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Injection Parameters Setting in High-Pressure Die Casting

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Abstract

The advancement of science and processing technology is highly essential for the development of human civilization for a better life. Mass production leads to the availability of goods at a lesser price. Aluminium die-cast components are widely used in the automobile, aerospace, and consumer goods market. Proper process parameters are required to produce components with minimum rejections and scrap. This paper studies optimum injection parameters to produce components without defects. The common defects encountered in high pressure die casting process (HPDC) are cold shut, flow line, blowholes, pinholes, shrinkage, gas entrapment porosity, etc. So, it is necessary to run a manufacturing process that gives high productivity and profit to the organization. This research analyses the effect of slow speed, fast speed, and intensification features which greatly affect the casting quality. Optimum value for the injection parameters such 1st phase length, 1st phase velocity, 2nd phase length, 2nd phase velocity, 3rd phase cavity pressure & holding time are estimated to reduce the rejection of components due to defects.

Keywords: Casting defects, Cavity pressure, Fill time, Gate area, Injection velocity

INTRODUCTION

Metals and alloys are widely used in all engineering applications. Aluminum and its alloys are used in automobiles, composites, and the aerospace industry due to their significant properties like high strength to weight ratio, lightweight, corrosion resistance, good electrical conductivity, thermal conductivity, etc. [1–6]. The die casting process is classified into Gravity die casting (GDC), Low pressure die casting (LPDC) & high pressure die casting (HPDC) [7–9]. In gravity die casting, the aluminum metal fills up the die cavity under the gravitational pressure of pouring metal and atmospheric pressure acting on the liquid. The mold is made up of steel which can be used for producing a large number of castings. Gravity die casting is recommended with parts wall thickness more than 6 mm. Simple and large size castings can be easily produced with this method [10–14]. Mention that casting weight ranges from 3 kgs to 25 kgs can be cast by GDC. The production rate is low compared to high-pressure die casting. The metal pouring temperature is very high in the order of 720–750°C. High metal temperature increases the metal fluidity and helps in easy filling up the die cavity. The gravity die is made up of two die parts. The two die halves can be open and close manually or with the help of a hydraulic cylinder mechanism. The die halves are coated with ceramic material which keeps the metal in liquid condition during the filling process. After closing the mold, liquid metal is

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poured into the mold till the runner, riser, and cavity are filled with metal. Sufficient time is allowed to solidify the molten metal in the mold. This solidification time depends upon the casting size and weight [15, 16]. After solidification, the component is withdrawn from the mold. The mold is made ready for the next cycle.

Low pressure die casting (LPDC) is a process in which liquid metal fills the mold cavity by pressurizing the holding furnace which is kept below the mold. Argon or nitrogen gas is used to pressurize the holding furnace. The pressure is in the range of 0.1–0.3 bar is suggested [9, 17]. The metal flows through the ceramic or cast-iron stack tube which is a connection to the center of the mold cavity and the holding furnace. The bottom portion of the ceramic tube is completely immersed in the liquid metal held in the holding furnace. After the solidification of liquid metal in the die cavity, the pressure in the holding furnace is released [18]. The liquid metal in the stack tube falls back into the furnace. The die is opened with the help of a hydraulic mechanism and the casting is ejected from the die. This casting is moved for further operations like deburring and machining. The die is cleaned with air and made ready for the next cycle of operation. Low pressure die casting process is used for producing automobile car wheels, cylinder heads, cylinder covers, clutch plates, etc. High-pressure die casting (HPDC) consists of a piston that drives the molten metal into the die cavity under high pressure and velocity [19–23]. The die set consists of two halves. One is a fixed or stationary die and the other one is an ejector die or moving die. The die main parts are made up of H13 hot die steel of high quality. The die steel can withstand high thermal loads, sudden shock loads and has good corrosion resistance and wear resistance properties. The die housings are made up of medium carbon steel. Main die inserts are hardened to 44 to 46 HRC [24, 25]. Nitriding surface heat treatment operation has been carried out to main die inserts to improve wear resistance and to protect the die from metal soldering [26]. Schematic diagram of high pressure die casting machine as shown in Figure 1.

The machine consists of two main hydraulic cylinders. Machine closing cylinder assists closing and opening of moving die half with the help of toggle link mechanism [27–32]. Metal injection cylinder assists in injecting the liquid aluminum metal into the die cavity. The cycle sequence consists of the following steps:

- Operate die closing push buttons to forward-moving die half and tightly fit with fixed die half with the help of a toggle link mechanism. Now the die is closed and held firmly with locking force.
- Transfer molten metal from holding furnace to injection sleeve by manual ladling or auto ladling.
- Operate shot button which pushes molten aluminum metal in injection sleeve into the die cavity with the forward movement of plunger tip fitted to the plunger rod. Now the die cavity is filled with metal.
- Allow sufficient solidification time to ensure that metal is completely solidified in the die cavity.
- After solidification, open the die and remove the solidified casting for further processes like deburring and machining.
- This cycle is continued till the required parts are produced.

The factors such as die temperature, pouring melting temperature, injection slow speed, fast speed, and intensification pressure play an important role during the casting process to get sound and defect-free castings. The different types of casting defects are gas porosity, blowholes, cold shut, flow lines, shrinkage, soldering that are encountered during the casting process. To control these defects, proper settings of metal injection parameters are essential. The die casting process under high pressure is characterized by rapid filling of a mold cavity with molten metal at pressures ranging from 1,500 to 30,000 psi. This results in precise, detailed, and dimensionally accurate parts suitable for high-volume production. The process supports a variety of materials, ensures consistent quality, offers excellent surface finish, and allows for thin-wall designs. Automation is common, enhancing efficiency and reducing labor costs.

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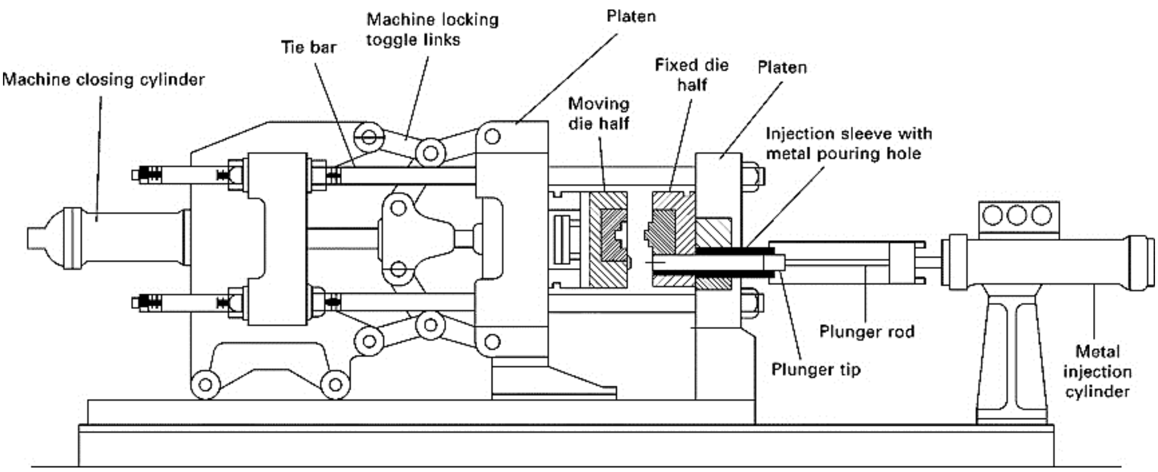

Figure 1. Cold chamber horizontal high pressure die casting machine.

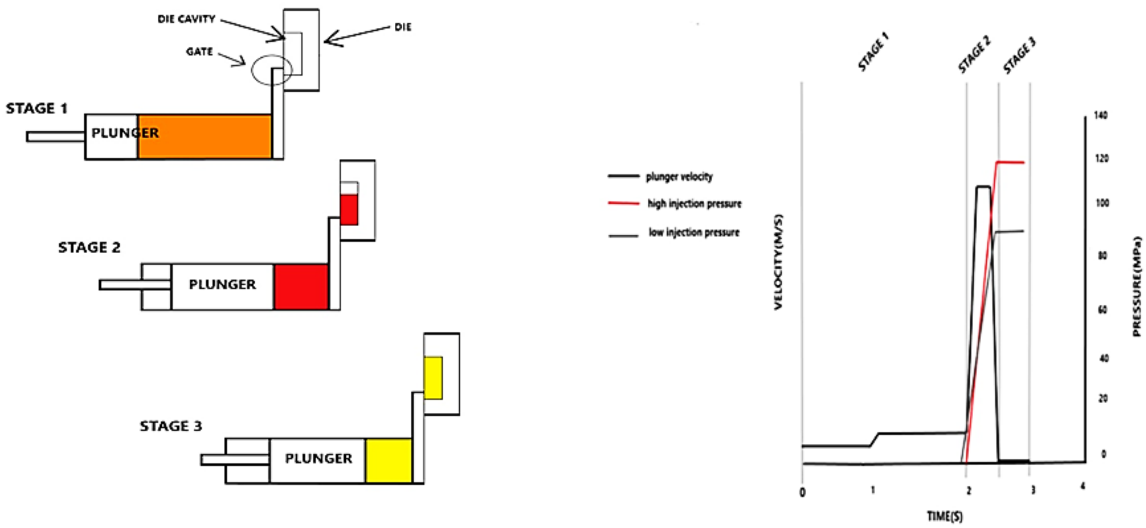

Figure 2. Three-phase injection system.

PROCESS PARAMETERS

The important injection parameters in high pressure die casting (HPDC) that affect the casting quality are slow speed, slow speed length, fast speed, fast speed length, intensification pressure, and intensification pressure holding time. Variation of any of these parameters results in casting defects. So, the three phases in the injection system are slow speed (1st phase), high speed (2nd phase), and intensification (3rd phase). These 3 phase injection systems have shown in Figure 2. Now, it is very important to discuss the following elements like Filling ratio, 1st phase length and velocity, 2nd phase length and velocity, and finally 3rd phase intensification pressure and holding time. The filling ratio is the volume of poured liquid metal in the injection sleeve chamber to the total volume of the injection sleeve chamber.

The filling ratio is important in the die casting process because it is linked with the problem of gas entrapment porosity. The evacuation of air in the injection sleeve within a short time is recommended during the filling of the die cavity. The best filling ratio is 60–70%. The low filling ratio tends to give porosity defects in the casting are proved [33–36].

1st Phase

The first phase is also called a prefilling phase. In this phase, the plunger moves the molten metal from the shot sleeve (injection sleeve) to near the in-gate with low velocity [37]. The slow velocity is in the range of 0.1 m/sec to 0.6 m/sec depending upon casting profile and weight. During this phase, all the air present in the shot sleeve and runner portion is completely removed and replaced by molten metal. At the end of 1st phase injection, there is an intervention position is called 2nd phase injection start point at which high-speed 2nd phase injection starts. Suppose if the metal is behind the change-over point, it results in porosity in the casting. On the other hand, if the metal is after the change-over point, a part of liquid metal enters into the die cavity which results in premature solidification of the first metal in the die cavity. Casting defects like non-filling, cold shut occurs. So, it is very important to calculate 1st phase length.

$$\mathbf{1st\ phase\ length\ =\ active\ sleeve\ length - 2nd\ phase\ length}$$

Active sleeve length is the gap between the plunger start positions to die end position when the die is in a closed position. 2nd phase length is the piston movement length required to fill the die cavity and overflows with liquid metal.

$$\mathbf{2nd\ phase\ length\ =\ \frac{(volume\ of\ the\ component + volume\ of\ overflows)}{plunger\ area}}$$

Once we calculate 1st phase length, the next step is to determine 1st phase velocity.

1st phase velocity: 1st phase velocity depends on filling ratio and plunger diameter. Too low 1st velocity causes cold shut and non-fill defects in the casting. On the other hand, too high 1st phase velocity results in air entrapment porosity defect in the cast product. So, the ideal 1st phase velocity is calculated by the formula given by the North American Die Casting Society (NADCA).

$$\mathbf{1st\ phase\ velocity\ (^{m}/_{sec}) = 0.579^{0.5}\left\{\frac{(100\% - f_r)}{100\%}\right\}\left(\sqrt{d}\right)}$$

Where f_r = filling ratio% and d = plunger diameter(m).

The standard slow velocity is in the range of 0.05 m/sec to 0.6 m/sec. After calculating 1st phase length and velocity, the next step is to find out 2nd phase length and velocity.

2nd Phase

The second phase is the die cavity filling phase. The piston pushes the liquid metal into the die cavity at a very high speed (0.4 m/sec–6 m/sec). The mold filling time is extremely short with 5 to 100 milliseconds. In this phase, it is difficult to remove all air present in the die cavity within this short time. This can be ensured by providing proper air vents in the die and along the die parting line.

$$\mathbf{2nd\ phase\ length\ (mm) = \frac{volume\ of\ metal\ to\ fill\ the\ die\ cavity\ (mm^3)}{plunger\ area (mm^2)}}$$

Now the next step is to find out 2nd phase velocity. In the 2nd phase, we need to fill the die cavity under the required fill time. Fill time is considered while designing the mold. Gate velocity is in the range of 25 m/sec to 45 m/sec based on wall thickness and weight of the component. Gate area is obtained from die design data. We know that,

$$\mathbf{plunger\ area\ \times plunger\ velocity = gate\ area\ \times gate\ velocity}$$

Therefore,

$$\mathbf{2nd\ phase\ velocity (^{m}/_{sec}) = \frac{gate\ area\ (m^2) \times gate\ velocity (^{m}/_{sec})}{plunger\ area (m^2)}}$$

Now the next step is 3rd phase intensification pressure.

3rd Phase

The third phase will start after the mold is filled with metal. After mold filling the metal start to solidify. During solidification time the extra metal is pushed into the die cavity to compensate for shrinkage porosity. This can be achieved by maintaining piston intensification pressure against the biscuit. This 3rd phase intensification pressure at the plunger tip helps in reducing shrinkage porosity, improve strength, dimensional accuracy, and solidification quality. Intensification holding time is normally less than 5 seconds. Within this time the liquid metal inside the die is converted into a solid state.

Intensification pressure is also called cavity pressure. The pressure inside the mold cavity makes molecule comes close to each other and hence density of material improves. Intensification pressure is derived from the following equation.

$$\boldsymbol{Intensification\ pressure} = \left(\frac{\boldsymbol{injection\ cylinder\ diameter}}{\boldsymbol{piston\ diameter}}\right) \times \boldsymbol{intensified\ hydraulic\ pressure}$$

The intensification pressure (cavity pressure) for a different type of casting is as follows [38–42]:

- For standard castings = 400–600 kg/cm^2
- For technical castings = 600–800 kg/cm^2
- For pressure-tight castings = 800–1000 kg/cm^2

For a good die casting component, the die cavity must be filled before the solidification of metal starts. The solidification time depends on the following factors such as solidification range of an alloy, metal temperature, die temperature, and wall thickness of the part. Directional solidification should occur to obtain sound casting. Directional solidification means the first main component should solidify and follow by in-gate, runner, and biscuit. After reaching the component temperature to 200–350°C, it must be removed from the die. Otherwise, the component gets stuck in the die and cannot be removed from the die. In case the component gets stuck in the die, it is advised to heat the component by gas torch to the temperature range of 200–300°C for easy removal from the die. Now we got a brief idea about 3 phase injection system in high pressure die casting process. This idea is used to study and reduce the die casting defects in engine housing component which is subjected to pressure tightness quality check before assembly.

RESULTS AND DISCUSSIONS

The following casting details are available for research and study of the engine housing component.

- Shot weight = 1200 gms
- Casting weight = 850 gms
- Gate area = 1.10 cm^2
- Plunger dia = 6 cm
- Active sleeve length =29 cms

Now we can calculate the injection parameters step by step.

$$\boldsymbol{Shot\ weight\ volume} = \frac{\boldsymbol{shot\ weight}}{\boldsymbol{density\ of\ liquid\ aluminum}} = \frac{\mathbf{1200}}{\mathbf{2.5}} = \mathbf{480}\boldsymbol{cc}$$

$$\boldsymbol{Casting\ weight\ volume} = \frac{\boldsymbol{casting\ weight}}{\boldsymbol{density\ of\ liquid\ aluminum}} = \frac{\mathbf{850}}{\mathbf{2.5}} = \mathbf{340}\boldsymbol{cc}$$

$$\boldsymbol{Shot\ sleeve\ volume} = \frac{\boldsymbol{active\ shot\ sleeve\ length}}{\boldsymbol{plunger\ area}} = \mathbf{29} \times \mathbf{3} \times \boldsymbol{\pi}^{\mathbf{2}} = \mathbf{820}\boldsymbol{cc}$$

$$\boldsymbol{Fill\ ratio} = \frac{\boldsymbol{shot\ weight\ volume}}{\boldsymbol{shot\ sleeve\ volume}} = \frac{\mathbf{480}}{\mathbf{820}} \times \mathbf{100} = \mathbf{58.53}\%$$

The best filling ratio is 60–70%. The actual fill ratio of 58.53 % is very near to the best filling ratio.

$$\boldsymbol{2nd\ phase\ length} = \frac{\boldsymbol{vvolume\ of\ casting\ weight}}{\boldsymbol{plunger\ area}} = \frac{\mathbf{340}}{\boldsymbol{\pi}\times\mathbf{3}^{\mathbf{2}}} = \frac{\mathbf{340}}{\mathbf{28.26}} = \mathbf{12.03}\boldsymbol{cm}$$

$$\mathbf{1st\ phase\ length = active\ sleeve\ length - 2nd\ phase\ length = 29 - 12.03 = 16.97 cm}$$

Table 1. Research analysis and results.

S.N.	Parameters	Before Research	After Research	Remarks
1	Gate area	1.10 cm^2	Same	
2	Casting weight	850 gm	Same	
3	Shot weight	1200 gm	Same	
4	Plunger dia	6 cm	Same	
5	Active shot sleeve length	29 cm	Same	
6	Intensifier hydraulic pressure	150 kg/cm^2	200 kg/cm^2	Cavity pressure improved
7	1st phase length	14 cm	16.97 cm	Air entrapment reduced
8	1st phase velocity	0.2 m/sec	0.077 m/sec	Air entrapment reduced
9	2nd phase length	15 cm	12.03 cm	Short cavity fill time
10	2nd phase velocity	1.2 m/sec	1.55 m/sec	Cavity filling time reduced
11	3rd phase intensification pressure	700 bar	933 bar	Pressure tightness improved
12	Intensification hold time	1 sec	3 sec	Porosity reduced
13	Total % of Rejection	8%	1.2%	Rejection levels reduced

$$\mathbf{1st\ phase\ velocity(m/sec) = 0.579^{0.5}\left\{\frac{(100\% - f_r)}{100\%}\right\}\left(\sqrt{d}\right)}$$

$$\mathbf{= 0.579^{0.5}\left\{\frac{(100\% - 58.53\%)}{100\%}\right\}\left(\sqrt{0.06}\right) = 0.077\left(^{m}/_{sec}\right)}$$

The value of 1st phase velocity (0.077 m/sec) is within the range of 0.05 – 0.6 m/sec.

$$\mathbf{2nd\ phase\ velocity = \frac{gate\ area \times gate\ velocity}{plunger\ area} = \frac{1.1 \times 40}{28.26} = 1.55 m/sec}$$

Gate velocity for component wall thickness of 2.5 mm is taken 40 m/sec.

The next step is to determine intensification pressure. Before research intensification pressure = (28/6) x 150 = 700 kg/cm^2. Intensifier hydraulic pressure is set to 200 kg/cm^2. So,

$$\mathbf{intensification\ (cavity) pressure = \left(\frac{28}{6}\right) \times 200 = 933\ ^{kg}/_{cm^2}}$$

For the casting subjected to pressure tightness check, the recommended cavity pressure is 800–1000 bar. After adjusting the intensifier hydraulic pressure, we got 933 kg/cm^2, which is well within the recommended range. The analysed results of injection parameters were given in the Table 1.

CONCLUSIONS

After researching injection parameters, the new parameters such as 1st phase length & velocity, 2nd phase length & velocity, and 3rd phase cavity pressure & holding time is set on machine and run production of 3 shifts. With the new setting % of rejections reduced considerably from 8% to 1.2%. The new machine setting results in sound casting quality, improved customer satisfaction, and improved profit to the organization. Optimal injection parameters in high pressure die casting process reduces defects and improves productivity and profit to the organization. It also enhances customer satisfaction.

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