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Study of Process Parameters in High Pressure Die Casting

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Abstract: ***A study has been carried out for the die casting process parameters in order to achieve the improved quality of high pressure die casting (HPDC) products, which is the challenge for the small and large scale manufacturers of HPDC products. Aluminum - Silicon alloys are the most extensively used, Aluminium alloys are widely used in high - pressure die casting (HPDC) of automotive components. Several process parameters need to be controlled during HPDC in order to obtain sound and reliable castings. . The objective was to reduce the defects in the components to obtain the good quality castings and increase productivity. The porosity is the most common defect frequently encountered in aluminium high pressure die castings, which increases the rejection rate and scrap rate and reduces the productivity. Porosity formation is closely related to die casting process. In this paper the effect of process parameters on porosity formation in HPDC have been presented.***

Keywords: High pressure die casting (HPDC), HPDC products, Process parameters, Improved quality, Quality castings, Productivity, Casting Defects.

1. Introduction

High Pressure Die casting is a type of metal casting process that is characterized by forcing molten metal under high pressure into a mould cavity. The mould cavity is created using hardened tool steel dies which have been machined into shape and work similar to an injection mould during the process. Most die castings are made from non - ferrous metals, specifically zinc, copper, aluminium, magnesium, lead and tin based alloys. Depending on the type of metal being cast, a hot - or cold - chamber machine is used [1].

The casting equipment and the metal dies represent large capital costs and this tends to limit the process to high volume production. Manufacture of parts using die casting is relatively simple, involving only four main steps, which keeps the incremental cost per item low. It is especially suited for a large quantity of small to medium sized castings, which is why die casting produces more castings than any other casting process. Die castings are characterized by a very good surface finish and dimensional consistency.

High Pressure Die Casting: High Pressure Die Casting (HPDC) is a versatile manufacturing process in which molten metal is injected with a die casting machine using considerable pressure into a steel mould or die to form products. High pressure die casting is often used for aluminium and brass in many industries including plumbing, automotive and agriculture [2].

Die casting is characterized by: 1. Technologically advanced equipment.2. High productivity.3. Castings with precise dimensions and even surfaces.4. Capability to produce thin-walled castings.5. Very little need for post-casting machining.5. Use of finishing agents can be kept to a minimum.7. Costly moulding dies whose amortization requires long production runs, usually at least 5000-10, 000 pieces.

In the die casting process, molten metal is pressed into a steel die. The cavity between the two halves of the die is filled rapidly due to the high pressure. The high pressure-injection speed makes it possible to cast the melt in thin sections and complex geometric shapes. The metal solidifies when heat is transferred from the melt to the die, after which the die is open and the ″shot″ is removed. There are two basic methods of die casting - cold chamber and hot chamber. For aluminium alloy castings, the cold chamber method is almost always used.

Cold chamber method:
With the cold chamber method, the melt is usually kept warm in a holding furnace beside the die-casting machine. A filling device transfers the molten metal from the furnace to the filling chamber of the die-casting machine. After that, the machines shot plunger forces the melt into the die [6]. The casting process usually consists of three phases as shown in Fig 1.1.

Phase1. The first phase begins when the filling device have transferred the melt to the machines filling chamber. The shot plunger then begins to advance with accelerating speed, up to a maximum speed of 0.5 m/s.
The purpose of the plunger relatively low speed is to avoid mixing air with the melt. The first phase ends when the metal has filled the entire gating system and its leading edge has reached the cavity inside of the mould.

Phase2. This phase is usually called the mould-filling phase, during this the cavity of the die is filled. The shot plunger moves relatively fast, between 2-6 m/s normally, the entire phase takes between 30-300 milliseconds.

The time must be kept short in order to fill the mould completely and avoid cold flows. It is important that the speed of the shot plunger increase from slow to fast exactly when the metal reaches the mouth of the mould cavity. The timing of the increase is determined either by measuring the motion of the plunger, or via a pressure sensor in the machines hydraulic system.

Phase3. This phase begins when the entire mould cavity is filled with molten metal. At that point, the die-casting machines hydraulic system encounters powerful resistance because the shot plunger cannot press more metal into the die. Extra hydraulic power is then activated to force the plunger forward a bit further.

This compensates for the metals shrinkage during solidification and compresses any air bubbles that may be trapped in the melt. The final pressure on the melt is usually between 400-1500 bars, the exact level depends on the requirements for the casting. A high final pressure makes the casting pressure tight and increases its mechanical performance level; but it also increases the wear on the die and the die-casting machine.

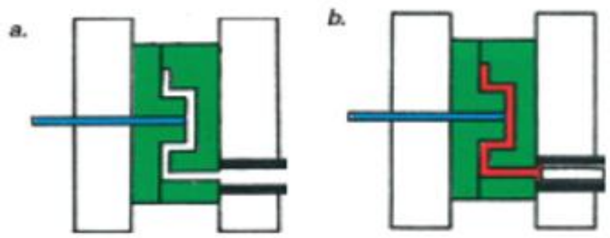

Figure 1.1: Different phases of die casting with a cold chamber machine: (a) Moulding die is closed, (b) The short plunger forces the melt into the mould, (c) Moulding die is opened [11].

In the Fig 1.1 (a) Moulding die is closed. The melt is poured into the filling chamber (often called cold chamber), in Fig 1.1 (b) The short plunger forces the melt into the mould cavity at high speed and pressure. The melt is also kept under pressure during solidification, and in Fig 1.1 (c) When the melt has solidified, the moulding die is opened and the casting is forced out of the movable die half by ejector pins.

Advantages of the Die Casting

Typical advantages of die casting process include

1) Excellent dimensional accuracy.
2) The smooth surfaces of Product.
3) Casted parts require no machining except the removal of flash around the edge and possible drilling and tapping holes.
4) High pressure die casting production is fast and inexpensive relative to other casting processes.
5) High quality: Parts created through die casting deliver a long service life.
6) High reliability: Uniformity of mass - produced parts is exceptional.
7) Quick production: Die cast tooling requires minimal maintenance.
8) Versatile design: Die casting can create virtually any size, part geometry, surface texture or luster.
9) Minimal assembly: Assembly features such as studs, drill holes and bosses can be integrated into mould design.

1.1 Defects in High Pressure Die Casting.

The most common types of defects occurs in high pressure die casting are listed in below table.

Table 2.1: Common types of defects and their causes

Defects	Causes
Flash	- Injection pressure too high - Clamp force too low
Unfilled sections	- Insufficient shot volume - Unfilled sections - Low pouring temperature
Bubbles	- Injection temperature too high - Non - uniform cooling rate
Hot tearing	- Non - uniform cooling rate - Cooling time too short
Ejector marks	- Ejection force too high

Many of the above defects are caused by a non - uniform cooling rate. A variation in the cooling rate can be caused by non - uniform wall thickness or non - uniform die temperature [3].

Depending on the location of the casting defects, they can be divided into two major categories, namely “Surface” and “Subsurface” defects.

Surface Defects:

Surface defects are occurring on the surface or near to the surface (exposed to surface) of the castings.

Surface defects in high pressure die castings can result from deficiencies at any stage of the manufacturing process.

1) **Flash:** The occurrence of molten material seeping out of the mould cavity and solidifying.
2) **Unfilled sections (Misrun):**

This is usually caused by the metal solidifying before it fills the cavity.

a) The metal was too cold.
b) It could be too small a sprue, gate.
c) Insufficient shot volume.
d) Slow injection.
e) Low pouring temperature.

1) Hot Tearing:

A part defect, sometimes called hot cracking, which describes cracks that result from shrinkage. If a part is not allowed to shrink freely and encounters an obstruction, the solidified material will crack. The main causes of problems are Non - uniform cooling rate.

Sub - surface Defects:

Sub - surface defects are not visible to the naked eye due to their occurrence below the surface of the castings.

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2) Non - metallic inclusions:
Inclusions occur as varying types with differing sizes and shapes.
a) Aluminium oxides are of different crystallographic or amorphous forms as films, flakes, and agglomerated particles.
b) Magnesium oxide is typically present as fine particulate.
c) Spinals can be small hard nodules or large complex shapes.
d) Refractory and other exogenous inclusions may be identified by their appearance and composition.

3) Shrinkage and Porosity defects:
Porosity and Shrinkage is the formation of voids inside the castings either through the entrapment of gas, improper pressure configuration in HPDC machines and improper Solidification of material.

The problem can be divided into three major types:
- **Gas porosity**: The gas porosity is the porosity in casting due to the presence of gas.
- **Shrinkage porosity**: The shrinkage porosity is due to shrinking of metal, so that the metal loses volume and hence more metal is required to fill the gaps (voids) produced.
- **Flow porosity:** Melt related porosity formation because hydrogen entrapment in HPDC is not a big problem. Hydrogen can be considered seriously if the scrap is re - melted.

Applications of Die Casting Process:
Die - casting is the largest casting technique that is used to manufacture consumer, commercial and industrial products like
1. Automobiles.2. Toys.3. Parts of a sink faucet.4. Connector housing.5. Gears.6. Most die castings are done from non - ferrous metals like magnesium, aluminium, etc.

1.2 Critical Process Parameters in High Pressure Die Casting.

Major process parameters in high pressure die casting include [2]
1. Flash. 2. Cast material. 3. Mould material.4. Poring temperature.5. Flow temperature.6. Solidification time.7. Shrinkage and porosity [3].

1. Flash: Flash or flashing is the material that is left on the casted part due to the 'seam' of the mould. The material enters into the seam of the mould slightly and when removed from the mould leaves a thin wafer of material attached. This is common and simple to remove with simple methods. Whilst simple to remove and clean, great care must be taken when designing a mould to ensure that the flashing will not interfere with the function (or aesthetics, if important) of the final product. This can be particularly relevant in parts with high tolerances, friction fits or areas that require a seal. Our experienced mould designers and tool makers will work with you and your product designers to ensure that any seam lines are non - obtrusive and hidden.

Figure 3.1: Flash

Flash can be described as any unwanted, excess metal which comes out of the die attached to the cavity or runner. Typically it forms a thin sheet of metal at the parting faces.

There are a number of different causes of flash, and the amount and severity can vary from a minor inconvenience to a major quality issue.

At the very least, flash is waste material, which mainly turns into dross when re - melted, and therefore is a hidden cost to the business.

Flash is often accompanied by an increase in the thickness of the whole casting. This adds mass to the part (and therefore increases metal cost) and increases its dimensions. Critical dimensions across parting lines can end up over top tolerance, leading to costly rejects.

Some of the causes of flash are:
1. Damage to die faces and die components.2. Parts of the die have insufficient strength.3. Bending, crowning of stretching of dies.4. Cavities offset from centre of platen.5. Insufficient machine clamp - up. Pressure spikes at the end of cavity fill.6. Excessive intensification pressure.7. Incorrect intensification timing.8. Damage, or wear, in toggle mechanisms.9. Machine hydraulic malfunction.10. Hydraulic valve or seal leaks [4].

1.3 Casting material

The four main metal groups used with this technology are **aluminum, zinc, magnesium and copper - base alloys**. High pressure die casting (HPDC) is a high volume manufacturing process for components of different sizes and shapes and there are some specifics of the process which can be discussed.
In die casting, non - ferrous metals are used to manufacture components, and the choice of alloy for a particular application depends on budget, weight and material properties [10].
a) **Aluminium:** Aluminium is one of the most important materials with a share of more than 80 %, followed by zinc and magnesium. However, copper, lead and tin can also be used. The alloys have different properties. For example, aluminium (600°C) and magnesium (520°C) have a high melting point, zinc (380°C) and lead (320°C) a low melting point.
Die casting alloys offer many advantages:
High corrosion resistance.2. High strength and hardness.3. High thermal conductivity.4. High electrical conductivity.5. Very good EMI/ RFI isolation.6. Good processing properties.

b) **Zinc:** Zinc plays an important role in the automotive industry. There it is used to manufacture die cast components for vehicles. Zinc die casting is used wherever safety and maximum stability are required in a vehicle. Zinc plays an important role in the automotive industry. There it is used to manufacture die cast components for vehicles. Zinc die casting is used wherever safety and maximum stability are required in a vehicle — often concealed and invisible to the eyes of drivers and passengers. Zinc die casting will be indispensable in the coming decades. The ease of processing, not only when it comes to large quantities, will ensures that the quantity used is going to increase rather than decrease.

High - Tech Products Made from Zinc Die Casting.
The market for car parts made of die cast zinc is highly important for the automotive industry. Its significance will increase even more with lightweight construction. This is because zinc is used to manufacture thin - walled parts which have a narrow scope of tolerance and are very robust. Zinc die casting is used especially for components where safety is a top priority and the life of the occupants is to be protected — for example, the rollers of the seat belt or belt pretensioners. But housings such as the wiper motor which provides a clear view are also made of zinc. Spark plug heads, the housing of many starter motors, the cylinders of modern door locks and even the door handles rely on zinc.

Car Parts Made of Zinc Die Casting.
In many of the latest car models, parts of the fittings, handles, dampers (e. g. ventilation flaps in the interior), switches and blinds are made of zinc. The advantage of zinc die castings is obvious. The die casting process can transform zinc into all kinds of shapes needed by the automotive industry. Additionally, alternative metals cannot keep up with its surface qualities. The parts maintain narrow tolerances and the surface of products made of zinc die casting is smooth. This means that all zinc parts have an exquisite look and increase the value of high - end cars.

Zinc Die Casting in the Car: A Sustainable Product.
It is right that the automotive industry is increasingly relying on the inherent properties of zinc. Its consistent ratio of dead weight to material strength makes it possible to reduce the weight of a vehicle. The corrosion protection provided by zinc ensures optimum service life for housings exposed to the weather, e. g. the housing of wiper motors. But zinc has more to offer than that: The more important autonomous driving becomes, the more important will parts that protect against electromagnetic and electrical influences become. These parts ensure that components that are essential to transmission do not correlate. Not to mention external influences this must also be shielded.

Zinc meets these requirements. And even if it is not feasible to produce the complete part from zinc, it can be applied by thermal spraying. Due to the high cost - effectiveness of zinc die castings not only in the production of large series, it is to be expected that the automotive industry will increasingly rely on zinc for instance in connectors or housings. Furthermore, zinc is a sustainable and resource - efficient material. It can be recycled perfectly and returned to the materials cycle. Zinc pressure parts are later used in the recycling process for example in the form of zinc alloys. Due to the closed material cycle, zinc ensures a responsible and sustainable use of raw materials. Zinc die casting meets the strict safety specifications that apply inside and on a vehicle. That is why belt pretensioners or belt rewinders which require strength and functionality in hazardous situations where life and death are at stake, are made of zinc. In addition to safety aspects, the material ensures long service life even under extreme weather or operating conditions [7].

a. **Magnesium:** Magnesium die castings have an enormous field of application. Many different engineering disciplines benefit from the special material properties of this nonferrous metal. Magnesium is one of the lightest and most pliable metals used in alloy die casting and machining today. While pure magnesium is too volatile, combustible, and corrosive to be used in its purest form, magnesium can be combined with other lightweight metals such as aluminum to be die cast into almost any shape or texture. These compound materials offer excellent potential for thin - wall and complex structure formation, making them a leading choice for use in projects requiring more delicate work. As it is commonly considered to be the eight most common element in the earth's crust, the cost - to - material ratio also makes it an attractive choice for use in bulk machining work or mass production. It is the lightest alloy (in terms of mass) commonly cast in modern die moulding.

Magnesium - aluminium alloy products, most commonly the material AZ91D, are used frequently in industrial and consumer products as EMI and RFI shielding, vehicle parts, and as structural components. However, the metal's high heat resistance, excellent electrical conductivity, and 100% reclamation rate when it is recycled make it extremely versatile. As aluminum shares many of the same properties as the light metal it is often favored for use in combined die casting. However, magnesium can be combined with many other die cast metals.

State of Magnesium Die Casting Industry: Magnesium is the lightest of all the engineering metals, having density of 1.74 g/cm3. Magnesium is 35% lighter than aluminum and over four times lighter than steel. Magnesium alloys reduce vibration 25 times better than aluminium, giving this material a clear advantage by reducing road vibration. Most steering wheels in use today have a magnesium core, over - molded with vinyl, which improves driver comfort by preventing vibration from reaching the driver’s hands. Magnesium is the eighth most common element in nature, constitutes about 2 % of the Earth's crust by weight, and is the third most plentiful element dissolved in seawater (about 1.3 kg per cubic meter).

It has good ductility, better noise and vibration dampening than aluminum, and excellent cast - ability. Alloying magnesium with aluminum, rare earths, zinc, or zirconium increases its strength to weight ratio, making the alloy very suitable wherever weight reduction is important, and where it is imperative to reduce inertial forces. The high specific strength and stiffness of magnesium are very desirable characteristics in applications wherever the weight of the product is an important feature. Besides having these innate characteristics, magnesium is also environmentally friendly. It is easily segregated from the recycling stream and is recoverable by re - melting. In addition, even if not recycled, it will naturally dissolve into magnesium oxide, which is harmless to people and to the environment.

b. **High Copper Alloys:** High Copper Alloys (C81400 - C82800). Next in order of decreasing copper content are alloys with a minimum designated purity of 94% Cu. The high copper alloys are used primarily for their unique combination of high strength and good conductivity. Their corrosion resistance can be better than that of copper itself. Chromium coppers (C8 1400 and C81500), with a tensile strength of 45 ksi (3 10 MPa) and a conductivity of 82% lACS (see page 86) (as heat treated), are used in electrical contacts, clamps, welding gear and similar electromechanical hardware. At more than 160 ksi (1, 100 MPa), the beryllium coppers have the highest tensile strengths of all the copper alloys. They are used in heavy duty mechanical and electromechanical equipment requiring ultrahigh strength and good electrical and/or thermal conductivity. The high copper alloys' corrosion resistance is as good as or better than that of pure copper. It is adequate for electrical and electronic products used outdoors or in marine environments, which generally do not require extraordinary corrosion protection.

The copper alloy families are based on composition and metallurgical structure. These, in turn, influence or are influenced by the way the metals solidify. Solidification behavior is an important consideration, both in casting design and when selecting a casting process. The following description of the alloys according to their structures and freezing behavior is intended as a brief introduction to a very complex subject. Coppers are metallurgically simple materials, containing a single face - cantered cubic alpha phase. Coppers solidify at a fixed temperature, 1, 981°F (1, 083°C), but there is usually some undercooling. Freezing begins as a thin chill zone at the mold wall, then follows the freezing point isotherm inward until the entire body has solidified. Cast structures exhibit columnar grain structures oriented perpendicular to the solidification front. Centerline shrinkage cavities can fonn at isolated "hot spots" and inadequately fed regions of the casting; this must be taken into account when laying out the casting's design.

High Copper Alloys. Like the coppers, the high copper alloys solidify by skin formation followed by columnar grain growth. With a few exceptions, the high copper alloys typically have very narrow freezing ranges and also produce centerline shrinkage in regions that are improperly fed. The chromium and beryllium coppers develop maximum mechanical properties through age - hardening heat treatments consisting of a solution annealing step followed by quenching and reheating to an appropri ate aging temperature. Conductivity is highest in the aged (maximum strength) or slightly overaged (lower strength but higher ductility) conditions, i. e., when the hardening element has mostly precipitated and the remaining matrix consist of nearly pure copper [7].

1.4 Mould material

The mold cavity is created using two hardened tool steel dies which have been machined into shape and work similarly to an injection mold during the process. Most die castings are made from non - ferrous metals, specifically **zinc, copper, aluminium, magnesium, lead, pewter, and tin - based alloys**.

When the mould is closed, the melt is pressed into the mold under a pressure of up to 1, 200 bar, achieving maximum mold filling **speeds of 150 m/s** (540 km/h). High closing and clamping forces are required to press the mold halves against each other and keep the molds closed: up to 8, 000 kN (800 t) in hot chamber die casting machines and up to 45, 000 kN (4, 500 t) in cold chamber die casting machines. By using such high forces, large - sized cast parts can be manufactured. Concerning material and design, the molds that are used for this purpose must be designed in such a way that they can permanently withstand the loads related to the large melt quantities. When the metal has solidified, the mold halves open and the cast part is ejected by bolts or removed by a robot and conveyed for further processing.

Die cast mold development is a versatile process that enables the production of a large quantity of small to medium - size castings.

Mold Manufacturing Processes: Die casting is a manufacturing process that is commonly used for producing accurately dimensioned, sharply defined, smooth, or textured surface metal parts. It is accomplished by forcing molten metal under high pressure into reusable metal dies. The die casting molds process follows the subsequent procedures regarding die cast mold manufacturing:

a) A mold is created in at least two sections to allow the proper removal of the casting.
b) The sections are mounted securely within the machine and are arranged so that one is stationary while the other is moveable.
c) The two are tightly clamped together.
d) Molten metal is injected into the die cavity where it quickly solidifies.
e) The die halves are drawn apart and the casting is ejected.

When compared with sand or permanent mould processes, HPDC (High Pressure Die Casting) is the fastest method in the industry for producing highly precise non - ferrous metal parts.

High Pressure Die Casting Mold Benefits

There are numerous advantages regarding the usage of die casting (or HPDC) process. Some of the advantages and disadvantages of the HPDC moulds process include the following:

HPDC Mould Advantages:

1. Net shape part configuration is achievable.2. High dimensional accuracy is achievable.3. Fast production.4. Thinner walls are achievable when compared to investment and sand castings.5. Wide range of possible shapes
external threads can be casted.6. Steel inserts can be over - molded.7. Holes can be cored to internal tap drill size

HPDC Mould Disadvantages:

a) A relatively large production volume is required to make the process cost - effective.
b) High initial cost (tool, set up).
c) Minimum wall thickness: 0.040".
d) Maximum wall thickness: 0.200". In some cases, acceptable up to 0.50".
e) Draft radii and fillets required on the casting.
f) Potential porosity issue.

Die Casting Moulds.

The moulds that are utilized within the die casting mould design process are constructed from premium, heat - resistant steel grades. The moulds are halved to form a cavity into which the liquid metal is pressed during the casting process. A die casting mould is so strong over a million parts can generally be created with a single mould. However, the actual life of the mould will solely depend on the die casting materials that are used.

Advantages of Die Casting Mould Development.

Die casting utilizes non - ferrous metals (such as aluminium alloys or zinc alloys) to manufacture components. The chosen alloy for an application depends on budget, weight, and material properties. Other benefits associated with the use of die casting mould design, include:
1. High thermal conductivity.2. High electrical conductivity.3. Good processing properties.4. High corrosion resistance.5. High strength and hardness.

Quality Die Casting Mould Design Benefits.

When it comes to high quality die casting mould development there are several influences that contribute to the overall success of the process. These factors include the following
First Class Engineering, die - cast tools design in house. Manage and oversee all aspects of tooling.
Developing injection process parameters: gate size, location, feeding speed, fill time, injection pressure, press size.
1. Parting line, runner, overflows, venting, cooling.2. Minimum and Maximum wall thickness.3. Choice of the mould material and hardness based on mould forces calculation.4. Superior or Premium Grade H13.5. Flow simulation.6. Draft, radii, filets.7. Establishing machining stock.8. Utilization of both domestic and overseas tooling suppliers.

Additional Considerations for Die Casting Mould Design.

Some of the additional factors that should be considered before starting a die casting mould development project include the following:
1. Gate calculation, feeding speed and fill time.2. Press size, clamping forces calculation.3. Shot sleeve choice and calculation.4. Venting and overflows.5. Establishing cast and technological Datum.6. Establishing machining stock.
4. Pouring temperature. In order to fill the mold cavity, which is usually larger than conventional ones, the pouring temperature needs to be **as high as 700°C** to prevent premature solidification.

Aluminium pouring temperature, together with the melting temperature, is the aluminium casting temperature parameters that much influence the mechanical properties and casting - ability of aluminium alloys.

Similar to melting temperature, the aluminium pouring temperature has to be provided sufficient, not too much, not too low to ensure the casting part quality. Adding too high pouring temperature can cause shrinkage, mould wrapping and reduce the dimensional accuracy of the aluminium casting products. On the other hand, the too low aluminium pouring temperature can result in the mould cavity is not fully filled due to the rapid solidification of aluminium alloys, causing casting defects and inaccuracy.

Additionally, it has been observed that pinholes in aluminium casting parts are formed due to the absorbed hydrogen. By providing an adequate pouring temperature to aluminium alloys, it helps to reduce the porosity created during the casting process.

The aluminium alloy pouring temperature requires being higher than the melting point**.**

Add extra temperature (superheat) during the aluminium alloy melting process helps to increase the fluidity, compensate the heat losses before they are in the mould cavity shape, and lower the heat extraction rate by mould. It has observed that the optimal pouring temperature range of aluminium alloys is 680°C to 750°C.

At this range, the aluminium casting parts are produced with good mechanical properties and casting quality.

And the best pouring temperature to aluminium alloys to obtain the best surface finish of aluminium casting products has to be tested in the range of 680°C – 700°C**.**

At a higher pouring temperature, it will obtain the very rough casting surfaces, lower the strength of casting, and trap gases causing casting defects such as blow holes. The effects of mould design on aluminium pouring temperature. Moreover, the pouring temperature of alloys is also partially influenced by the different mould sizes and capacities relating to the wall thickness of the casting. Accordingly, a higher pouring temperature is applied for thin wall aluminium casting parts, whereas, a lower pouring temperature is usually used for thick wall castings or solid pieces. It recommends that thick - walled casting parts are preferred to pour between 620°C while the thin - walled design should be poured at up to 730°C.

1.5 Flow temperature

What is the proper die temperature?
The die temperature will depend on what alloy you intend to cast. You want to avoid putting excess strain on your die, stressing the die will lower the life expectancy of the die itself. It is best to pour your alloy into your die when it is approximately 50° to 70° degrees higher than the crystallization temperature of the alloy. The die needs to be maintained at approximately a third of the alloy's temperature.

What is the proper die casting chamber/machine temperature?
The temperature required for the die casting machine is a complex calculation that includes things such as the alloy type, die type, size of the part to cast, and more. The chamber temperature needs to be determined by an experienced die caster.

What is the proper alloy temperature?
Alloy temperatures vary greatly depending on the material. Here are two examples of the most common die cast alloys – aluminium and zinc.

What happens if the temperature is incorrect?
If the temperature of the metal being cast is too hot for the mold it can damage the mold, which dramatically shortens the effective usage life of the mold. If the temperature is too cold the metal will cool too quickly as it is flowing into the mold which can cause defects (such as porosity problems or misruns).

1.5 Solidification time

The solidification time of Aluminium - %Sn alloys in sand casting is always greater than the solidification time of Aluminium - %Sn alloys in die casting. The major difference here is that the mold material has a much larger thermal conductivity than sand, and so the solidification will be much more rapid. In the insulating mold (sand mold) the rate of transfer in the sand was the rate limiting step. In permanent molds the rate limiting step is at the interface between the metal and mold, where heat is transferred between the solidifying metal and the permanent mold. Also presence difference between theoretical and experimental value of solidification time, this difference may be because the sands with high moisture contents extract heat faster than sands with low moisture, then lead up to difference between theoretical and experimental value of solidification time. The experimental and theoretical value of solidification time for aluminium - 20%Sn alloy in sand casting is 105.88 sec and 83 sec respectively. Also the solidification time of Aluminium - 20%Sn alloy in die is 2.5 sec and 1.77 sec respectively. While the experimental and theoretical value of solidification time for aluminium - 40%Sn alloy in sand casting is 111.33 sec and 91 sec respectively. While the solidification time of the same alloy is 2.88 sec and 1.98 sec respectively.

1.6 Shrinkage and porosity

Reasons of Shrinkage Porosity of Aluminum Die Casting.

1) What's the shrinkage porosity:
Shrinkage and shrinkage porosity usually occur inside the casting, which is one of the common defects in the formation of aluminium alloy die castings. Shrinkage porosity of aluminium alloy die - castings generally occurs in thick parts at the root of the riser near the inner runner, wall thickness transition points, and thin walls with large flat surfaces. The fracture of aluminium castings in the as - cast state is gray, light yellow, and grayish - white, light yellow, or gray - black after heat treatment.

2) The reason for shrinkage porosity:
a) During the solidification process, the casting cannot be supplemented from the aluminium distributing liquid and form holes.
b) The pouring temperature is too high, and the mould gradient distribution is unreasonable.
c) The injection ratio is low and the boost pressure is too low.
d) The inner gate is thin, the area is too small, and it solidifies prematurely, which is not conducive to pressure transmission and liquid metal feeding.
e) There are hot spots or cross - sections in the casting structure that change drastically.
f) The amount of molten metal pouring is too small, the remaining material is too thin, and it cannot be used for feeding.

3) How to improve the shrinkage porosity:
a) Lower the pouring temperature and reduce the shrinkage.
b) Increase the injection pressure and boost pressure to improve the compactness.
c) Modify the inner gate to make the pressure better, which is conducive to the feeding effect of liquid metal.
d) Change the structure of the castings, eliminate the metal gathering parts, and make the wall thickness as uniform as possible.
e) Speed up the cooling of thick parts.

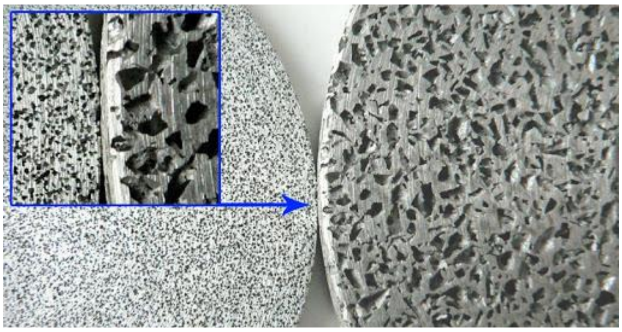
Figure 3.2: Shrinkage and porosity defect

Porosity In Aluminium Alloy Die Castings.
Porosity is a big concern in die casting which includes two basic types: gas porosity and shrinkage. Both can cause costly waste loss and limit the use of die - cast parts in critical high - strength applications. Each takes a completely different corrective action, however they can look similar. In this article, we introduce the causes to porosity in aluminium casting and measures to solve the gas porosity of die castings & how to reduce the porosity of aluminium casting [10].

What is Porosity in Die Casting?
Porosity is one of the most common die casting defects. This porosity is found when there are small voids, holes or pockets of air that is found within metal. Porosity is inherent in die casting manufacturing. Typically, the porosity occurs when air is trapped into the metal by the die casting machinery, often leaving gaps at the top of the die or filling a mould too slowly and having some solidification occur too soon. It can also be created when the air used to force molten metal into the mould isn't completely forced out or able to escape via vents and overflows. The two most

common types of casting porosity types are: gas porosity and shrinkage porosity.

What Causes Porosity In Aluminum Casting?

In the production of aluminium alloy die casting**,** people often call small holes on the product gas porosity in general **[**10**]**. There are many causes of gas porosity in aluminium die casing**.** In summary**,** aluminium die casting gas porosity can be divided into the following categories**:**

- Gas porosity caused by the poor quality of fine wall degassing**.**
- Refining gas porosity caused by poor discharge**.**
- Gas porosity caused by poor exhaust channel of the mould and the poor mould exhaust design structure**.**
- Uneven wall thickness of aluminium alloy discs and cylinders**.**
- Gas porosity caused by entrainment air due to improper die casting parameters**.**
- Shrinkage porosity of aluminium alloys**.**
- Gas porosity caused by excessive difference of the product wall thickness.

How to Reduce the Porosity of HPDC Casting Process

Take these measures to fix die casting gas porosity:

1) In the process of material selection, we should choose dry and clean alloy materials to avoid generating too much water vapour. When melting aluminium alloy, we must strictly follow the operation procedure and avoid entertaining gas as much as possible. Control the melting temperature, avoid overheating and select high quality refining agent or inert gas (such as nitrogen) to ensure gas removal during aluminium alloy melting process. We should select coating that has less volatile gas and ensure evaporation under low temperature and evenly apply coating to prevent the volatilized gas from entering the molten alloy [3].
2) The filling speed should not be too high or too low as it's determined according to the die - cast alloy and structural characteristics of the casting. Under the premise of satisfying the casting moulding and the die casting process conditions permitting, try to reduce the molten aluminium casting temperature as much as possible during die casting. This can reduce the volume shrinkage of the casting, reducing shrinkage holes and shrinkage porosity.
3) Vacuum impregnation is a method that seals the aluminium alloy die casting resulting from porosity. The impregnating material is introduced into the voids within the casting wall thickness through the vacuum and pressure methods. This method is an economical and effective permanent solution to solve the problem of aluminium alloy die casting porosity. There is no limit to the size of castings that can be impregnated.
4) For gas porosity caused by poor discharge, we should improve the exhaust channel of the mould and clean the residual aluminium skin on the mould exhaust channel. Change the thickness of the gate and the direction of the gate, and we can set the overflow and discharge groove at the position where the air hole is formed, so that the gas can have a chance to be discharged. The total cross - sectional area of the overflow chute should not be less than 60% of the total cross - sectional area of the inner gate, otherwise the slag discharge effect will be poor [8].
5) Adding core pulling, cold iron or water cooling or increasing cool - down rates for the mould should be considered when the mould is designed. In the production of die - casting, attention should be paid to the amount of super cooling in the thick parts, and the pouring temperature should be appropriately decreased [8].

How to Test the Porosity of Aluminum Casting?

For the porosity test of aluminium casting, several positions should be considered: the position of maximum stress in finite element analysis, the position of air entrainment in the simulation analysis of parts, the key parts of parts. Generally, the die castings can be inspected by X - ray. After defects are found, the parts are cut for further inspection. In process control, ASTM E505 grade 2 controls and ASTM E505 grade 1 control shall be adopted for key parts. The surface of pores is generally smooth, round or oval, sometimes isolated, sometimes clustered together. However, the shape of shrinkage cavity and porosity is irregular, and the surface colour is dark and not smooth. Dendrite structure can be found in the defect position under microscope and electron microscope.

The 5 Types of Aluminium Casting Defects and How to Treat Them [10].

It's not uncommon for defects to arise during the aluminium casting process. Some are so small as to be tolerable, and some can be easily repaired. Others, though, are so severe that we have no recourse but to throw the casting out and start again. Of course, this is far from ideal. Fortunately, we have numerous ways to treat defects. Here are the five main types of irregularities found in aluminium castings [9]:

- **Shrinkage –** Shrinkage defects occur during the solidification process. Open shrinkage defects are found on the surface of castings, whereas closed shrinkage defects are formed within the casting, when isolated pools of liquid are allowed to form within the solidified metal.
- **Gas Porosity** – Liquid aluminium can hold large volumes of dissolved gas, whereas solid aluminium cannot. As a result, the gas can form bubbles within the metal as it cools, reducing the overall strength of the casting. Gas porosity is most commonly caused by dissolved hydrogen in the molten metal.
- **Pouring Metal Defects –** A few things can go wrong when pouring molten metal. The liquid metal may not fill the entire mould cavity, resulting in an unfilled portion. Alternatively, two fronts of metal may not fuse properly within the mould cavity, resulting in a weak spot.
- **Metallurgical Defects –** Sometimes, the chemical composition of the metal does not allow for optimum cooling conditions. This can result in hot spots – hard areas on the surface of the casting that cooled quicker than the surrounding metal.
- **Mould Defects –** Metal is weaker when it's hot. If the mould has been poorly designed, it can cause residual stresses in the material as it cools, resulting in hot cracking.

How Do We Treat Casting Defects

Our approach to treating irregularities in our castings will vary depending on the nature of the defect. But as usual, prevention is better than a cure. At Harrison Castings, we have a dedicated, onsite laboratory that is committed to ensuring that all of our castings have the finest metallurgical properties. In this way, we reduce the chances of defects even occurring in the first place.

We to continuously monitor our mechanical processes, our sand compositions, and our alloys. As a result, we have been able to abandon any inefficient processes that have historically resulted in lower quality castings, whilst perfecting any processes that lead to higher yields and superior metallurgical properties [4].

2. Conclusions

A detailed study of process parameters in high pressure die casting are explained with advantages and disadvantages of many parameters along with HPDC defects such as shrinkage and porosity with their effects.

The following observations were made,

1) Casting defects are very serious for the manufacturing industry making HPDC products.
2) For better quality all kinds of defects should be minimized or free of defects.
3) In this paper review of different research papers have been presented and discussed.
4) The study must be validated through experimental methods to accept the results obtained through analytical or simulation approach.
5) At higher temperatures rough casting surfaces are obtained, decreases the strength of casting, due to trapped gases causing casting defects such as blow holes.

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