Optimisation of Casting parameters of Squeeze cast LM-24 Al-Si Alloy

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Abstract. The conventional die casting employs metal flow with high gate velocity resulting in nonlaminar fluid flow affecting the quality of the cast product. A potential defect, commonly found in conventionally die cast components is porosity attributed to solidification shrinkage and gas entrapment. The high integrity die casting processes like Squeeze casting, and semi-solid casting(like Thixocasting and Rheocasting [1]) have been developed . Squeeze casting, however, is a simpler process than semisolid and will be more economical.
The Squeeze casting process utilizes relatively slow feeding velocity of the melt into the die and application of high pressure during solidification. Investigation reveals that slower injection speed causes less turbulence and less retention of air and the applied pressure during solidification eliminates shrinkage and gas porosity, decreases thermal resistance and accelerates solidification effecting improvement in microstructure and mechanical properties of the cast material. The suitability of the process for light weight non-ferrous metal alloys has made increasing demand for this emerging process for automobile and aerospace industry.

A study of the Direct squeeze casting process was conducted on aluminiun-silicon alloy LM-24 with 9% Si. LM- 24 is essentially a widely used pressure die casting aluminium alloy with excellent casting characteristics suitable for thin walled casting .The experimental design and the parameters has been organized with variation of pressure, pouring temperature and die temperature.

The result shows increase of density of squeeze cast material indicating near elimination of porosity, improvement of surface finish, improvement in microstructure and increase in hardness and tensile strength . The feed rate is controlled to a lower value to avoid turbulence. For LM-24 aluminium alloy a pouring temperature of 700ºC,die temperature of 200ºC and a pressure of 100 MPa is found to be the optimum combination for better mechanical properties.

Keywords: Squeeze casting; Process parameters; Aluminium alloy.

1. INTRODUCTION

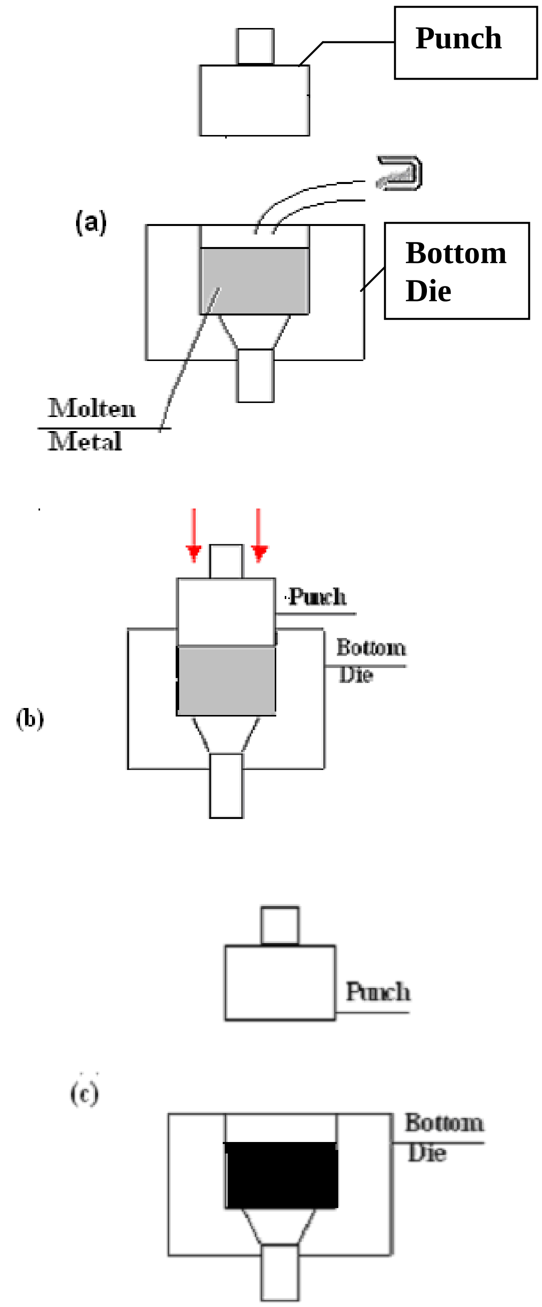
1.1 History

As early as 4000 years BC the art of forming metals by casting was known. Pressure die casting came into existence in the early 1820s in response to the expanding need for large volumes of casting. Injection of metal under pressure into metallic dies was at first purely mechanical using hand cranks. Later pneumatic and hydraulic systems were used as application grew. Progress was, however, limited until development of cold chamber process in 1920s. The idea of Squeeze casting originated as early as 1878 by Chernov to apply steam pressure on molten metal while being solidified. It was not until 1931 that the first squeeze casting experiment was scientifically carried out in Germany on Al-Si alloy by G. Welter who was joined by V. M. Plyatskii in1937. The bulk of work in the West has focused on Aluminium alloys,copper alloys and magnesium alloys.

1.2. The Squeeze casting process

The Squeeze casting process utilizes relatively slow feeding velocity of the melt into the die and application of high pressure during solidification.
Variants: Direct Squeeze casting.- where pressure is applied on the entire surface of the liquid metal.
Indirect Squeeze casting-where pressurisation is done through a plunger.
Direct squeeze casting: In case of direct squeeze casting a pre-measured quantity of molten metal is poured directly into an open

die.The upper die is then lowered, forcing the molten metal under pressure into the cavity until it fills the annular space between the die halves. After the metal has solidified the upper die is lifted and the cast product is ejected by ejectors.
Figure 1 depicts the stages of direct squeeze casting.
(a) Molten Metal Pouring (b) Pressurising
(c) Lifting of top die (d) Ejection



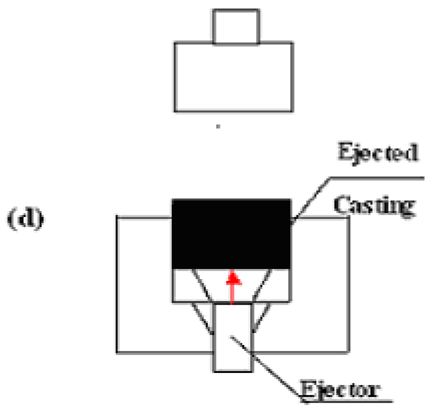


Figure- 1

Advantage/constraint: A potential defect, commonly found in conventionally die cast components, is porosity. Porosity is attributed to two main sources: solidification shrinkage and gas entrapment. Since the last metal solidified inside the mold does not get sufficient metal feed when the rest of metal has already solidified, shrinkage porosity forms . Gas porosity will occur due to liberation of dissolved gases in hot metal during solidification.

In squeeze casting process slower speed of injection and higher pressure during solidification eliminates turbulence, effect closer contact of the molten metal with the die surface producing a rapid heat transfer condition that yields pore free fine grain structure in the cast product.

The direct squeeze casting process has its advantage in that the application of pressure is on the entire surface or larger part of the surface area of the casting, producing casting of full density. The metal fluidity is not a major problem and alloys other than conventional cast alloys like wrought alloys can be used. The molten metal is poured directly on the open bottom die and there is no requirement of runner or riser. The method is economical in the sense that there is nearly 100% material utilisation.

The constraint that requires to be taken care of is metal filling. Highly accurate metering system is required. The metal pouring and punch lowering is to be synchronised as higher die filling rate may lead to turbulen t flow and the time delay between metal pouring and pressurization may lead to premature solidification.

Operating Parameters: The following parameters can influence the casting quality in squeeze casting process

- Die Temperature
- Pouring Temperature
- Pressure level & Timing
- Die Coating & Lubrication
- Design of Casting
- Injection Speed

2. ELEMENTS FOR STUDIES

Material: Aluminium-Silicon alloy LM-24 (BS1490:1988) with 9% Si and melting temperature of 615-550ºC with composition mentioned at Table-1.

Furnace: Crucible furnace with electrical resistance heating (Maximum temperature-1200º C) Upon initiation of melting of aluminium alloy, the temperature of the furnace is raised to a little above the prefixed pouring temperature. Pre-measured quantitity of alloy material is put in a graphite crucible and the furnace temperature is prefixed. Industrial argon gas is injected into the furnace to create an inert condition, to prevent occurrence of oxidation during melting.

Squeeze casting machine: The simplest form of squeeze casting machine is an open die into which molten metal is poured and the pressure is then applied by a mechanically or hydraulic operated ram or punch. A comprehensive direct squeeze casting machine with co-related facilities for die heating , pressurization during solidification and of cast ejection metal has been utilised. Figure-2 shows a schematic diagram of Squeeze casting m/c.

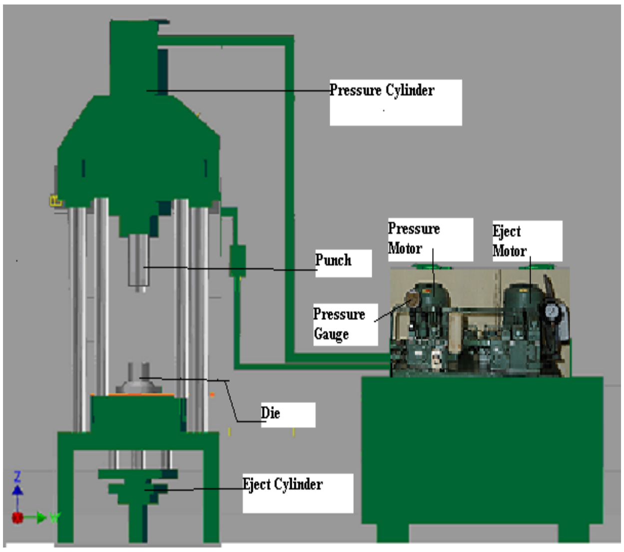


Figure-2

The die and punch are mounted in the bottom and top part of the machine respectively.The ejector pin at the bottom is operated by a separate hydraulic system. Molten aluminium alloy is poured manually into the die cavity, the hydraulic press activated, applying a pressure to the solidifying metal through the top plunger.
Specification of the squeeze casting machine: (a) M/C

Capacity: 50 T

(b)Capacity of eject cylinder: 25 T

(c)Approach Speed:100 mm/sec

(d) Pressing Speed : 1-10 mm/sec

Temperature Measurement: For measuring temperature of mould as well as temperature of molten metal 'K' type chromel alumel thermocouples have been inserted in the mould wall and also in the mould cavity. The other end of the thermocouples are connected to the data logger.

Table-1

Cu	Mg	Si	Ni	Fe	Mn	Zn	Pb	Sn	Ti	Al
3.0-4.0%	0.3 max	7.5-9.5%	0.5 max	1.3 max	0.5 max	3.0 max	0.3 max	0.2 max	0.2 max	balance

Die Block: Die casting die plays a critical role in successful application of squeeze casting . The squeeze casting dies are exposed to severe thermal and mechanical cycle loading which may cause thermal fatigue,cracking etc.

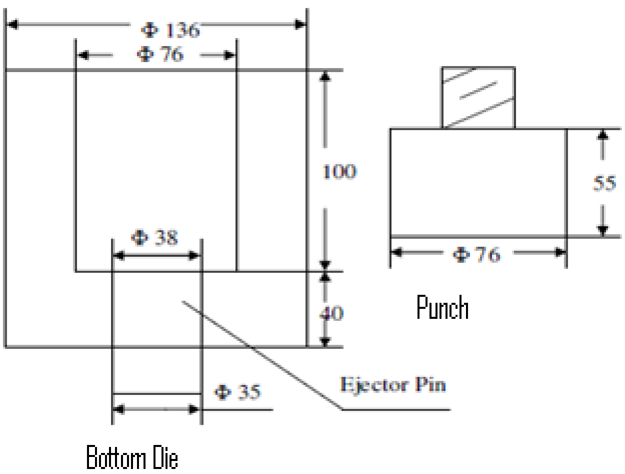


Figure-3

Bottom die : The die is split into two sections so that casting can be removed after it has been formed – (i) Cover die or punch and (ii) Bottom die. Half of the casting is formed in the cover die and half in the bottom die. The die and punch were made from hardened steel EN24 (Figure-3) . The top and bottom dies are sprayed with Molybdenum sulphide (MoS_2) .

Die Preheating: Die preheating temperature has been taken as 200º, 250º C. Metallic mould is enveloped with electric heater to preheat the mould to the required temperature. The die preheating is done by a portable heater for heating the die upto a maximum of 300 º C. A digital temperature controller controls the preset die temperature of the portable heater .

Metal Delivery System: The Direct squeeze casting process requires slow feeding velocity and metering of molten metal.Prior to pouring, a mixture of boric acid and sulphur is sprinkled on the melt surface. This aids in preventing spontaneous oxidation of the surface of the molten metal. The melt is skimmed before pouring to remove the oxides and impurities .

A metered amount of liquid metal is poured into the lower die cavity directly from crucible. The die cavity is filled with molten aluminium alloy at a speed to minimize the amount of entrapped air and also avoiding premature solidification. The optimum filling time is chosen as a compromise between the two.

3. EXPERIMENTAL PROCESS

The casting process begins with loading of measured quantity of the alloy ingot into the graphite crucible and placing the crucible with its content into the center recess of the furnace. Once the metal has reached the casting temperature the crucible with molten metal is taken out from the furnace for pouring into the pre-heated die coated with Molybdenum sulphide (MoS_2). The punch lowered into the die and pressure is applied For gravity die casting no pressure is applied and molten metal is allowed to cool down to room temperature. The solidified casting is then ejected from the die. The pouring of molten metal takes about 5(Five) sec. The punch lowered into the die and pressure was applied. The lowering of punch to the surface of metal takes around 6(Six) sec.

was achieved using 0.5-micron alumina powder suspended in distilled water and diamond paste. Each specimen after etching, is mounted on an electron microscope and the microstructure observed and photographed.

Sl No	Pressure (MPa)	Roughness (Ra) Mean Value (µm)
01	00	2.7
02	40	1.2
03	60	1.1
04	80	0.9
05	100	0.8

4.RESULTS & DISCUSSION

4.1 Surface Finish

The surface finish in terms of RMS value measured for products at different pressure shows better surface finish for squeeze casting process at higher pressure of 100 MPa(Table2) **Table-2**

3.1 Experimental Parameters

1. Pressure: 0,40, 60, 80, 100 Mpa
2. Pouring temp : 660,700, 750 ºC
3. Die temp: 200,250 ºC

3.2 Experimental Measurements

The quantitative experimental measurement has been done for measurement of mechanical and metallographic properties .

Mechanical Properties: The tensile properties has been tested in Hounsfield Tensometer for Ultimate tensile strength, Proof stress, Percentage Elongation with 6.5 mm dia test specimen. Hardness was determined using the Brinell hardness test machine. The surface finish in terms of RMS value is measured .

Metallographic Properties: The samples casted under different parameters were mechanically polished using standard metallographic techniques before the examination. Final polish to near-mirror finish

4.2 Mechanical Properties

Table-3 shows UTS, Proof Stress, Hardness and % Elongation of cast component at different pressure and pouring temperature. The 0(zero) pressure signifies gravity casting. The squeeze cast specimen shows better mechanical properties in terms at 100MPa pressure and pouring tmperaure of 700º C. The percentage elongation has also been increased substantially. The % improvement of UTS, Proof stress and Hardness at 100 MPa pressure (from '0' pressure) against pouring temperature is graphically represented at Figure-4.

Sl. No.	Pressure (MPa)	Pouring Temp (^{0}C)	Die Temp (^{0}C)	UTS (MPa)	Proof Stress (MPa)	Hardness (BHN)	% Elongation
01	0	660	200	200	110	80	2.0%
02	40	660	250	200	110	80	2.0%
03	60	660	250	220	120	80	2.5%
04	80	660	200	230	130	82	3.0%
05	100	660	250	235	135	88	3.5%
06	0	700	200	190	105	80	2.0%
07	40	700	200	210	115	82	2.5%
08	60	700	200	230	130	85	2.5%
09	80	700	250	235	135	85	3.0%
10	100	700	200	240	140	90	4.0%
11	0	750	250	190	105	75	2.0%
12	40	750	200	210	115	80	2.0%
13	60	750	250	225	125	82	3.0%
14	80	750	200	225	125	85	3.0%
15	100	750	250	230	130	85	4.0%

Table-3

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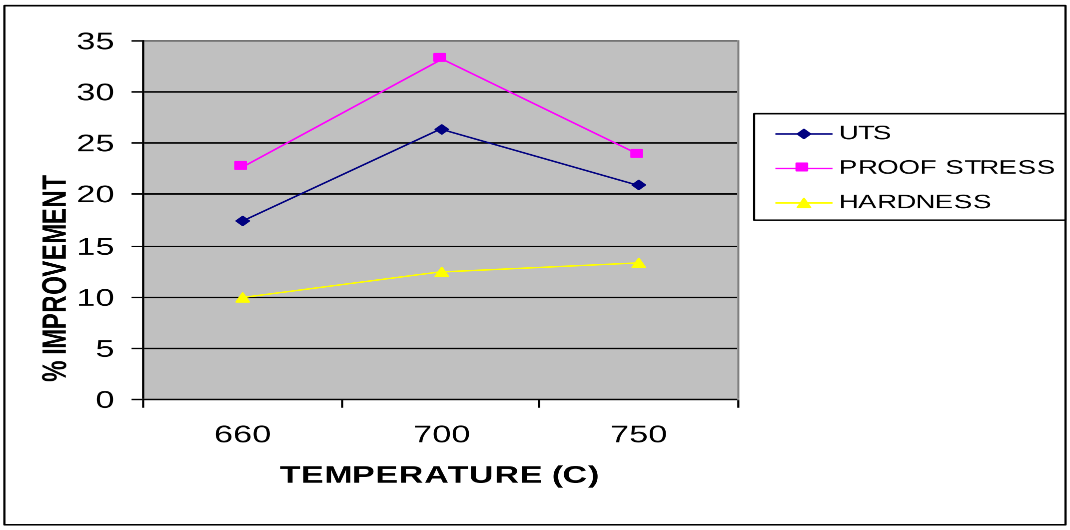
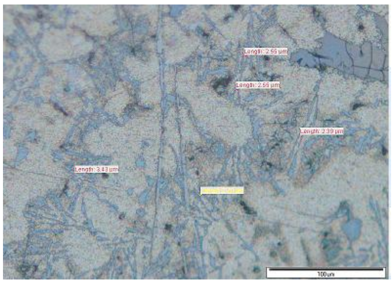


Figure-4

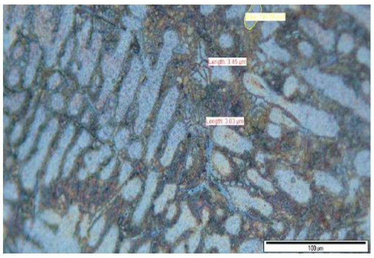
4.3 Microstructure

The application of pressure during solidification affects phase relationships in an alloy system by increasing the freezing temperature (Clausius-Clapeyron equation $\Delta T_f / \Delta P = T_f (V_l - Vs) / \Delta H_f$)[2].

The consequences of such changes in the phase diagram are a significant improvement in the microstructure and mechanical properties of squeeze casted component[5]. Also application of pressure reduces/eliminates the air gap between the molten metal and die wall resulting in increase in heat-transfer coefficients, i.e., greater cooling rate thereby achieving finer grain size.The grain refinement is quite noticeable in squeeze cast parts. Figure-5 gives a comparison of the microstructure of gravity die cast and squeeze casting at100 MPa pressure and pouring temp of 700º C.



a) Gravity Die Casting



(b) Squeeze Casting
Figure-5

5. CONCLUSION

The squeeze-casting process has been proven to be an ideal way to produce near net-shape high quality engineering components, especially for the automobile and aerospace industry, in both conventionally-cast and wrought-alloy compositions[3].

_The direct squeeze casting method will result in better pressurization compared to indirect squeeze casting process.

_Slower injection speed causes less turbulence and less retention of air .

_The combination of high pressure and metal mould in squeeze casting leads to high heat transfer coefficient[9] which in turn leads to refinement of microstructure thereby improvement in mechanical properties.

_ Density of squeeze cast material increases indicating near elimination of porosity.

_ Achievement of near net shape and improvement of surface finish .

_ Squeeze casting may be carried out without feeding system, runners, gates etc and shrinkage compensating units like risers, the yield is quite high with almost no scrap for recycling.

_ Fluidity or castability is not very important because the filling of the dies are achieved by pressurisation

_ The thermal limitation of die specifically for die material the squeeze casting process should be kept limited to lower melting point alloys like aluminium and magnesium alloys for their low melting point and wide range of application.

_ Pouring temperature has its effect in that the fluidity increases with increase in temp resulting in better metal-mould contact . However the solidification time will increase.[4]

_ Compared to other high integrity die casting processes like Thixocasting and Rheocasting, squeeze casting is a simpler process and is more economical.

_ For LM-24 aluminium alloy a pouring temperature of 700ºC,die temperature of 200ºC and a pressure of 100 Mpa gave good result.

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