SEMI-SOLID CASTING

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INTRODUCTION

The conventional casting often contains internal structural defects that lead to poor mechanical properties. The dendritic morphology in conventional casting is also responsible for low mechanical properties and fracture toughness. The tips of the dendrites act as a stress raiser. Thus, to improve the mechanical properties it is required to modify the dendritic microstructure of the alloys. The dendritic morphology can be altered by grain refinement, rapid solidification processing etc. Dendritic morphology can also be broken during its initial growth by some means in the agitation of melt itself. That means the alloys are processed in the partially solid and partially liquid state, which is known as semi-solid processing. Different semi-solid processing routes are rheocasting, thixocasting, strain induced melt activation, spray deposition technique and squeeze casting.

RHEOCASTING

Rheocasting involves stirring the alloy either continuously during solidification or maintaining an isothermal state to produce semi-solid non-dendritic slurry then pouring/injecting the slurry directly into the die to give a final product. With some process modification rheocasting process can also be adapted to produce complex-shaped components. In the rheocasting process the metal slurry can be produced by mechanical or magneto hydro dynamic (MHD) stirring. In these process the main parameters that affect microstructure and mechanical properties are; average shear rate, average cooling rate, volume fraction of primary solid, grain size, time of shearing, time of solidification and holding temperature of the slurry. The average shear rate (γ_{av}) can be evaluated using the following equation; $\gamma_{av} = 2\omega K/(1-K^2)$, where ω = rotational speed = $2\pi N/60$, N is the rpm, K= perimeter of the rotor/ perimeter of the mixing chamber. The viscosity is decreased with increase in average shear rate and vice-versa. Microstructure agglomeration and de-agglomeration is often associated with this. When shearing time is less in the initial stages of stirring a decrease in particle size will be observed due to the fragmentation of the dendrites and grain boundary melting. But with the subsequent increase in the shearing time the size of primary particles will increase due to Ostwald ripening and particle coalescence. The average equivalent diameter of primary particles decrease with an increase in the stirring speed at any given solid fraction.

There is an initial decrease of the shape factor of the primary particles followed by an increase in shape factor as the stirring speed is increased. The average cooling rate can be defined as follows: $\varepsilon_{av} = \Delta T_s(g_s)/t_f$, where g_s is the volume fraction of primary solid particles in the slurry, ΔT_s is the difference between the liquidus temperature and the temperature of the existing slurry, and t_f is the residence time of the alloy in the mixing chamber while in the solidification range. More dendritic microstructural morphology and hence higher viscosities for a given fraction solid are resulted in an increase in average cooling rate.

Rheocasting Mechanisms

1. Dendrite arm fracture, in which arms shear off as a result of the force on the arm from the fluid flow.
2. Re-melting of the arm at its root as a result of normal ripening. The function of fluid flow in this case is to alter or accelerate the solid diffusion involved in ripening and carry the dendrite arm away from its "mother grain".
3. Re-melting is enhanced by thermal perturbation, which results from turbulent convection.
4. The melting at the root is accelerated by the stress introduced at the dendrite root as a result of the force of fluid flow.
5. The melting at the root is further enhanced by a high solid content in the solid at the dendrite root.
6. Re-crystallisation as a result of the stress introduced by the force of the fluid flow, with rapid liquid penetration along the new grain boundaries.

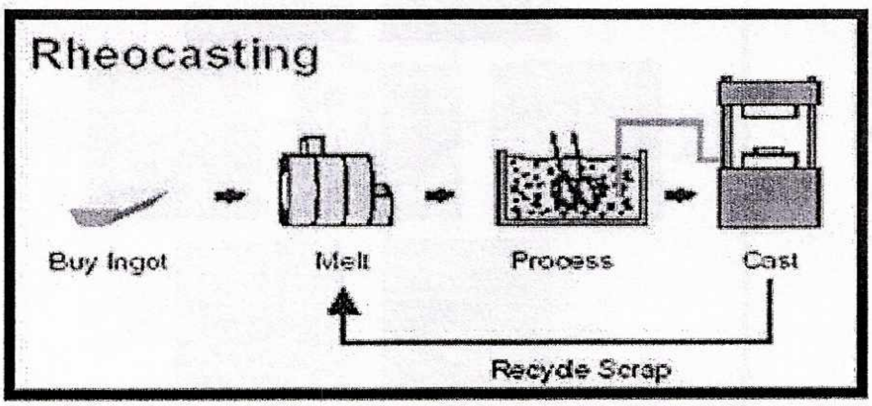

Fig. 1 : Schematic layout of rheocasting process

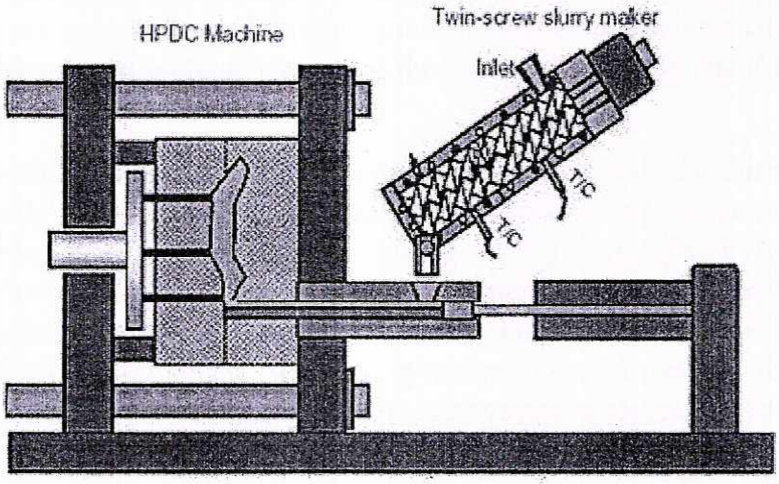

Fig. 2 : Schematic layout of rheo-diecasting process

The newly formed dendrite fragment will grow dendritically. With continuous shear and time during solidification the dendrite morphology becomes that of rosette, as a result of ripening, shear and abrasion with other grains. With sufficiently slow cooling and high shear, the grains become spheroidal, usually with a small amount of entrapped liquid. Schematic layout of rheocasting and rheo-diecasting processes are shown in Fig. 1 and Fig. 2. In the rheocasting process it is possible to obtain uniform microstructure throughout the component e.g., the component manufactured from LM24 alloy is shown in Fig. 3.

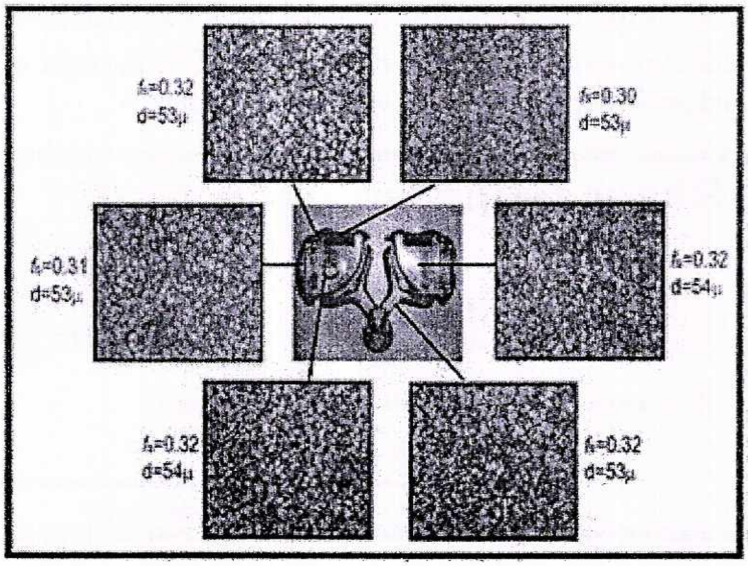

Fig. 3 : Uniform microstructure throughout the component (LM24)

THIXOCASTING

Thixoforming is a general term coined to describe the near net shape forming processes from a partially melted non-dendritic alloy slug within a metal die. In this process, a solid billet, with a fine-grained equiaxed microstructure, is partially remelted to the semi-solid state. The billet is then transferred to the shot chamber of a die cast machine and injected into the die. If, the component shaping is performed in a closed die, it is referred to as thixocasting, while if, the shaping is achieved in an open die, it is called thixoforging. There are two separate stages involved in the thixoforming process. The first stage is uniform heating and partial remelting of the alloy slug so that it is homogeneous throughout. In the second stage, the semisolid slug is transferred to a forging die or shot chamber by robot handling where it is injected in a controlled manner into a die cavity by a hydraulic ram. After solidification, the shaped component is removed from the mould for further processing, such as minor machining or grinding. Reheating to the semisolid state is a particularly important phase in the thixoforming process. It aims to provide semisolid slug with an accurately controlled solid fraction of fine and spherical particles uniformly dispersed in a liquid matrix of low melting point. To achieve this semisolid microstructure, the important processing parameters during the reheating process include accuracy and uniformity of heating temperature and heating duration. It is the heating temperature that determines the solid fraction in the slug. Too high a heating temperature causes instability of the slug resulting in difficulties for slug handling, while too low a heating temperature leads to unmelted, coalesced, polyhedral silicon phase in the slug in the case of hypoeutectic cast aluminium alloys having a detrimental effect on the rheological properties during die filling and on the ductility of the finished parts. In addition, the composition of the alloys currently used are not optimised for semi-solid metal processing, a small variation in temperature can cause a large difference in solid fraction. Therefore, temperature accuracy affects the stability of the forming process and the consistency of the product quality. Furthermore, a uniform temperature distribution throughout the slug is important, because a non-uniform distribution of temperature may lead to fluctuation in solid fraction and rheological characteristics, which in turn may cause solid/liquid separation during mould filling. Finally, the heating duration has to be optimised; too long a heating time will cause structural coarsening, while too short a heating time will lead to incomplete spheroidisation of the solid particles compromising the rheological properties and leading to difficulties during mould filling. Currently, reheating is achieved mainly by induction heating, although a convection furnace is also used in some cases. Induction heating has the advantage of precise and fast heating, which is necessary for semi-solid metal processing. The relatively low energy efficiency of the induction heating station is a draw back. Possible improvement of energy efficiency can be achieved by preliminary heating to a critical temperature in a convection furnace followed by induction heating for temperature homogenisation. Induction heating is currently implemented in two different ways: vertical and horizontal heating. A vertical heating system has been conventionally used. It suffers from the slug instability problem when the height/diameter ratio is not correctly chosen. The horizontal heating system is a relatively new development, in which the slug lies in a tray and is heated to the optimal processing state monitored by an automatic control loop. Advantages of the horizontal heating system include reduction of the shape stability problem, possibly using higher liquid fractions and alloys with a short freezing range. However, it has a higher system cost and higher space requirement. It is clear from the above discussion that reheating is a complex process. Optimisation of the processing parameters is a critical step to ensure a high quality of formed parts. There have been substantial research efforts directed towards process optimisation and modelling of the heating process. The forming process takes place either with casting (thixocasting) or with forging (thixoforging). At present, thixocasting through horizontal cold chamber die-casting is the dominant process. A robot arm transfers the semisolid slug into the shot chamber and the plunger injects the material into the die cavity. All the thixocasting machines are real-time controller and thus permit a reaction to possible fluctuation during the forming process. At this stage, smooth laminar mould filling is the crucial step for the forming process. This can be achieved by an optimised shot profile tailored for specific alloys and their physical conditions. Another important aspect during the forming process concers the design of the gating system and die cavity and the correct choice of die temperature. Such a design process has to consider the flow characteristics of the semisolid metals. The forming process can be optimised through process simulations using various computer-modelling techniques. Flemings has summarised the major advantages and disadvantages of the thixoforming process. The main specific advantage of the thixoforming route is that the forming facility is free from handling liquid metal, and the process can be highly automated using approaches similar to those employed in forging and stamping. This basic concept of completely separating the two main parts of the process (forming of the desired structure and forming of the part) has been intuitively appealing and much work has been done in developing the process route industrially. As time progresses, the disadvantages of the thixocasting route are also becomes apparent. It has been difficult to obtain fully homogenised billets in MHD stirred continuous castings. Typical billets have some degree of inhomogeneity with respect to both structure and composition. There is metal loss during the reheating process, which may amount to as much as 10% of the total part weight. Gates and risers can not be recycled within the forming facilities, but must be sent back to the ingot producer. Thus, the metal former pays a premium to the continuous caster not only for the unique thixotropic structure in the metal, but also for the recycled materials. Currently, the cost for thixotropic feedstock could account for upto 50% of the total component cost. Schematic layout of thixocasting process is shown in Fig. 4. The comparison of microstructure between thixo-diecasting and rheo-diecasting is shown in. Fig. 5.

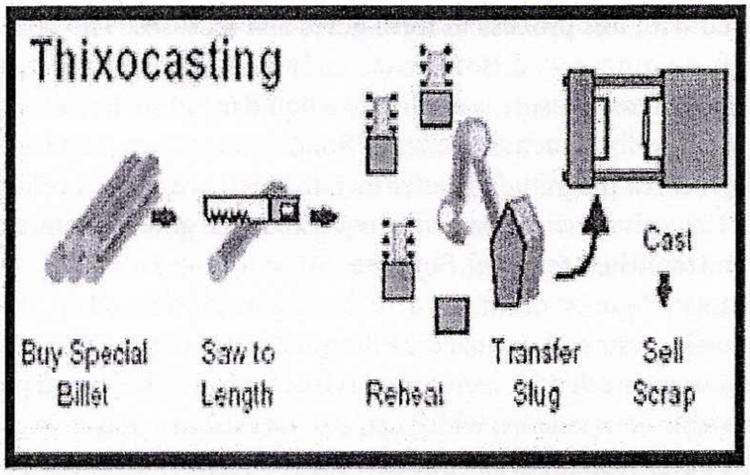

Fig. 4 : Schematic layout of thixocasting process

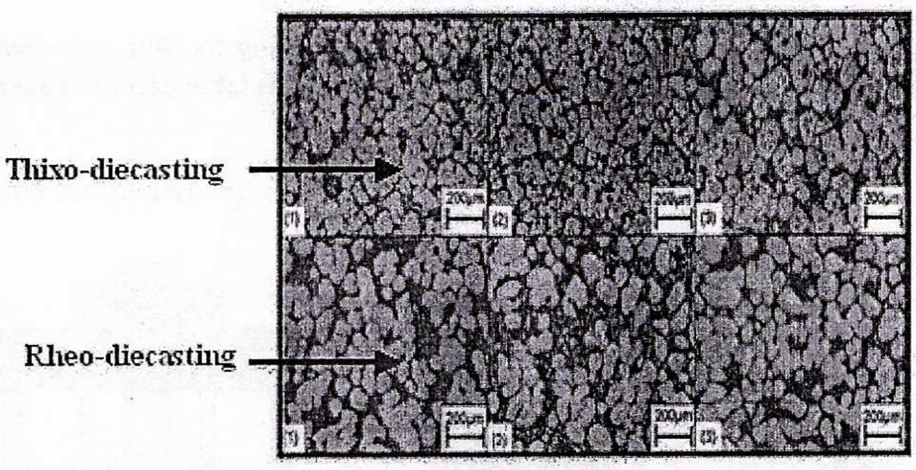

Fig. 5 : The comparison of microstructure between thixo-diecasting and rheo-diecasting

APPLICATIONS OF SSM TECHNOLOGY IN THE AUTOMOTIVE INDUSTRY

Brake callipers, Clutch cylinders, Suspension arms, Wheels, Pistons, Knuckels, Engine mounts, Pulleys, Rocker arms, Belt covers, Motor housings, Space frames.

SQUEEZE CASTING

This is known as liquid metal forging is a combination of casting and forging process. The molten metal is poured into the bottom half of the pre-heated die. As the metal starts solidifying, the upper half closes the die and applies pressure during the solidification process. The amount of pressure thus applied is significantly less than used in forging, and parts of great detail can be produced.

Coring can be used with this process to form holes and recesses. The porosity is low and the mechanical properties are improved. Both ferrous and non-ferrous materials can be produced using this method. In this process pressure is applied to a liquid metal such as aluminum allowing it to infiltrate a reinforcing preform such as a ceramic. Solidification is accomplished at a high pressure, which is several orders of magnitude greater than the melt pressure developed in conventional foundry practice. Extensive nucleation and an equiaxed, fine grain structure is obtained because of undercooling and rapid heat removal. Squeeze cast composites offer lightweight materials that resist heat and fatigue. Squeeze casting is a die casting method based on slower continuous die filling and high metal pressures. Laminar die filling and squeezing, i.e. the application of pressure during solidification, ensure that the component is free from blowholes and porosity. The method produces heat treatable components, which can also be used in safety-relevant applications and are characterised by higher strength and ductility than conventional die castings. Squeeze casting can also serve as a basis for the NRC (New Rheocasting) process.

Advantages of squeeze casting

Whereas, the die is filled at high speed during pressure die-casting, the filling process takes longer - from 0.5 to 3 seconds - during squeeze casting. However, this latter permits a die filling that is

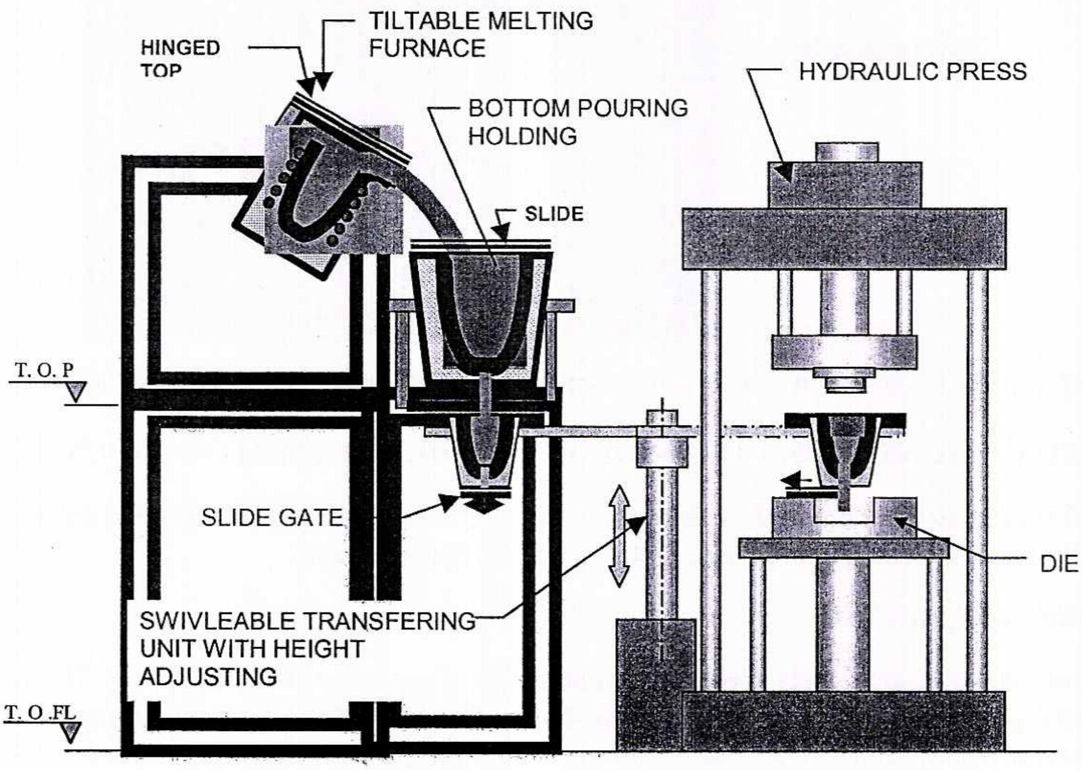

Fig. 6 : Schematic layouts of squeeze casting process

virtually free of gas entrapment. Using this method it is thus possible to produce heat-treatable castings. It has come to be known as "squeeze" casting because the casting is squeezed in a controlled fashion under high pressure to complete the filling of the die (comparable to pressure die-casting). Another big advantage of squeeze casting is the possibility of using preforms (high-porosity bodies made from specially selected materials). By infiltrating these with molten metal under high pressure it is possible to further improve the properties of the aluminum through composites and hence create extremely hard-wearing working faces. Schematic layout of squeeze casting process is shown in Fig. 6.

Component suitable for squeeze casting

Brake Drum, Clutch Housing, Steering Wheel, Suspension Arms, Automotive Wheels, Pistons, Cylinders, Engine Blocks.