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## Automobile Parts Casting-Methods and Materials Used: A Review

Madhav Goenka<sup>a</sup>, Chico Nihal<sup>a</sup>, Rahul Ramanathan<sup>a</sup>, Pratyaksh Gupta<sup>a</sup>, Aman Parashar<sup>a</sup>,  
Joel J<sup>b\*</sup>

<sup>a</sup>*B.Tech Mechanical Engineering, Vellore Institute of Technology, Katpadi, Vellore, TamilNadu, India*

<sup>b\*</sup>*Assistant Professor (senior), Vellore Institute of Technology, Katpadi, Vellore, TamilNadu, India*

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### Abstract

Automobiles are becoming more and more sophisticated with every passing year. Manufacturers have been trying their best to bring down the kerb weight of their automobiles by using various materials with high strength to weight ratio. The different parts of the automobile are being made much stronger than before in order to comply with the high standards set by NCAP. Hence, this pushes automobile makers to come up with new and innovative methods to manufacture the parts of their automobiles. Our paper addresses the various casting processes used to make automobile parts and also touches on the various materials used to make the components. The casting methods discussed are- Green sand casting, Centrifugal casting, Lost- foam casting, Die casting and Squeeze casting. In the paper we discuss about the most suited materials used for each component and briefly discuss about the pros and cons of each process.

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### 1. Introduction

Casting is the process of pouring a liquid metal into a mold of specific dimensions in order to obtain a desired shape. Casting is preferred in industries as it is cost effective and produces dimensionally accurate components. Casting can be carried out using most metals, however the metals most predominantly used are iron, aluminum, steel and copper based alloys.

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\* Corresponding author. Tel.: +91 9003509595

*E-mail address:* [joel.j@vit.ac.in](mailto:joel.j@vit.ac.in)

## Nomenclature

NCAP	New Car Assessment Programme (European)
MMC	Metal Matrix Composite
CGI	Compacted Graphite Cast Iron
CI	Cast Iron
HRB	Brinell Hardness Number

According to Sacred records the use of casting to shape metals can be traced back to 5000 BC. It was established that metal casting was first discovered in the Middle East and later on moved to China and India. During the initial years, the progress of casting was relatively slow. The first metals to be cast were gold and silver, followed by copper and bronze. The next era of foundry started to develop towards the culmination of the 15th century. The start of the 16th century saw the use of the blast furnace for the first time and pig iron was introduced, paving the way for iron and steel molding. As the casting process developed, the latest technologies were incorporated and different casting techniques like squeeze casting, centrifugal casting, lost wax casting, shell molding, stir casting etc. were introduced. As the number of applications of castings increased, the materials used also got more and more sophisticated. Starting with gold and silver, materials used in the present day and age are MMCs, Al-Si alloys, Zinc etc.

One major application of metal casting is in the automobile industry. Metal casting is a huge market for cast products using ferrous, non-ferrous metals and their alloys. There are many processes to produce automobile parts and accessories efficiently that are light in weight, inexpensive to make and have a good life. Zinc die casting and aluminum die casting are the most popular casting processes to produce automobile parts. The weights of these parts are generally around one third the weight of the steel parts with the parts having good thermal properties. The major automobile components made using casting are pistons, engine blocks, valve covers, wheels, transmission housing, carburetors, fan clutches etc. With the constant need to make the automobiles lighter and stronger, Magnesium alloy and Titanium casts have grown due to their superior corrosion performance. Al-Si alloys are popularly used for casting internal combustion engine components owing to their excellent thermal conductivity preventing thermo-mechanical damage and lower density providing light weight components. The automobile industry offers a myriad of applications of casting processes which are constantly being worked on and improved in order to fall in line with the established standards of the industry.

## 2. Casting Methods and Materials Used

### 2.1. Green Sand Casting

Hieu Nguyen[1] discussed about cast irons and aluminium alloy used to manufacture engine blocks using green sand moulding. Green sand is usually a mixture of 5-11% bentonite, 1% anthracite, 3% water, silica and chromite sand. Grey cast iron alloys was preferred owing to its low cost, good mechanical properties and availability. These alloys contain 2.5-4 weight % carbon 0.2-1.0 weight % manganese and about 1-3 weight % silicone. These alloys have great wear resistance, and a very good damping capacity making it ideal for engine blocks. However, a major trade off is that Grey cast irons are weak and prone to deformation. Aluminium alloys were used as it provided a high strength to weight ratio required to manufacture the engine block. The Aluminium alloy 319 is normally used to make engine blocks and comprises of 85.8-91.5 weight % aluminium, 3-4 weight % copper and 5.5-6.5 weight % silicone. Now days CGI is preferred due to its better strength to weight ratio and mechanical properties as shown on table 1.

Table 1. Differences in mechanical properties of CGI and Grey cast iron

An example of a column heading	Grey Cast Iron	Compacted Graphite Cast Iron
Modulus of Elasticity; GPa	98-110	170-190
Tensile Strength; Mpa	160-320	300-600

Adeleke Victor Adedayo [2] spoke about the influence the chemical composition of cast iron has on the mechanical properties of sand cast components. He discussed how the cooling rate of molten cast iron during solidification influences the microstructure of the component. An accelerated cooling rate promoted the formation of cementite due to the suppression of the graphitization process. A mixed microstructure consisting of cementite and graphite was formed during slow cooling.

Hieu Nguyen [1] discussed about the use of green sand moulding in order to cast the engine block. The process of green sand moulding was described in detail and the key aspects were highlighted. Firstly, a mix of silica, clay and water was poured into the pattern. Mould compaction was carried out by jolting and squeezing. The core which consists of hardened sand is then used for support. The molten metal is then poured into the mould and it is allowed to solidify. After solidification the moulds were removed and the cylinder block was cleaned and inspected. Heat treatment was done on the block to improve its properties.

One of the main advantages of green sand casting is that it gives a good design flexibility thus stating that casting can be done for any size and weight of component. Using this casting process, even complex shapes can be cast very easily with very minimal expenditure on tooling and equipment. Also, a wide range of materials can be used with a very short lead time in comparison to the other casting processes. On the other hand green sand casting process does not provide with adequate strength due to its high porosity. Also, there is low dimensional accuracy and a very poor surface finish. A secondary machining operation is often required to give the component the adequate tolerance. Also, defects such as shrinkage, porosity and surface defects are unavoidable.

## 2.2. Centrifugal Casting

D. Anantha Padmanaban [3] stated that Al-Si alloys exhibit a considerable amount of precipitation hardening, thus allowing for the improvement of its mechanical properties on heat treatment. These enhanced mechanical properties give this alloy a distinct advantage over other alloys when it comes to manufacturing automotive parts using centrifugal casting.

The process of centrifugal casting has been mainly used for cylindrical parts. There are two basic types of centrifugal castings: horizontal and vertical. As their name suggests, the horizontal types rotate about the horizontal axis and the vertical about the vertical axis. Horizontal types are used to make pipes, tubes, sleeves and tubular castings that are simple in shape. Vertical types are used to make a huge variety of things like gear blanks, wheels, yokes, brackets, valve bodies. These types can even make castings that are not cylindrical or symmetrical.

The centrifugal casting process provides with a high degree of metallurgical cleanliness and homogenous microstructures. A test was done by the mechanical engineering department at the Minho University, Portugal where the material used for castings was an aluminium alloy AS12UN with the following composition: Fe-0.75%, Si-(11.50–13.00)%, Zn-0.20%, Mg(0.75–1.30)%, Ni-(0.80–1.30)%, Pb-0.10, Sn-0.05%, Ti-0.20% [4]. Three tensile specimens were cut out from the casting to compare the mechanical properties of the different places of the casting with each other. Cylindrical components of up to 8m in diameter and 17 m in length with a wall thickness in the range of 2.5-125mm can be cast by centrifugal casting.

K.Venatesvaran [5] discussed about the use of Silumin (Al-Si alloys) in centrifugal castings. The silicone content in this alloy ranges between 3-50%. This material is preferred due to its light weight, high castability, high corrosion resistance and high machinability. The reason why Silumin is preferred over cast iron for centrifugal casting of pistons is because of its weight (3 times lighter than CI). It also possesses a higher thermal conductivity, allowing it to dissipate heat very easily as compared to cast iron.

Aqeel Ahmed, M. S. Wahab [6] stated that out of the numerous casting methods used to manufacture pistons, each process has its pros and cons and each process has its own impact on the mechanical and physical properties as well as on the microstructure of the piston. They analysed pistons manufactured by centrifugal casting and observed that the hardness from the piston skirt to the piston head increased by 23.7HRB. They compared the properties of a piston made by centrifugal casting to a piston made from gravity permanent mould casting. It was observed that the piston made by centrifugal casting had a coefficient of linear expansion as  $15.3 \times 10^{-6} \text{ K}^{-1}$  which is about 23% lower than gravity permanent mould casting. The improvement in wear analysis of the piston made from centrifugal casting was found to be 70.4% more than the piston made from gravity permanent mould casting.

Most of the casting processes solidify both from the inside as well as the outside thus risking the formation of mid-wall shrinkage, whereas in centrifugal casting it solidifies from outside to inside thus resulting in a part free of shrinkage and porosities. Because of the centrifugal force the high density metal gets pushed outside and at the same time the lower density components float towards the inside, because these lower density materials float inside such as the oxides, sulphides and gases there are no inclusions in the casting. Another major advantage of this casting is that it reduces micro-porosity. One of the limitations of this casting is the limited length to diameter ratio which is 2:1. Another challenge that one can face is the irregular shape of the cast and the cost to make its die. Also casting of very small inside diameters using this process is also difficult.

### 2.3. Lost Foam Process

P.Scarber, H.Littleton [7] elaborated on the use of aluminium and iron alloys in the lost foam casting process. Compacted Grey cast iron is the only iron alloy used, owing to the lack of lustrous carbon defects and undesirable carbon pick-ups in the final casting. They also state that due to the high elastic modulus and tensile strength of CGI, it is used in the lost foam process. According to them, these superior properties of CGI were achieved by modifying the morphology of graphite. Mousa Javidani [9] briefly explained that Mg has an advantage over Al as it is 33% lighter and have a specific strength which is 14.075% more than Al. However the specific stiffness of Al was found to be 0.7% more than that of Mg. Magnesium alloys are another type of preferred materials used in lost foam casting owing to their high strength to weight ratio. These alloys exhibit good workability at high temperatures and are thus widely used in the lost foam process. It is also widely used due to its ability to be moulded into thin-walled intricate castings which are predominantly made using the lost foam process. The weight of castings that can be cast in this process range from 0.5 kg to 1 tonne, with a minimum wall thickness of 2.5mm.

Hieu Nguyen [1] discussed about the different casting processes used to make the engine block. He described lost foam casting as the most reliable technique to manufacture engine blocks. He subsequently describes the lost foam process and stated the important factors in order to achieve a good dimensional accuracy and surface finish. Some of the factors discussed were the heating of the tool before the polystyrene beads were injected into it. Over-fusion of the beads takes place if they are heated for an extended period or not cooled to a desired temperature, thus resulting in surface variations in the moulding. They stated that the mould assembly can be stiffened by placing it in a vat along with a water based ceramic liquid. This helps to prevent the molten metal from destroying the mould. Once the casting is complete, it undergoes heat treatment to enhance the mechanical properties.

### 2.4. Die Casting

Acknowledgements and Reference heading should be left justified, bold, with the first letter capitalized but have no numbers. Text below continues as normal.

The European Aluminium Association discuss how cylinder heads are made using gravity die casting. They use this process as it allows the engineers to achieve a high solidification rate in the flame deck region, thus resulting in a very fine microstructure with low porosity. Sand cores were used to realise a sophisticated water jacket cooling system of complex geometry. They also discuss how the Rotacast process which is a type of gravity die casting provides higher productivity due to a considerably lesser amount of runners and feeders. We also know about the use low pressure die casting to manufacture the cylinder head. The major advantages of this process being almost no process scrap. However, this process decreases the productivity of the manufacturing as the cycle time is relatively high. Usually, die cast components can have walls of 0.75 mm with a smooth surface finish of about 2.2 micrometres, making it useful for thin walled automotive components. Table 2 shows typical die temperatures and life of Al & Mg

Table 2. Typical die temperatures and life of Al and Mg [16]

Parameters	Al	Mg
Max die life (number of cycles)	10,00,000	1,00,000
Die temperature ( °C )	288	260
Casting temperature ( °C )	660	760

In place of cast iron, Al-Si alloys are more frequently used because these alloys have high strength-weight ratio and high thermal conductivity. Another advantage of using alloys is that the composition can be varied depending on the demand of the operating conditions on the material properties. However, hypoeutectic Al-Si alloys may soften (hampering the surface characteristics) at very high temperatures even though performance of the engine increases at said temperature [8]. Thus, this challenge calls for strengthening of the alloy. In a start-stop cycle an engine might be warmed up to 243-523 K in a cold winter. Thus, in case of cylinder head, if we consider three different loads- the assembly load, combustion load (combustion pressures as high as 200 bar), and thermal load-thermal load [9] will be the maximum due to non-uniform thermal expansion and contraction.

Automobile parts require uniformity and high surface finish which can be accomplished by using casting methods that work in a controlled environment- pressure die casting. In fact, die casting was originally developed specifically for automotive applications. The idea is to produce parts that are light, easy to handle and cheap. Thus, die casting is widely applied to zinc and aluminium which are lighter than cast iron. Figure 1 shows the aluminium die cast parts of an automobile.

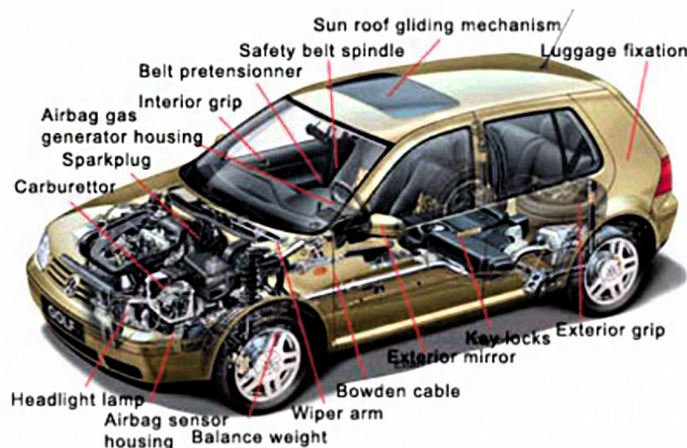


Fig. 1. Aluminium Die Cast Parts.

Die casting is mostly used because a large number of parts need to be manufactured in a short amount of time (hundreds to thousands per day) with high accuracy. Parts like valve covers, wheels, transmission housings, engine block, wheel spacer, carburettor, impellers and fan clutch, alternator housing, airbag gas generator housing, etc. are all made through aluminium die casting method.

Aluminium or Al-Si alloys are used for Die casting. During this process, molten metal is injected at a high pressure into a die (made of metal) which is a permanent mould comprising of two parts of the desired shape attached together. Once the metal cools, these segments are detached and the cast part is obtained. Since the die is a permanent mould, it can be used multiple times for casting the same component with the same dimensional accuracy and surface finish, thus producing a uniformity in the cast parts. However, since the component is cast in a metal in contrast to sand in sand casting, certain factors like cooling and solidification time, dissolved gas removal, etc. also come into play. Appropriate modifications must be done to the die to alleviate these challenges which makes the designing of the die difficult. An appropriate draft angle ensures that the cast part is removed easily.

Alloys used for making the cylinder heads and blocks must have good fluidity, density, machinability, etc. It has been observed that addition of sodium or strontium in nugatory quantities increases the fluidity of the metal.

The Al-Si alloy is being used extensively nowadays for the production of complex wheel geometries that weigh less. This composition of alloy is not only used in the automotive industry but also in the aeronautic and aerospace industries because of their high strength-to-weight ratio and also because of the improvement in their mechanical properties upon heat treatment. Other than this grain refinement can be done which promotes the formation of finer grains thus improving the mechanical properties. These are generally used in the forms of bars which are directly added to the molten metal. This effect is based on Ti and B. Therefore, the refiner used is Al-5Ti-B or ATB [10]. The process which is predominantly used for the production of wheels is the low-pressure die casting (LPDC)

because of the higher quality products that it delivers along with the reduction in porosity. Also the large scale production for this process is easier than that of gravity die casting (GDC). Some of the defects that are found in the aluminium alloy are macro-porosity, micro-porosity and exogenous oxide inclusions [11]. These defects affect a lot on the wheel cosmetics, air-tightness and wheel mechanical performance.

### 2.5. Squeeze Casting

Reinforcements are often added to metal alloys to improve certain properties of the alloy-specific stiffness, strength, wear resistance, high- temperature properties and thermal expansion. M. Dudyk [10] found that the best way to reduce shrinkage of cast parts was by using AlSi6Cu2Mg alloy with Sb. AlSi6Cu2Mg along with strontium and antimony lowers fluidity of the alloy by 25% and 15% respectively as compared to unmodified alloys. Ceramic particulates [12] are normally composed of silicon carbide or aluminium oxide with volume fraction in the range of 5-70%. Other ceramic- fibre materials like carbon fibre are also used which find a popular application in automobile bodies. The purpose of addition of the said reinforcements is centred at reducing the weight for the brake and engine components and increased length for the driveshaft. MMCs result in reduction of reciprocating weight, noise, fuel consumption, and emissions and increase in engine power. For instance, components like connecting rods are fabricated from either fibre or particulate reinforced aluminium alloys. The components of squeeze casting were found to have 20-30% better mechanical properties than die casting.

Wu Shenqing and Li Jun [15] gave an elaborate discussion on the material and the type of casting used to make pistons. In the paper they describe how Aluminium Pistons are manufactured using a eutectic aluminium and silicone alloy. The process flow of MMC partially reinforced pistons starts with the pre-treatment of the ceramic fibres. The fibres were kept to a length to diameter ratio of 50 – 150. A bonding agent was added to the short fibres in a suitable ratio, so that the fibres can take the shape of the die sets. The preform was dried and sintered to a temperature of 800°C, thus making them porous. The composite piston was then manufactured by squeeze casting. The mother preform is injected with the molten aluminium alloy. The liquid alloy penetrates into the 3-D spaces in the fibres and solidifies. Figure 2 shows flow chart of manufacturing of MMC pistons using squeeze casting process.

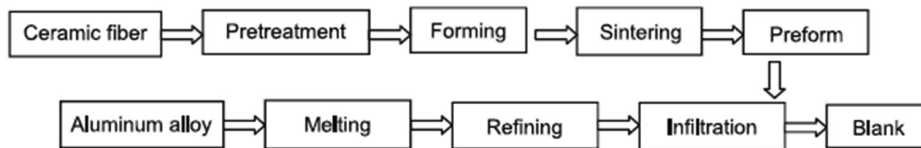


Fig. 2. Flow chart of manufacturing of MMC pistons using squeeze casting.

The horizontal squeeze casting process can be used for the production of engine bracket mounts. [3] The process followed for the production starts by the controlled flow of molten metal into a heated sleeve. This is followed by the plunger slowly moving until the sleeve and runner are completely filled as to avoid the seepage of air inside the die. Figure 3 shows the four process of squeeze casting.

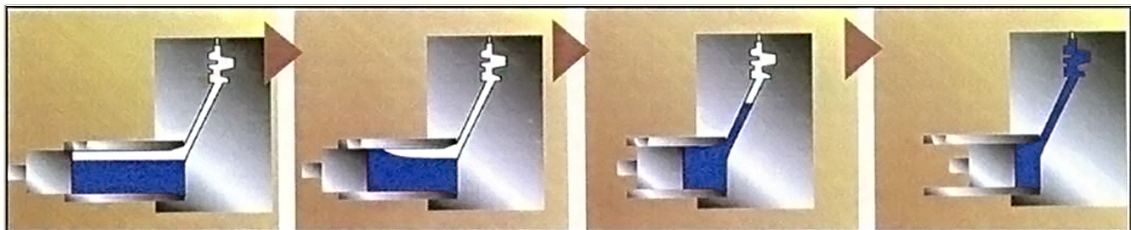


Fig. 3. The process of squeeze casting. (a) Initial pouring of molten metal; (b) Plunger moving; (c) Plunger moving to reach the gate of molten metal; (d) Plunger moving to completely filling of die cavity.

The squeeze casting has many advantages with porosity reduction being the most important one. Also using this process a near net shape can be achieved and also the mechanical properties can be enhanced. This process is extremely suitable for mass production. The squeeze casting process is being used in the fabrication of automobile parts which satisfies the high strength [13] requirement and the desired elongation. It has been seen that the squeeze casting process can be used in a very limited manner when it comes to the vertical type process.

### 3. Conclusion

In this paper the casting processes which are most specifically used in the automobile industry have been discussed and attempts have been made to give a comprehensive evaluation of the processes which would be most suited for casting a particular part. During the course of this evaluation it was found that Die casting finds a ubiquitous application in casting most of the automobile parts, despite its high cost. Other processes like green sand casting can be used as an inexpensive alternative for casting parts which are less demanding on dimensional accuracy and surface finish. Based on the requirement of the part to be cast, specialised processes can be used the material and process parameters of which have been elucidated in this paper.

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