Choosing the right metal casting process

Selecting the right manufacturing process for making a component is an important consideration at the early stages of product design. Studies have revealed that although the cost of product design is on average only around 5% of the total product cost, decisions made during the design stage affect 70 to 80 % of the final product cost[1].

Making those early decisions, however, can be a complex and challenging task. In metal casting, for example, Design Engineers have a bewildering range of casting process options, each one exhibiting strengths and weaknesses that make them more or less suitable for the manufacture of a specific component. Bear in mind as well that the selection of the casting process will be influenced by, and will influence, many other considerations, including the component geometry, alloy selection, performance criteria, cost, production run, etc.

Within a guide of this kind, it would be impossible to cover, in depth, all the factors affecting the decision-making process as many of these will be specific to each individual component. What we can do, however, is provide an overview of the main factors affecting casting process selection that Design Engineers should consider and discuss with their foundry engineers as early as possible in the design process. At NovaCast, we are happy to work closely with our customers, bringing many years of foundry experience to bear and helping to optimise component design.

Sand Casting

Why Use Nova Cast sand casting?

Sand casting has several benefits including:

- Low tooling costs and fast set-up compared to investment or die casting.
- Complex and intricate castings can be achieved with multiple internal cores.
- Up to 70% of the sand used in the process is reclaimed.
- Sand casting is best suited to low volume or complex non-ferrous castings or large ferrous castings.
- Large casting sizes possible. NovaCast is able to cast Aluminium alloys up to 110kg and ferrous alloys up to 3000kg using sand casting methods.
- It is possible to achieve low gas porosity for pressure tight castings.
- Very versatile; many different kinds of metal alloy can be cast using this process.

Limitations of the process

There are some limitations with this process including:

- Relatively slow casting rate.
- Wall thicknesses need to be a minimum of about 4mm and linear tolerance can be relatively poor.
- The surface finish can be fairly course so some finishing is usually required.

The Casting Process Selection Challenge

Usually, at the beginning of the conceptual design stage, designers are given functional requirements and relevant business requirements such as time to market, likely production volume, and total production quantity. During the conceptual design stage designers will identify critical design requirements such as size, material requirements, gross shape, form features, tolerances, surface finish requirements...etc. at this stage there is usually enough information to start preliminary process planning (e.g. material and process selection). A selection of optimal and alternative casting processes with compatible alloys that can meet these critical requirements, taking account of cost constraints, will be considered.

The casting process selection decision will be constrained in part by a range of geometric features, such as minimum section thickness and minimum core size, but also by achievable quality, taking account of surface finish, porosity, etc, and production parameters, such as sample lead-time and economic production run. The selection of casting process will also influence other major decisions such as the type of tooling, process parameters, and extent of machining, heat treatment, and quality control procedures. These in turn affect the economic quantity, tooling, labour costs, and lead time forecasting.

It is clear, therefore, that the selection of casting process cannot be made without considering a great many other factors. It is not surprising, therefore, that once the design engineer has resolved a solution encompassing all these factors, there is a degree of frustration when discussions start with foundry engineers who will often introduce a further set of considerations and constraints relating to the optimisation of the casting process and the consequential effect on component geometry.

Gravity Die Casting

Why use NovaCast Gravity Die Casting?
Gravity die casting delivers many benefits including:

- Excellent dimensional accuracy.
- Smooth cast surfaces.
- Thinner walls can be cast allowing intricate shapes.
- Inserts, such as threads, heating elements and high-strength surfaces can be cast-in.
- Secondary machining is reduced or eliminated.
- Production rates can be rapid making longer production runs possible.
- Tensile strength is higher than with sand casting.
- Specialist Aluminiun casting foundry.

Limitations of the process
There are some limitations with this process including:

- Relatively slow casting rate.
- Wall thicknesses need to be a minimum of about 4mm and linear tolerance can be relatively poor.
- The surface finish can be fairly course so some finishing is usually required.
- The initial tooling cost will be higher than for sand casting.

The Casting Process Selection Challenge

As stated, the selection of a casting process depends on the interaction of various decisions. The following are the main factors affecting the choice of casting process:

Material Type: Choosing the most appropriate alloy for a cast component can be a daunting process given the range of alloys available and their widely varying capabilities and limitations. The process of elimination usually starts with consideration of various performance indices for the product such as mass, energy density, and power-to-weight ratio.

The values for these performance indices will depend on three factors: the function of the product, the geometry and dimensions of the product, and the environment under which the product needs to work. These factors determine the possible set of metal alloys that could be used in casting the component. It may also be that the identification of the most appropriate alloy will exclude some of the available casting processes, even at this early stage. If it were decided, for example, that one of the cast Stainless Steels or Cast Irons were the most appropriate alloy, then this would preclude the use of Die Casting.

In addition, the designer will have to work within other parameters regarding the appropriate material to select. These could include material cost, manufacturing cost, end-product weight, the size of the product, and the temperature range that the selected material can hold.

Shapes: The overall shape of a cast component can exclude some casting processes. Centrifugal casting, for example, can only cast cylindrical parts or shapes that are symmetrical about the axis of rotation.

The Required Quantity: The quantity required, or production run of a component has a big influence on the selection of the casting process. Each process will have a different break-even point that will dictate whether the process is viable at the proposed production quantities. Die design and fabrication costs can account for a significant percentage of the production cost of a component. This percentage differs from process to process. For example, the reusable die design and fabrication cost for die-casting is considerably more than the pattern and expendable-mould production cost for sand casting. The higher production rates achievable with die casting, however, mean that it becomes more viable with higher volumes. By contrast, sand casting is well suited to smaller production runs.

The reality is that if the foundry engineering team is involved early in the conceptual design stage, they can help streamline casting process selection, provide input at an early stage of geometry design, and advise on material selection, given their extensive, hands-on foundry experience.

Geometric Attributes

Size: Size is often a deciding factor in the selection of casting process. For example, it is only possible to Die Cast a component up to about 500mm but Sand Casting can be used to cast parts unlimited in size.

Part Weight: Each casting process has a range of casting weights that it can produce under normal conditions. Lighter components can be produced using a wide variety of casting processes and the decision as to which casting process to use is more likely to be dictated by other factors. There will be fewer casting options for larger components. For example, NovaCast can Gravity Die Cast Aluminium and Copper-based alloys up to 110kg, it can Investment Cast Stainless Steel up to 250kg but can Sand Cast Carbon Steel up to 4,000kg.

Section Thickness: When designing component geometry, consideration must be given to the minimum section thickness required as this will dictate the casting process options. If Sand Casting is the preferred option for other reasons, then the minimum wall thickness should be no less than 3 to 5mm (depending on the individual foundry capabilities). If very thin section thickness is a critical requirement then this may dictate that another process be used. Investment Casting, for example, can achieve minimum section thicknesses of just 1.5mm on some features. It should be noted, however, that section thickness that can be cast depends on the investment casting material, the surface area and the complexity of the casting. For Aluminium and Zinc, the typical wall thickness is 2 to 3 mm. Thicker walls are needed for castings in Steel or Copper based alloys, usually 3 mm or more, but a thickness of 2 mm or less can be cast over small areas.

Investment Casting

Why use NovaCast investment casting?
Investment casting delivers many benefits including:

- Great versatility; suitable for casting most metals
- High volume production can be achieved with low repeat costs
- Will allow very intricate castings to be produced
- Smooth surface finishes are possible with no seam line so machining and finishing are reduced or eliminated
- Allows un-machinable parts to be cast accurately instead
- Excellent dimensional accuracy
- Can be used to prototype and prove designs prior to die casting tooling investment
- Is ideally suited to smaller, intricate or complex designs although we can cast up to 250kg

Limitations of the process
There are some disadvantages to this process including:

- Preparation of the wax patterns and shell moulds is time consuming so can be expensive
- The initial tooling cost will be higher than for sand casting
- Investment casting is not well suited to very high volume manufacturing due to the cycle times

Geometric Attributes

Hole Size: Hole size is the minimum or maximum diameter for hole that can be made in the cast part. Each casting process will have parameters that must be worked within. Some processes, such as Sand Casting, create these features using cores while other processes can create internal holes, voids and slots without the use of cores. In general terms, holes and slots should be kept as short as possible in relation to their diameter or width. Blind holes should be avoided where possible as these can create casting issues.

Tolerance: Tolerance is defined as the acceptable variation to the ideal or nominal dimension. Tighter tolerances than normal will lead to increased cost and lead-time. Generally, tolerances depend on the geometry of the part. However, foundries will generally state the tolerances that can be obtained by using its processes and provide guidelines to the designer to work towards these tolerances. These tolerances are called “as cast” tolerances because they are obtained without any additional processes such as machining. Tighter linear tolerance than available in the chosen casting process can, however, usually be obtained by secondary processes such as machining.

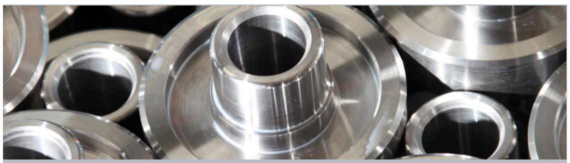
Surface Finish: The surface finish of a part determines its appearance, affects the assembly of the part with other parts and may determine its resistance to corrosion. The surface roughness of a part must be specified and controlled because of its influence on fatigue failure, friction, wear, and assembly with other parts. In metal casting processes, each casting process can produce a different surface finish, depending on the moulding material used. Sand casting will usually deliver a rougher “as cast” surface finish while investment casting will generally produce excellent results, even without additional finishing.

Complexity: The complexity of a part refers to its shape, size, and the number of features that it contains. As the shape of part becomes more complex, the selection of a suitable process becomes more important. Casting processes are particularly suitable for intricate and non-symmetrical shapes but which is selected depends in part on other factors. Sand Casting can, for example, produce both small and large parts of intricate geometry but the surface finish and tolerances will not be able to compete with Investment Casting if these are important factors. Gravity Die Casting is better for producing less complex shapes in larger quantities.

Mechanical Properties

Mechanical properties, such as strength and hardness, have the biggest influence on part size and shape but they also have a bearing on process selection. The type of casting process selected is affected by the quality of the mechanical properties that the process can deliver and the effect that process has on the selected alloy. As an example, taking a common Aluminium alloy LM6, the tensile strength achieved by various casting processes is as follows: Sand Casting 160-190 N/mm2, Gravity Die Casting 190-230 N/mm2, Pressure Die Casting 280 N/mm2.

Casting Defects: Defects may be internal to the part or concentrated mainly at the surface. Casting processes can be susceptible to predictable casting defects, so it is important to take account of the possibility that these will occur. Some alloys are also more prone to these than others but most defects can be managed, eliminated or remedied during the finishing processes. Defects can include porosity, cavities, shrinkage, inclusions, discontinuities and dimensional inconsistencies.



Pressure Die Casting

Why use NovaCast pressure die casting?
Pressure Die Casting delivers many benefits including:

- The capability of casting large quantities
- The ability to cast complex shapes quickly and accurately
- Castings are high strength
- Surface finishes can be exceptionally good
- Production rates are rapid
- Production lines are not labour intensive
- Scrap metal can be recycled

Limitations of the process
There are some disadvantages to this process including:

- The need to trim components
- Equipment and tooling costs are high
- Die life is limited
- Lead times to set up production can be long

Economic Considerations

Tooling: Tooling costs are driven by the material and manufacturing (mainly machining) of the tooling, and the complexity of the component geometry. Tooling costs can be a major factor in deciding which casting process is most appropriate. Tooling includes both a pattern and core box manufacture for sand casting but these are relatively cheap to produce and can be made from a variety of materials. Die-casting moulds are used in a very aggressive environment so are usually made from cast iron or steel and can be quite expensive to make as complex machining is often involved. Metal moulds are also required for Investment Casting but these can be made from Aluminium, which is considerably easier to machine.

Shell Mould Casting

Why Use NovaCast Shell Mould Casting?

Lost Foam Casting delivers many benefits, including:

- It can be completely automated which lowers labour costs and facilitates mass production
- Good and consistent surface finishes result in lower machining costs compared to sand casting
- As no moisture is present in the shell, very few gases are produced and those that are escape through the thin shell walls easily as the sand is permeable
- The burning of the resin binder on the surface of the shell helps to make removal from the cast component easy
- Tooling costs are low and short lead times are possible
- Little scrap is produced and what there is can be recycled. The sand-resin mix can be recycled by burning off the resin at high temperatures.
- A wide variety of metal alloys can be cast with this process
- Typical tolerances are just 0.005 mm/mm and the cast surface finish is 0.3–4.0 micrometers (50–150 μin) – this is better than with sand casting because a finer sand is used. The resin also assists in forming a very smooth surface.
- The process allows complex shapes in a large range of sizes with good surface finish to be cast

Limitations of the process

There are some disadvantages to the Shell Mould casting process including:

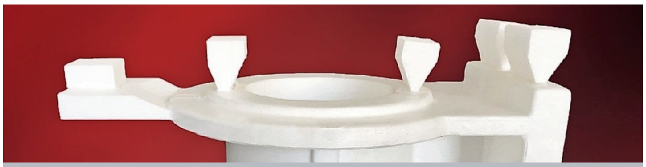
- The gating system must be part of the pattern because the entire mould is formed from the pattern, which can be expensive.
- The phenolic resin is expensive, although not much is required because only a shell is being formed.
- Equipment costs can be high
- Shrinkage can be a problem
- Secondary machining often required even though the surface finish is better than can be achieved with sand casting.
- Labour costs can be high if the process isn't automated.
- Poor material strength is achieved compared to other casting processes
- High porosity can be a problem

Production Considerations

Production Rate: The quantity of a component required combined with the rate at which they are required are important factors in casting process selection. Each process will have a range within which it is a viable option. Sand Casting is generally well suited to low volume production due to the time taken to create the expendable mould for each casting. Gravity Die Casting is fast and can be automated but requires longer production runs to justify the cost of creating the dies. Investment Casting and Shell Moulding can deliver very high quality and low repeat costs but are not well suited to very high production runs due to the cycle times.

Lead Time: Lead-time is the time required to prepare and setup tooling and equipment needed for the casting process prior to full-scale production. Generally, Sand Casting lead-times are shorter than for the processes that require complex dies but lead times are getting shorter now. New technologies, such as 3D printing of prototype moulds and casting simulation software are allowing foundry engineers to reduce or eliminate many of the design iterations that used to be necessary to iron out casting issues and reduce defects.

Process Flexibility: Process flexibility is important if component design is likely to change or evolve frequently. The cost of changing dies in Gravity and Pressure Die Casting can be extremely high due to the difficulty in re-working cast Iron or Steel. By contrast, patterns used in Sand Casting and Dies used in Investment and Shell Mould casting can be re-worked or adapted more readily as they are generally made from softer materials. Likewise, the foam patterns used in Lost Foam Casting are easy to manipulate and modify.



Lost Foam Casting

Why Use NovaCast Lost Foam Casting?
Lost Foam Casting delivers many benefits, including:

- Dimensionally accurate with typical linear tolerances of just ±0.005mm/mm
- Maintains an excellent surface finish, typically between 2.5 and 25µm
- Requires no draft to aid removal from the mould
- Has no parting lines and no flash is formed providing a better, more consistent surface finish without the need or further machining
- Unbonded sand is used which is simpler and cheaper than greensand or resin bonded sand
- Fewer steps are involved than with investment casting so costs are lower
- Minimum wall thicknesses are just 2.5mm with no upper limit
- Risers are not normally needed so less metal is used and less finishing is required
- Natural directional solidification takes place, so casting is more predictable with fewer defects
- Foam patterns are easy to manipulate, carve, glue and handle
- Multiple parts can be consolidated in a single complex casting, reducing the need for post casting assembly
- Process is suitable for Aluminium and Nickel alloys, Steels and Cast Irons. It can also be used for casting Stainless Steels and Copper alloys.
- Versatility: Cast parts can range from 0.5kg to several tonnes

Limitations of the process
There are some disadvantages to this process including:

- Preparation of the wax patterns and shell moulds is time consuming so can be expensive.
- The initial tooling cost will be higher than for sand casting
- Investment casting is not well suited to very high volume manufacturing due to the cycle times.
- Patterns are light and easy to handle but are easily damaged or distorted

Conclusion

It will be obvious from the range of considerations briefly touched on in this document, that decisions relating to casting processes are involved, dynamic and complex. Each of the factors can influence and be influenced by many others.

Designers need to establish clear priorities at the outset and establish which functional and business requirements are critical to the success of the project. Once these have been established, it will be possible to eliminate some casting process options and to identify the combination of process and alloy that will deliver on the project requirements.

It is important that design engineers become familiar with these considerations and involve foundry engineers at an early stage in the design process. Foundries like NovaCast are also able to offer the services of their design engineering team to their customers, which can reduce lead times and speed up time to market.

It should also be noted that although decisions made relating to the production process may be optimised for initial production runs, evolving product design or production requirements can mean that a different casting process may become more economic at a later date. Likewise, many design engineers that have opted for fabricated or assembled components have subsequently found that casting the component or assembly may deliver both cost savings and performance enhancements. It is a good idea, therefore, to revisit production process decisions over time and particularly when component design or production requirements change.

About NovaCast

NovaCast has over 40 years of ferrous and non-ferrous metal casting experience extending into markets as diverse as transport, utilities, offshore and general engineering. The company's non-ferrous foundry, based in Melksham, England, is supported by a fully risk-managed supply chain that extends out to the Far East allowing NovaCast to provide a single source solution for precision cast and machined components. NovaCast has particular expertise in the production of pressure-tight valve and industrial pump components, complex non-ferrous castings and a

wide range of precision castings for many engineering applications. Metals cast include alloys of Carbon and Stainless Steel, Copper, Aluminium and many others with a full range of testing, machining, surface treatment and finishing options.

1 Yusheng Chen Saty and Gupta K, "A Web-Based Process/ Material Advisory System ". ASME International Metal Engineering Proceedings, Orlando, Florida, 2000.