ENHANCED METAL CASTING METHODS WITH ADDITIVE MANUFACTURING TECHNIQUES

ABSTRACT

The science of Additive manufacturing is widely regarded as the fire that ignited the current industrial revolution. This paper is the fruit of rigorous research undertaken by the authors in the hope to draw a link between the budding science of additive manufacturing and the age-old processes of metal casting. The current industrial revolution deals with integrating 3D Printing with various manufacturing processes in order to make them more cost-efficient and faster in addition to adding more design possibilities. The importance of manufacturing and increasing its efficiency is common knowledge in the 21st Century, however, casting technologies are not as popular to the general public as much as say a lathe operation for example. The authors hope to educate the community as a whole regarding the importance of casting, in the same breath provide insight on integrating additive manufacturing to elevate its efficiency as well as economy on a scale hitherto undreamt of.

BACKGROUND OF ADDITIVE MANUFACTURING

The term "additive manufacturing" references technologies that grow three-dimensional objects one superfine layer at a time. Each successive layer bonds to the preceding layer of melted or partially melted material. It is possible to use different substances for layering material, including metal powder, thermoplastics, ceramics, composites, glass and even edibles like chocolate. It is used in a variety of industries to describe a process for rapidly creating a system or part representation before final release or commercialization.

In other words, the emphasis is on creating something quickly and that the output is a prototype or basis model from which further models and eventually the final product will be derived. AM takes full advantage of many of the important features of computer technology, both directly (in the AM machines themselves) and indirectly (within the supporting technology). Objects are digitally defined by computer-aided-design (CAD) software that is used to create.

STL files that essentially "slice" the object into ultra-thin layers. This information guides the path of a nozzle or print head as it precisely deposits material upon the preceding layer. Or, a laser or electron beam selectively melts or partially melts in a bed of powdered material. As materials cool or are cured, they fuse together to form a three-dimensional object. The journey from. STL file to 3D object is revolutionizing manufacturing. Gone are the intermediary steps, like the creation of moulds or dies, that cost time and money.

MATERIALS

Traditionally, 3D printing focused on polymers for printing, due to the ease of manufacturing and handling polymeric materials. However, the method has rapidly evolved to not only print various polymers but also metals and ceramics, making 3D printing a versatile option for manufacturing. Layer-by-layer fabrication of three-dimensional physical models is a modern concept that "stems from the ever-growing CAD industry, more specifically the solid modelling side of CAD".

Before solid modelling was introduced in the late 1980's, three-dimensional models were created with wire frames and surfaces" but in all cases the layers of materials are controlled by the printer and the material properties. The three-dimensional material layer is controlled by deposition rate as set by the printer operator and stored in a computer file. The earliest printed patented material was a Hot melt type ink for printing patterns using a heated metal alloy.

PRINTING

Before printing a 3D model from an STL file, it must first be examined for errors. Most CAD applications produce errors in output STL files, of the following types: holes; faces normal; self-intersections; noise shells; manifold errors.

A step in the STL generation known as "repair" fixes such problems in the original model. Generally STLs that have been produced from a model obtained through 3D scanning often have more of these errors as 3D scanning is often achieved by point to point acquisition/mapping. 3D reconstruction often includes errors.
Once completed, the STL file needs to be processed by a piece of software called a "slicer," which converts the model into a series of thin layers and produces a G-code file containing instructions tailored to a specific type of 3D printer (FDM printers). This G-code file can then be printed with 3D printing client software (which loads the G-code, and uses it to instruct the 3D printer during the 3D printing process).
Construction of a model with contemporary methods can take anywhere from several hours to several days, depending on the method used and the size and complexity of the model. Additive systems can typically reduce this time to a few hours, although it varies widely depending on the type of machine used and the size and number of models being produced simultaneously.

FINISHING

Though the printer-produced resolution is sufficient for many applications, greater accuracy can be achieved by printing a slightly oversized version of the desired object in standard resolution and then removing material using a higher-resolution subtractive process.
The layered structure of all Additive Manufacturing processes leads inevitably to a stair-stepping effect on part surfaces which are curved or tilted in respect to the building platform. The effects strongly depend on the orientation of a part surface inside the building process.
Some printable polymers such as ABS, allow the surface finish to be smoothed and improved using chemical vapor processes based on acetone or similar solvents.
Some additive manufacturing techniques are capable of using multiple materials in the course of constructing parts. These techniques are able to print in multiple colours and colour combinations simultaneously, and would not necessarily require painting.
Some printing techniques require internal supports to be built for overhanging features during construction. These supports must be mechanically removed or dissolved upon completion of the print.
All of the commercialized metal 3D printers involve cutting the metal component off the metal substrate after deposition. A new process for the GMAW 3D printing allows for substrate surface modifications to remove aluminium or steel.

ADVANTAGES OF ADDITIVE MANUFACTURING

The growing success of additive manufacturing is due to its advantages over conventional manufacturing. However, these strengths often come along with certain weaknesses. Theweaknesses provide opportunities for corrective action through the development of new polymeric materials.
Product designers and engineers can realize several benefits of using an in-house additive manufacturing system. There are some important points to consider, however, and key decision makers will need to weigh additive manufacturing's advantages and disadvantages before implementing it in their R&D cycles.
Elimination of design constraints. Part can be printed directly from the 3D model without the need for a drawing. Allow parts to be produced with complex geometry: honeycomb structures, cooling channels, etc., and no additional costs related to complexity Build speed; reduction of lead time. Flexibility in design. Less tooling for smaller batches compared to traditional machining. Production tooling can be printed. Different materials can be mixed during the printing process to create a unique alloy. No expensive tooling requirements.
Prototypes can be made quicker allowing designers to check different iterations resulting in quicker design cycle phase. Dimensional accuracy. Complex 3D geometries with internal features can be printed without any tooling. Reduced waste compared to machining. Wide range of materials (polymers, metals, ceramics). Well suited to the manufacture of high value replacement and repair parts. Different sections of the part can be different variant of the same alloy. Green manufacturing, clean, minimal waste. Small footprint for manufacturing and continually shrinking equipment costs

Of course, additive manufacturing is not a cure-all for your production woes. If you are looking to complement your capabilities with an additive manufacturing system, here are some points to consider.
Surface roughness. Because the technology still in its infancy the build process is slow and costly. High production costs because of the equipment cost. Low density, porosity. Various post-processing required depending on the type of additive manufacturing used. Lack of data regarding end-use properties to be expected of parts (e.g., thermal and chemical stability, strength, etc.). Small build volume compared to other manufacturing part size such as sand casting. Poor mechanical properties hence need post-processing. Poor surface finish and texture. Limited to relatively small parts. Limited to low volume manufacturing.

TYPES OF ADDITIVE MANUFACTURING

Many companies have invented and introduced new techniques and because the technology is fairly new, the companies who develop and introduce different techniques come up with their own marketing terms for the process, even though the core technique might be the same. Mentioning each and every process is virtually impractical. We hit on the highlights below:

Vat Photo Polymerization: In this process, a liquid photopolymer is selectively cured by light-activated polymerization to create a 3D part. It is based on curing and hardening of photopolymers on exposure to the ultraviolet radiation. Main types of this technology are Stereolithography (SLA), Digital Light Processing (DLP) and Continuous Digital Light Processing. Only Plastic can be printed using these technologies.

Binder jetting process: As the name implies this technique selectively deposits bonding agent a binding liquid to join the powder material together to form a 3D part. This process is different to any other AM technologies as it does not employ heat during the process like others to fuse the material.
Directed energy deposition: Direct energy deposition uses focused thermal energy such as a laser, electron beam, or plasma arc to fuse materials by melting as they are being deposited. Types include LENS, EBAM.

Material extrusion: Material Extrusion is an additive manufacturing technique which uses continuous filament of thermoplastic or composite material to construct 3D parts. Fused Deposition Modelling (FDM) only type in this category and both Plastic and composite can be printed using this technology.

Material jetting: In Material jetting, build material droplets are selectively deposited layer by layer into the build platform to form a 3D part. The Powder Material Jetting includes the following commonly used printing technologies: UV cured Material Jetting, Drop on demand (DOD), Nanoparticle jetting (NPJ).

Powder bed fusion: Powder bed fusion is an Additive Manufacturing technique which uses either laser or electron beam to melt and fuse the material together to form a 3D geometry part. The Powder Bed Fusion includes the following commonly used printing technologies: Multi Jet Fusion (MJF), Direct metal laser sintering (DMLS), Electron beam melting (EBM), Selective heat sintering (SHS), Selective laser melting (SLM) and Selective laser sintering (SLS).

Sheet lamination: Material sheets are stacked and laminated together using either adhesives, chemical, ultrasonic welding or brazing to form a 3D part. Once the object is built, unwanted sections are then cut layer by layer. The Sheet lamination includes the following commonly used printing technologies: Laminated Object Manufacturing (LOM), Selective Deposition Lamination (SDL) and Ultrasonic Additive manufacturing (UAM).

APPLICATIONS OF ADDITIVE MANUFACTURING

From prototyping and tooling to direct part manufacturing in industrial sectors such as architectural, medical, dental, aerospace, automotive, furniture and jewellery, new and innovative applications are constantly being developed.

Aerospace: Aerospace companies were some of the first to adopt additive manufacturing. Some of the toughest industry performance standards exist in this realm, requiring parts to hold up in harsh conditions. Engineers designing and manufacturing for commercial and military aerospace platforms need flight-worthy components made from high-performance materials. With ITAR registration and both ISO 9001 and AS9100 certifications, Stratasys Direct Manufacturing has had the opportunity to see a range of innovative designs transform the production of aerospace parts for major companies. Common applications include environmental control systems (ECS) ducting, custom cosmetic aircraft interior components, rocket engines components, combustor liners, tooling for composites, oil and fuel tanks and UAV components.

Medical: The rapidly innovating medical industry is utilizing additive manufacturing solutions to deliver breakthroughs to doctors, patients and research institutions. Medical manufacturers are utilizing the wide range of high-strength and biocompatible 3D printing materials, from rigid to flexible and opaque to transparent, to customize designs like never before. From functional prototypes and true-to-life anatomical models to surgical grade components, additive manufacturing is opening the door to unforeseen advancements for life-saving devices. Some applications shaking up the medical industry are orthopaedic implant devices, dental devices, pre-surgery models from CT scans, custom saw and drill guides, enclosures and specialized instrumentation. Stratasys Direct Manufacturing continues to expand its offering to support medical applications such as seamless medical carts, anatomical models and custom surgical tools.

Transportation: Life in the fast lane means endurance to tough environments like extreme speeds and heat. The transportation industry needs parts that stand up to harsh testing and are lightweight enough to avoid unnecessary drag. With a wide array of rugged, high temperature materials and additive manufacturing technologies and the ability to build very complex geometries, transportation companies are just scratching the surface of what can be made additively manufactured for their vehicles. We have helped automotive suppliers and companies develop consolidated, lightweight components that lead to more efficient vehicles. Some of the applications that have transformed the industry include complex duct work that can't be fabricated with conventional manufacturing methods, resilient prototypes, elastomeric models, grilles, custom interior features and large panelling.

Energy: Success in the energy sector hinges on the ability to quickly develop tailored, mission-critical components that can withstand extreme conditions. Additive manufacturing's advancements in producing efficient, on-demand, lightweight components and environmentally friendly materials provides answers for diverse requirements and field functions. Some key applications that have emerged from the gas, oil and energy industries include rotors, stators, turbine nozzles, down-hole tool components and models, fluid/water flow analysis, flow meter parts, mud motor models, pressure gauge pieces, control-valve components and pump manifolds.

BACKGROUND OF THE CASTING

The development of casting was in correlation with the industrial revolution, can be regarded as the backbone of the manufacturing industry. It is one of the oldest manufacturing processes known to mankind. With the onset of the industrial revolution, the demand of Iron and other metals grew rapidly, in the same time, the casting technologies also improved greatly. The manufacturing industry is in its current developed state due to the advancements that were brought out since these times. Nowadays, metal casting is a complex and intricate process which requires exact chemistry and flawless execution

The basic workflow of metal casting involves pouring molten metal into the mould cavity that has dimensions with proper clearances for metal shrinkage due course of solidification. Generally, Iron, Aluminium, steel and copper-based alloys are cast, while a lot many metals can be casted, the process is sometimes limited by the high melting temperatures and the intricacies involved in the design. Parts weighing a few grams to those weighing a few tonnes can be casted and are done so, on a daily basis.

The new trend in casting appears to be casting at home, i.e. resin casting, different types of resins are cast at home as they do not require high temperatures or any exorbitant expertise or experience. The materials that are generally used in this casting include resins, liquorice, chocolate etc. Hobbyists, enthusiasts and engineers alike exploit this lucrative technique to make and sell personalized items and collectibles. While this casting does not involve metal, hence it is considerably easier to finish with a smaller number of complications and risk factors.

Through the metal casting process, molten metal is poured into a mould that matches the final dimensions of the finished product. While all metals can be cast, the most predominant are iron, aluminium, steel and copper-based alloys. Castings range in weight from less than an ounce to single parts weighing several hundred tons.

The metal casting process follows a strict order to make new products. This order is:

Pattern making – A pattern is a replica of the exterior of the casting. Patterns are typically made of wood, metal, plastic, or plaster. Patternmaking is incredibly important for industrial part-making, where precise calculations are needed to make pieces fit and work together.

Core making – If a casting is hollow, an additional piece of sand or metal (called a core) shapes the internal form to make it hollow. Cores are typically strong yet collapsible so they can be easily removed from the finished casting.

Moulding – This is a multistep process that will form a cast around the pattern using moulding sand. In casting, a mould is contained in a frame called a flask. Green sand, or moulding sand, is packed into the flask around the pattern. This is known as metal sand casting. Once the sand is packed tight, the pattern can be removed and the cast will remain. Moulds can be classified as either open or closed. An open mould is a container, like a cup, that has only the shape of the desired part. The molten material is poured directly into the mould cavity which is exposed to the open environment. This type of mould is rarely used in manufacturing production, particularly for metal castings of any level of quality. Alternatively, a two-piece, non-destructible metal mould can be created so that the mould can be used repeatedly to cast identical parts for industrial applications.

Now the impression in the mould contains all the geometry of the part to be cast. This metal casting setup, however, is not complete. In order for this mould to be functional to manufacture a casting, in addition to the impression of the part, the mould cavity will also need to include a gating system. Sometimes the gating system will be cut by hand or in more adept manufacturing procedures, the gating system will be incorporated into the pattern along with the part. Basically, a gating system functions during the metal casting operation to facilitate the flow of the molten material into the mould cavity.

Melting and Pouring Molten Metal – After metal is melted, it is poured into the cavity of the mould and left to solidify. Once solidified, the shakeout process begins. This is one of the most important steps in the entire process of casting. The moulds undergo vibration to remove sand from the casting. Removed sand is typically collected, cooled, and reclaimed to be used once more in future castings. The end results are a clean cast and sand ready for the reclamation process.

Cleaning – In this final step, the cast metal object is removed from the mould and then fettled. During the fettling, the object is cleaned of any moulding material, and rough edges are removed.

There are many different metal casting processes used in the manufacture of parts. Two main branches of methods can be distinguished by the basic nature of the mould they employ. There is expendable mould casting and permanent mould casting. As the name implies, expendable moulds are used for only one metal casting while permanent moulds are used for many.

ADVANTAGES OF METAL CASTING

As a branch of manufacturing that has been around for so long, there are many advantages to this process.

Some are as follows:

- Wide range of low-prices raw materials, such as scrap, scraped components, chips, etc.
- The casting method has obvious advantages of low production costs, compared with other forming processes.
- Casting is a producing technique which poured liquid metal to the required mould. So, casting processes can produce very complex shapes, especially the various custom metal components with complex internal cavities.
- Casting processes are not limited in size, weight and production volume, and can produce a variety of metals or alloys. So, casting process is more flexible.
- Large components can be produced in one-piece cast. Materials that are difficult or expensive to manufacture using other manufacturing process can be cast. Near net shape often without or very minor post-processing.

Because of the above reasons metal casting is one of the important net shape manufacturing technologies. But as with many other processes, this process comes with a fair share of disadvantages too.

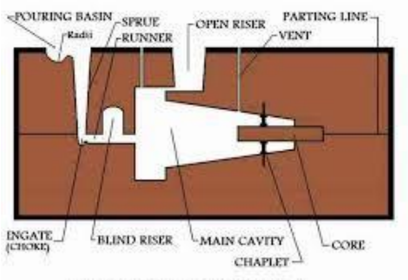
DISADVANTAGES OF THE CURRENT CASTING TECHNIQUES

Although this technology has been around for so long, there are still many disadvantages to this process. Constant work towards relieving these are continuously put into motion.

- If using same material, the mechanical properties of casting components are not as good as the forging parts.

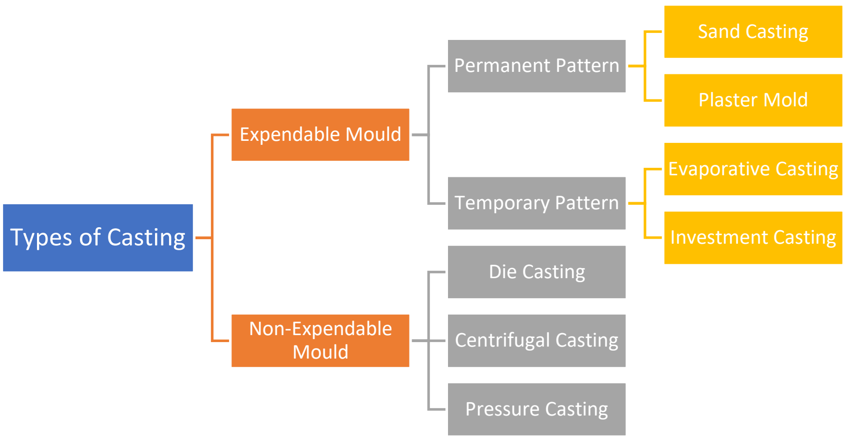
- The quality of metal castings is not stable because of too many production process. And the influencing factors are complex. So, the casting process is difficult to control.
- The casting products easily have various defects and deficiencies, such as pores, shrinkages, pinholes, inclusions, blisters and cracks inside the casting components. The casting dimensional accuracy is low, compared with machining components. The working conditions of foundry production are poor.
- Metal casting such as shell moulding has a limit in terms of size and the pattern. Patterns are time-consuming and expensive to make although additive manufacturing processes such as binder jetting are being used lately to make a mould.
- Die casting can be very expensive for smaller to medium quantities due to high die cost. Part size and material choices depend on the casting process chosen. For instance, only non-ferrous metal can be used for permanent mould castings.

The presence of so many disadvantages that can be worked upon warrants the induction of additive manufacturing technologies to better the situation.



GATING SYSTEM FOR CASTING

TYPES OF CASTING IN USE



1.Expendable Mould Casting

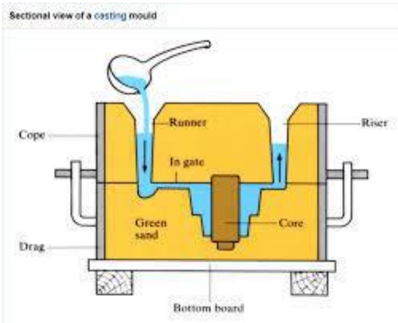
Expendable mould casting is a classification of casting which includes mould made up of sand, plastic, shell, plaster, and investment (lost-wax technique). This method of mould casting involves the use of temporary, non-reusable moulds.

1.1 Sand Casting

Sand casting relies on silica-based materials, such as natural bonded sand or a synthetic one. Sand casting generally consists of finely ground, spherical grains that can be tightly packed together into a smooth moulding surface. This type of casting is generally designed to reduce the potential for tearing, cracking, or other flaws by allowing a moderate degree of flexibility and shrinkage during the cooling phase of the process.
Automotive products such as engine blocks are manufactured through sand casting.
The main advantages as a casting process include:

- Relatively inexpensive production costs, especially in low-volume runs.

- The ability to fabricate large components.
- A capacity for casting both ferrous and non-ferrous materials.
- A low cost for post-casting tooling.



1.2 Shell Moulding

Shell moulding which is also known as shell-mould casting. It is an expendable mould casting process that uses resin covered sand to form the mould. As compared to sand casting, shell moulding process has better dimensional accuracy, a higher productivity rate, and lower labor requirements. This process is used for small to medium parts that require high precision.

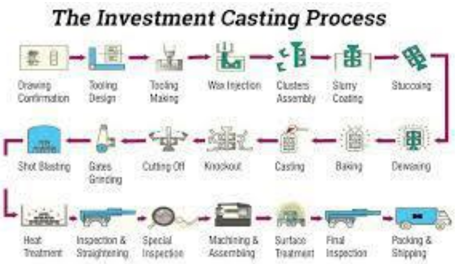
The advantages that are offered by shell moulding are:

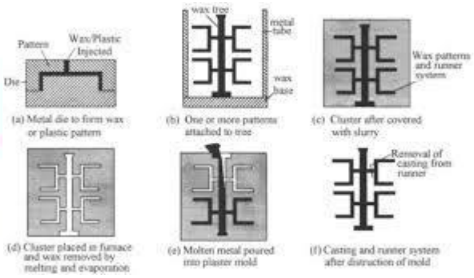
- Shell moulding can be completely automated for mass production.
- The high productivity, low labor costs, good surface finishes, and precision of the process can more than pay for itself if it reduces machining costs.
- Complex shapes and fine details can be formed with very good surface finish, high production rate, low labor cost
- Low tooling cos.
- Little scrap generated.
- Many materials option.

1.3 Investment Casting

Investment, or lost-wax, casting is a type of casting which uses a disposable wax pattern for each cast part. The wax is injected directly into a mould, then removed, then coated with refractory material and a binding agent. There are usually several steps required to build up a thick shell for the casting process. Once the shells have hardened then the patterns are inverted and heated in ovens to remove the wax. Next molten metal is then poured into the remaining shells where it hardens into the shape of the wax patterns. Lastly refractory shell is broken away to reveal the completed casting.

Investment casting is often used to manufacture parts for the automotive, power generation, and aerospace industries, such as turbine blades.





Some of the advantages of investment casting include:

- A high degree of accuracy and very precise dimensional results.
- This process has the ability to create thin-walled parts with complex geometries also.
- It can work with both ferrous and non-ferrous materials.
- Relatively high-quality surface finish and detail in final components.

1.4 Evaporative-pattern casting

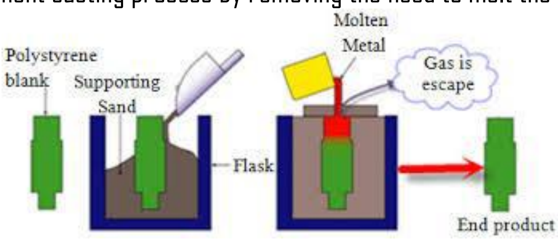
This is a type of casting process that uses pattern materials that evaporate during the pour, that is there is no need to remove the pattern material from the mould before casting. The two main processes are lost-foam casting and full-mould casting.

The two major evaporative-pattern casting processes are:

- Lost-foam casting
- Full-mould casting

1.5.1 Lost-foam casting

Lost-foam casting is a type of evaporative-pattern casting process that is similar to investment casting except that the foam is used for the pattern instead of wax. This process has advantages of the low boiling point of foam to simplify the investment casting process by removing the need to melt the wax out of the mould.



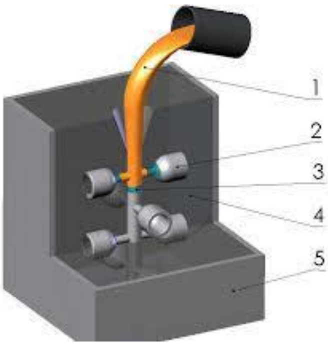
Some advantageous and disadvantages of lost form casting are:

This casting process is very advantageous for very complex shapes and also has a high dimensionally accuracy, maintains an excellent surface finish and has no parting lines so no flash is formed.

The two main disadvantages are that pattern costs can be high for low volume applications and the patterns are easily damaged or distorted due to their low strength. If a die is used to create the patterns there is a large initial cost.

1.5.2 Full-mould casting

Full-mould casting is an evaporative-pattern casting process which is a combination of sand casting and lost-foam casting. It uses an expanded polystyrene foam pattern which is then surrounded by sand, much like sand casting. The metal is then poured directly into the mould, which vaporizes the foam upon contact.
Some advantageous and disadvantages of full mould casting are:
This casting process is very advantageous for very complex shapes and also has a high dimensional accuracy, maintains an excellent surface finish and has no parting lines so no flash is formed. As compared to investment casting, it is cheaper because it is a simpler process and the foam is cheaper than the wax.



2. Non-Expendable Mould Casting

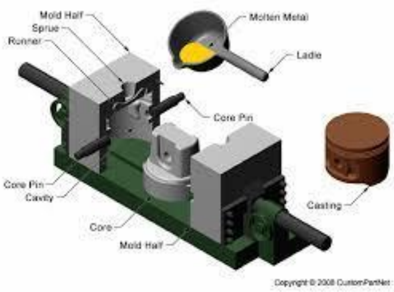
Non-expendable mould casting differs from expendable processes in that the mould need not be reformed after each production cycle. This technique includes at least four different methods: permanent, die, centrifugal, and continuous casting.

This form of casting also results in improved repeatability in parts produced and delivers Near Net Shape results.

Source: Google images

2.1Permanent mould casting

Permanent mould casting is a metal casting process that uses reusable moulds that are usually made from metal. The most common process is use of gravity to fill the mould also gas pressure or a vacuum process are also used. A variation on the typical gravity casting process, called slush casting, produces hollow castings. Common casting metals are aluminum, magnesium, and copper alloys. Other materials include tin, zinc, and lead alloys and iron and steel are also cast in graphite moulds.



Source: Google images

Typical products are components such as gears, splines, wheels, gear housings, pipe fittings, fuel injection housings, and automotive engine pistons.

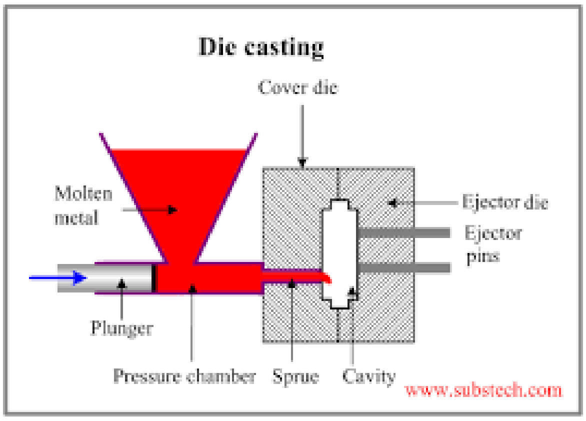
Source: Google images.

Some of the advantages are:

These are reusable moulds, good surface finish, good dimensional accuracy, and high production rates. Fast cooling rates created by using a metal mould results in a finer grain structure than sand casting. Retractable metal cores can be used to create undercuts while maintaining a quick action mould.

2.2 Die casting

Die casting is a casting process that is characterized by forcing molten metal under high pressure into a mould cavity. The mould cavity is created using two hardened tool steel dies which have been machined into shape and work. Most die castings are made from non-ferrous metals, specifically zinc, copper, aluminum, magnesium, lead, pewter, and tin-based alloys. Depending on the type of metal being cast, a hot- or cold-chamber machine is used.



Source: Google images

Die castings are characterized by a very good surface finish (by casting standards) and dimensional consistency.

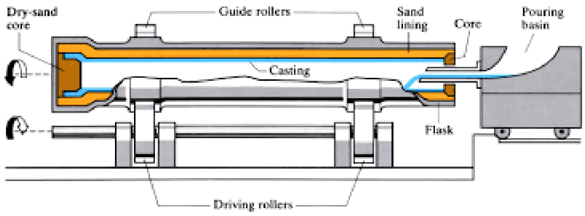
Some of the advantages of die casting are:

- Excellent dimensional accuracy
- Smooth cast surfaces
- Thinner walls can be cast as compared to sand and permanent mould casting
- Reduces or eliminates secondary machining operations.
- Rapid production rates.

2.4 Centrifugal casting

This is a type of casting process where molten metal is poured in the mould and allowed to solidify while the mould is rotating. Metal is poured into the center of the mould at its axis of rotation. Due to inertial force, the liquid metal is thrown out towards the boundaries.

Source: Google images

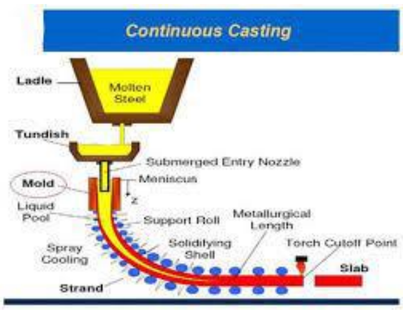


Small art pieces such as for jewellery this type of casting is often used to cast as the forces enable the rather viscous liquid metals to flow through very small passages and into fine details such as leaves and petals. This effect is similar to the benefits from vacuum casting, also applied to jewellery casting.

Source: Google images

2.5 Continuous casting

Continuous casting is a type of casting process for the continuous, high-volume production of metal sections with a constant cross-section. Molten metal is poured into an open-ended, water-cooled mould, which allows a 'skin' of solid metal to form over the still-liquid center, gradually solidifying the metal from the outside in. After solidification, the strand, as it is sometimes called, is continuously withdrawn from the mould. Predetermined lengths of the strand can be cut off.



Source: Google images.

Continuous casting is used due to the lower costs associated with continuous production of a standard product, and also increased quality of the final product. Metals such as steel, copper, aluminium and lead are continuously cast, with steel being the metal with the greatest tonnages cast using this method.

Source: Google images

2.6 Resin casting

Resin casting is a process of plastic casting where in a mould is filled with a liquid synthetic resin, which then hardens. It is primarily used for small-scale production like industrial prototypes and dentistry. It can be done with little initial investment, and its major applications are in the production of collectible toys, models and figures, as well as small-scale jewellery production.

The synthetic resin for such processes is a monomer for making a plastic thermosetting polymer. During the setting process, the liquid monomer polymerizes into the polymer, thereby hardening into a solid.

Some Advantages of Resin Casting are:

- The resin sand castings have high dimensional accuracy, and the external outline is clear; the castings have smooth surface, and the appearance is in good quality; the structure is compact, and the castings have good integrated quality.

- Resin sand does not need drying process, so the production cycle is shortened, and the energy is saved

INTERVENTION OF 3D PRINTING

The Additive manufacturing industry is regarded as a god's send to the manufacturing industry. The advantages as well as the ins and outs of this method has been eloquently explained in the above sub headings. We now shall deal with the elephant in the room, the most important question of all, how is casting benefitted by 3D printing?

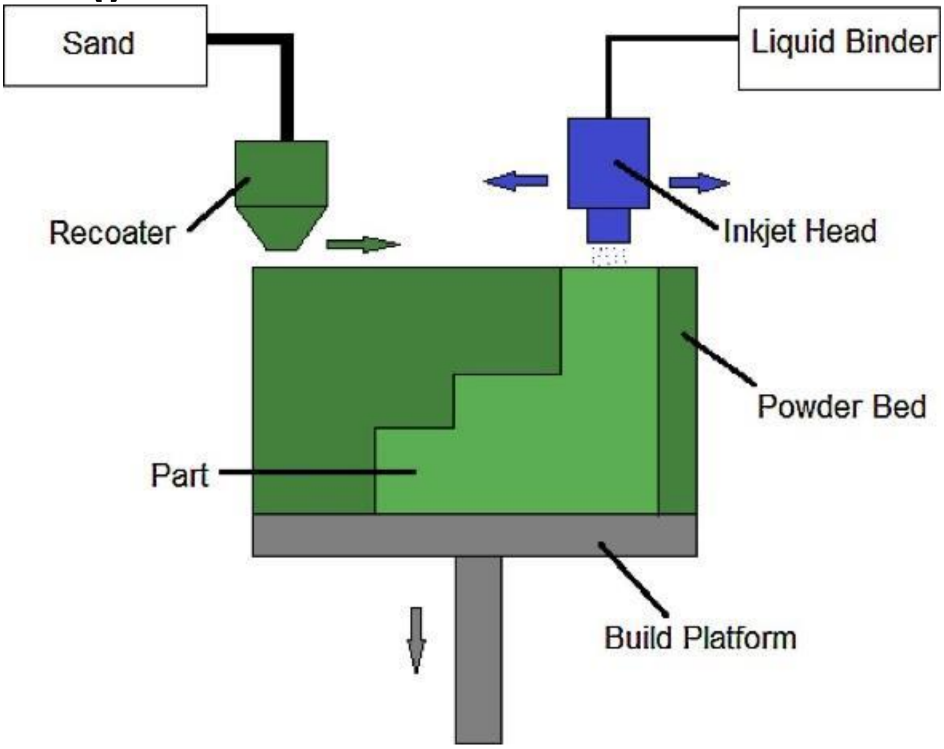
3D printing with its infinite possibilities helps making the process of casting hassle-free and cost-effective. The additive manufacturing sciences contributes in a major way, thanks to its high speed, accuracy, versatility and precision. Most of the different casting processes that are aforementioned can be benefitted from the integration of 3D printing.

In the age old and conventional foundry process of sandcasting. The different areas in which 3D printing can help is the making of mould; 3D printed moulds have some disadvantages as well as advantages. The disadvantages are that these moulds produce toxic gases that are very damaging to the environment as well as the human respiratory and central nervous system when hot molten metal is poured into it.

As a comparison between 3D printed moulds and conventional sand binder systems, ExOneTM printed based specimens had higher strength owing to the proper distribution of binder and sand. At higher temperatures, the 3D printed mould held together its integrity, form, shape and consistency. These studies suggest that 3D printed moulds are better when compared to conventionally made moulds containing lower and controllable amount of binder, consequently forms less amount of gasses and improved castings. One more important variable to consider would be the thermal gradient at the metal mould contact face. This attributes to smoother features, better cooling capacity and low degradation.

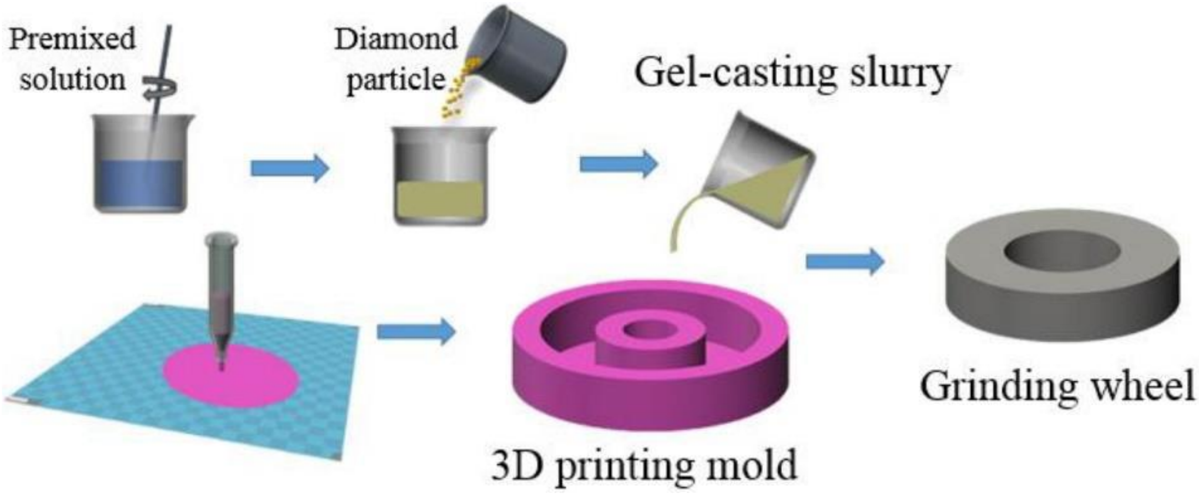
The surface roughness of the parts is a concern now as the 3D printed parts are slightly less hard and have worse surface finish. The gases produced during solidification may have played a role in spoiling the surface finish beyond a point where sand particles size could have affected it.[1]

Source: [1]



The next factor to compare is the designing "complexity factor". The conventional moulds produced do not have very complex shapes, a pattern is made and the same is used with the use of cores and runner, risers etc. But in the additive manufacturing way, the core, mould cavity are made into a single part and hence promote the complexity of the designs that can be realized via casting. Before, only sparse and simple design could be moulded, now all kinds of complex shapes can be casted thanks to the magical science of 3D printing.

A recent example is the fabrication of vitrified bond diamond grinding wheel using gel casting method. This revealed that the removal rate, surface roughness, grinding ratio of the grinding wheel prepared by additive manufacturing (gel casting) are similar if not better to those made by cold press forming. Additionally, the special porous structure is better than the normal one. The cost is very less when the comparison is made per batch and the time is exponentially lesser. Taking into considerations all the factors, 3D printed production would be better for small batch production.[2]



Another category in which 3D printing ventures into the science of casting is the art of pattern making. A pattern as explained previously is any object that resembles the final product of the casting. Traditionally, patterns are made of wood or metal. Metal patterns are difficult to be fabricated with forming or other techniques. Wood patterns absorb moisture from the sand and decrease the moisture in addition to the life of the pattern decreasing.

The main aim of the pattern is to be dimensionally accurate with the least of the distortions and highest of precision. To have a good surface finish as that will be the surface finish of the final produced part. The conventional methods spend a lot of money on making patterns and it is an exact science.

The additive manufacturing sciences can positively replace pattern making with direct 3D printing, the tolerances in this process are very high, the exact pattern can be obtained directly from the CAD file with little to no expertise required. The surface finish required can be easily controlled with tweaking the print settings to match the requirement of the operation. The weight and strength of the pattern can also be controlled something that was not possible before. A wide array of materials can be 3D printed, this aids in changing the material as required by the water absorption. Metal patterns, patterns made of polymers can be made, some interesting research into 3D printing wood as chippings of wood has also been done, leading to the same 3D printed wooden patterns if need be.[3]

3D sand-printing technology (3DSP) is a method offering a new age of cultured, rapid and dependable form of mould manufacture technique for metal castings. This technology can be used to advance through the modern foundry supply chains through capital investment, lead time, tooling expenses, quality management and among many others.

There are few case studies that are presented through which 3DSP is established to provide innovative manufacturing solutions when conservative mould making is limited by its intrinsic manufacturing limitations.

The summary of the few industrial case studies are:
1. 3DSP is established to resolve shrinkage-related porosity by contributing freedom to optimally orient of the corresponding cast part in the mould without the need for drafts, undercuts, etc.
2. 3DSP is made known to reduce lead time by nesting numerous cast parts within a single mould. Real-world solutions to resolve misran and shrinkage-related issues are also offered.
3. 3DSP is shown to fit in effortlessly with conventional casting system and help in its growth by offering exclusive advantages through enabling rapid manufacture of complex mould shapes and structures. [4]

Crucial foundry features of mould materials used in 3D printing are examined using statistical design of trials. Mathematical models are established for both compressive strength and permeability of the printed mould samples using linear regression. Both properties seem to have been influenced by the effective curing of the binder and the subsequent fusing of low melting phases as temperature or time baking increased. Further mathematical processing allowed optimisation of the parameters for the best permeability and strength.[5]

3D printing is not just a building technique it will also transfigure the outline of result, fabrication and fragments, such as castings, designs, cores, frameworks and shells in casting production. The solid framework of castings and moulds will be remodelled hereafter into truss or spatially agape and skeleton form.[6]

The motive of this study is to verify the feasibility and judge the dimensional accuracy of two rapid casting (RC) solutions based on 3D printing machinery: investment casting starting from 3D-printed starch patterns and the ZCast process for the manufacturing of cavities for light-alloys castings.[7]

A functional framework can be bought with the required gas absorptive, toughness, and heat assimilated feature, and hence the process makes sure of a high success rate of calibre castings with an enhanced frame for weight reduction. It defeats many of the limitations in traditional framework design with a very restricted number of parts in the mould build.[8]

An intermediately edentulous stone cast was chosen representing mandibular. The cast was optically scanned using desktop ordered light scanner and the initiated 3D model data was be exported as STL file then imported to universal reverse engineering software. The cast was digitally noticed according to the chosen route of insertion then all unwanted undercuts were taken, removed and blocked by flat surfaces.[9]

Difficult and personalization scales make the choosing of products into different parts of the map with same levels of the three impute. A geometric complexity factor developed for cast parts is changed for a more general application. Parts with different geometric complexity are then checked and mapped into parts of the complexity, personalised, and assembly volume model.[10]

MATERIALS

NAME	PROCESS USED	MELTING POINT
Nylon 11	FDM, SLS, Multi Jet Fusion	220-250 deg C
Nylon 12	FDM, SLS, Multi Jet Fusion	190-200 deg C
ABS	FDM	190-270 deg C
Silicone	DLP	1414 deg C
PET	FDM	260 deg C

3D PRINTING OF JEWELRY – A CASE STUDY

Jewelry is something that is a part of everyday life for Indians. 3D printing these artifacts of affection and stature can help reduce their cost, making them available to the less fortunate. It eliminates the possibility of the material being non-authentic precious metal. There are many more advantages as elucidated below:

ADVANTAGES

1. Unimagined freedom of design

3D printing works based on 3D modelling so the only thing limiting the design is one's imagination. Without a 3D model, you can't produce anything. And here comes the new design freedom you can reach thanks to 3D modelling. Basically, anything you can imagine can be designed on a computer and then brought to life, layer by layer. Traditional technologies would struggle or even fail to produce complex geometries and great details on such a small scale, such as earrings. 3D printing gives you the freedom to design abstract shapes or interlocking structures. It can even give you the option to enclose one object inside another and produce them in parallel.

2. Weight is no longer a problem

Because the method we are using is additive manufacturing, we have diverse ways of reducing the weight. In traditional jewellery making processes, the weight was a severe problem. If the item was heavy it could become uncomfortable to wear and impractical, with no ways to reduce the weight other than changing the base design. 3D printed jewellery can also be filled with lattices. Bigger designs such as decorative ornaments, brooches, or necklaces don't have to be solid inside. Lattice structures are an interesting solution to lightweight 3D printed jewellery. The parts used in this process of additive manufacturing can be hollowed. There are some 3D printing materials that may not allow it, but there are plenty of options to choose from where hollowing is allowed and even advised.

3. Quality

The olden times 3-D printers did not make such high-quality prints which can be made now.
The 3D printing technologies have now advanced. In the earlier 3D printers, there was a problem of the layers being seen on the printed object. But now, the 3D printers are said to produce HD prints.
Depending on the technology, Additive Manufacturing is capable of reaching layer thickness as little as 25 μm, which is 0.025 mm. For comparison, the average thickness of human hair is 100 μm. New production techniques allow you to reach the ultimate quality, also at a low cost.

4. Innovative 3D materials
Metal 3D printing can also be beneficial for you, you can produce your designs in precious metals such as Brass, Bronze, or Silver with different plating options.
However, even plastic can be used for 3D printed jewellery.
Also, worth mentioning are resins. Both plastic and resin for 3D printing are strong materials, robust and resistant to scratching. For instance, Vero White resin can give you 3D printed jewellery with a very smooth surface thanks to UV curing and is available in 12 colours. Other resins, such as EPU, are flexible and can be recommended for bracelets or watch straps.

5. Manufacture 3D printed moulds

Some might say that Additive Manufacturing is not the right technology to produce jewellery, it can still be a great asset to your design process. An interesting application of 3D printing is moulds. Your production process can be improved thanks to 3D printing as it can provide you with a perfect master model to later be used for mould making.

6. Minimum wastage

While is the case with jewellery casting like most others, research has been under taken in order to prevent the wastage of material in redundant places like rafts, skirts, brims, unnecessary supports.[11]

MATERIALS

The most common misconception about 3D printing is that it can only print plastics, resins and metallic plastics. But that is not the case this method can also be used for metals to produce a solid piece of jewellery out of most of the precious metals.[12]

1. Gold

Gold comes with a high gloss finish, provides us the option to choose from between 14 and 18 karats. This is not a gold-plated item, but the entire design will be made in 14 or 18 karats solid gold.
Besides those options, three different colour finishes for gold namely yellow, white, or red gold can also be applied. These colour options are achieved by adding different metal alloys to the gold. For red gold, we use a higher amount of copper, whereas white gold contains a palladium alloy.

2. Sterling Silver

Sterling silver is one of the favourite choices when it comes fashion jewellery

- The first of these finishes for silver 3D printing is a gloss finish, which is achieved by post-processing your model in a magnetic tumbler. This technique is the least aggressive process for silver items. While this finish is perfect if you want to keep a high level of detail, the surface of your model would be not as smooth as with our high-gloss finish.
- High Gloss models undergo a particularly vigorous mechanical polishing process that will round off any sharp corners on your model. As a result of this, the surface will have the lowest level of detail of all the finishes, but the highest level of smoothness and shine.
- Satin models are manually post-treated with a wire brush in order to obtain the effect of lines on the metal.
- Sandblasted models, on the other hand, are treated with an abrasive blasting method. The surface of your model will be even and smooth, and your print will have a great mat look to it.
- And last but not least, there's Antique Silver. It is characterized by very shiny and smooth outer surfaces, while deeper areas remain darker and unsmoothed. This gives your item a great colour contrast.

3. Brass

Brass is also one of the most common and liked materials when it comes to making jewellery.
Different textures and polishes of brass can give it elegant but quite a unique look. Some of the polishes and textures chosen by jewellery enthusiasts round the globe are listed below:

- Untreated brass

Image courtesy of RoyalDesign.com

Source: google

- Natural PU coating

Image courtesy of i.materialise

Source: google

- Polished yellow-gold plating

Image courtesy of Shapeways

Source: google

- Polished black color-plating for brass

Image courtesy of Sertae

Source: google

• Polished red-gold plating for brass

Source: google

• Polished chrome-plating for brass

Source: google

• Polished rhodium plating

Source: google
4. Bronze

Bronze is an alloy that consists primarily of copper and it's quite an affordable material. By nature, bronze has a somewhat reddish-yellow colour. An **uncoated model** will oxidize over time and won't be protected against scratches.

FUTURE POSSIBILITIES

The additive manufacturing industry has a very bright future. The process of 3D printing is already replacing conventional methods of casting, soon, 3D printing has the calibre to replace the process of casting itself. New types of 3D printing using innovative techniques are being experimented on every single day. Different types that are continuous printing, techniques for manufacturing the part on a heated conveyer belt. Not only the 3D printing techniques but also the materials that are being 3D printed have changed drastically, new materials that were never thought of before. In the casting industry itself, moulds made of PM (Powder metallurgy), Composites are being used but the research on those topics is fairly in the process as of now.

When the applications of 3D printing are considered, they are ever-growing. These applications are limited to only by the imagination of the user not by the technology.

CONCLUSION

There is great potential in the incorporation of the antediluvian process of metal casting and contemporary additive manufacturing. Though, as studied above there are certain limitations of the integration but we can certainly say that the advantages surely outweigh them. The limitations are also not herculean to resolute, they can be resolved easily with a few uncomplicated steps. We can conclude from the various examples quoted that the parts casted from assistance of the additive manufacturing sciences have higher mechanical attributes, physical attributes, such as hardness, strength and surface finish. They are also less harmful to the environment as most 3D printed plastics are bio degradable and the fumes generated are also comparable to the conventional methods. It is also easier to manufacture patterns and moulds with 3D printing, with perfect geometric dimensioning and tolerances. The most important of all, at a fraction of the cost!

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