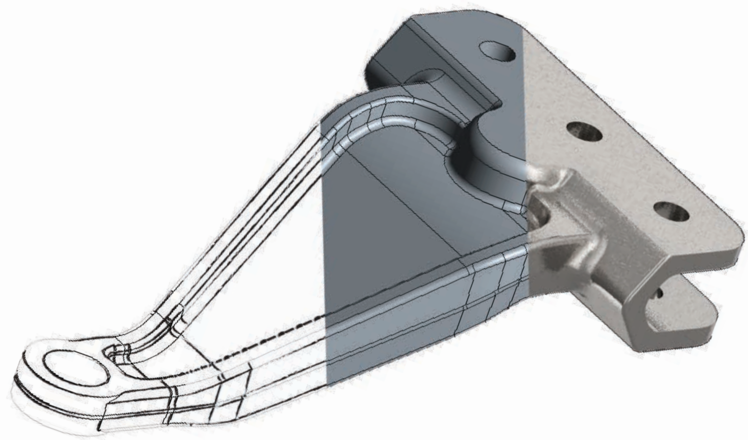
TAPANI HONKAVAARA

CAST PRODUCT DESIGN GUIDE



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This guide is derived from a graduate thesis.

The central question of the thesis was:
"What does a product designer need to know about designing cast products?"

The dissertation has been done at the Casting Technology Research Unit of the Department of Mechanical Engineering, Aalto University School of Engineering.

The thesis was funded by Valutuoteteollisuus ry.

Images: Tapani Honkavaara

Espoo, 21 March 2014

To the reader

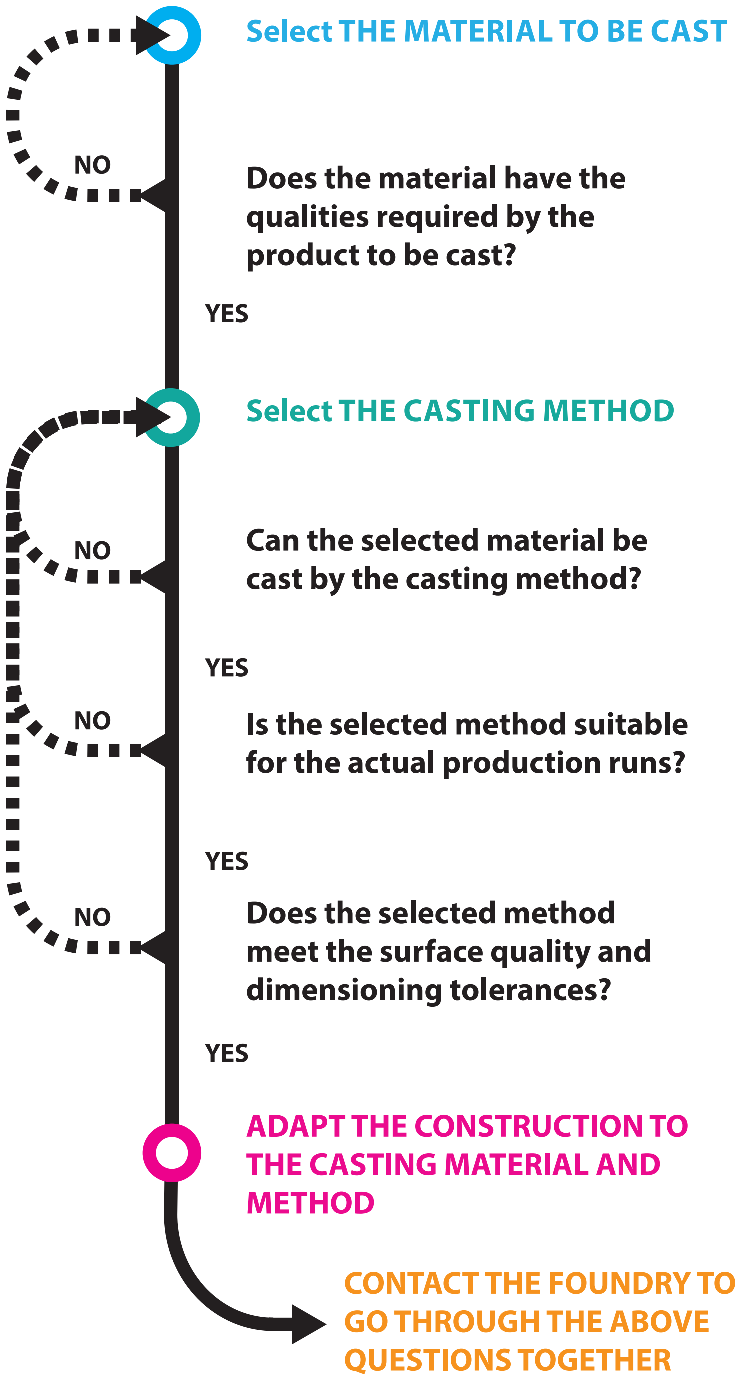
Casting is a manufacturing method that can be used to make fairly complex pieces. Taking into account the limitations and possibilities of the manufacturing method from the very beginning of the design process, the best quality and the lowest manufacturing costs can be achieved. The matters discussed in this guide are generalisations about the most common casting techniques, so you should contact the foundry at the earliest possible stage to get the most out of casting as a manufacturing method.

This guide has two aims, the first of which is to get the designer to ask *why*? This may make the designer want to know more about why a particular feature of casting should be done exactly as it should, and how it can be realised in the best possible way. The second aim is to get the designer to contact the foundry at the earliest possible stage, so that already at the design stage the foundry's manufacturing know-how can be utilised to obtain the best possible product.

This guide consists of four parts. The first part deals with casting materials on a general level. The second part introduces the most common casting methods. It is only the third part that actually deals with the design of cast products, and the kind of things a designer should take into account when designing a cast product. The fourth and last part deals with quality and with how the designer should take quality into account already at the design stage, although most of the quality only becomes concrete when the product is ordered. Finally, there is a collection of source literature using which this guide has been compiled.

Hopefully you will not be content for too long with merely reading this guide.

Designing cast products



“Much will be gained, both technically and economically, if the designers can think from the outset in terms of casting so that the castings receive the right shape. Far too much construction is done only on the drawing board without being in contact with the foundries. Only when the construction is complete will the man from the foundry have the opportunity to present his views, and this may happen too late.”

- ***Alrik Österberg***, *Valukappaleiden rakennesuunnittelu*
(‘Structural design of castings’), 1967

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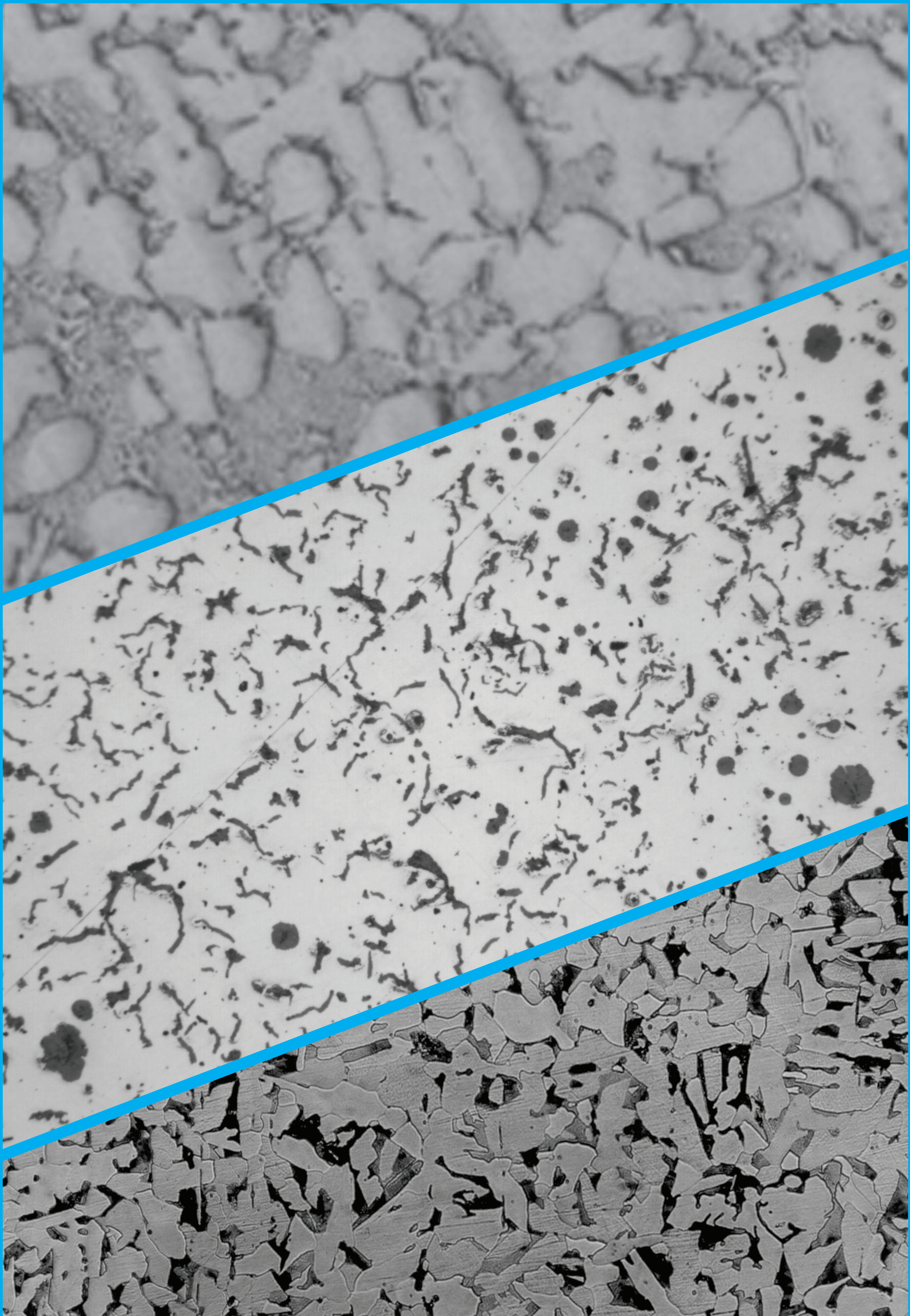
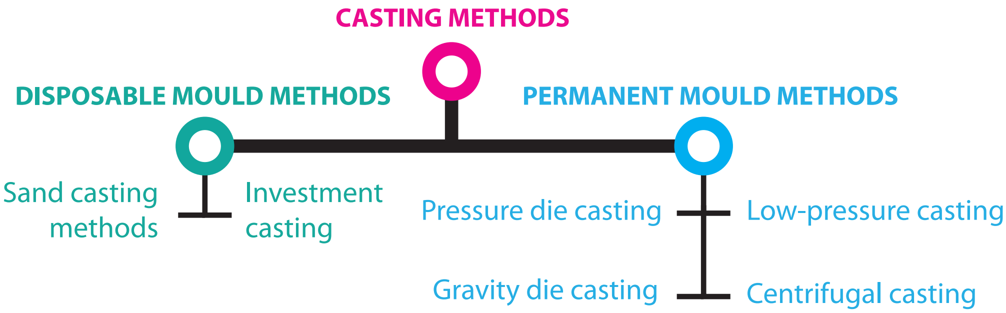


1 Materials

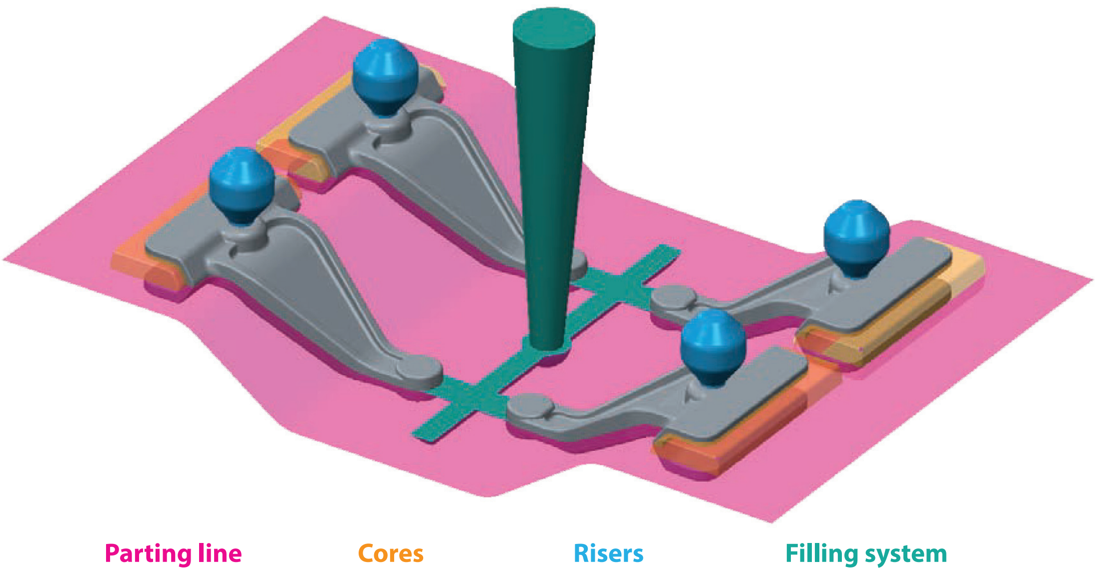
A brief introduction to casting

“In casting, the material is melted from a solid state – scrap metal or metal ingots – into a fluid state in a smelting furnace. The molten metal is poured into a mould made of fireproof material, which has a cavity in the desired form in which the metal solidifies into the desired shape.”

The material, shape and size of production run usually determine whether disposable or permanent moulds are used. In disposable moulds, the cooling of the material is slower and the moulds are broken after each casting. In permanent moulds, the material cools quickly, and they can withstand up to thousands of castings. The casting materials are highly recyclable.



Once the metal has solidified and the mould has been disassembled, any possible burned-on sand and solidified parts of the casting system used to bring the molten metal into the mould (filling system) and compensate for shrinkage during solidification (risers) are removed from the finished casting.

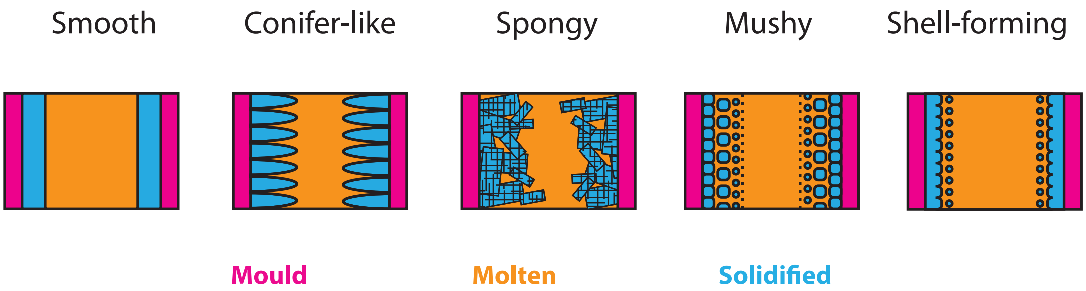


The designer should keep in mind that regardless of the material being cast, the material must go into the cavity formed by the piece at some point (inputs). In addition, the risers for shrinkage of the material must be placed somewhere (usually in the thickest part) of the piece in order to obtain the most intact piece possible.

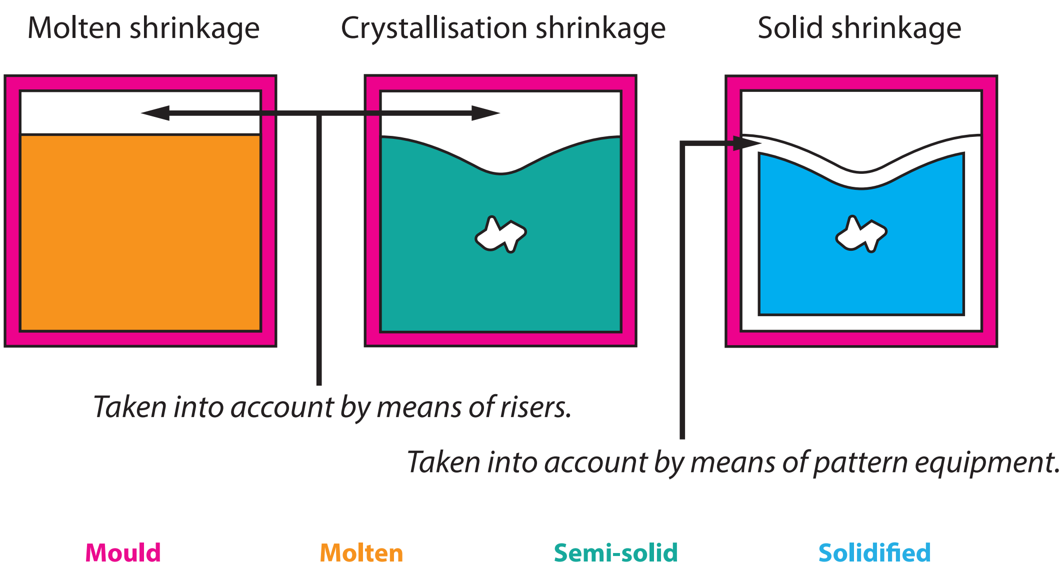
Casting of materials

"When the material is melted and then cools again, it is no longer of uniform quality because the different parts of the casting solidify at different times. The desired material properties may also vary in different parts of the product because the solidification rate has varied."

Different materials solidify differently, and there may be different types of solidification in the same piece because conditions vary in different parts of it. Solidification determines the microstructure and properties of the piece. In practice, types of solidification can be divided into five different categories.



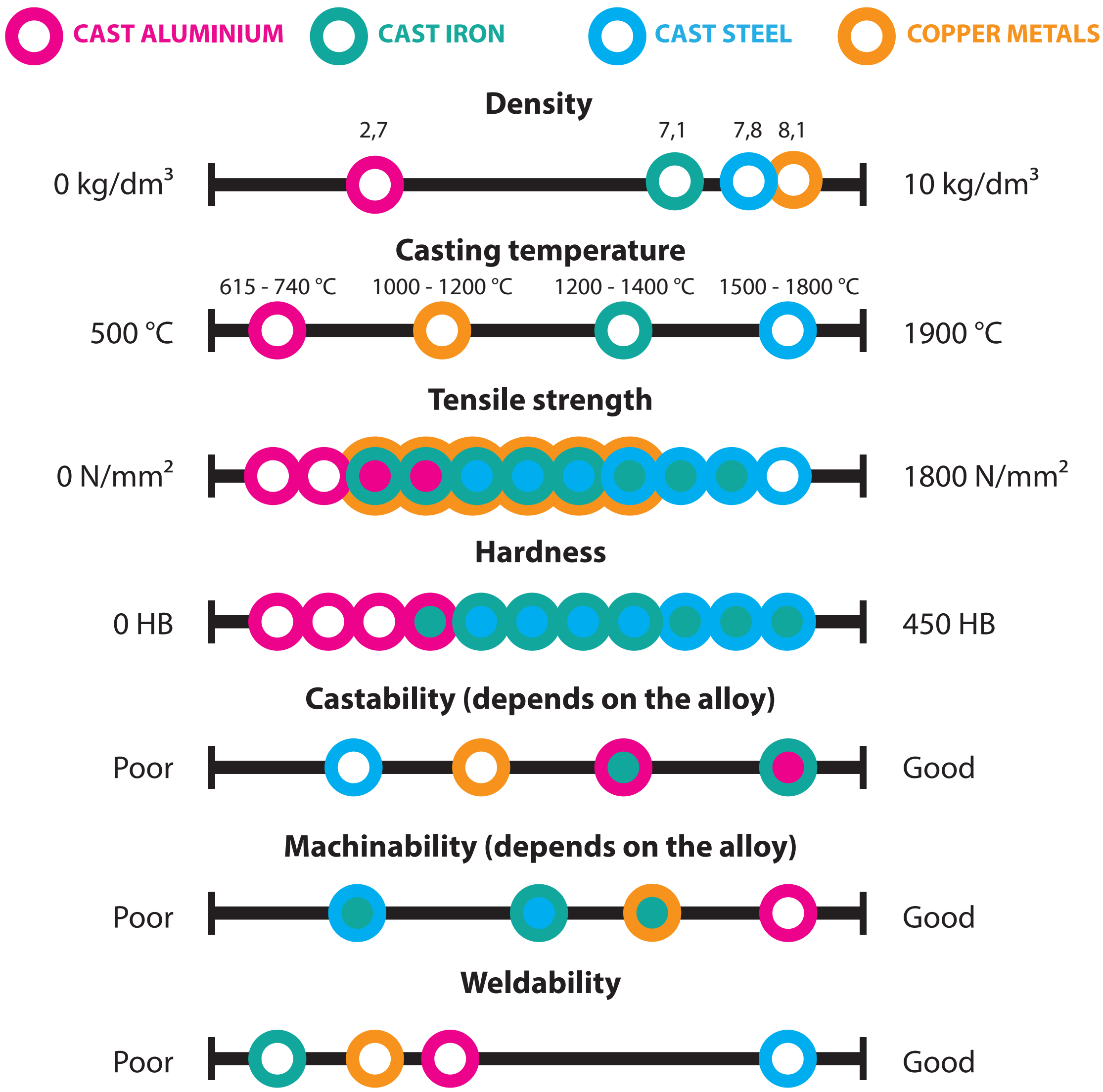
The molten metal shrinks as it solidifies, and this must be taken into account when the piece is made. Already when designing a product, the designer can take into account that the piece solidifies from the thinnest points towards mass concentrations that are easily fed with risers. Mass concentrations should be kept to a minimum.



Differences between materials

"Each material has its pros and cons. The requirements of the intended use of the product largely determine the properties of the material to be cast. There is no single right casting material; the challenge is to find the most cost-efficient material that meets the requirements of the product."

It is advisable to inquire from the foundry about the most suitable material that corresponds to the intended use of the future product. Each foundry can also have its own non-standard materials. In addition, not all foundries cast all material mixtures, and they may not have the desired casting method in use.



Aluminium SFS-EN1559-4

"Cast aluminium can be cast by any casting method. An alloy defined by a standard can be found for each method. The properties of aluminium alloys can be modified by alloying. Aluminium alloys are light, tough, dense and reasonably strong. They conduct heat and electricity well and are resistant to corrosion. The mechanical properties of aluminium depend on the casting method and the state it is processed in."

Indicative values for properties of cast aluminium

Material	*Cast aluminium*	*Al*	*AlSi*	*AlSiMg*	*AlSiCu*	*AlCu*	*AlMg*
Standard title	***AC***						
Standard	***SFS-EN 1706***						
Density (kg/dm^3)	***2.57 - 2.88***	***2.7***	***2.68***	***2.65***	***2.79***	***2.79***	***2.68***
Tensile strength (MPa)	***75 - 370***	***75***	***150 - 180***	***140 - 290***	***150 - 230***	***280 - 370***	***150 - 180***
Hardness (HB)	***17 - 120***	***17***	***45 - 55***	***50 - 90***	***60 - 100***	***60 - 100***	***50 - 65***
Property		***Thermal conductivity***	***Castability, corrosion resistance***	***Mechanical properties***	***Low thermal expansion, Abrasion resistance***	***Strength and toughness***	***Corrosion resistance in marine conditions***

To find the best alloy, you should contact the foundry. Each foundry may also have its own materials from outside the standards, so their use must be agreed with the foundry.

Castability and properties of aluminum alloys

The majority of aluminum castings are made using permanent moulds. Pure aluminium is somewhat difficult to cast, due to its strong tendency to oxidise and the oxide layer that is formed. The strength of aluminum alloys can be increased by alloying. The main alloying elements are silicon (improves melt flow, hardness and strength), copper (improves machinability) and magnesium (improves hardness, strength and corrosion resistance). The corrosion resistance of aluminium alloys is based on a dense and rapidly regenerating oxide layer formed on the surface of the metal. Due to creep, operating temperatures are usually limited to a maximum of 250 °C.

Indicative values for the design of aluminium alloys for the smallest dimensions

Main dimension of the casting	*Wall thickness*	*Rounding radius*	*Draft*	*Hole diameter*
Pressure die casting	***1 - 3 mm***	***1 mm***	***1 °***	***2.5 mm***
Gravity die casting	***2 - 4 mm***	***1 - 2 mm***	***2 °***	***3 mm***
Sand casting	***4 - 5 mm***	***2 - 3 mm***	***3 °***	***4 mm***

The values are indicative; more specific values must be discussed with the foundry. Aim for even variations in wall thickness; the larger the wall surface area, the greater the wall thickness must be, as with permanent moulds it is more difficult to feed material concentrations than with disposable moulds, because the metal solidifies faster.

Cast iron SFS-EN 1559-3

"Cast iron is an alloyed iron whose main constituent in addition to iron is carbon, of which there is more than 2.1% in cast iron. Cast iron is divided into three main groups: flake-graphite, ductile and vermicular graphite cast iron. In addition to these there is also white cast iron and malleable cast iron. The graphite structure strongly affects the properties and is determined during solidification. In addition, the formation of the microstructure of cast iron is influenced by the alloying elements and the cooling rate after casting. The metal matrix of cast iron can be modified after casting by heat treatment."

Indicative values for properties of cast irons

Material	*Flake graphite*	*Spheroidal graphite*	*ADI*	*Malleable iron*	*Vermicular graphite*	*Wear resistant*
Standard title	***GJL***	***GJS***	***GJS***	***GJM***	***GJV***	***GJN***
Standard	***SFS-EN 1561***	***SFS-EN 1563***	***SFS-EN 1564***	***SFS-EN 1562***	***SFS-EN 16079***	***SFS-EN 12513***
Density (kg/dm^3)	***7.1 - 7.3***	***7.1 - 7.3***	***7.3***	***7.3***	***7.1 - 7.2***	***7.1 - 7.2***
Tensile strength (MPa)	***100 - 350***	***350 - 900***	***800 - 1400***	***300 - 800***	***300 - 500***	
Hardness (HB)	***150 - 240***	***130 - 360***	***250 - 480***	***150 - 320***	***140 - 260***	***340 - 630***
Property	***Sliding properties, vibration damping***	***Extensive applications, mechanical properties***	***Nearly the mechanical properties of steel***	***Hard and brittle, wear resistance***	***Highly resistant to heat shocks***	***Wear resistance***

To find the best alloy, you should contact the foundry. Each foundry may also have its own materials from outside the standards, so their use must be agreed with the foundry.

Section sensitivity of cast irons

Section sensitivity refers to the deterioration of strength properties as the wall thickness increases. The section sensitivity of cast irons is affected by both the chemical composition of the iron and the cooling conditions of the casting. This is especially pronounced with flake-graphite cast irons, as they are delivered in the casting state, but other cast irons also show a similar dependence. Heat treatment reduces the effect of section sensitivity. When casting iron with high wall thicknesses, the microstructure may no longer be of uniform quality, and this must be taken into account in the design of the entire piece.

Minimum wall thicknesses of cast irons in relation to the size of the piece

Main dimension of the casting	*100 mm*	*250 mm*	*500 mm*	*1000 mm*	*2000 mm*
Flake graphite	***3 - 4 mm***	***3 - 5 mm***	***4 - 6 mm***	***6 - 9 mm***	***10 - 15 mm***
Spheroidal graphite	***5 mm***	***5 mm***	***8 mm***	***12 mm***	***15 mm***

The values are indicative; more specific values must be discussed with the foundry. Large variations in wall thickness should be avoided; the larger the piece being designed, the higher the thinnest wall thickness should be.

Cast steel SFS-EN 1559-2

"Cast steel is an iron-carbon alloy with a carbon content of less than 2.1%. The properties of cast steels, which include a high level of toughness and weldability, can be modified by alloys and heat treatments. Alloys are applied to cast steels for improved resistance to heat, corrosion, fire or wear. If weldability is required for the piece, cast steel is one option to consider. Virtually all cast steels are heat treated, which increases their manufacturing costs."

Indicative values for properties of cast steels

Material	*General cast steels*	*Corrosion resistant*	*Fire resistant*	*High pressure steels*	*Structural steels*	*Austenitic manganese cast steels*
Standard title	***GS***	***GX***	***GX***	***GP, GX***	***GS, GX***	***GX***
Standard	***SFS-EN 10293***	***SFS-EN 10283***	***SFS-EN 10295***	***SFS-EN 10213***	***SFS-EN 10340***	***SFS-EN 10349***
Density (kg/dm^3)	***7.7 - 8.3***	***7.7 - 8.0***	***7.7 - 8.3***	***7.8 - 8.0***	***7.7 - 8.3***	***7.7 - 8.3***
Tensile strength (MPa)	***350 - 1795***	***430 - 1100***	***420 - 550***	***420 - 960***	***380 - 850***	
Hardness (HB)	***115 - 300***					
Property	***Mechanical properties in slightly corrosive environments***	***Corrosion resistance***	***Good oxidation resistance and creep strength at high temperatures***	***Pressure tightness***	***Mechanical properties***	***Wear resistance***

To find the best alloy, you should contact the foundry. Each foundry may also have its own materials from outside the standards, so their use must be agreed with the foundry.

Casting of cast steels compared to cast irons

Casting steels have a higher risk of suction defects, due to the very low amount of shrinkage-reducing graphite (carbon) in the casting steels. The flowability of cast steels is also less than that of cast irons, so the castability of cast steels is worse. When designing a piece from cast steel, the designer should pay attention to the smoothest possible wall thickness and to the smoothness shapes. The designing of pieces from cast steel is more challenging than with cast iron, so it is worthwhile to be in touch with the foundry already at an early stage of the design work.

Minimum wall thicknesses of cast steels in relation to the size of the piece

Main dimension of the casting	*50 mm*	*150 mm*	*400 mm*	*700 mm*	*1500 mm*
Cast steel	***5 mm***	***6 mm***	***8 mm***	***11 mm***	***20 mm***

The values are indicative; more specific values must be discussed with the foundry. Large variations in wall thickness should be avoided; the larger the piece being designed, the higher the thinnest wall thickness should be.

Copper metals

"Cast copper metals are divided into cast coppers and copper alloys. The most important property of copper metals is their corrosion resistance. Other essential properties of copper metals are good electrical and thermal conductivity, good sliding properties and the lack of sparking. Copper metals are dense, so they should be carefully dimensioned to avoid their becoming too heavy. The casting properties of cast copper are weak, but those of cast copper alloys are better. The modulus of elasticity of copper alloys increases with decreasing temperature, so the structure does not become brittle under cold conditions."

Indicative values for properties of cast copper metals

Material	*Copper metals*	*Cu*	*CuZn*	*CuSN*	*CuSnPb*	*CuAl*	*CuNi*
Standard title	***CB / CC***						
Standard	***SFS-EN 1982***						
Density (kg/dm^3)	***7.28 - 9.03***	***8.95***	***8.1***	***8.8***	***8.8***	***7.55***	***8.8***
Tensile strength (MPa)	***100 - 930***	***145 - 160***	***200 - 350***	***220 - 510***	***220 - 510***	***410 - 850***	***150 - 180***
Hardness (HB)	***20 - 220***	***17***	***50 - 85***	***60 - 170***	***45 - 80***	***110 - 195***	***50 - 65***
Property	***Corrosion resistance***	***Thermal conductivity***	***Corrosion resistance***	***Corrosion resistance***	***Pressure tightness***	***Strength, corrosion resistance at high temperatures***	***Corrosion resistance in marine conditions***

To find the best alloy, you should contact the foundry. Each foundry may also have its own materials from outside the standards, so their use must be agreed with the foundry.

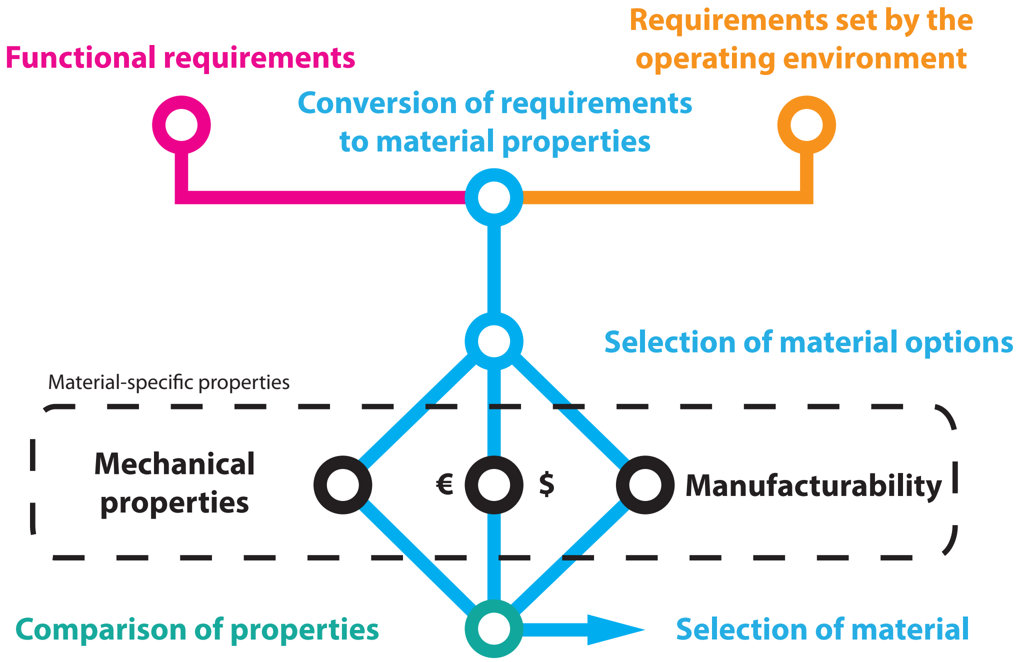
Properties of different copper metals

Coppers with high conductivity are used when high electrical and heat conductivity is required. **Brasses** (*copper-tin alloys*), where tin is the major alloying element, are easy to cast and machine. They are also highly resistant to corrosion in air and fresh water. They are commonly used in pipe fittings, and more alloyed (and thus durable) ones in marine technology. **Tin bronzes** (*copper-tin alloys*), where the proportion of tin is approximately 10% to 12%, are more challenging to cast than brasses, but they offer better resistance to corrosion. They have a good tolerance of acidic water and boiler feed water, and are sometimes also used in locations where resistance to wear is required. **Lead tin bronzes** (*copper-tin-lead alloys*) are commonly used in bearings with high loads and rotation speeds. **Red brasses** (*copper-tin-zinc-lead*) are best suited for sand casting, and offer a good combination of castability, machinability and solidity with good corrosion resistance. They are widely used in complex, pressure-resistant castings, such as pumps and valves. They can also be used in bearings whose loads and speeds are in the middle range. **Aluminium bronzes** (*copper-aluminium alloys*), where aluminium is the main alloying element, combine high solidity and good corrosion resistance, but are more challenging to cast. They are used in shipbuilding for propellers, pumps and valves. They are also used to manufacture spark-free tools.

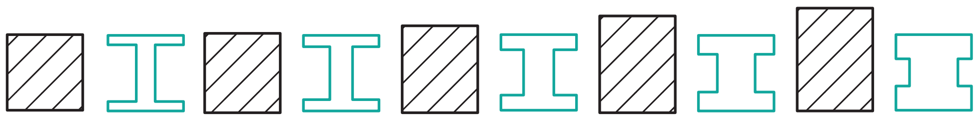
Selection of materials

“The choice of materials is an important part of the product design process, as it can affect the properties, manufacturability and price of the product. For example, when the design goal is a piece that is as light as possible while meeting the requisite demands for strength, the most suitable material may not be the cheapest in terms of actual cost or lightest in terms of specific gravity. The material options should be compared already at the design stage, as changing the material at a later stage will affect the construction of the piece.”

Simplified process of material selection



The material chosen also has a significant effect on the shapes to be designed. The relative on effects of different materials on shapes with the same bending stiffness are described below.



	GX		GJS		CB		GJL		AC	
Bending stiffness	***100***	***100***	***100***	***100***	***100***	***100***	***100***	***100***	***100***	***100***
Area	***100***	***44***	***105***	***49***	***116***	***63***	***124***	***72***	***136***	***85***
Weight	***100***	***44***	***95***	***45***	***131***	***71***	***113***	***66***	***45***	***29***
Cost	***100***	***44***	***12***	***6***	***213***	***115***	***12***	***7***	***21***	***13***

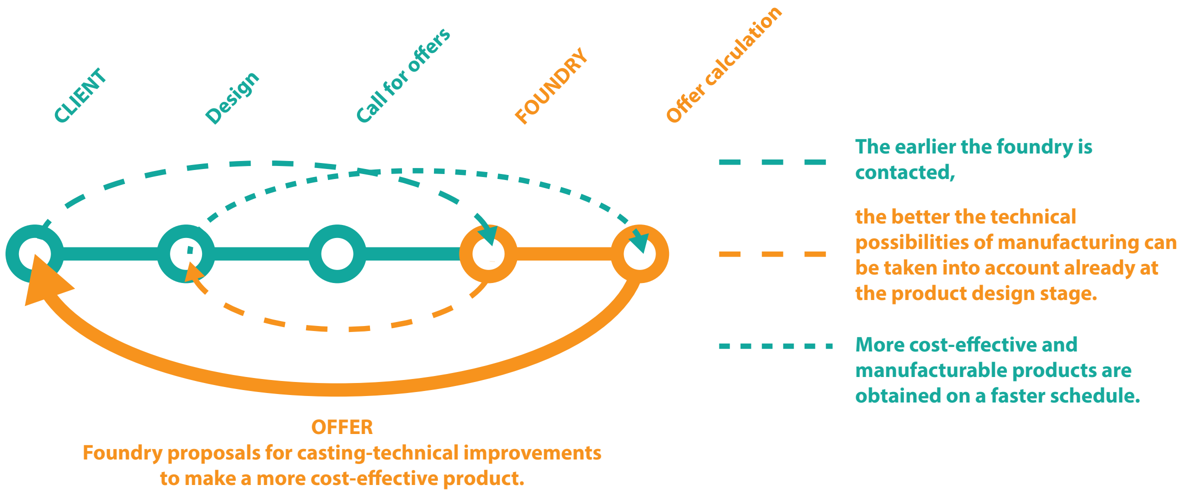
The values are indicative. The bending stiffness is calculated as the product of the modulus of elasticity (average of the alloys in the material group) and the stiffness moment. The cost is based on the price per kilogram of material and does not take into account manufacturing costs.

2 Methods

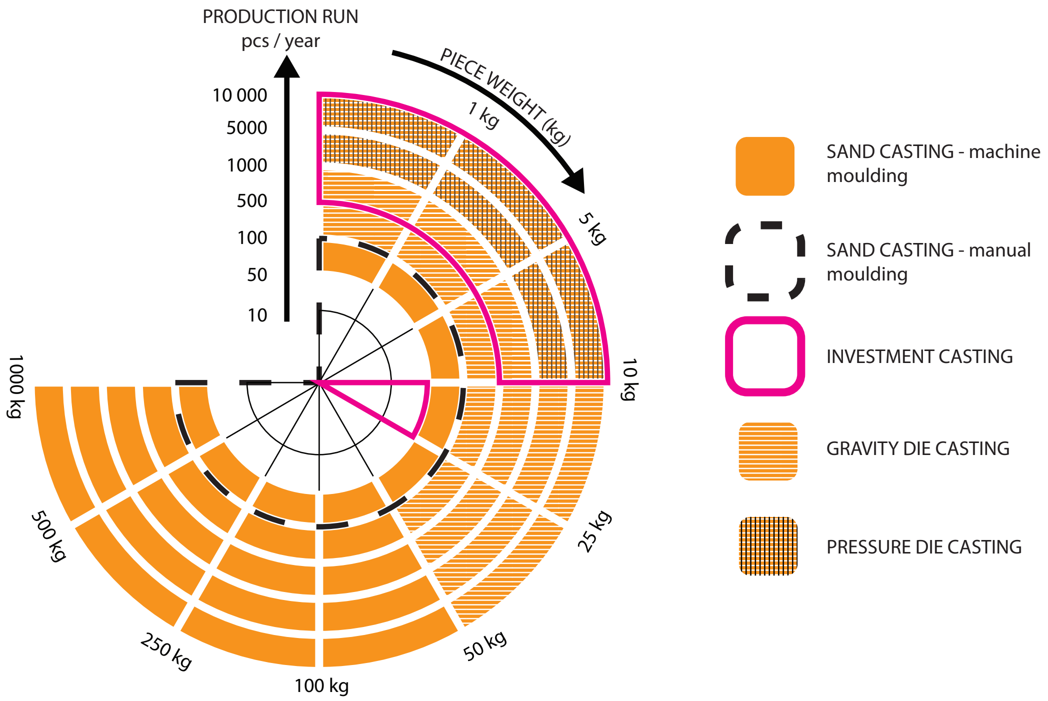
Selection of method

"Based on the method, bids are sent to specific manufacturers. It must also be verified that the manufacturer in question uses the desired material."

Selection of method → selection of foundry

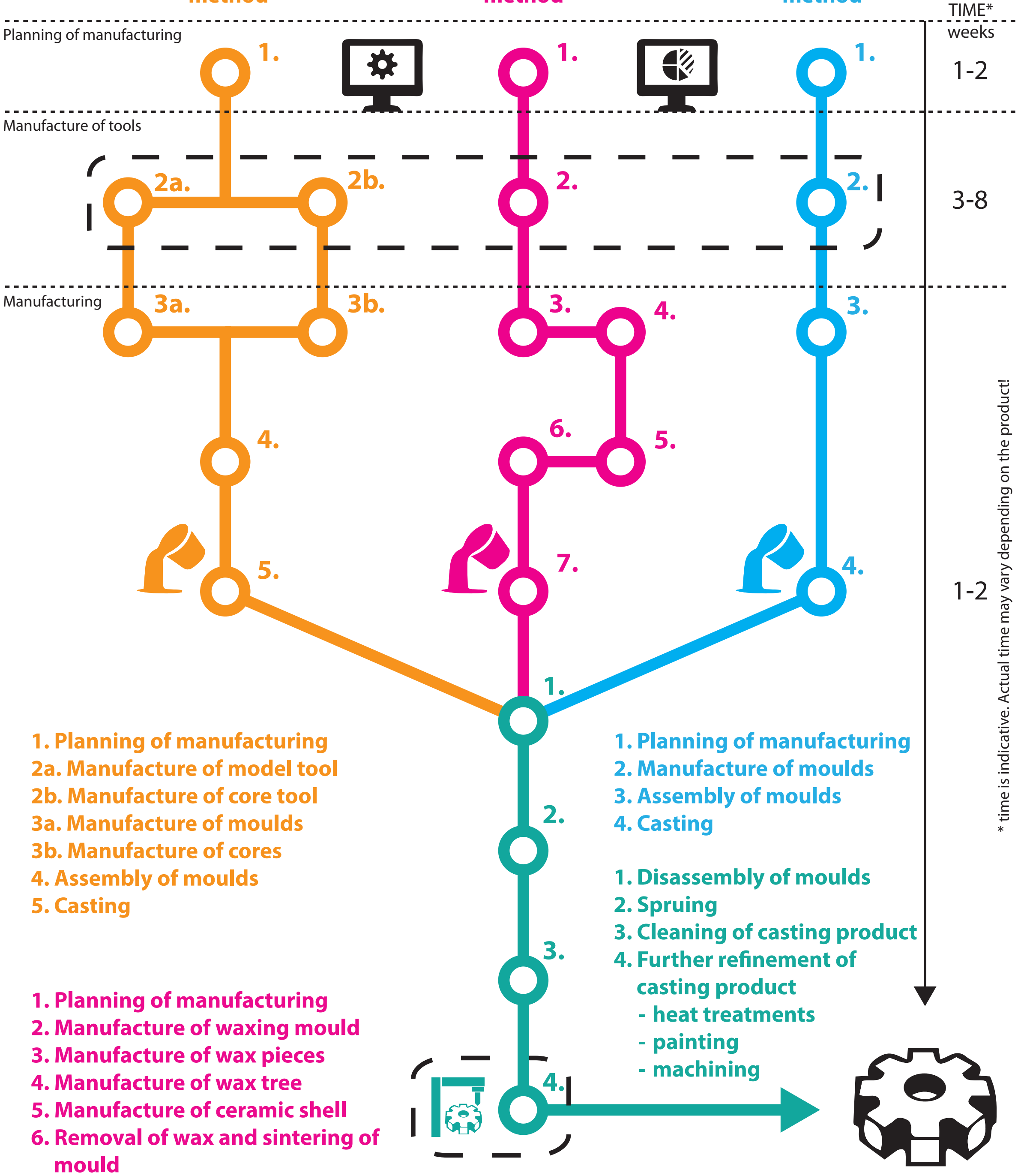


Influence of piece weight and production run size on selection of method:



Manufacture of casting products

"Once the offer is accepted, the product can start to be manufactured."



1. Planning of manufacturing
2a. Manufacture of model tool
2b. Manufacture of core tool
3a. Manufacture of moulds
3b. Manufacture of cores
4. Assembly of moulds
5. Casting

1. Planning of manufacturing
2. Manufacture of moulds
3. Assembly of moulds
4. Casting

1. Planning of manufacturing
2. Manufacture of waxing mould
3. Manufacture of wax pieces
4. Manufacture of wax tree
5. Manufacture of ceramic shell
6. Removal of wax and sintering of mould
7. Casting

1. Disassembly of moulds
2. Spruing
3. Cleaning of casting product
4. Further refinement of casting product
   - heat treatments
   - painting
   - machining

SUBCONTRACTING

Model tools of disposable moulds

"Casting is not possible without a casting model that can be made of wood, plastic, wax or metal. If cores or loose pieces have to be used in the casting model, the manufacturing costs increase, but these can be used to produce shapes that cannot be made by other manufacturing methods. In general, it is the foundries that order the model tools, as they affect the manufacturing of the piece."

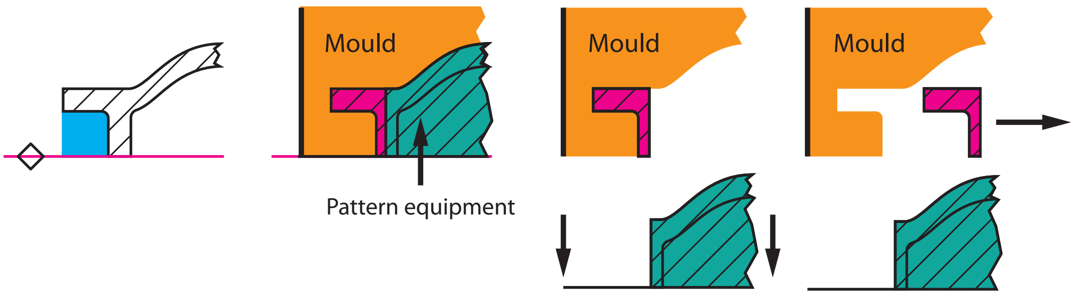
Depending on the casting model, the mould has to be divided in several different ways. A parting line is formed between the parts of the mould. To enable the casting models to be removed from the mould, they must have drafts. To make complex shapes, loose pieces can be used in the casting model or cores in the mould.

The desired form; the blue area forms the undercut

The pattern equipment consists of two parts

The first part of the pattern equipment is drawn away

The loose piece is finally drawn out of the mould

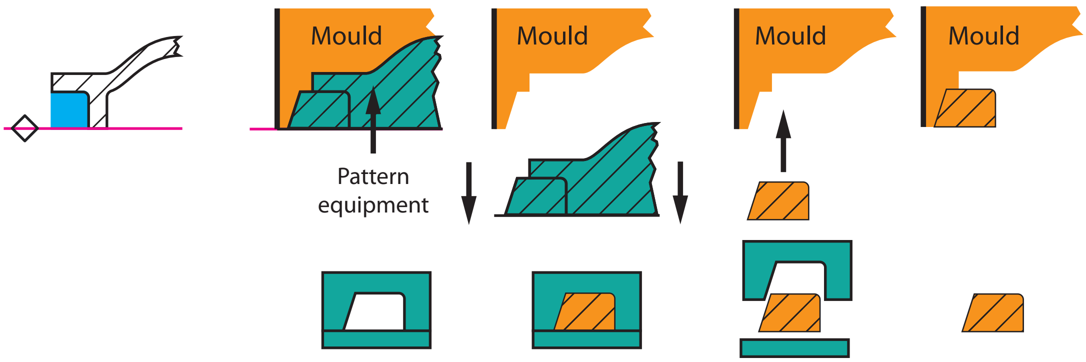


The cores are parts of the mould that are made separately and added to the mould when it is assembled. They are used to achieve shapes that are not possible naturally. A separate tool, a core box, is needed to make the cores. The core boxes must also have drafts to enable the cores to be loosened.

The desired form; the blue area forms the undercut

The position of the core is taken into account in the pattern equipment, which is pulled away

The core is afterwards placed in the mould in its own place



Core box

Core box is filled with sand

Core box is opened

Finished core is placed in the mould

Model tools of permanent moulds

"Permanent moulds usually consist of a two-part mould made of tool steel One half of a two-piece mould is called fixed (magazine side) and the other movable (core side). A parting line is formed between these halves of the mould. Permanent moulds can be very complex and include separate pull-out cores, which can make them relatively expensive."

The piece should be placed in the mould so that it remains attached to the movable part of the mould, from which it can be pushed by means of ejectors. Pull-out cores can be used to make difficult shapes and ones involving back draft.

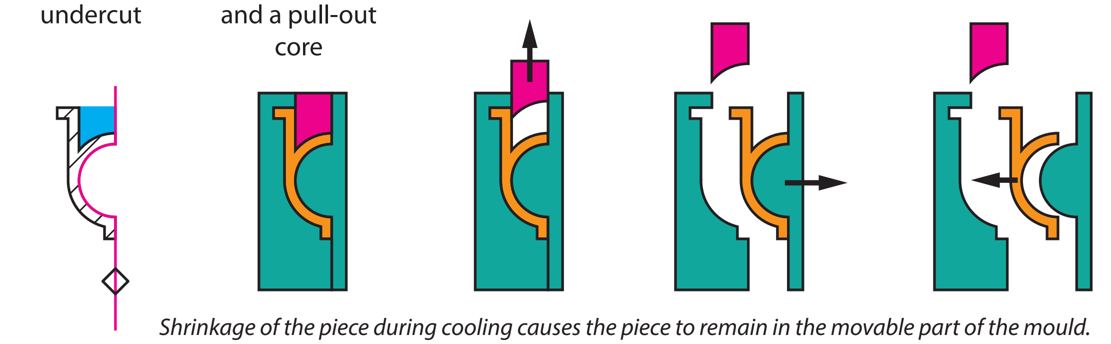
The desired form; the blue area forms the undercut

The mould package consists of two moulds and a pull-out core

1. The core is drawn out.

2. The piece is stuck in the movable mould half

3. Ejectors push the piece out of the mould



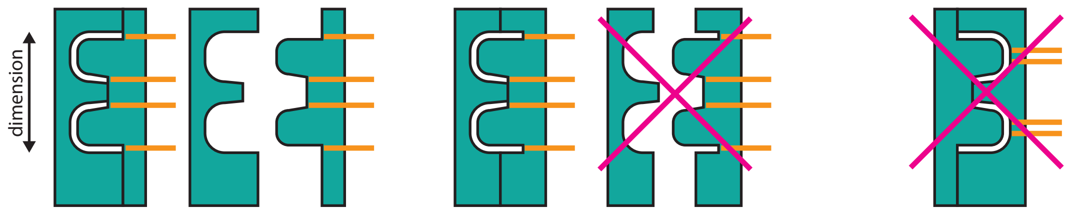
Shrinkage of the piece during cooling causes the piece to remain in the movable part of the mould.

From the viewpoint of machining costs and dimensional accuracy, it is advantageous to design the piece so that all the shapes are in the same mould half. Deep/tall and narrow shapes should also be avoided. If there are requirements for the appearance of the piece, this surface should be in the fixed half of the mould, as the protrusions will leave marks on the piece.

The dimensioned shape is in the same half of the mould

The dimensioned shape is divided into both halves of the mould

The ejectors push the piece loose along the outer surface of the piece



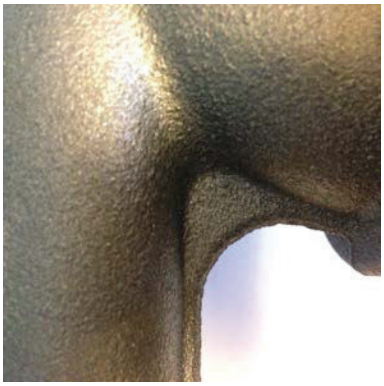
Only a certain size of mould will fit into the casting machine in use. The size of the piece and the number of magazines determine the size of the mould used. In moulds, it should be noted that the injection port often settles on the parting line below the piece. The piece should be shaped so that the material has an unobstructed flow to the extreme parts of the piece. The mould's becoming filled affects the quality of the piece.

Sand mould method

"In the sand mould method, the moulds are made with the help of a casting model from sand that is hardened with a binding agent. The shaping frame is placed on top of the pattern equipment, and these are then filled with sand which is allowed to harden. The pattern equipment is removed from the hardened sand mould. To enable the equipment to be detached from the mould, the equipment must have drafts in the direction of loosening. Cores can be used in the mould or loose pieces in the pattern equipment, and in this way the method can produce even very complex pieces. Finally, the halves of the mould are put together and the desired material is cast in the mould."

Indicative values for the sand mould method

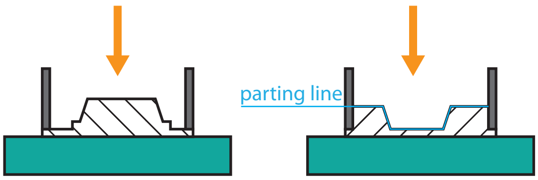
Weights of pieces	***100 g - 200,000 t***
Materials to be cast	***any***
Economical production run	***1 - 100 (manual moulding) 50 - 1000 (machine moulding)***
Lowest wall thickness	***3 - 5 mm (depending on material)***
Freedom of design	***Very good***
Cost of pattern equipment (1 = inexpensive 5 = expensive)	***1 - 2 (manual moulding) 3 (machine moulding)***



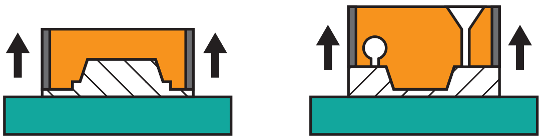
The sand method achieves a surface quality of 300 - 900 RMS (surface quality is affected by the sand and method used)

Phases of the sand mould method

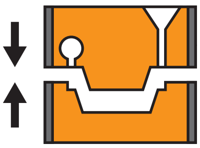
1. THE SHAPING FRAME IS FILLED WITH SAND



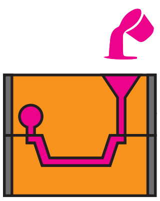
2. THE MOULD IS FINISHED AND IS DETACHED FROM THE PATTERN EQUIPMENT



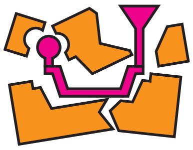
3. ASSEMBLY OF MOULDS



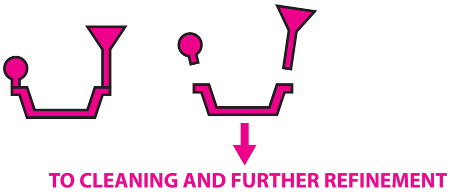
4. CASTING



5. DISASSEMBLY OF MOULDS



6. SPRUING

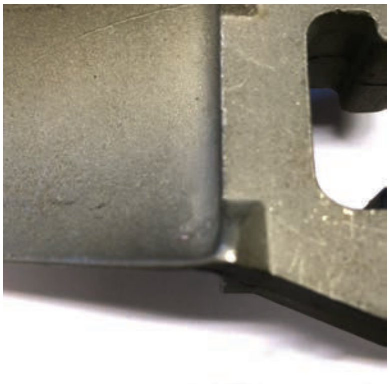


Investment casting method

"Investment casting uses ceramic moulds. The ceramic moulds are obtained by using wax models upon which a ceramic shell is made. The wax is then melted off, and the desired material can be cast in the mould. Investment casting can be used to cast individual pieces and small prototype series, but it is also economical for large series. The material costs of ceramic moulds are high, but they are very suitable for pieces with high precision requirements. Ceramic moulds limit the size of the piece, but offer a great deal of design freedom."

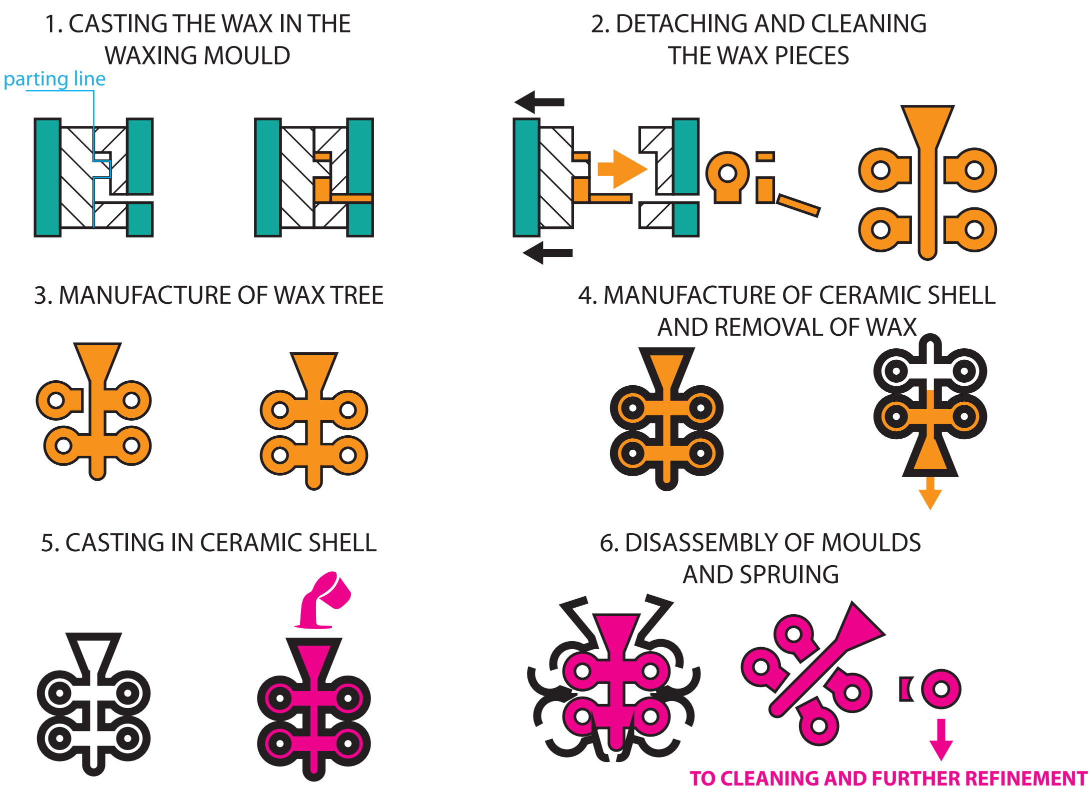
Indicative values for the investment casting method

Weights of pieces	***1 g - 10 kg (25 kg)***
Materials to be cast	***any***
Economical production run	***1 - 50 (prototypes and large pieces) 500 - 10,000 (small pieces)***
Lowest wall thickness	***2 - 5 mm (depending on material)***
Freedom of design	***Very good***
Cost of pattern equipment *(1 = inexpensive 5 = expensive)*	***2***



With investment casting, a surface quality of 50 - 125 RMS can be reached

Phases of the investment casting method



Permanent mould method: Pressure die casting

"In die casting, molten metal is pushed into the mould at high speed, and the piece solidifies very quickly. Due to the high velocity, the flow in the mould is very turbulent, and the piece is full of micropores. In pressure die casting, it should be noted that the piece is filled and fed from the same direction. Die casting is generally used to make small and thin-walled pieces, where it achieves very good dimensional accuracy."

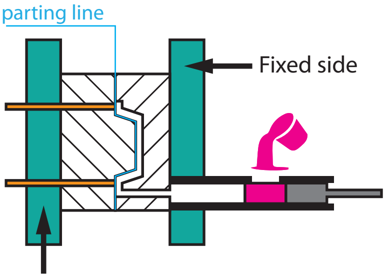
Indicative values for the pressure die casting method

Weights of pieces	***10 g - 10 kg***
Materials to be cast	***Al, Mg, Zn, Sn***
Economical production run	***1000 +***
Lowest wall thickness	***1 - 3 mm (depending on material)***
Freedom of design	***Moderate***
Cost of pattern equipment (1 = inexpensive 5 = expensive)	***5***

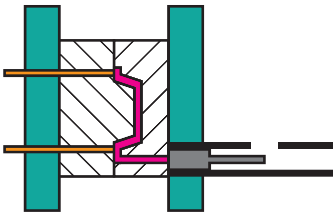
Surface quality of pressure die casting. With permanent moulds, a surface quality of 20 - 120 RMS can be reached

Phases of the pressure die casting method

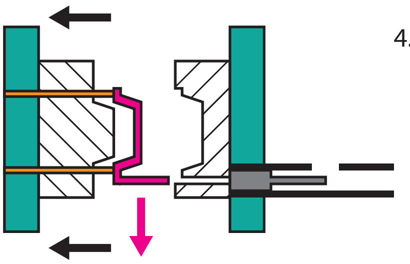
1. THE MOULD IS CLOSED AND THE CASTING CHARGE IS DISPENSED IN THE PRESSURE CYLINDER



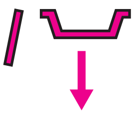
2. THE PISTON PRESSES THE CASTING CHARGE INTO THE MOULD WITH HIGH PRESSURE



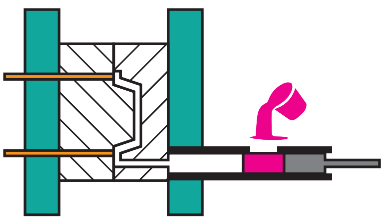
3. THE MOULD OPENS AND EJECTORS PUSH THE PIECE OUT OF THE MOULD



4. SPRUING



5. THE MOULD IS CLOSED AND A NEW CASTING ROUND STARTS



TO CLEANING AND FURTHER REFINEMENT

Permanent mould method: Gravity die casting

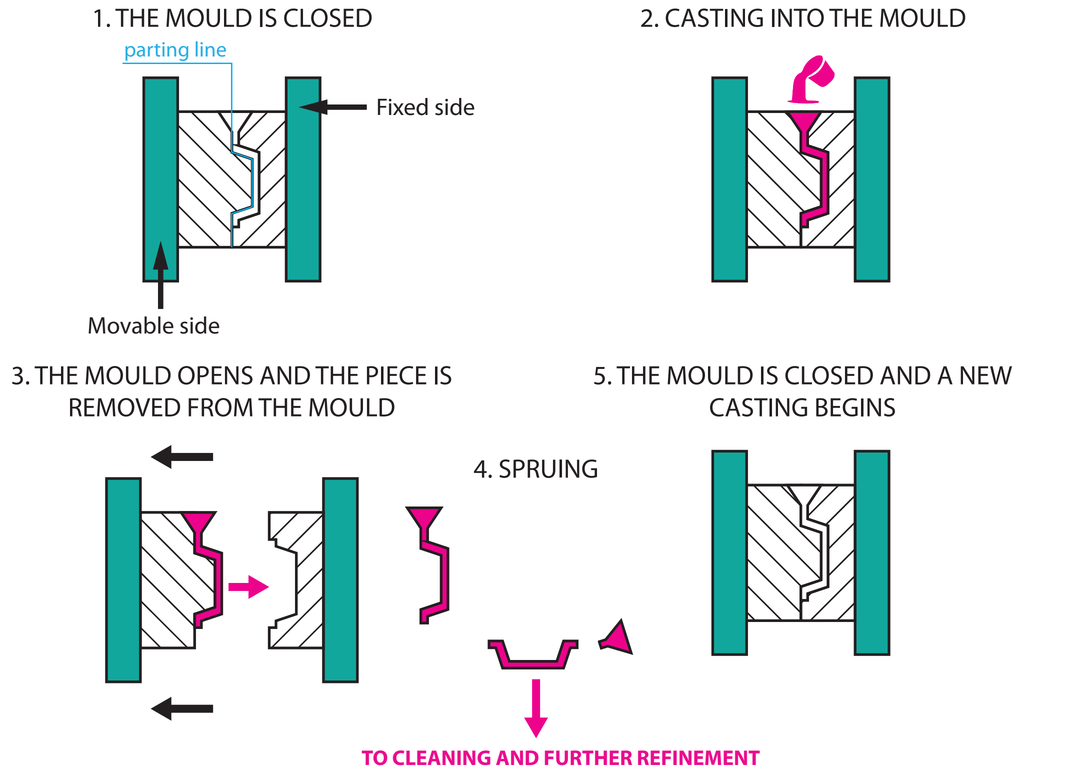
"In gravity die casting, the piece cools and solidifies quickly, so that the casting receives a fine-grained and dense microstructure and thus good mechanical properties. It is a good idea to shape the piece so that it can be removed from the mould manually, so it must have sufficient drafts and a reasonably thought-out parting line, as well as suitable places for the casting system. In gravity die casting, the mould may have one or more vertical or horizontal parting lines."

Indicative values for the gravity die casting method

Weights of pieces	***10 g - 50 kg***
Materials to be cast	***Al, Mg, Zn***
Economical production run	***100 - 10,000***
Lowest wall thickness	***2 - 4 mm (depending on material)***
Freedom of design	***Limited***
Cost of pattern equipment (1 = inexpensive 5 = expensive)	***3 - 4***

Surface quality using gravity die casting. With permanent moulds, a surface quality of 20 - 120 RMS can be reached

Phases of the gravity die casting method



Permanent mould method: Low-pressure casting

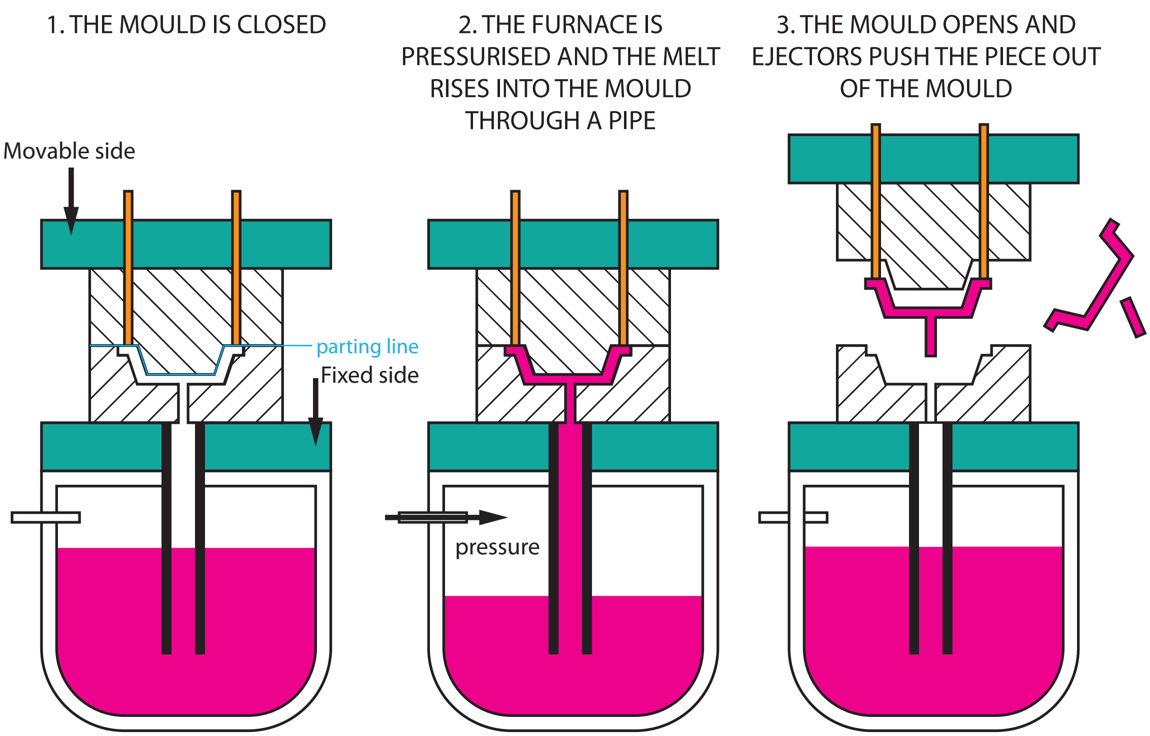
"In low-pressure casting, the mould is located on top of the furnace and a slight overpressure is led to the furnace, as a result of which the molten metal rises calmly up a pipe into the mould. Once the piece has solidified, the overpressure is removed and the melt settles back into the furnace. The pieces are designed in the same way as in gravity die casting and are fed mainly through the casting ductwork. In low-pressure casting, sand cores can also be used in some applications for awkward shapes."

Indicative values for the low-pressure casting method

Weights of pieces	***5 kg - 25 kg***
Materials to be cast	***Al, Mg, Zn, Sn***
Economical production run	***2000 - 10,000***
Lowest wall thickness	***4 - 10 mm (depending on material)***
Freedom of design	***Limited***
Cost of pattern equipment *(1 = inexpensive 5 = expensive)*	***4 - 5***

Surface quality of pressure die casting. With permanent moulds, a surface quality of 20 - 120 RMS can be reached

Phases of the low-pressure casting method



Permanent mould method: Centrifugal casting

"Centrifugal casting is mainly used to produce cylindrical or cup-shaped pieces that are axially symmetrical. Centrifugal casting can also be used for simple casting of shapes. In centrifugal casting, molten metal is poured into a metal mould that rotates either vertically or horizontally, where the melt is pushed against the walls of the mould by centrifugal force and an empty space is formed in the centre of the piece."

Indicative values for centrifugal casting

Weights of pieces	***1 kg - 5000 kg***
Materials to be cast	***Ferric metals, Cu alloys***
Economical production run	***10 - 10,000***
Lowest wall thickness	***9 - 125 mm (depending on material)***
Freedom of design	***Limited to axially symmetrical***
Cost of pattern equipment (1 = inexpensive 5 = expensive)	***3 - 4***

Surface quality using centrifugal casting. With permanent moulds, a surface quality of 20 - 120 RMS can be reached

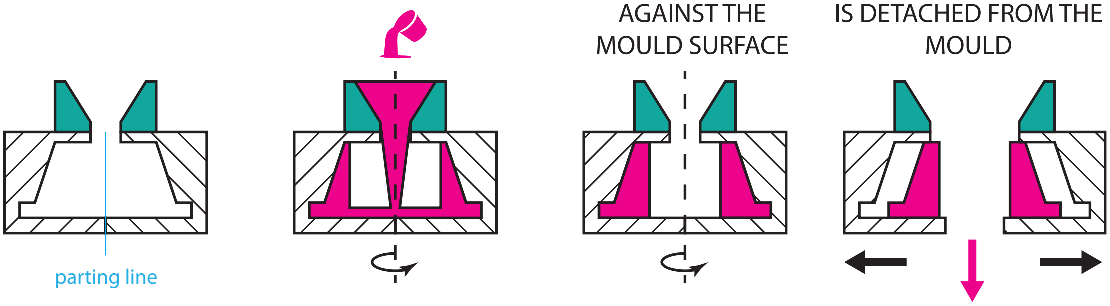
Vertical centrifugal casting

1. THE MOULD IS CLOSED

2. THE MOULD ROTATES AROUND THE AXIS AND IS CAST

3. THE MOLTEN MATERIAL SOLIDIFIES AGAINST THE MOULD SURFACE

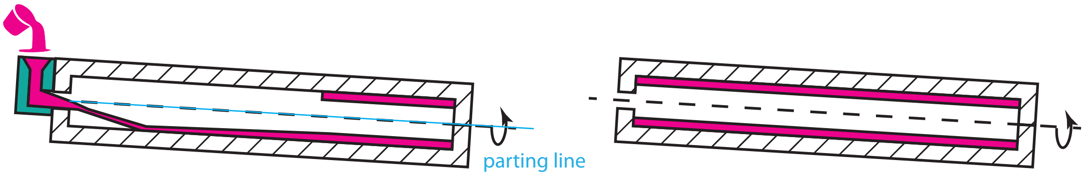
4. THE MOULD IS OPENED AND THE PIECE IS DETACHED FROM THE MOULD

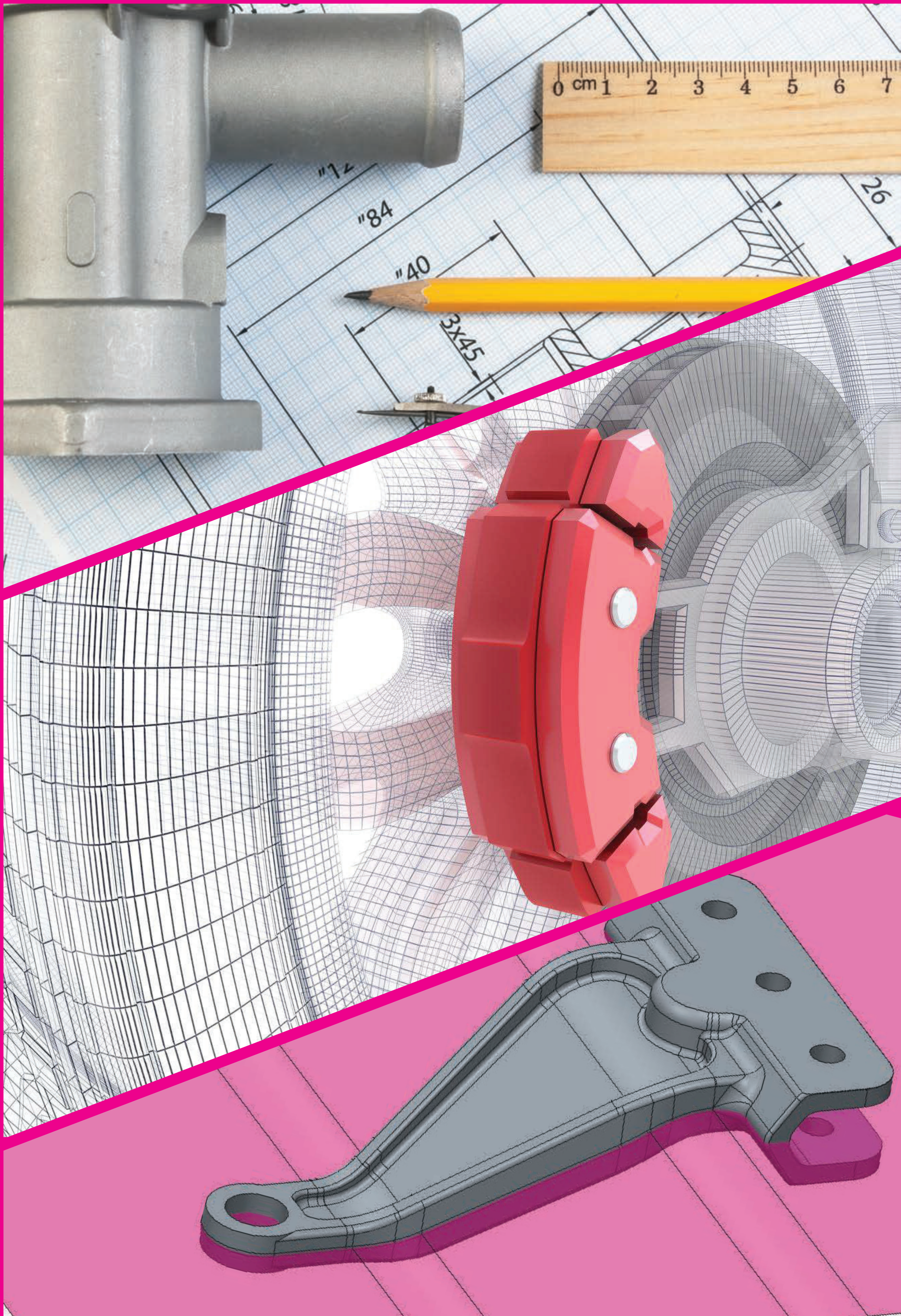


Horizontal centrifugal casting

1. THE MOULD ROTATES AROUND THE HORIZONTAL ROTARY AXIS WHILE MELT IS BEING CAST IN THE MOULD

2. THE MOLTEN MATERIAL SOLIDIFIES AGAINST THE MOULD SURFACE AND THE PIECE IS LEFT HOLLOW




0 cm 1 2 3 4 5 6 7
"84
"40
3x45
26

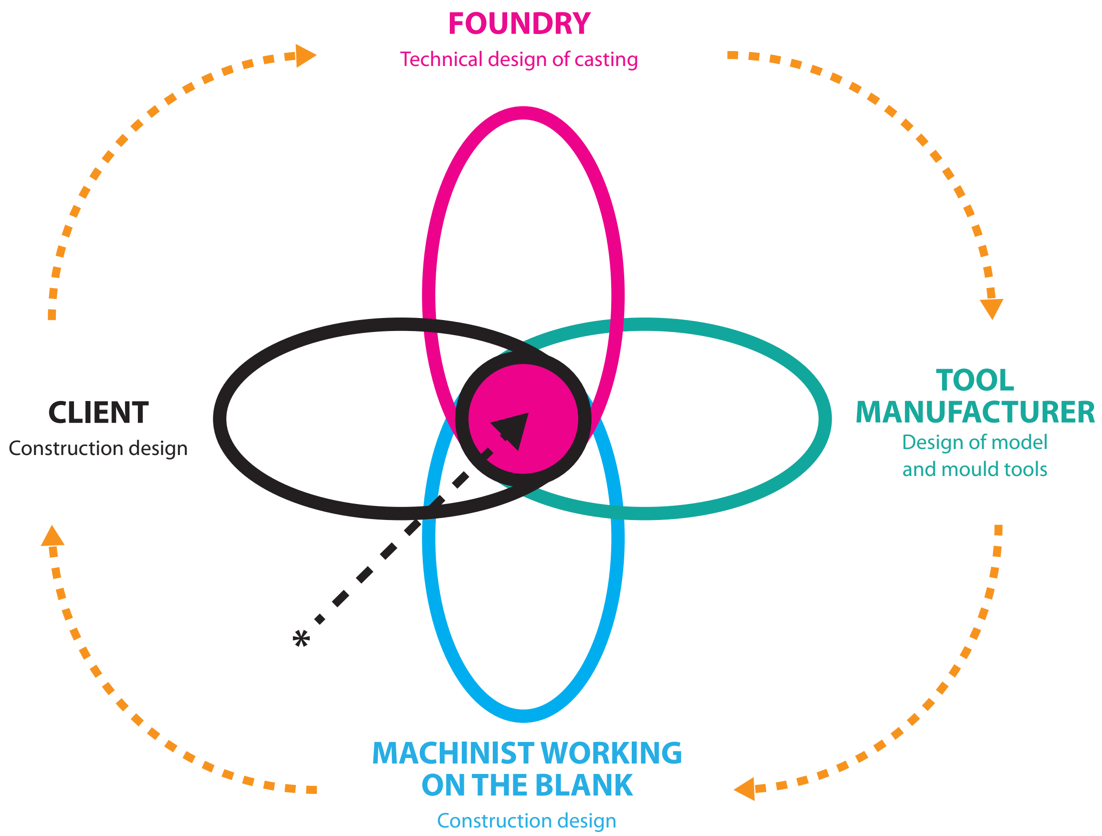
3 Design

Designing cast products

"The special features of the design work on cast product are related to the operating environment of the final product, the properties required of the product, the material chosen and the casting method. In addition, it is also affected by the operating methods of the selected foundry. The best result is achieved by contacting the foundry as early as possible and by designing the product in cooperation with the manufacturer."

The cast product itself is very rarely an end product, but is instead a subset of some actual end product. To avoid unnecessary machining, castings are designed as blanks for machined pieces. Machining is usually one of the most expensive work steps in manufacturing.

Parties and design steps involved in the design of castings

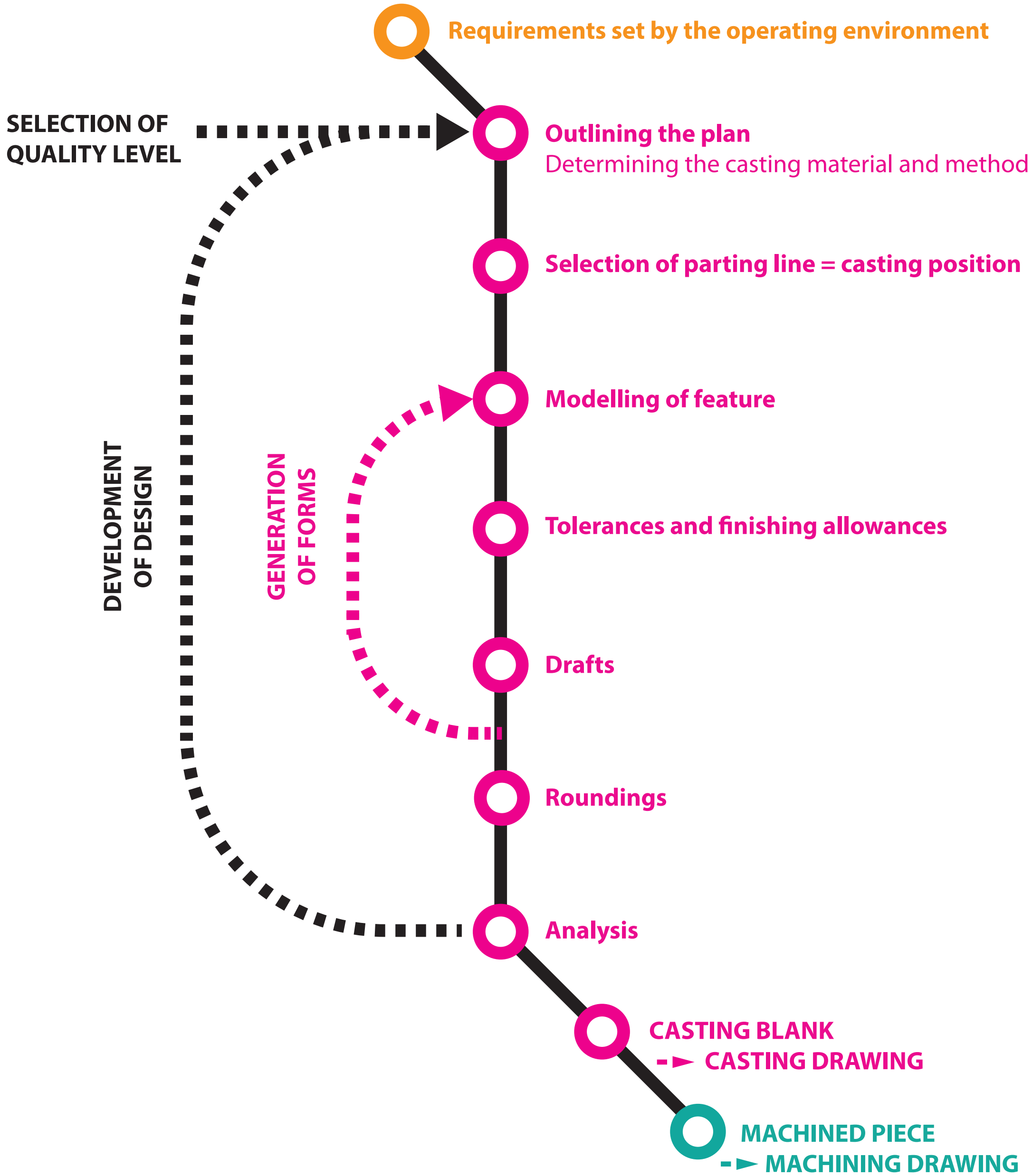


If the design steps are performed sequentially, it is difficult to intervene in the solutions made at an earlier stage. Time spent on design may increase, and this may also cause significant additional costs from product development.

* The best products of all are designed in collaboration with every actor involved, so that the possibilities and limitations of the manufacturing process can be taken into account at the earliest possible stage. Cooperation may seem challenging at first, but once the common rules of the game have been agreed, the time spent on this pays for itself many times over in the form of a high-quality product and an earlier start to production.

The design process

"There is no unambiguous design process for the design of castings, as the product may be a new, functionally modified version of an old one, or it may have been previously manufactured by some other casting method. The end result of the design process is to provide documentation that contains all the essential information needed to manufacture the piece. At least the following things must be taken into account in the design of castings."



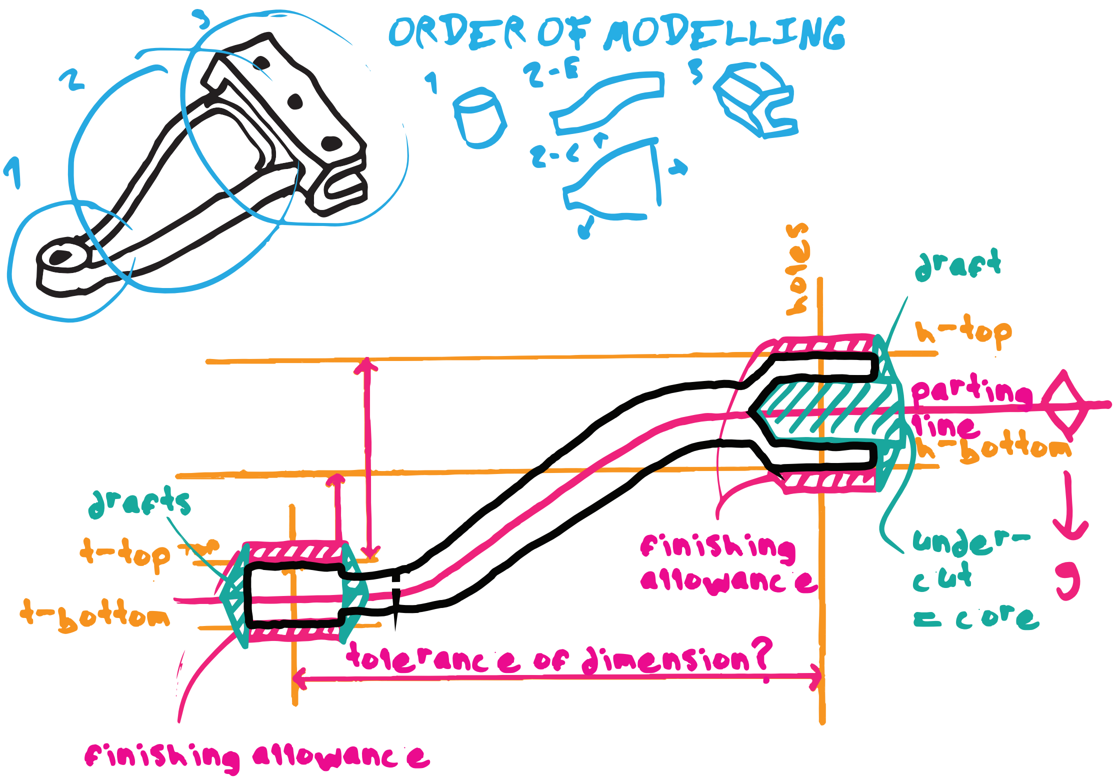
The design of cast products is not easy, but the more you can take into account the technical manufacturing solutions already at the design stage, the better the prerequisites are for a cost-effective product of high quality. The designer needs to be aware of which factors contribute to a successful outcome and what may need to be discussed with the foundry. If you are unsure about something, then it is worth postponing doing it and contacting the foundry as early as possible.

Outlining the design: With pen and paper

"Well planned is half done. Before embarking on modelling, it is a good idea to outline a preliminary plan on paper. In this way the whole can be controlled better, and the implementation of the plan is only a technical achievement."

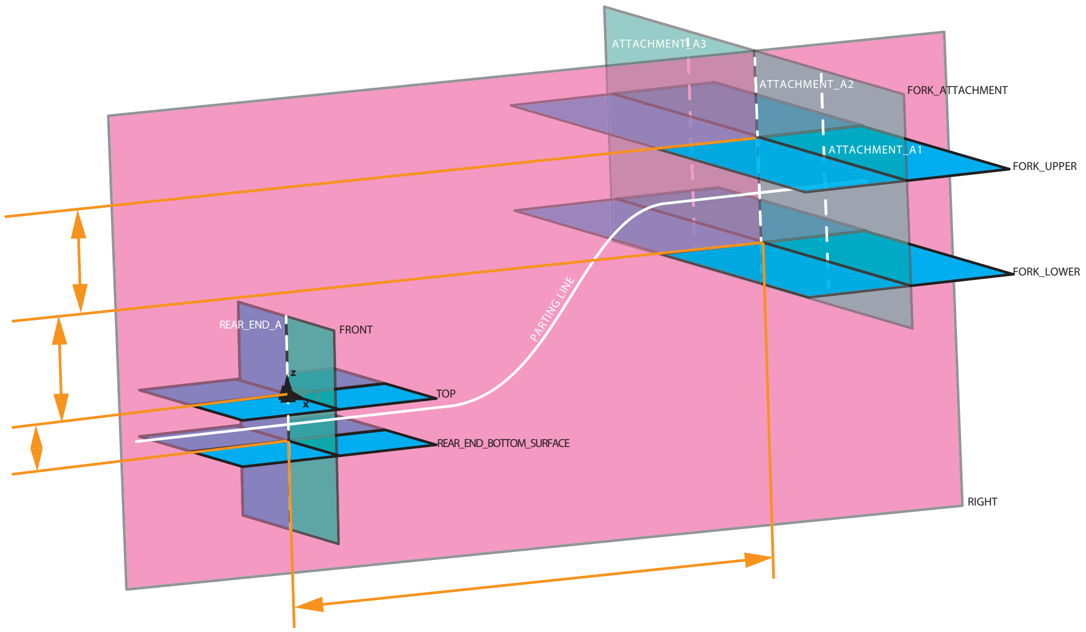
- **Main dimensions**
- **Surfaces to be machined**
- **Parting line = casting position**
- **Drafts and forms with undercut = need for cores**
- **Positioning of coordinate system**
- **Auxiliary level locations**
- **Modelling order of features**
- **Naming of features**

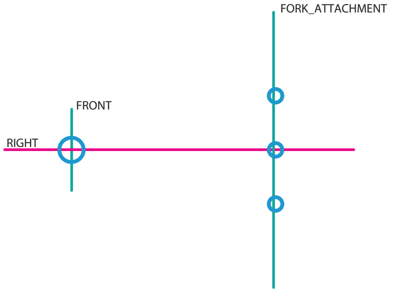
It is a good idea to at least consider the above points in the plan.

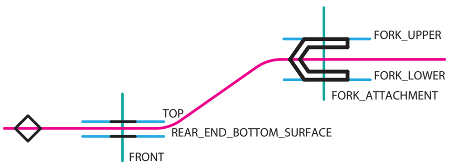


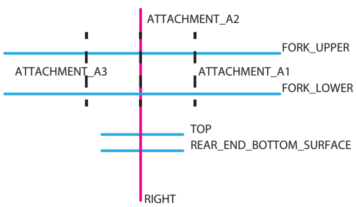
Outlining the plan: Auxiliary planes

"In the technical implementation of the plan, it is advisable to use the software's auxiliary planes, coordinate systems, axes and points, which are formed according to the main dimensions and the surfaces to be machined, as well as the defining features. When the features of the shapes are bound to these auxiliary planes, the 3D file remains better controlled, and the dimensions can be easily changed afterwards by changing the positioning of only these planes."







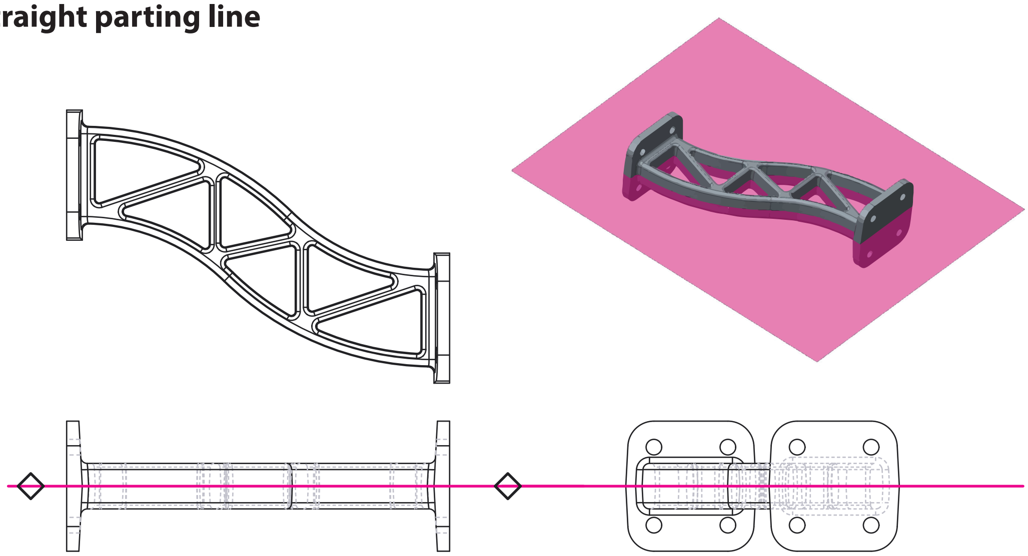


There may be a number of auxiliary features in complex products, so it is important to plan in advance which auxiliary features are important. They should also be named appropriately. Planning auxiliary features in advance can save significant time in implementing the plan. In addition, some shapes may require auxiliary features during modelling.

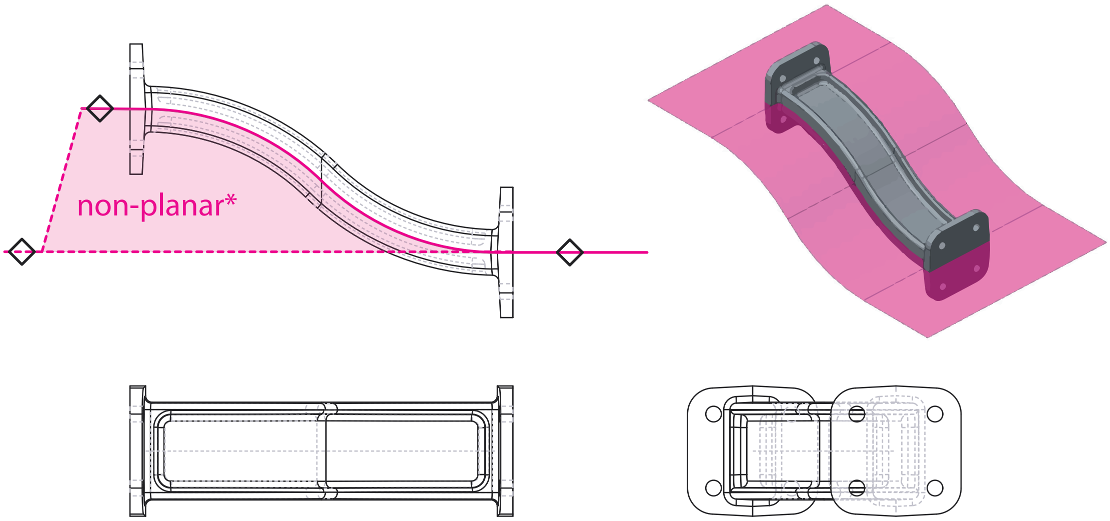
Parting line

"Each casting product has a parting line (parting surface), which is the contact surface between the two mould parts. The parting line is the basis for the design of cast products. In terms of cost and manufacturability, a straight parting line would be ideal. A complex parting surface forms a non-planar shape in the moulds, which increases the manufacturing cost. It must be noted that the parting line level leaves a visible shape in the final product."

Straight parting line

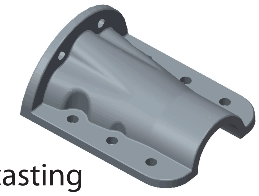


Irregular parting line = complex parting surface



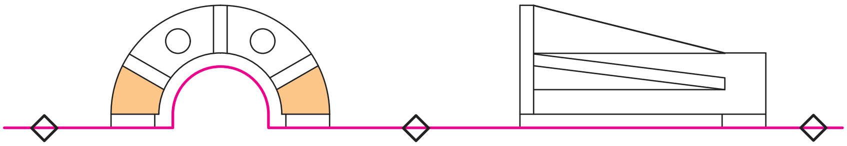
* The complex parting surface always deviates from the departing parting line, having a non-planar form because it always returns to the parting line proper. This involves a protrusion on a mould half that points towards the opposite half.

Parting line: Casting position

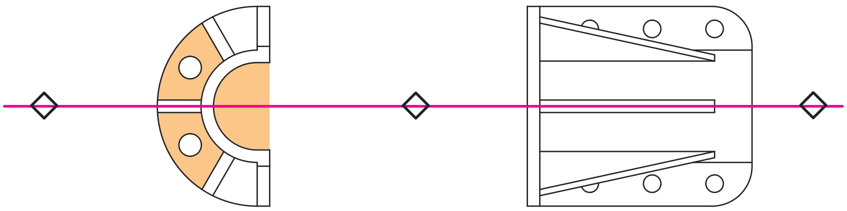


"The casting method and the parting plane determine the casting position of the product. The casting position means the position of the piece in the mould in relation to the direction of gravity, the parting line, the sprues or any possible feeds. The aim should be to position the casting in the direction of gravity in such a way that the thickest points are at the top under the risers and thick points are not left surrounded by thin points. The casting position significantly affects the castability of the product."

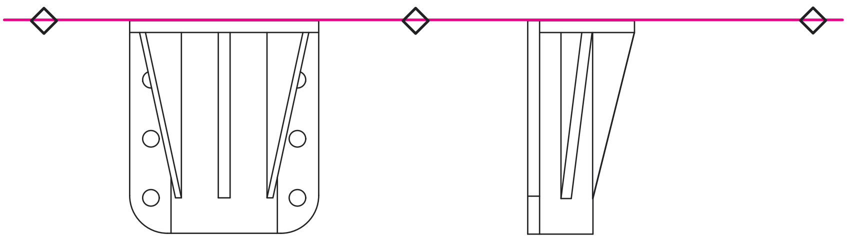
Complex parting surfaces should be avoided (= they should not however be feared).



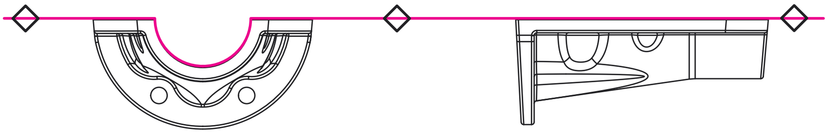
Cores and separate loose pieces increase the price of the product.



Large surfaces to be machined should preferably be placed either vertically or downwards.



The casting should be placed in the mould as low as possible.

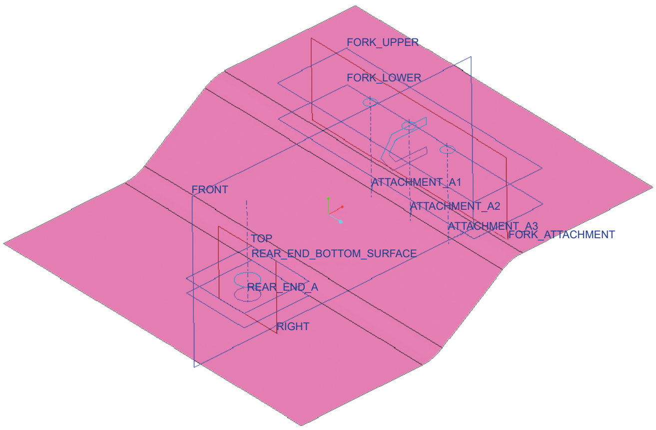


The casting position determines the drafts of the casting. The shape forms back drafts in relation to the parting line, so it has to be done with a core. Back drafts can be avoided by shaping the piece or changing the casting position.

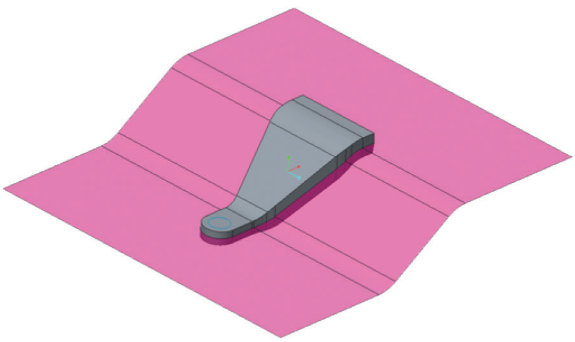
Creation of shapes

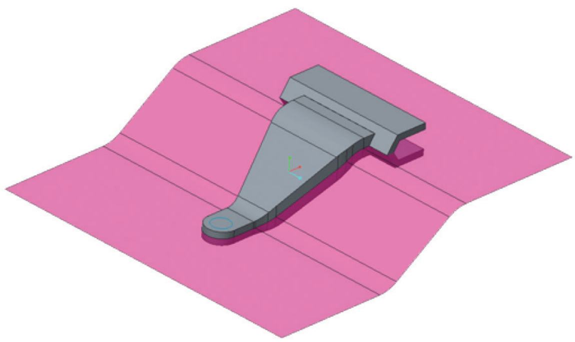
"The creation of shapes is a technical performance that combines functionalities to each other by means of the required shapes, taking into account the factors that limit design. Simple shapes form a beautiful whole, so every shape of a cast product should serve some purpose. The shapes are created according to the parting line and the defined auxiliary planes, forming a whole."

The parting line is the first shape to be modelled. The parting line serves as the basis for the shapes, and it is advisable to use the simplest possible basic shapes, from which the necessary shapes are obtained by extrusion and cutting.



Cast products have a great deal of design freedom, so a product with the same properties can be obtained with many different shapes. For the required shapes, it is a good idea to think about the order in which you want to model the shapes.

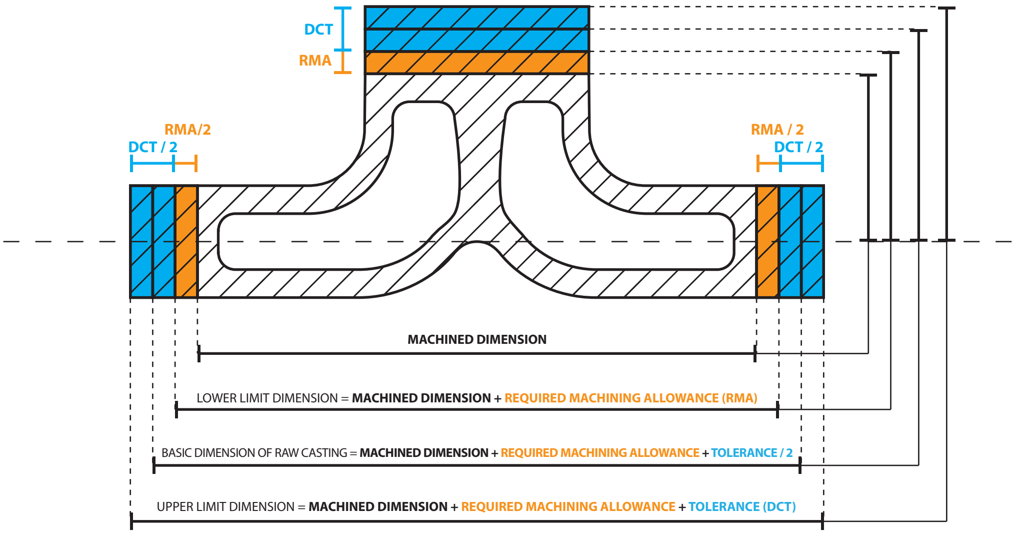




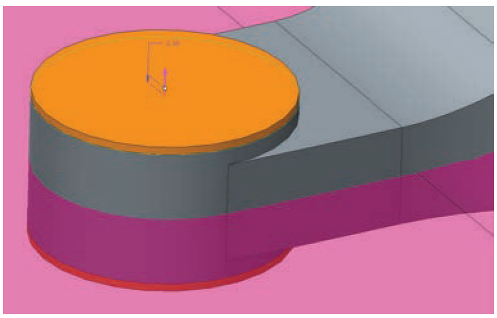
Tolerances and finishing allowances

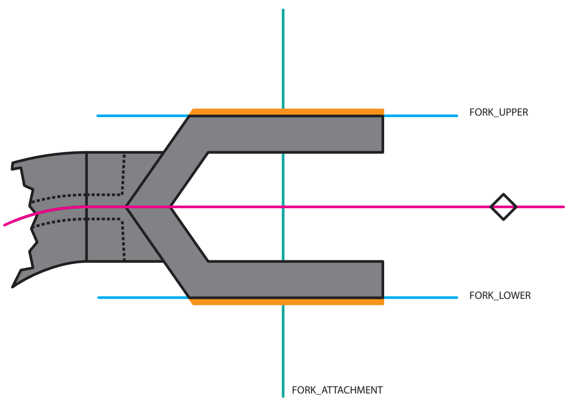
“Castings always deviate from the designed dimensions and shapes. Dimensional and shape deviations are due to the crystallization and shrinkage properties of the casting material as well as the mould. Tolerances should be taken into account already at the design stage. Tolerances always increase the dimensions, so care must be taken to ensure that the required dimensions are achieved with the lower and upper limits of the tolerance.”

The casting method determines the tolerances specified for a piece.



Tolerances and machining allowances should be modelled as their own features (if possible), so that they can be easily changed afterwards if necessary. It is a good idea to separate the surface to be machined with a small platform, so the boundary of the machined surface is clear in relation to the unmachined surface.





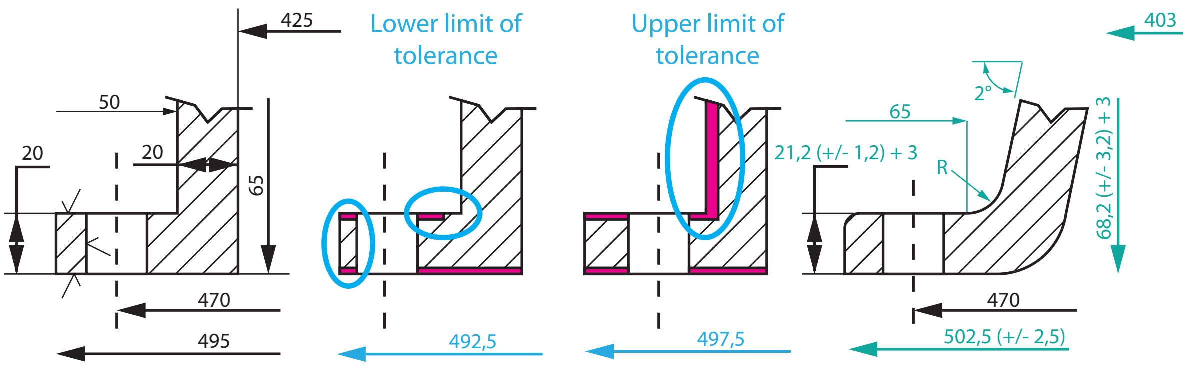
Standard **SFS-EN ISO 8062-3** Geometric Product Specification (GPS) defines the dimensional tolerances and geometric tolerances of moulded pieces. (General dimensional tolerances for castings, general geometrical tolerances and machining allowances.)

Dimensioning of tolerances

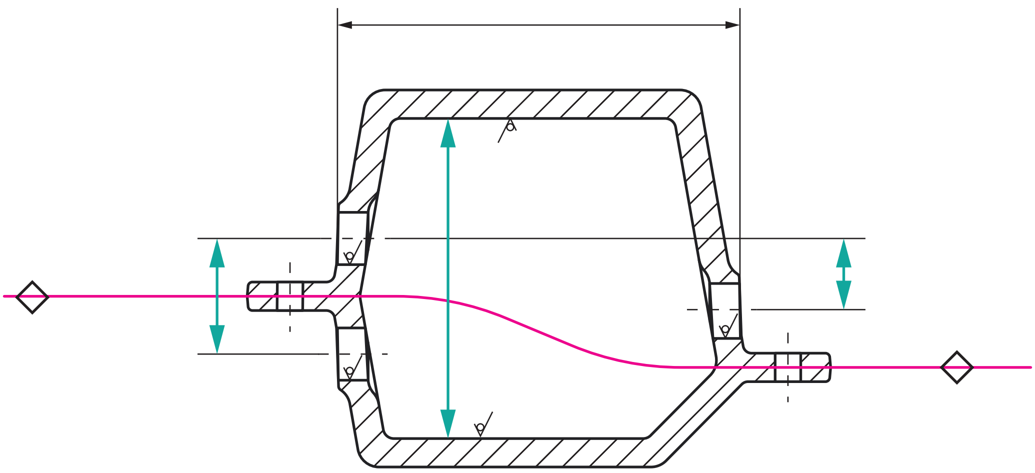
"Tolerances (and machining allowances) should be taken into account already at the design stage, as they affect the defining dimensions of the piece. The piece must be designed in such a way that dimensional changes within tolerances do not affect its characteristics. It is recommended to select a loose overall tolerance for the piece, with only the dimensions for which greater accuracy is required being marked with deviations."

If tolerances and machining allowances are not taken into account in the design, there is a risk that the piece will be machined too much at the upper limit of the tolerances and too little at the lower limit. There is then a risk that most of the products will be rejected. When dimensioning tolerances, the effect of drafts and rounding should also be taken into account.

General tolerance ISO 8062-3 - DCTG 10 - RMA 3 (RMAG F)

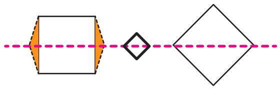


Dimensional accuracy over the parting line is worse than with the dimensions of the piece in the same half of the mould. Cores also always reduce dimensional accuracy, because they have clearances.



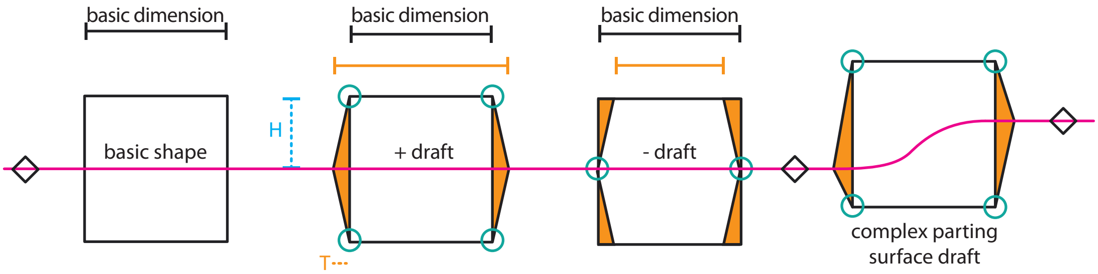
The predominant dimensions formed over the parting line or from the cores are less accurate dimensionally than dimensions in the same mould half.

Drafts



"Drafts are the bevelling of the walls vertical to the parting line in order to get the model tool to detach from the mould or the piece to detach from the mould tool. Cast products cannot be manufactured without drafts. Drafts in the product can be avoided by means of cores, but the cores must also have drafts accordingly."

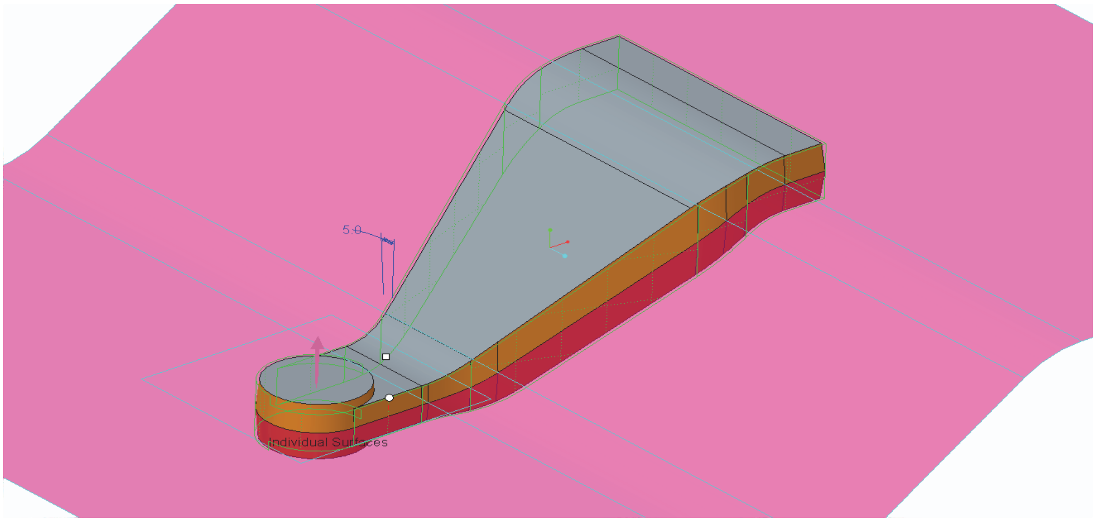
Draft types



Draft is practically always a material-adding feature, which preserves the basic dimensioning. - Draft always reduces the basic dimension, and because of this the piece may no longer meet the dimensional requirements. The draft hinge angle (○) determines the draft type. The table below provides indicative draft values for the sand casting method.*

Shape height (H)	*H ≤ 30 mm*	*30 mm < H ≤ 80 mm*	*80 mm < H ≤ 180 mm*	*180 mm < H ≤ 250 mm*
Draft (T)	***1 mm***	***2 mm***	***3 mm***	***4 mm***
Draft (○)	***4 °***	***3 °***	***2 °***	***1 °***

It is advisable to model the drafts as a separate feature (e.g. with the draft tool), so that the magnitude of the draft can be easily changed if necessary. Drafts are always done relative to the parting line.

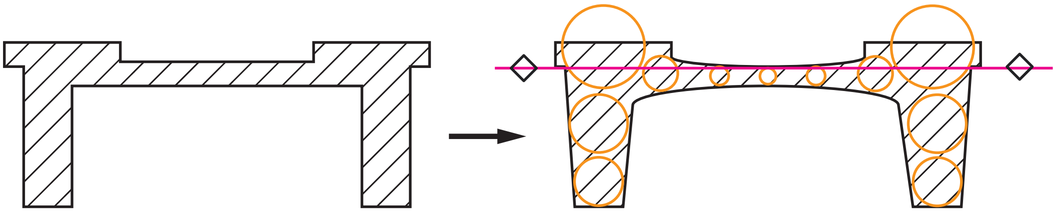


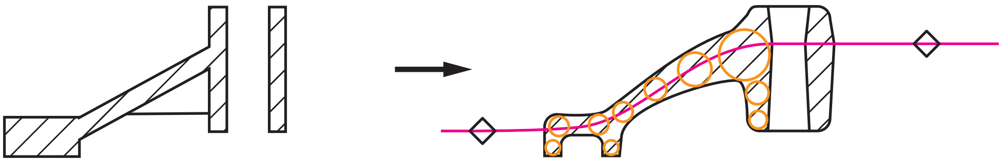
* Each foundry has its own indicative values for draft sizes. Standard SFS-EN 12890 has more information on the size of drafts. Draft is practically unnecessary for investment castings, and permanent-mould products have their own drafts.

Directional solidification

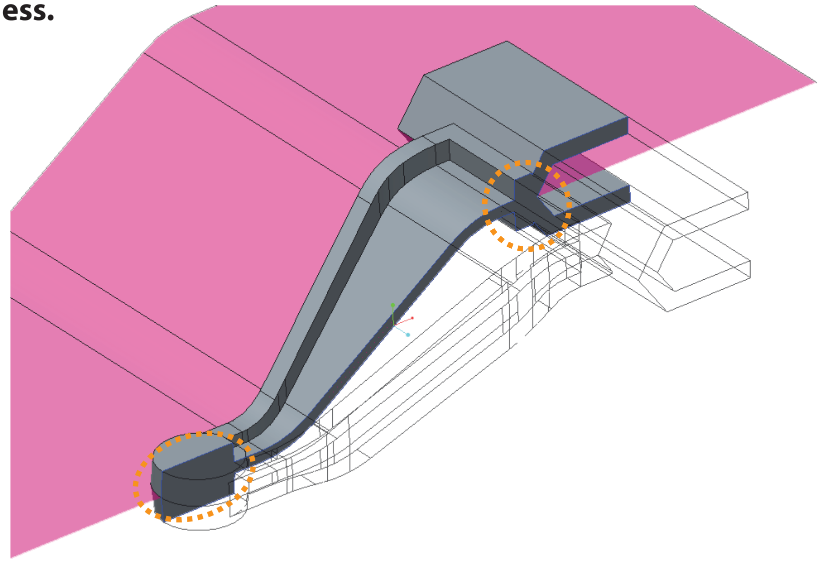
"A cast product should be shaped so that solidification starts at the thinnest points of the product and continues evenly towards the thickest parts. Unnecessarily thick spots should be avoided in castings, and the wall thickness should be as even as possible to avoid unnecessary porosity. The aim should be to design the piece so that there is only one concentration of mass, i.e. the feed area."

Shapes can be outlined using circles of different sizes that grow towards the thickest part of the product.





The thick parts of the product can be lightened without compromising the strength, e.g. by using a beam structure in order to minimise variations in wall thickness.

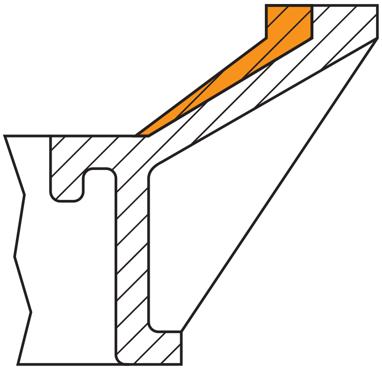


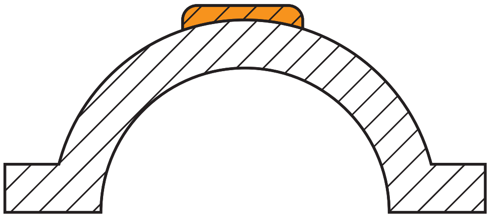
The thicker parts left in the product form feed areas where the risk of suction porosity increases. In order to make manufacturing more cost-effective, the aim should be to have as few different feed areas as possible in the product.

Feed fillings

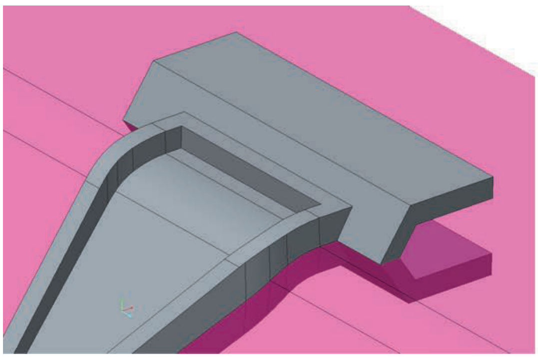
“Feed fillings can be designed in a cast product to improve the directional solidification of the product if it is not occurring naturally. Feed fillings are used to control the solidification of the cast product so that it can be produced cost-effectively. The feed fillings can be machined off afterwards, but they can also be part of the product.”

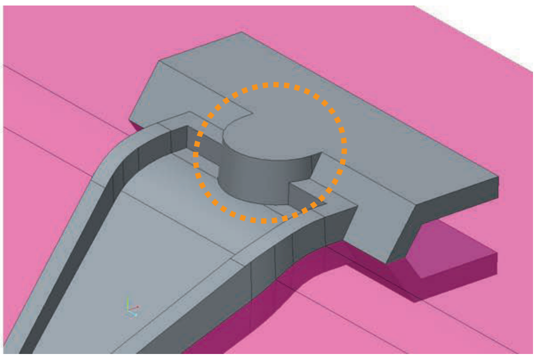
The feed fillings can be used, for example, to direct solidification or to make even areas on round surfaces to get a place for the riser.





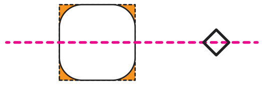
The feed fillings can be used, for example, to combine several mass concentrations into one or to facilitate the placement of the riser so that it affects the feed area.





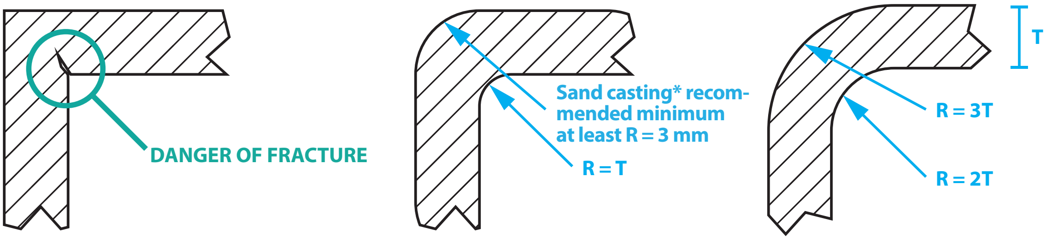
The designer does not necessarily have to design the feed fillings directly into the product, because it is the job of the foundry to get the product made. However, it is good to be aware of what feed fillings are used for, as there is a high probability that the foundry may suggest using them. They are intended to facilitate the manufacture of the product in order to obtain a more cost-effective product.

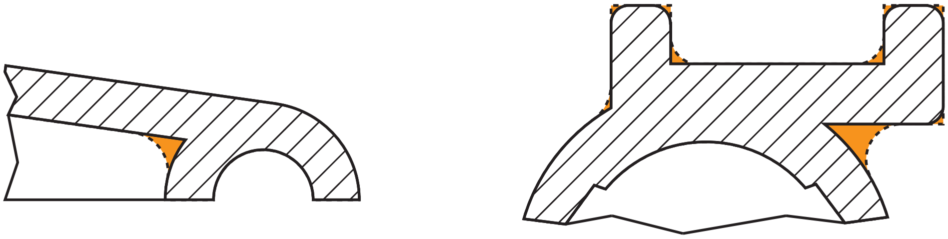
Roundings



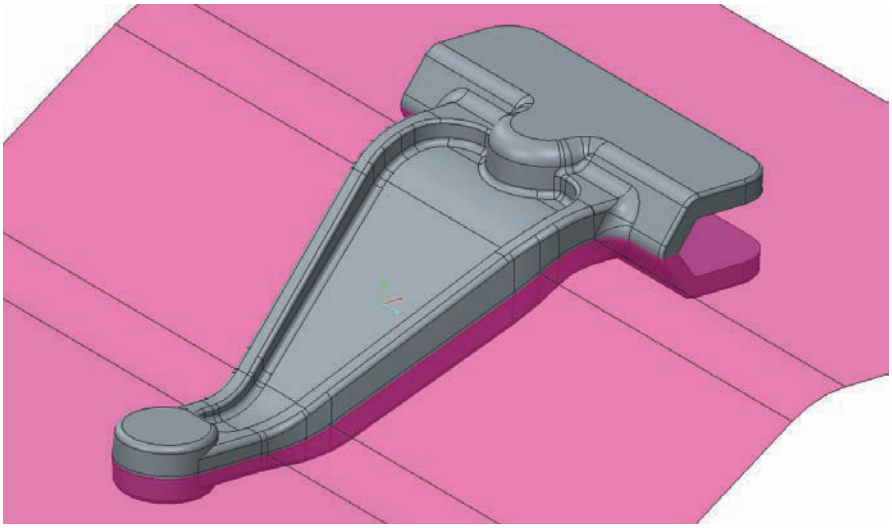
"It is advisable to use smooth shapes in the castings in order to create a beautiful and smooth shape and to solidify it as evenly as possible. Sharp corners should be rounded to prevent stress peaks caused by high strain, which can lead to cracks, fractures and variations in material properties."

There is a risk of cracking at sharp inside corners if it they are not rounded.





Roundings should only be done as the last features, as they may cause problems with the 3D file. If possible, use rounding radii as similar in size as is feasible.



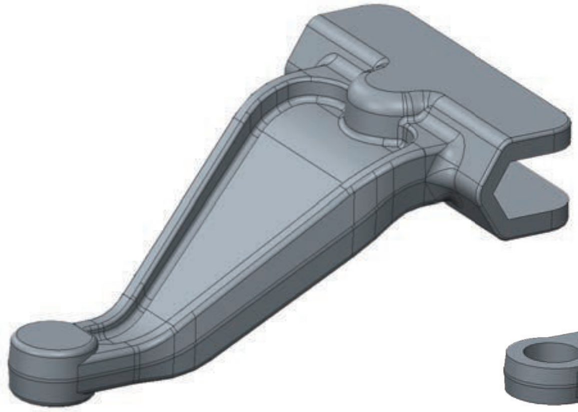
* Investment and permanent mould castings can use tighter roundings than sand casting. The size of the rounding should not be less than half the wall thickness. It is a good idea to discuss the right size of the roundings with the foundry.

Cast vs. machined

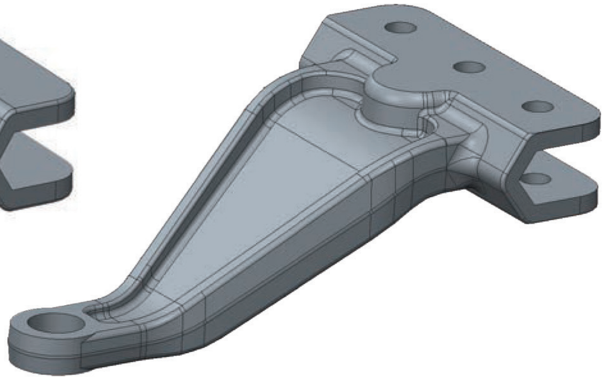
"With moulded products, the designer designs two products in practice. The end product is always a machined product, and it must meet all the requirements set for the product. The final product is obtained by machining it from a casting blank, which must take into account the technical requirements of manufacturing."

The casting blank is completed at the foundry and taken to post-processing. Prior to finishing, the parts of the casting system are removed from the casting blank, and it is usually also cleaned and honed. The final product is obtained only after post-processing, including machining.

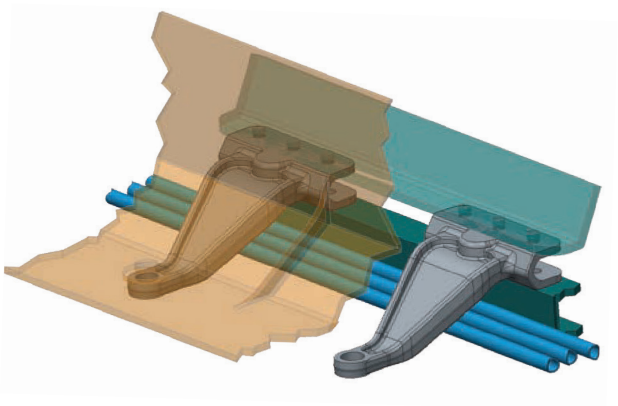
CASTING BLANK

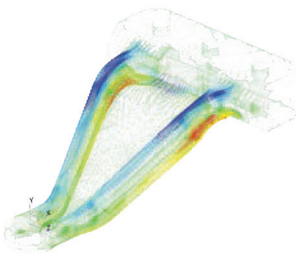


FINAL PRODUCT



The final product can be used, for example, in assemblies, or if the piece is exposed to special stresses, it can be subjected to various stress simulations. In this way, critical areas are identified for which stricter quality criteria can be set.





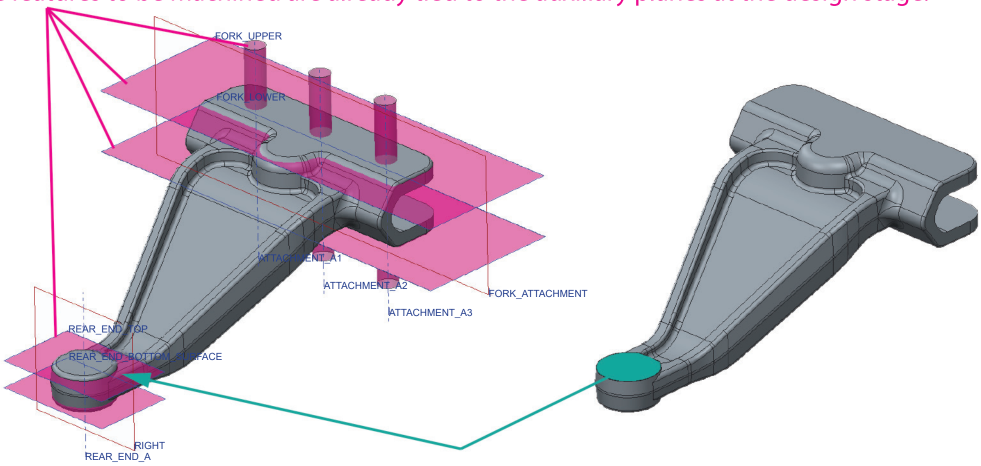
The machined product is easily obtained from the casting blank by cutting the necessary surfaces and holes according to the auxiliary planes. In this way the model can be tested and used as part of an assembly, for example, thus ensuring that the product is suitable for the final product. It is a good idea to send a sample of both the casting blank and the machined product to the foundry.

Machining of the casting

“The designer should take into account already at the design stage that each casting blank is machined. It is important for machining that the piece can be attached to the machine from a preferably flat surface and has sufficient machining tolerances. In a cost-effective piece the surfaces to be machined are as small as possible and can be machined with a single attachment.”

The surfaces to be machined should be used in the design phase as the starting levels for dimensioning, based on which the shapes to be designed for the piece are created. In the castings, one surface is initially machined, which then serves as a reference surface for the other features of the piece to be machined.

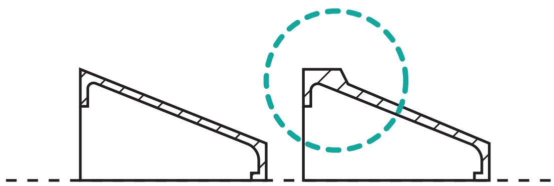
The features to be machined are already tied to the auxiliary planes at the design stage.



The starting surface for machining, which acts as a reference surface for other surfaces.

For machining, the most important thing in the design of a casting is that it can be attached to the machine. To help with the attaching, various protrusions can be designed on the piece. These can be part of the product, or they can also be machined off afterwards. In order to design appropriate protrusions, it is advisable to be in contact with the foundry.

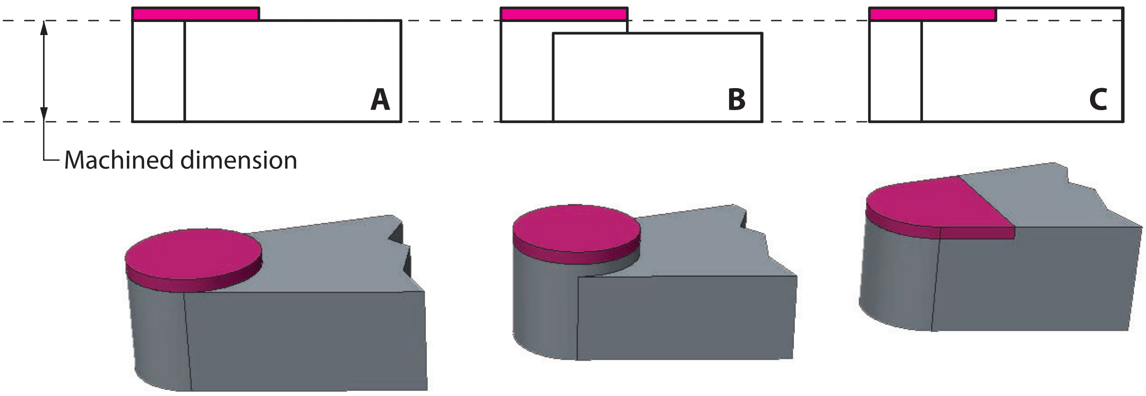
To enable sturdy attachment of the piece, the attachment surfaces should be straight.



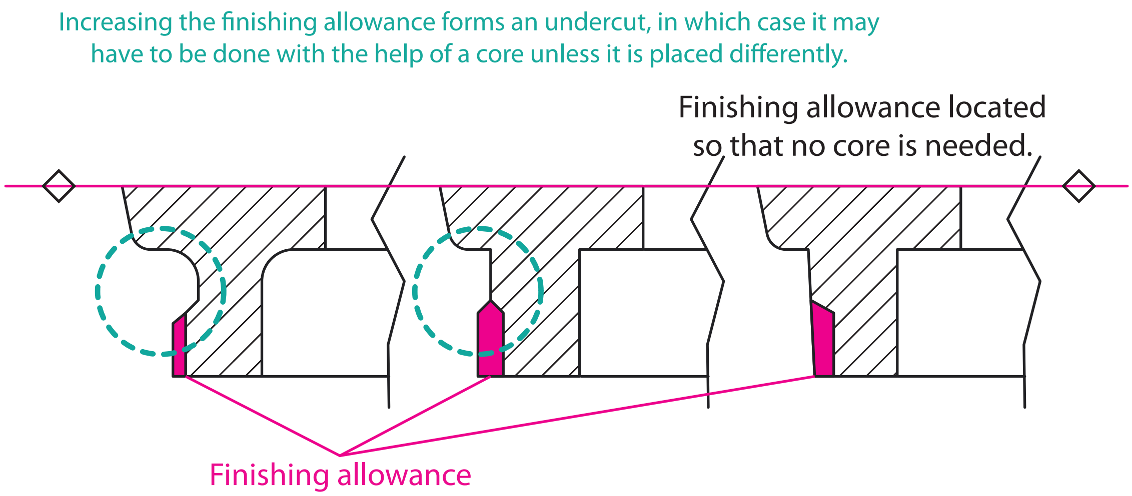
Location of machining tolerances

"The designer must ensure that the surfaces to be machined have a sufficient machining tolerance, because the machining must be able to reach below the casting surface and casting defects in the vicinity of the surface. The size of the machining allowance depends on the position of the surface in the mould; more inclusions accumulate in the upper surfaces of the piece, so large surfaces to be machined should face downwards in the mould."

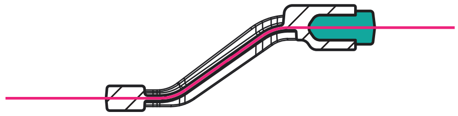
The machining tolerance can be placed in the piece in many different ways. Option A is a bad one, because the boundary between the unmachined and machined surface is unclear. There should be a clear boundary separating the surface to be machined from the casting surface (B and C). Option C simplifies the casting model and the making of the mould.



Machining can also be facilitated by making the surfaces to be machined as small as possible, which reduces machining time and reduces the number of casting defects that may emerge. However, care must be taken to ensure that the placement of machining allowances does not create undercuts that make it difficult to manufacture the product.

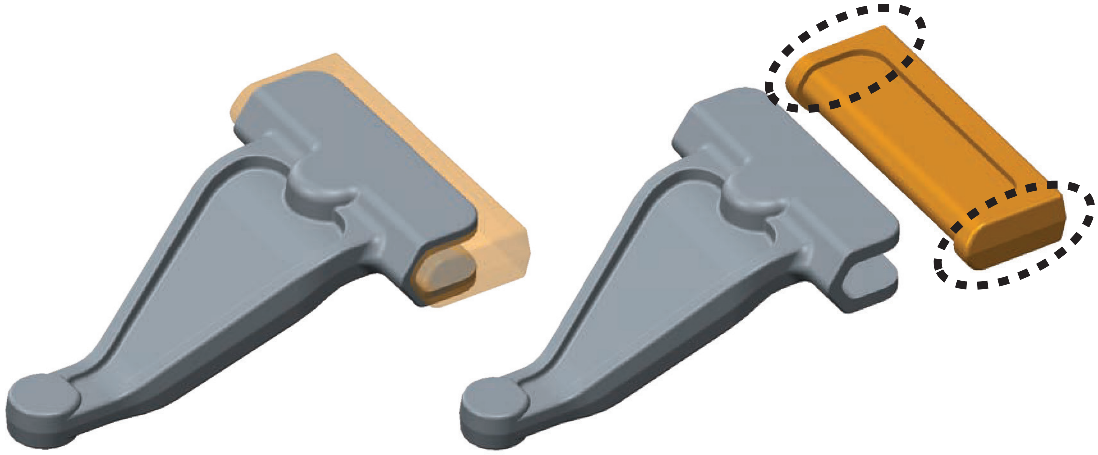


Cores

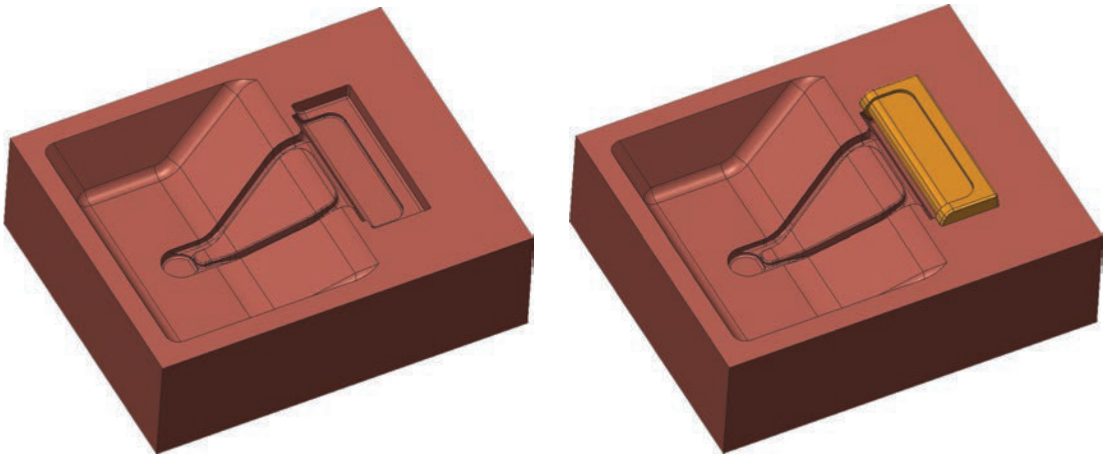


"Cores are parts of the mould that are used to create awkward internal and external shapes. Typically cores increase the cost, but if the product requires complex pattern equipment, it may be more cost-effective to use cores. If cores have to be used, the designer must ensure that they have a simple structure and are easy to manufacture, handle and place in the mould."

Undercut forms of the casting, made with cores. The cores must have core prints on which they rest in the mould.



Pattern equipment give the mould a shape in which the core sets. The designer should note that the cores also affect the dimensional accuracy, as they must have a small clearance to fit in the space reserved in the mould. The core should rest firmly between the two halves of the mould. It should be noted that the boundary between the cores and the mould affects the surface properties.



Simulation

“In casting simulation, a mathematical model is created of a casting event that can be used to examine what occurs in the casting event. In general, simulation is a tool used in foundries, but it can be used already at the product design stage. It can be used, for example, to look at how directional solidification takes place and in which parts of the piece feed areas are formed.”

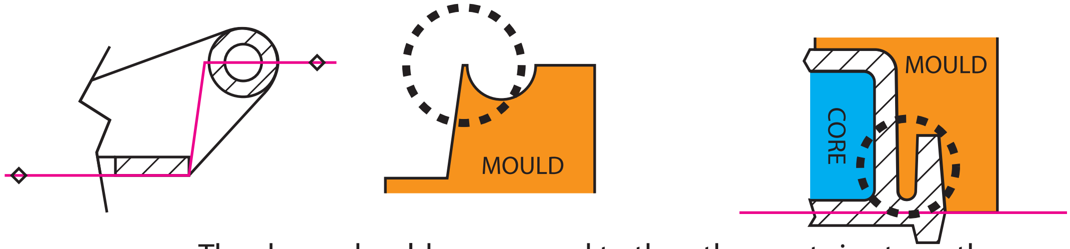
Simulation can be used to ensure that designing a feed filling for a piece transforms two feed areas into a single feed area.

Simulation can be used to examine how a casting solidifies from molten to solid and how well the principle of directional solidification is realised.

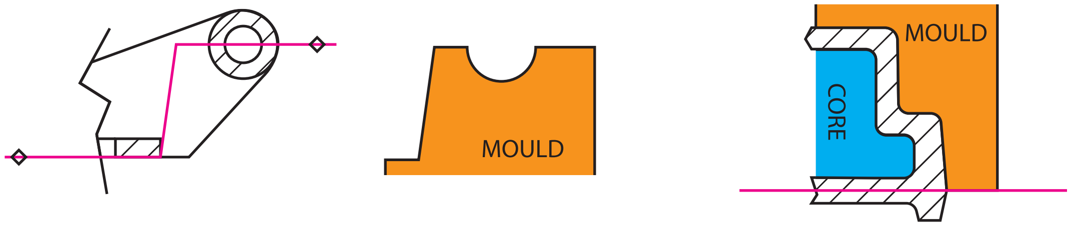
Design notes 1

Sharp corners and thin shapes should be avoided in the design of a piece to optimise the manufacturability of the moulds and cores. Sand can be difficult to pack tightly, and in addition, thin walls are prone to breakage. They also overheat during casting, which can cause casting defects.

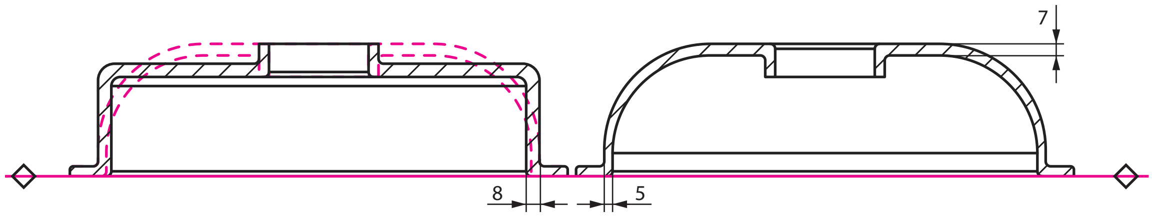
Thin shapes should be avoided in the mould.



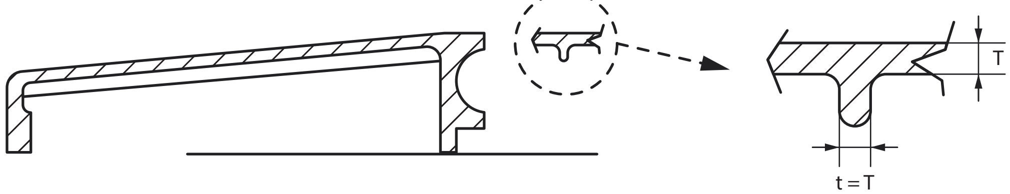
The shape should correspond to the other parts in strength



Smooth shapes help the flow of the cast metal. If the metal has to flow for long distances, it is advisable to increase the wall thickness of the piece, so the metal does not solidify before it reaches its destination. Due to smooth shapes and directional solidification, the wall thickness may be reduced from the original.

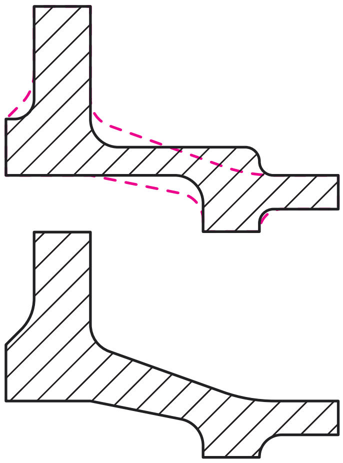


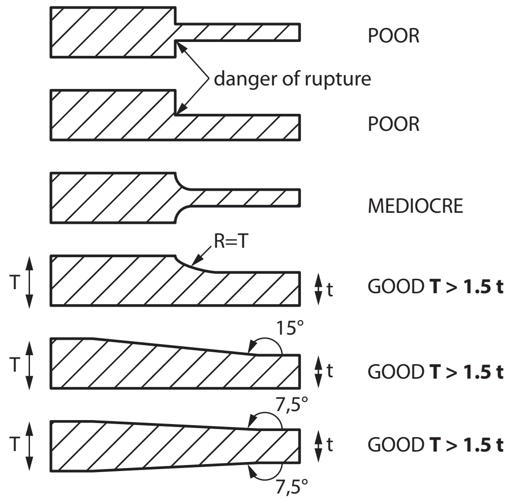
In long and even walls, increasing the wall thickness can be avoided by designing reinforcement strips in



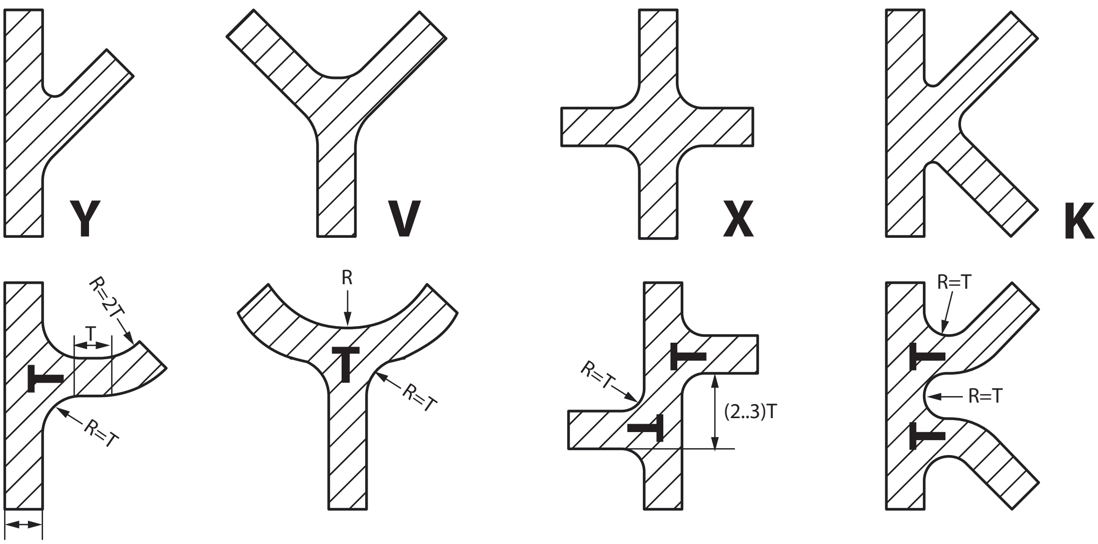
Design notes 2

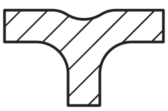
Variations in wall thickness may cause weak points in the casting. Variations in wall thickness can be prevented by suitable rounding, but it should be noted that the change in wall thickness should be as smooth as possible.





Small mass concentrations are easily formed at the junctions in the casting, which can be reduced by suitable structural changes. "Y," "V," "X," and "K" wall junctions should be replaced with a "T" junction more suitable for casting and metal solidification.

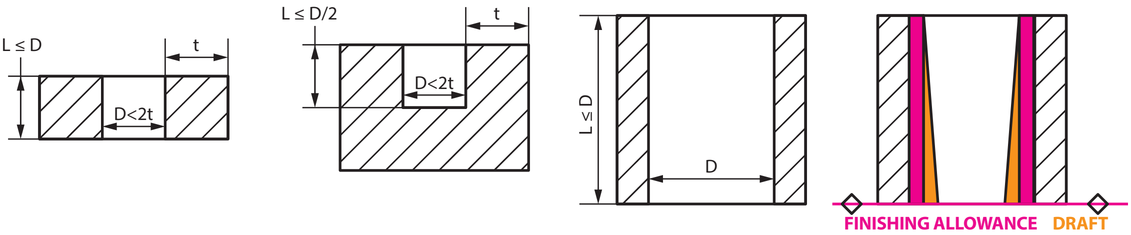




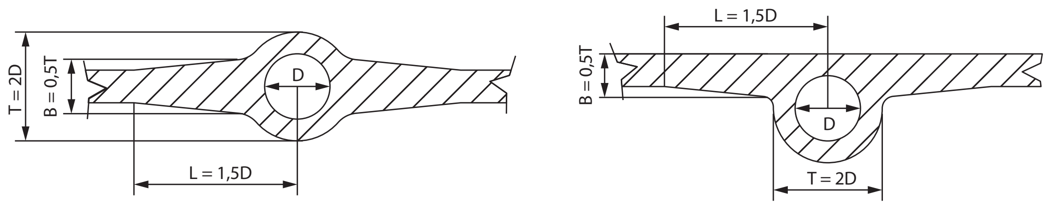
If necessary, the T-shape can be lightened to avoid concentrations.

Design notes 3

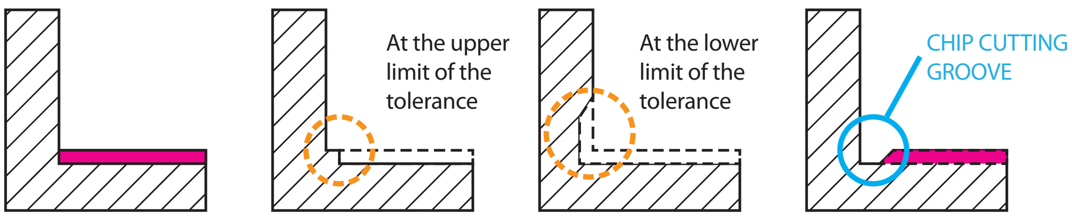
Holes can be made in the piece by casting. However, issues with moulding technology may limit the size of the hole. If a hole has to be machined, it is also necessary to take into account the finishing allowance and draft, which reduce the castable diameter of the hole. Dimensioning examples for making holes with the mould; otherwise the holes will have to be made with the help of cores.

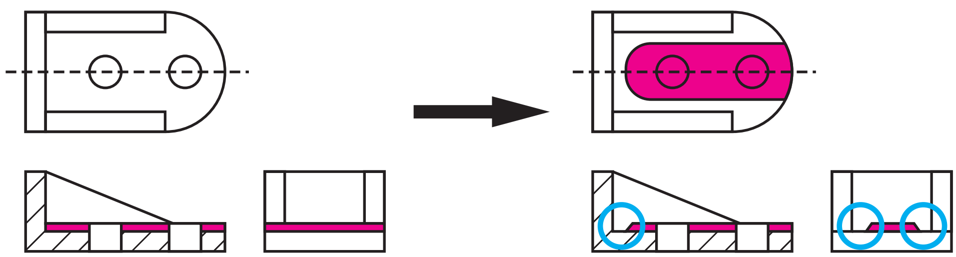


If a hole parallel to the wall is to be made by casting, it must have a thickening to enable the hole to be made.



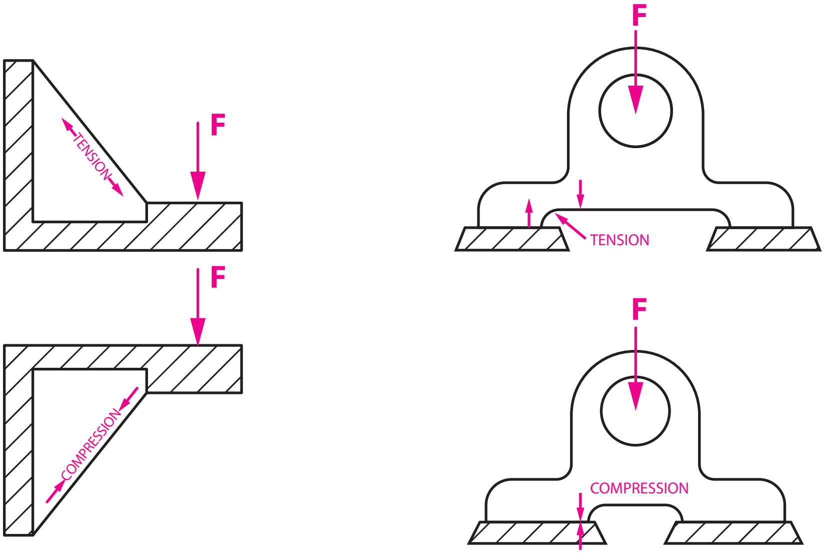
If the surface to be machined ends in a wall with a cast surface, it may be difficult to machine so that the machining ends on precisely this surface. At the upper limit of tolerance, a small protrusion may remain after machining, and at the lower limit, a small slice may be left missing from the wall after machining. In order to obtain the cleanest machining result, the finishing allowance can be designed to have a chip cutting groove, which allows the chip to be cut neatly before the wall with the cast surface. It must be ensured that the groove does not form a back draft.



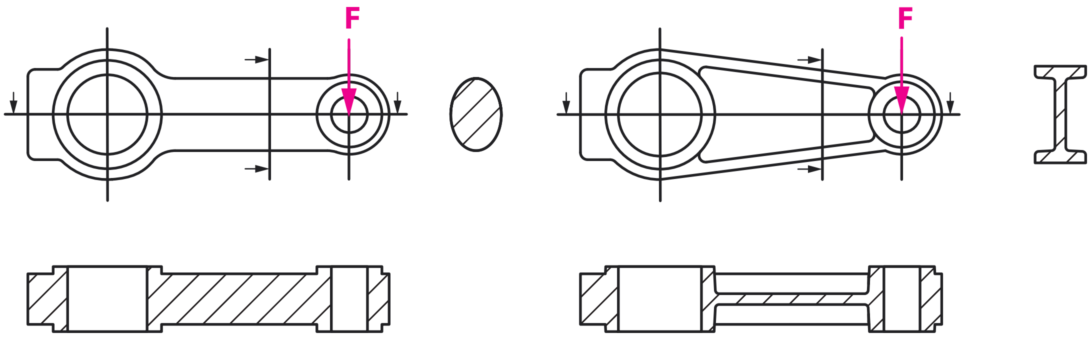


Design notes 4

Even if the material does not have a higher compressive strength than the tensile strength, the castings should be designed so that they are always subjected to compression. Potential inhomogeneities are more risky under tensile stress than under compressive stress.



In terms of the strength of a casting, the design may be more important than the material chosen. Strength can be increased with different structural solutions, and in some cases a cheaper material (lower strength) can be chosen and still achieve the same properties as a more expensive material with higher strength. For example, in the structure at left, the stress peak on the surface area is 3 times greater than in the structure at right.



Weight = 100   Weight = 85


mm
in
ORIGIN
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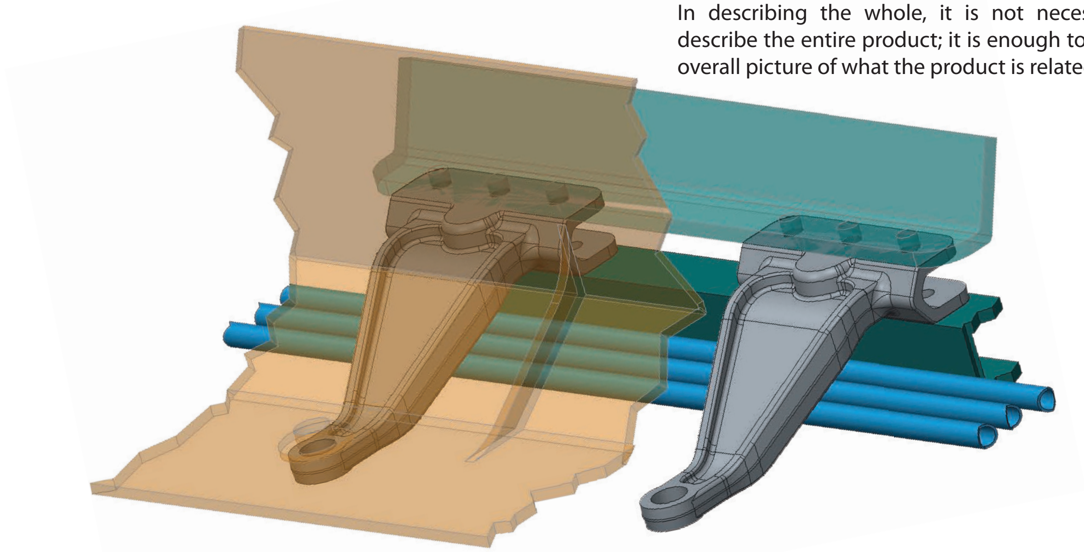
4 Quality

The quality of cast products

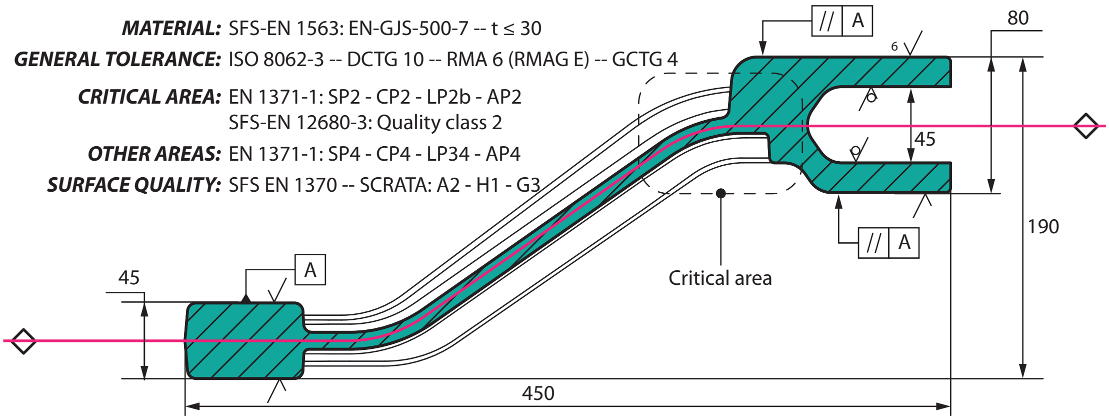
“The design of cast products must take into account that castings always have defects and that these can be assumed to be part of the properties of the piece, so they should be designed in the product. It is easier to increase material strength in critical areas than to increase quality. Excessive quality is expensive, and quality assurance is not always possible if the requirements are too strict.”

As castings are always part of some whole, it would be a good idea to give the manufacturer an overall picture of which whole this is, and of the operating environment the casting is related to. This helps the manufacturer to understand the required quality.

In describing the whole, it is not necessary to describe the entire product; it is enough to give an overall picture of what the product is related to.



It is essential, first, that what is required is clearly defined and that the requirements are clearly linked to the quality grades in the standards, and second, that the realisation of the quality is monitored. The quality requirements can be simply specified in the drawings.



In terms of quality, everything essential must be defined, including the maximum sizes of internal and external defects; surface quality; dimensional and shape accuracy; and material properties. Casting defects or features detrimental to the functioning, usability or commercial appeal of the piece are prohibited. In addition to this, it is also important to define the procedures by which quality is maintained (who checks, by what method, how errors are corrected and how they are reported).

What you order is what you get

SFS-EN 1559-1

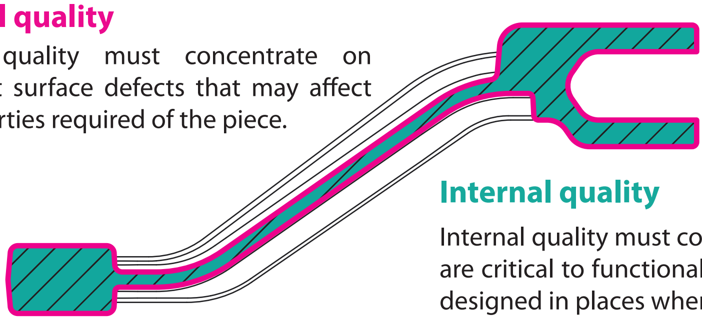
"The more precisely what is being ordered is determined, the more certainly it will be received. According to standard SFS-EN 1559-1 Castings: Technical delivery conditions, the buyer shall specify the requirements for the castings according to their intended use, and the manufacturer shall manufacture the castings in accordance with the requirements. It is pointless to demand something that cannot be controlled or that has no bearing on the functionality of the piece."

The buyer must unambiguously provide at least the following information in connection with enquiries and orders

A	**Production run Timetable**	Number of castings to be delivered, allowed tolerances on this number and delivery schedule. *(A **realistic** estimate of the current need, as well as an estimated annual need in the future, should also be provided here)*
B	**Material**	1) cast metal standard number 2) title based on the casting metal IDs or numerical title
C	**Documents**	Drawings, standards and technical specifications; when exchanging data electronically, the accuracy of the data must be ensured
D	**Tools**	Delivery of pattern equipment, core boxes and permanent moulds
E	**QUALITY**	Requirements for the external and internal status of the casting
F	**Machining**	Machining requirements, such as location and anchor points

External quality

External quality must concentrate on significant surface defects that may affect the properties required of the piece.



Internal quality

Internal quality must concentrate only on areas that are critical to functionality. Casting defects must be designed in places where they do not matter.

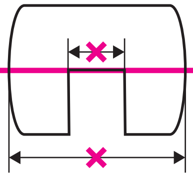
Internal defects very rarely cause damage, so make sure that external things are in order first. The quality requirements imposed on a piece and the measures taken to ensure it determine the total cost of the piece to a large degree. The designed quality of the casting must thus meet the properties required of it.

Casting defects

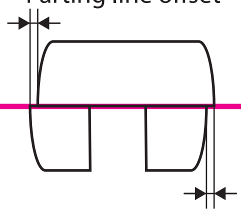
"A casting defect is a quality feature. It is a structural defect in the casting, that may be caused by factors such as design, tools, moulds, smelting, casting or related work steps. It is good for the designer to be aware that flawless castings do not exist, so the designer must be able to determine which defects are detrimental to the operation of the product and to what extent."

Dimensioning and shape defects may emerge in different parts of a piece. If they have significance for the functionality of the piece, they should be defined.

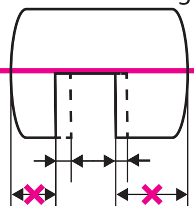
Dimensioning defect



Parting line offset

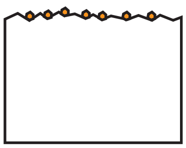


Substance thickness too low or too high

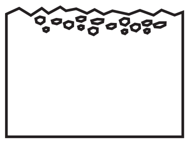


Defects on or just below the surface can affect the machinability of a piece, and in critical areas also its mechanical properties.

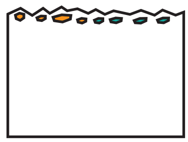
Sand burned on



Surface porosity

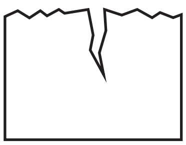


Sand or slag inclusions

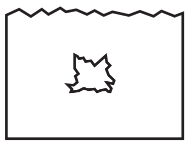


Surface defects, shrink cavities and suction porosity can significantly affect the mechanical properties of a piece, especially in critical areas of the product.

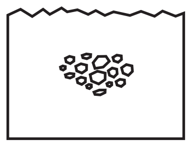
Crack



Shrink cavity

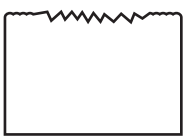


Suction porosity

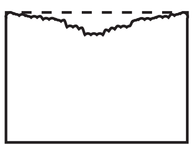


Surface defects in a piece can also affect the appearance of the piece, but they are usually the factor that affects usability the least. If appearance has significant commercial significance, the visual requirements for appearance should also be specified.

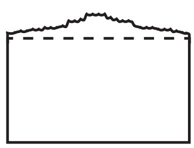
Rough surface



Suction depression



Swelling



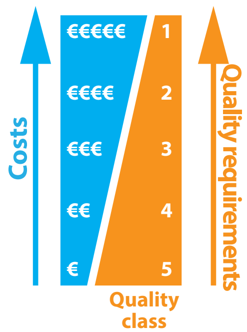
Quality control

"Quality control monitors that the required quality criteria are met. The quality control criteria corresponding to the required quality level must always be defined, but checking pieces can be agreed on separately when an order is made. Checking always increases the cost, and it is useful to remember that even the most stringent quality classes allow defects of a certain proportion."

When ordering, the customer must indicate what checks are demanded to be made to ensure quality. Some the most common inspection methods that can be used to inspect castings are listed below.

1. **Dimensional accuracy** – Depending on the size of the piece, the casting method and the goals agreed for the measurement, the dimensions are checked with a probe, a calliper, a coordinate measuring machine, a camera system or some other such tool.
2. **Material** – The chemical composition of the casting material can be checked by means of an analyser to verify the standard compliance of the material.
3. **Mechanical properties of the material** – The mechanical properties are checked to ensure that the casting material complies with the standard and is manufactured correctly. They can be inspected by tensile, hardness or impact tests on a test bar.
4. **External defects** – External defects in the casting can be checked visually by either the magnetic powder or the penetrant method.
5. **Internal defects** – Internal defects in castings can be inspected by ultrasound, and in some cases also radiographically.
6. **Pressure tightness** – The pressure tightness can be checked by various methods which search for defects extending all through the piece.

The number of pieces to be inspected, the inspections to be carried out and the acceptance criteria must be defined in accordance with the standards.



Dimensional accuracy		**SFS-EN ISO 8062-3** (SFS-EN ISO 10135)
Mechanical properties	***Creep***	**SFS ISO 204's**
	Hardness Brinell	**SFS-EN ISO 6506-1**
	Tension	**SFS-EN ISO 6892-1**
	Fatigue	**SFS ISO 1099's**
	Impact toughness	**SFS-EN ISO 148-1**
External defects	***Visual***	**SFS-EN 13018 and SFS-EN 1370**
	Magnetic particles	**SFS-EN 1369**
	Penetrant	**SFS-EN 1371**
Internal defects	***Ultrasound***	**SFS-EN 583-1 and SFS-EN 12680-1-2-3**
	Radiographic	**SFS-EN 12681**

“Metal casting has been an art long before it was a science.
In some areas the science has yet to catch up with the art.”

- ***Steve Chastain***

Final comments

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