Modern High Pressure Die-casting Processes for Aluminium Castings

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ABSTRACT

There are about 33 processes commercially available for the production of aluminium castings. About 70% of the castings are produced using conventional high-pressure die-casting process. It's main drawbacks are 1) Air and gas blow holes 2) Unable to weld 3) unable to heat treat to enhance mechanical properties. To overcome these, many modern processes have been invented. A few of them are 1) High Integrity die-casting processes such as 1) Squeeze casting 2) Local casting spot pressurising 3) Ultrahigh vacuum process 4) Massive vent process 5) Vacural process 6) Minimum fill time process 7) Nissan Innovative process 8) Controlled filling process 9) Vacuum high vac –V process 10)Semi -solid casting processes . In this paper a brief account of the above such processes are given.

Keywords: Aluminium High pressue Die-casting, Turbulence, Air and gas blow holes, High integrity die-casting processes, Ultra high vacuum process, Semi-solid casting processes, reduce casting weight, increase casting quality, minimum casting wall thickness, squeeze pins, suppress blow holes, pin holes.

INTRODUCTION

Aluminium was discovered in the year 1825 by a Denmark scientist Mr. Hans, using chemical process. Due to very high cost, equivalent to that of silver, there was no major developments until the "Electrolysis" method was invented by Charles M Halls. New developments started.

In the year 1876, the first Aluminium casting was produced using sand moulds. By 2010, there about 33 plus different methods are available. Out of these, one of the most commercially successful process is "Conventional high pressure die-casting ". But it has some major drawbacks as well, such as air and gas blow holes , shrinkages, severe surface defects like cold shuts, swirl, sink and many more. These are also unable to weld and heat-treat to enhance the mechanical properties of the castings. To overcome these defects, many newer processes have come up. In these, the above drawbacks are overcome, casting strength is increased, castable casting minimum wall thickness has come down from 6 mm (sand casting) to 0.8 mm in the Vacuum die-castings and still upto 0.5 mm.

Such marvellous achievements are very much advantageous to the highly competitive auto industries. Lot of money had been invested in developing the modern processes through process R&D by several companies in the world .By this their components are of better quality and they gain competitive advantage. In this paper, a brief account of some of the new processes, that resulted in the above marvellous achievements, are given.

ORIGIN OF HPDC

From Fig.1, it can be noted that in the year 1915 the first high pressure die-casting machine was brought to market by H.H.Doehler. At first, Zinc die-castings were produced, then aluminium. In the year 1928, M/s. Buhlers , Switzerland , brought out a PDC machine which attracted the market. This is a landmark in PDC. Then, many changes took place due to the advancements in hydraulics , electrical and electronics.

CONVENTIONAL HIGH PRESSURE DIE-CASTINGS PROCESSES

Machines are available with the locking forces from 60 to 7200 tonnes for production .Castings ranging from about 50 grams to 50 kg are being produced. Two types of machines are used in general.

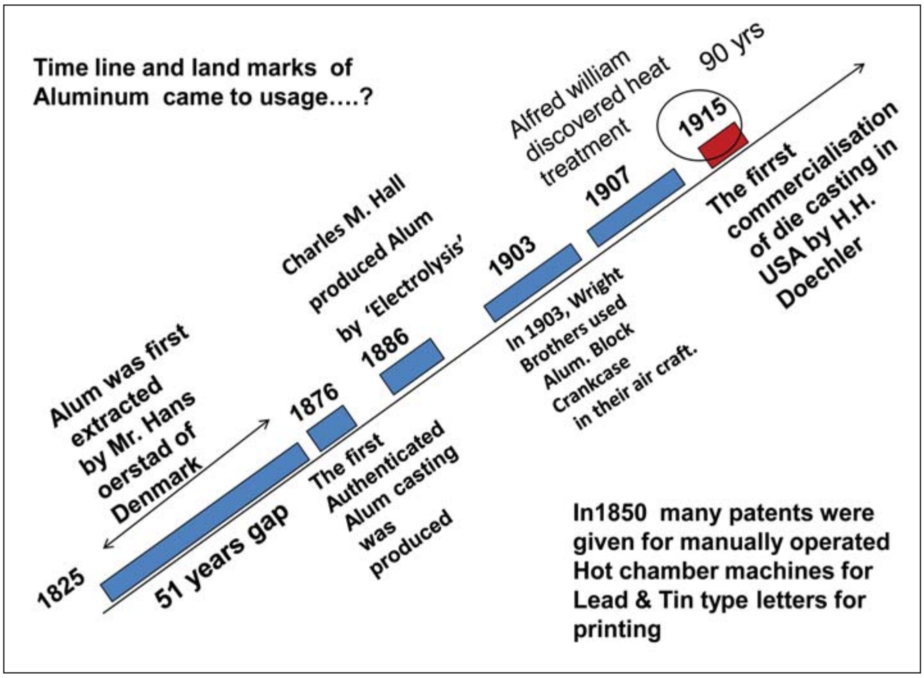


Fig. 1: Traces 9 years of development of the processes.

1) Horizontal Cold Chamber High Pressure Die-casting machines, for most types of castings.

2) Vertical High Pressure Die-casting machine especially for electrical motor parts with encast winding.

DRAWBACKS OF THE ABOVE CONVENTIONAL PROCESSES

By nature, the HPDC process is very violent and turbulent. It is like a strong, wild Horse. Metal is injected into the die cavity at a pressure between 200 to 1000 kg/cm^2 max. Molten aluminium enters in the die cavity with the speeds from about 20 to 45 meters /sec, limited to the maximum gate speed of 60 meters /sec.

This results in a lot of turbulence causing air entrapment. The injection takes place in milli-seconds. Hence, there is no sufficient time available for the air in the cavity to escape.

Considerable quantity of air and gases still remain inside the casting itself even after providing air venting in the die. Moreover, there is a need to maintain the impurity element Iron in the alloy composition to a level of 0.8 to 1.0% max, to avoid sticking of castings with the die cavity. This affects the strength of the casting. Scientists and Engineers have pushed the Conventional HPDC process to the edge of its limits. But not able to meet the present day product design requirements. Hence ,there is pressing need for developing newer processes. Air / gas blow holes are inevitable in the conventional HPDC. Also these castings cannot be heat-treated and are not weldable. These are really some major drawbacks in spite of several plus points.

LIST OF A FEW MODERN CASTING PROCESSES WITH BRIEF OUTLINE

Slow Shot Die-casting Processes

- **Squeeze casting Process:** Molten metal is poured into an injection sleeve, which is kept in an inclined position Fig.2 at the start .Then it is straightened and connected to the die cavity through the gate. Metal is injected into the die at a very slow speed of about 0.4 meters/sec max ;unlike the very high speeds of (45 meters/sec) conventional HPDC . Very quite and turbulent free cavity filling is achieved. Then a pressure of 500 to 1100 kg/cm^2 is applied on the castings until the solidification is completed. Shrinkage porosity and gas voids are suppressed out. Due to slow metal injection, air entrapment is very much reduced. Gas inclusion is as low as 1cc/100 gm of aluminium. Hence, T6 heat treatment and welding are possible. Iron is limited to 0.5% only, hence the casting strength is improved. There are two types of machines available i) Horizontal ii) Vertical types. The typical process parameters are: Metal temperature 720 °C, Die temp: 300 °C, Injection speed 0.2 m/sec upto the gate, gate velocity: 0.3 to 0.35 m / sec, Alloy :356. . The method of metal injection is shown Figs. 2 and 3.

- **Acurad Process:** (Fig. 5) This was introduced by General Motors Corporation, USA. One of the features is a 'thick gate and low injection speed' for laminar filling for reducing air blow holes. Another one is directional solidification by judicial temperature control and "forced feed" by another plunger to squeeze gas and shrinkage porosity. By slow injection of metal, turbulence is reduced to a large extent. Hence air entrapment is minimised (Fig 4). Plunger 1 injects metal slowly into the die cavity .When the casting becomes just semi solid, the 2nd plunger, which is located annularly in the 1st plunger, moves forward and apply high pressure until the solidification is complete. This pressure suppresses the shrinkage and gas voids to a large extent. This process is NOT suitable for thin castings. Machine problems are very much, hence not popular. Yet its basic idea is utilised in the recent modern die-casting processes.

Local Pressurising Processe (Fig. 6): In this process, high pressure is applied, using moving pins, located within the die itself, on the casting spots where shrinkage is occurring and there is no way to provide cooling or core pins. The pressure is applied when the casting is in the semi-solid condition. The squeeze pin engagement time is kept between 1and 3.5 sec. For each type of situation, this time and also the start and end timings are determined by experimentation only. There are 3 types are available. 1) Local 'casting- spot' pressurising process, 2) Squeeze pin feedback control system 3)Local runner spots pressurising process. Out of these "Local 'casting-spot' pressurising process is widely used in India by many foundries.

Squeeze Pin Feedback Control System: This was developed by 'Toyota of Japan. The squeeze pin movement is regulated in accordance with reaction force measured during pushing of the pin.

New Injection Process: In this process metal is directly supplied to the die cavity by an electro magnetic pump or by air pressure. Then, pressure is applied by a plunger until the solidification is completed. Powder type lubricant is applied for avoiding the casting sticking to the die cavity. In this process, conventional high speed filling is used. After a set time, a pressurising pin is pushed forward in an appropriate location of the casting, where

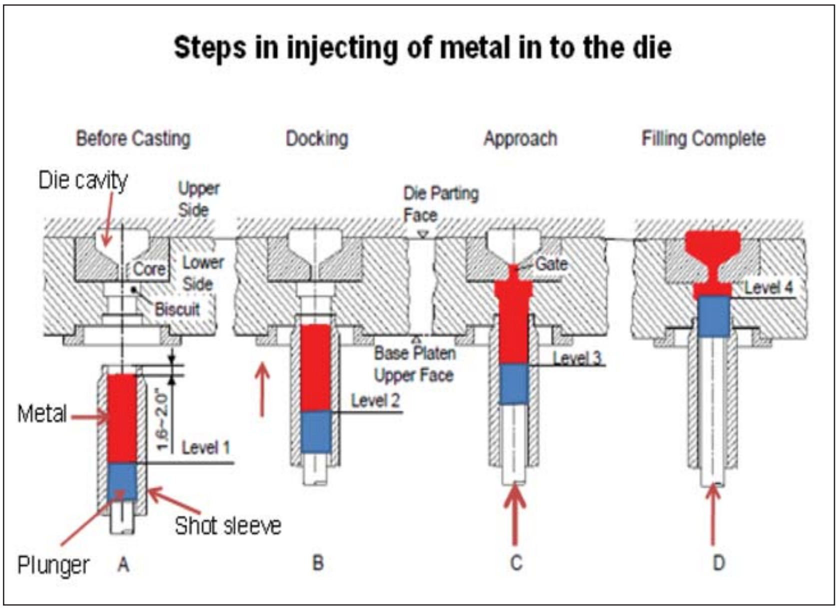


Fig.: 2

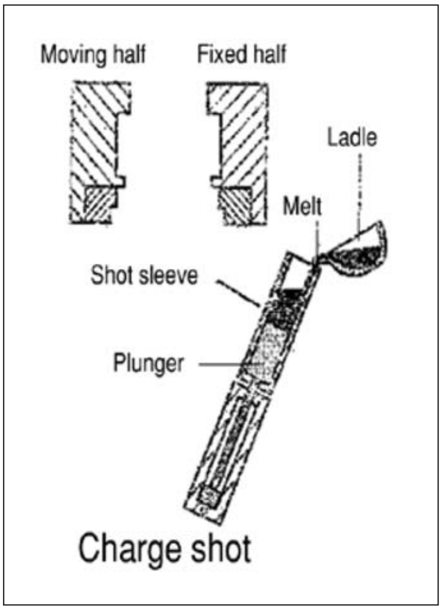


Fig.: 3

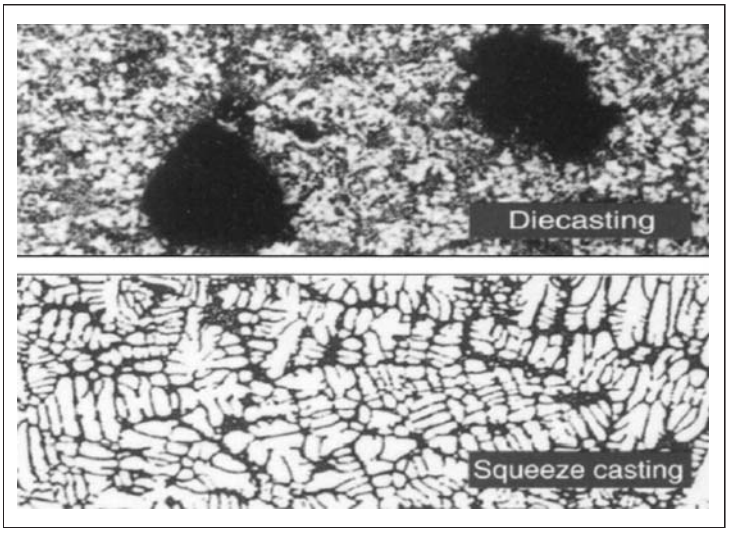


Fig.: 4

The microstructure in the squeeze casting is not as fine as that observed in conventional die casting, & the dendrites are much more pronounced.

The cycle time is longer than the conventional die-casting due to slow injection & longer solidification times

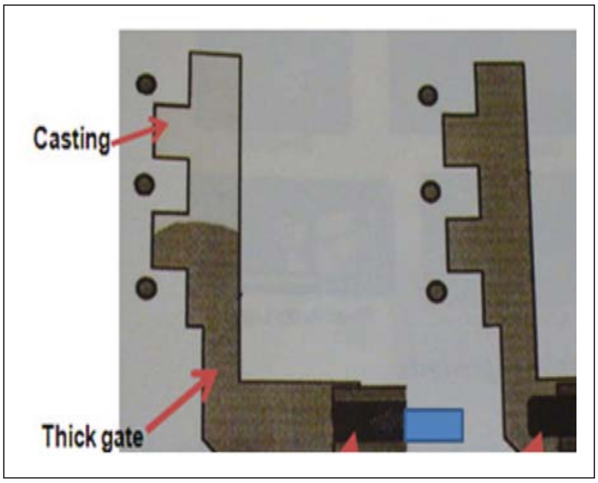


Fig.5: Acurad Process.

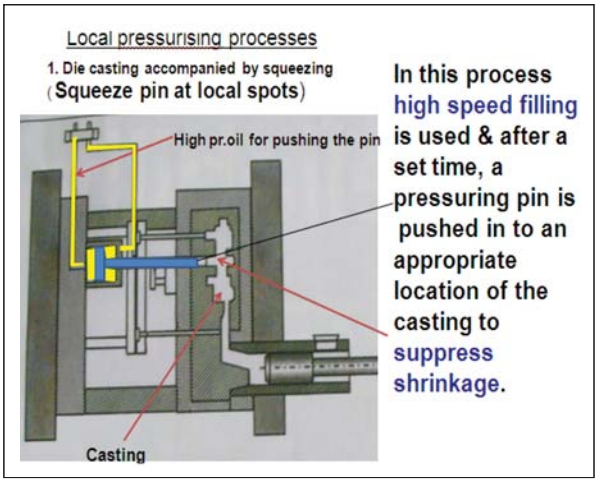


Fig.: 6

shrinkage occurs. By this high pressure, the shrinkage gets suppressed.

Vacuum Die-casting Processes. In the conventional vacuum process, vacuum is 20 to 50 kP and the gas contained in the casting is 5 to 20 cc/ 100 gms Aluminium. And hence, T6 heat treatment and welding are not practical.

- **Ultra High Vacuum Process:** In the ultra vacuum process, vacuum pressure is below 10 kp. In this process (Fig. 7), air and gas content is below 5 cc per 100 grams of Al, hence the castings are heat-treatable and weldable.

- **Vacural Process:** In this process, to achieve heat treatment of castings, many improvements are made. Improved sealing at the parting line, ejector pins, plunger tip, metal injection method are also improved. The molten metal in the holding furnace is sucked in to the shot sleeve through a pipe by lowering the pressure in the die cavity and shot sleeve (Fig. 8). The sucking is continued for a long time until the pressure becomes as low as 5 kp. The gas /air content in the casting is as low as 1 to 3 cc / 100 grams of aluminium. Hence, T6 heat treatment and welding is possible. This process is being followed by Daimler-Chryslers for making engine parts, Porche and Nissan for suspension parts and Hitachi for making Snow mobile parts.

Nissan Innovative Casting Process (NICS): This is a modified version of 'Vacural Process'. Suspension

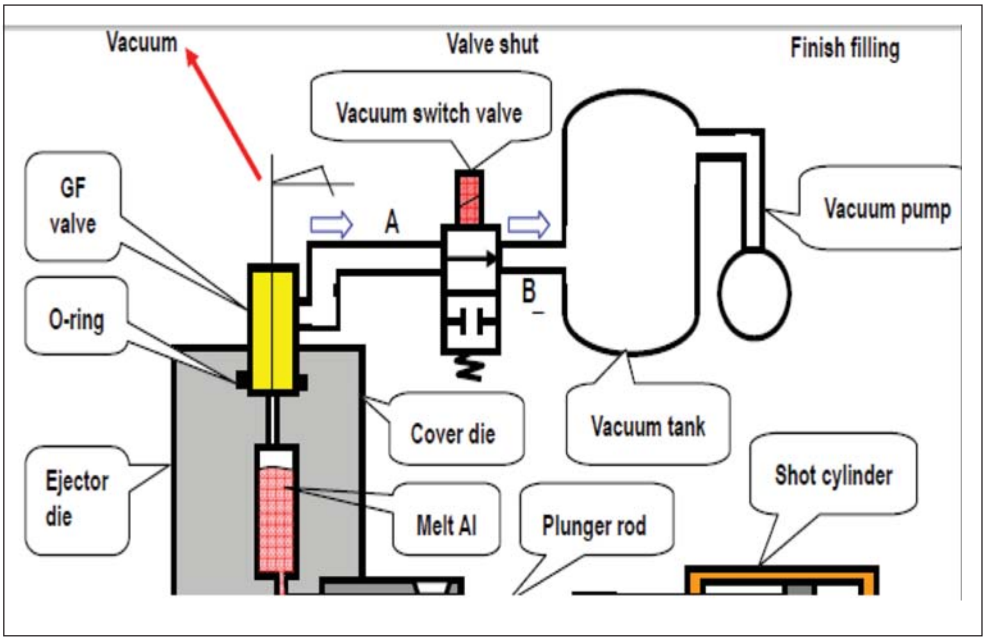


Fig.: 7

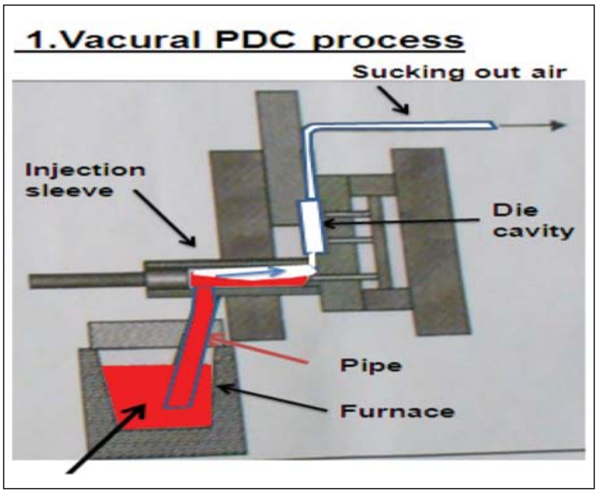


Fig. 8: Molten aluminium in holding furnace which is tightly sealed.

parts which require high strength, endurance, ductility are now made using this process.

Hitachi Vacural Process (HIVAC–V): This is also a modified form of 'Vacural Process' which is used for producing Snow mobile parts**.**

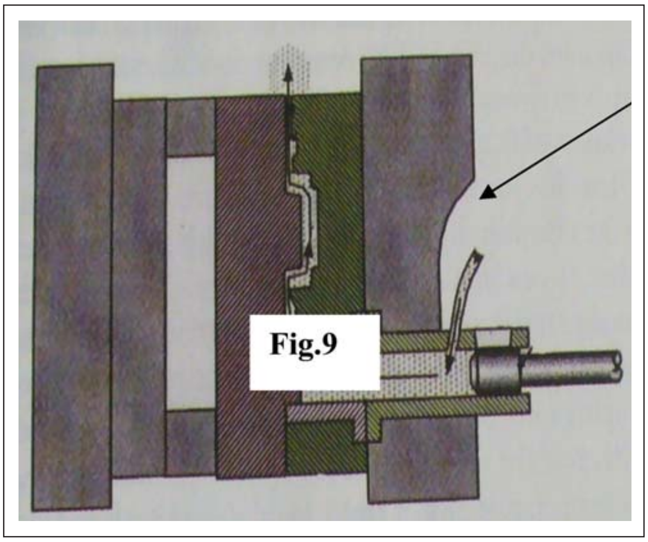
PF (pore free) Process : In this process, air in the cavity, runner, shot sleeve is replaced by **oxygen gas**. This reacts with the molten aluminium which is injected at high speed through pin gates. Vacuum is formed in the die cavity by the oxidation reaction of molten metal. The oxides are finely dispersed. Thus air blow holes are reduced. T6 heat treatment and welding is possible. This is also called as Otivac process. Fig 9.

Minimum Fill Time Process: This process was developed by Alcon- BMW. In this process metal is filled using a multi runner system in the cavity in the shortest time. This happens by virtue of large total gating area.

Semi Solid- Liquid metal casting processes: When the normal dendritic microstructure is modified to a non- dendritic, spheroidal microstructure, the resulting material has a remarkably low shear strength even at relatively high solid fractions- It becomes Thixotropic.

The benefits are 1) Lower operating temperature of the metal 2) Longer die life. In the 'Semi-solid metal working', many improvements are noticed. 1. Reduced amount of entrapped gases, 2. Reduced amount of solidification shrinkage, and 3. Fine microstructure of the alloy.

Thixocasting Process: This is also called 'semi-liquid ' casting process. A billet is made by solidifying an alloy while stirring, which is reheated later to provide a 'solid –liquid mixture' for forming. Cast microstructure is excellent. Castings are of very high quality. Strength is high. But the cost of making billet is very high.



Oxygen is filled through this tube in to the shot sleeve.

Fig.: 9

Rheotech Casting Process : This does not need any prepared billets. Hitachi Metals, Japan_ has developed a process in which solid-liquid mixture is prepared before injection by pouring liquid alloy into the injection sleeve equipped with an electro magnetic stirrer. The metal is stirred and when the desired solid: Liquid fraction is reached, the metal is injected in to the die.

UBE , Japan,_has also developed a process in which solid-liquid is first poured into a slurry making vessel, where solid –liquid mixture with an appropriate solid fraction is formed and then transferred in to the injection sleeve. The flow pattern is shown in the Fig.10 which is always Planar.

New 'Hot Chamber' Die-casting Process for Aluminium: In the earlier days, hot chamber die casting process for alum was a failure due to iron contamination. But in this new process, some of the major drawbacks, are taken care of. The nozzle and injection chamber are separated out by a ceramic structure. This process is used to produce large quantities of small heat sink castings. The tonnage of the machines is also limited to 14 to -50 tonnes.

An Important Note: The micro details of the above new processes are not readily available for common foundry use, since these are developed by big corporate

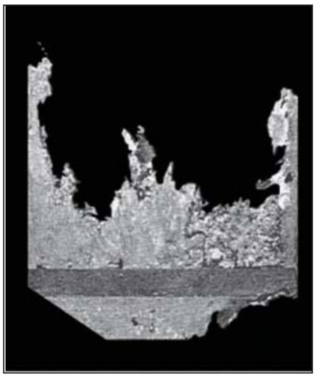


Fig. 10: Non planar filling, which is not desirable.

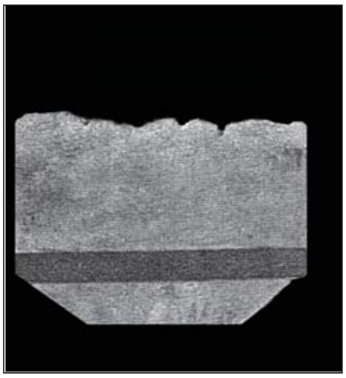


Fig. 11: Planar filling.

Fig. 12

Some typical Automotive components manufactured using semi- solid metal working processes, Fig 11. There are about 60 different foundries producing from 5 gms to7 kg wts of castings in USA (Fig. 12)

The Trend and Direction in the Aluminium Component Production (Fig. 13)

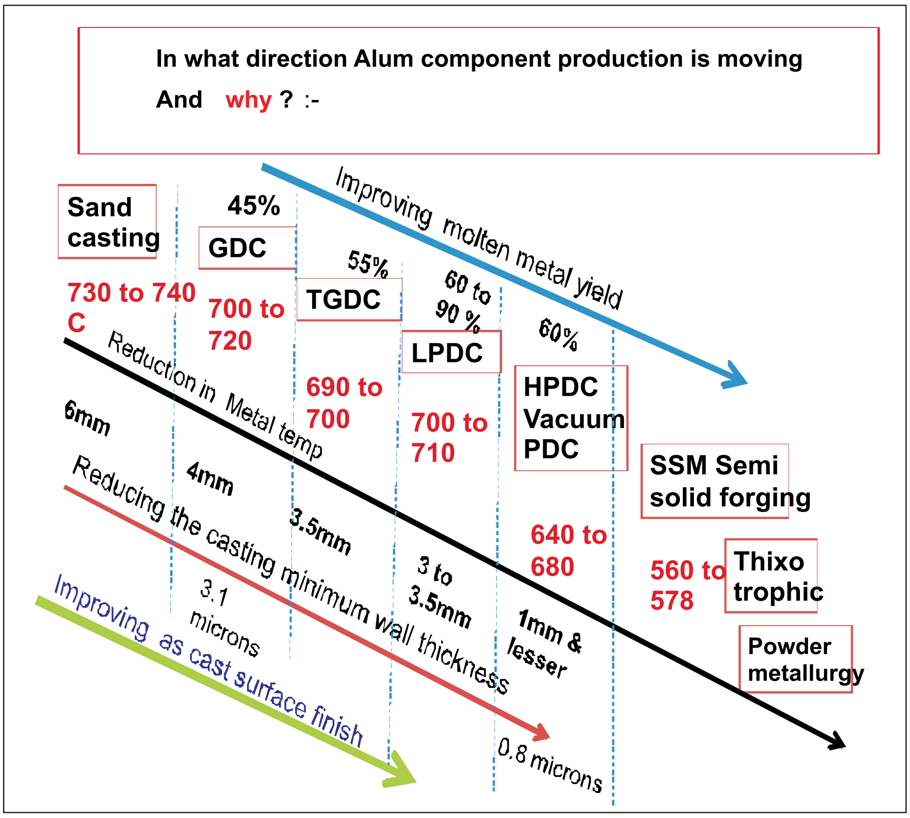


Fig. 13

companies, using their own R&D. And they keep them as their proprietary knowhow.

Conclusion

1) In the modern casting processes, the turbulence while filling the die cavity is almost eliminated.

2) Air and gas blowholes are very much minimised/ avoided.

3) Microstructure is excellent.

4) Casting wall thickness has come down to around 0.5 mm, which cannot be obtained in conventional HPDC.

5) Local shrinkages are squeezed out.

6) Castings are heat-treatable and weldable. ■