ADVANCES IN SQUEEZE CASTING TECHNIQUE FOR PROCESSING DISCONTINUOUS CERAMIC FIBRE REINFORCED METAL MATRIX COMPOSITE MATERIALS

Thoguluva Raghavan Vijayaram
Department of Mechanical and Manufacturing Engineering, Faculty of Engineering,
Universiti Putra Malaysia, UPM 43400 Serdang, Selangor Darul Ehsan, Malaysia
(vijayaram1@lycos.com)

ABSTRACT

Squeeze casting is used for processing of ferrous, non-ferrous materials and metal matrix composites for different metals as well as alloy based matrices. The advantages of the squeeze casting method include the minimization of porosity, pinhole and shrinkage defects, a 100 percent casting yield, an improved attainment of part details having complicated contours, a good surface finish, better dimensional accuracy, high strength to weight ratio, better wear resistance and corrosion resistance, improved hardness, better heat resistance, improved fatigue and better creep strength. Hence engineering components manufactured using squeeze casting processes require fewer post machining operations.

INTRODUCTION

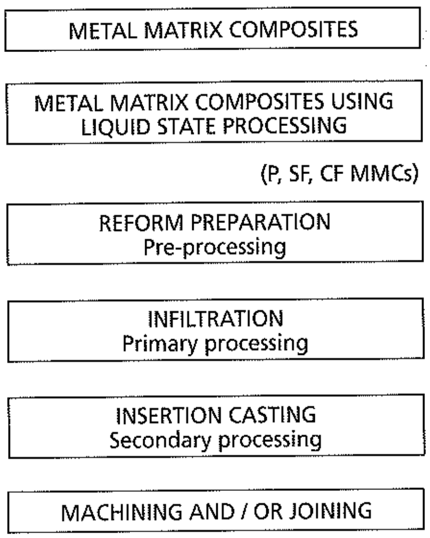
Squeeze casting which is also known as liquid forging has advantages of traditional high pressure die casting, gravity permanent mould casting and forging. It is a new developing casting process often known as squeeze forming, liquid pressing, extrusion casting, liquid metal stamping, pressure crystallization and corthias casting. This technology was first discovered by the Russians and later, it was developed in the USA, Europe and Japan.

Metal matrix Composites (MMCs) castings have been developed with greater success by using fibre reinforcements in metallic materials (ASM Metals Handbook on Casting, 1988). An overview for the flow chart of metal matrix composites processing using liquid metallurgy route is shown in Figure 1.

Several difficult challenges need to be overcome inclusive of but not limited to issues such as higher processing temperatures, fibre-matrix bonding and the ability to produce desired geometries (Franklin and Das, 1984). However these problems can be solved.

ADVANCES IN SQUEEZE CASTING PROCESS

Based on current research, the future of these materials lies in the ability to economically produce desired shapes by pressure infiltration systems and the need for improvement in fibre-



P: Particle reinforced MMCs
SF: Short fibre reinforced MMCs
CF: Continuous fibre reinforced MMCs

Figure 1.
Flow Chart for processing of MMCs using liquid metallurgy route

matrix bonding and perhaps significant alloy development (Clegg and Lim, 1996). Fibre reinforced metal matrix composites have fibres that are discontinuous and they are typically circular and vary in diameter from 0.1 cm to 0.1 mm (Stefanescu, 1993).

Fibre-matrix bonding is a key factor in the effective transmission of load from the matrix to the fibre. In order to obtain proper bonding, wetting of the fibre by the matrix material is essential. Hence, squeeze casting is used to apply very high pressures to increase the bonding between the liquid metal and alloy with the fibre.

The most common method used to apply the reinforcement in the desired location has been with the use of fibre preforms (Askeland, 1984). A fibre preform is similar to a sponge made of fibres that will incorporate with the composite. The main challenge to the use of preforms is the high pressures currently used to infiltrate the metal. These high pressures may break the preform.

Theory on Squeeze Infiltration kinetics

Liquid metal is injected into the interstices of short fibres referred to as a preform. Preforms are made up of alumina-silicate fibres and are designed with specific shapes to form an integral part of finished products in the as-cast form (Kaczmar *et.al,* 2000). The pressure required for infiltration can be calculated readily on the basis of the necessary meniscus curvature and corrections can be made for the melt-fibre wetting. In most cases, fibres do not act as preferential crystal nucleation sites during melt solidification (Strong, 1989).

One consequence of this is that the last liquid to freeze which is normally solute-enriched tends to be located around the fibres. Such prolonged fibre-melt contact often under high hydrostatic pressure and with solute enrichment tends to favour the formation of a strong interfacial bonding (Taha, 1992).

Reasons for selecting Squeeze Casting Technology

In processes like pressure die casting, the molten metal is forced into the die cavity through a gating system with an enormous amount of pressure. Air is also injected into it ,causing porosity, while releasing during solidification. The castings are subjected to shrinkage porosity, thereby producing an air gap between the casting and the mould wall (Peng *et al.,* 2002; Mortensen *et al.,* 1989; Mortensen, 2000).

This causes a lower heat transfer rate and grain size will be higher in the produced castings. This favorably lowers the properties like hardness and strength. The casting yield is also low in the pressure die casting process. But, in the squeeze casting process, no gating system is provided, and a metered quantity of molten metal is poured into the die cavity. There, it forms a tight contact with almost no air gap formation between the casting and the mould wall. Since pressure is applied throughout the process, molten metal flows into the shrinkage cavities and gases like hydrogen dissolve and remain in the solution.

Hence, defects like porosity and shrinkage are eliminated. The casting yield is 100% due to the absence of a gating system (Cornie, 1995). Because of the higher interfacial coefficient values, the heat transfer rate will be more and castings of finer grain size will be produced. Hence this produces high strength castings.

Steps in Squeeze Casting process

Steps in the squeeze casting process are shown in Figure 2. The basic steps are pouring the liquid melt into the plunger and then applying pressure to eject it into the die cavity by docking. The pressure is maintained until the liquid metal is fully solidified.

PROCESSING METAL MATRIX COMPOSITES USING SQUEEZE CASTING TECHNOLOGY

Ceramic fibre reinforced MMCs are produced by liquid forging and the process steps are explained in Figure 3 (Chawla, 1992; Dullien, 1992).

The process involves placing ceramic fibre perform, having known volume fraction of fibres expressed in percentage, in a die cavity and pouring metered quantity of molten metal over it. Further pressure is applied for infiltrating the molten metal into the porous preform (Serope and Steven, 2001).

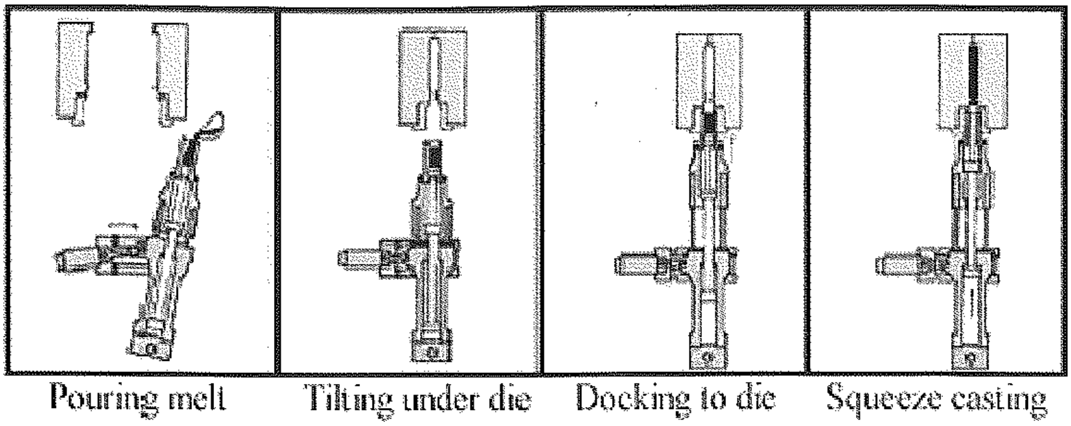


Figure 2. Squeeze casting process

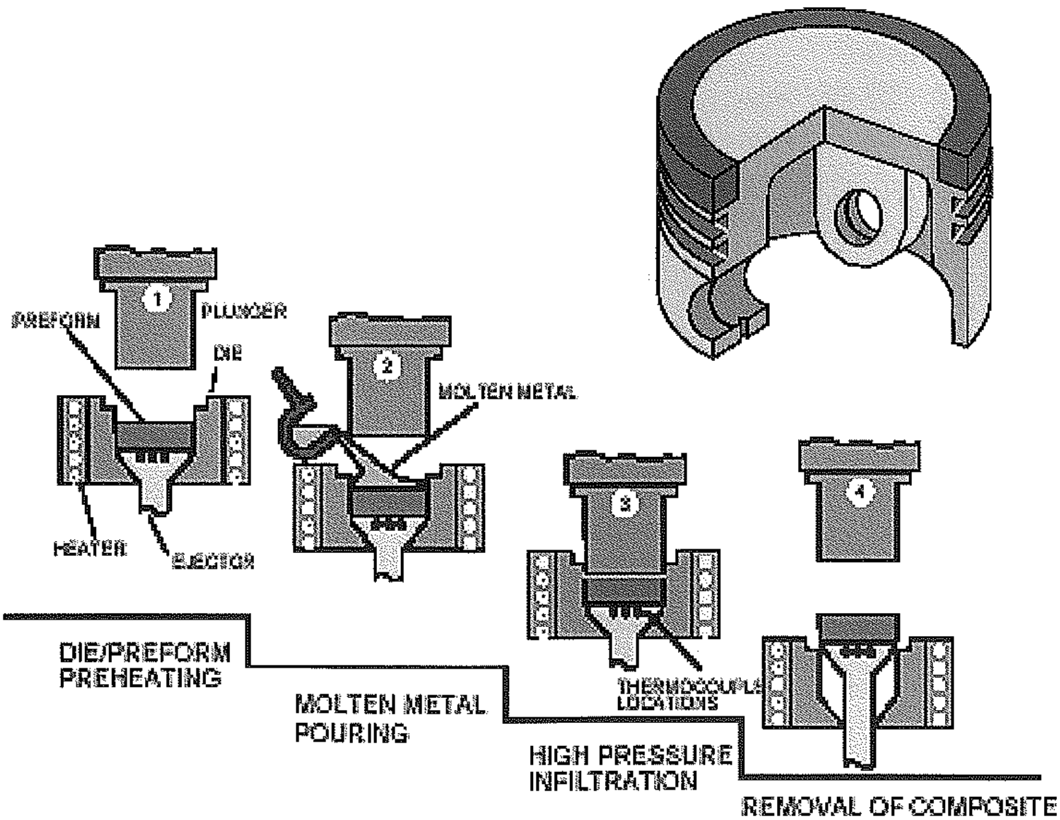


Figure 3. The production of fibre reinforced metal matrix composite diesel engine piston processed by squeeze casting technology.

The pressure is applied until the solidification is completed and the metal matrix composite castings are produced. The parameters involved in this process are pouring temperature, preform preheating temperature, die temperature, applied pressure, pressurization rate and duration (Clegg, 1991). This process leads to the development of selectively reinforced metal matrix composite pistons using this technique.

Process parameters in Squeeze Casting
A list of process parameters involved in the squeeze casting process is cited below:

1. Molten metal pouring temperature
2. Melt volume
3. Melt quality and quantity
4. Preform preheating temperature
5. Die temperature
6. Applied squeeze pressure
7. Pressurization rate
8. Pressure applied duration
9. Lubrication

This helps to control different variables involved in the squeeze casting process in order to get good quality composite castings. The most important parameters are the die temperature and the design of the gates to control the squeeze pressure applied to the molten aluminum alloy as it fills the mold.

By improving the squeeze casting process, new options will be available to the casting industry for producing the complex, lightweight aluminum parts that are increasingly in demand in competitive markets such as that for automotive components. This will result in melting-related energy savings due to the lower melt temperature for aluminium versus alternative metals. An investigation of the process parameters in the squeeze casting process is a must and it should be optimised too.

POSSIBLE CASTING DEFECTS IN SQUEEZE FORMING
Optimization of process parameters is a must in the squeeze casting process. Failure to do so results in a number of casting defects. The most common and important casting defects which occur in this process are listed below:

1. Oxide inclusions
2. Porosity and voids
3. Blistering
4. Cold laps
5. Sticking

Due to the oxidation of molten metal, oxides are formed on the surface of the melt. To avoid or minimize inclusions in the metal transfer system, filters must be used. Turbulence should also be reduced while pouring molten metal into the die cavity. Porosity and void defects are observed in this process because of insufficiently applied squeeze pressure. Normally, 70 MPa is applied to produce sound castings (Cole, 1993).

The only way to avoid such defects is by increasing the pressure when other variables are optimized. Air or gas, from the melt, that is trapped below the surface during turbulent die filling, forms blisters on the cast surface upon the release of pressure. This defect is called blistering (Donomoto *et al.*, 1983). Degassing the melt, preheating the metal handling transfer equipment and reducing the pouring temperature are the methods used for avoiding these defects.

Cold laps are caused by molten metal overlapping previously solidified layers with incomplete bonding between them. To avoid this, metal pouring temperature or die temperature, should be increased. Sticking is actually a thin layer of casting skin that adheres to the die surface because of the rapid cycling of the process without sufficient die or punch cooling and lubrication. Die temperature and pouring temperature must be reduced to eliminate this defect.

MAJOR ENGINEERING COMPONENTS MANUFACTURED BY SQUEEZE CASTING TECHNIQUE
Engineering components required by foundries and automotive industries are produced by applying this technology. Non-ferrous metal parts made from aluminium, magnesium and copper alloy are readily manufactured by this casting method. This process has been explored for a number of applications using various metals and alloys, aluminium dome, ductile iron mortar shell,

stainless steel blades, super alloy discs, aluminium automotive wheels and gear blanks of brass and bronze (Cui *et al.*, 1997).

Applications include aluminum alloy pistons for engines, disc brakes, brass and bronze bushings, gears, differential pinion gears, steel missile components and cast iron parts. This special casting process is also used to produce castings of space frame nodes, knuckles and cross members for structural applications.

CONCLUSIONS

In the squeeze casting process, the liquid metal is pressurised while it solidified and hence near net shapes can be produced with sound and dense quality. The microstructural refinement of squeeze cast products is desirable for many critical applications.

This process is simple, economical and the operational steps of squeeze casting machines used in this technique can be automated easily by a Programmable Logic Control (PLC) unit. The process generates the highest mechanical properties attainable in a cast product. So this process has been adopted to make composite castings more affordable.

The properties of castings manufactured by normal liquid metallurgy route, are inferior and of poor durability. In order to improve its performance in working conditions, the old technological processing methods are obsolete and they must be altered and modified. Squeeze casting is adopted to produce superior quality composite castings. The composite castings produced by this method are application-oriented products, which can be manufactured by mass production. The easy availability of ceramic fibre performs, in required size and shape, favours and helps the production of composite castings. Finite Element Method (FEM) techniques are applied to undertake modeling of composites solidification process, which help the manufacturing industries, to study and analyse the temperature history of the casting.

SUGGESTIONS FOR FUTURE RESEARCH

The squeeze casting process is not only applied to process metal matrix composites, but also to produce light metal castings made from lithium, titanium and its alloys. It can be used to process ferrous castings like stainless steel and alloy cast iron engineering components. Foundry researchers and metallurgists should concentrate on recycling the composites processed, and hence they can reduce the production cost.

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