SSM processing of magnesium alloys

Progress is only to be made in the field of lightweight materials and components if, besides research into new material classes, development of corresponding innovative production methods occurs, write J. Aguilar, M. Fehlbier, and P.R. Sahm of the Foundry Institute, Aachen University, Germany.

The thixocasting process is based on conventional high pressure diecasting technology, and is the special case where the mould is filled with semi-solid metal.

The thixotropic properties of the material enable a lamellar filling of the mould which produces as a consequence components with lower gas porosity and non-metallic inclusions. SSM parts show good mechanical properties and in contrast to conventional high pressure diecast parts they are weldable, heat treatable and pressure tight.

Using SSM technology it is possible to substitute cost intensive forgings with SSM components. This requires the development of new cast alloys for the different service areas and also a deep knowledge of the material properties. Another important issue is to ensure the stability and dependability of the SSM process in all of its steps during series production.

At the Foundry Institute at Aachen University of Technology (RWTH Aachen) in Germany, the potential of semi-solid metal (SSM) processing has long since been acknowledged. The technical equipment at the Foundry Institute for the research of SSM consists of a modified real time controlled diecasting machine from Bühler with a locking force of 725 t, an inductive billet heating device from Elotherrn that enables precise horizontal or vertical heating of the slugs, a Fondarex vacuum system, a Kontron image analysis system and the numerical simulation software MAGMASoft with a special module for thixotropic metals. Other facilities for pre-material production, melting, metallographic analysis, strength measurement, etc complete the infrastructure of the institute.

A lot of work has been done, especially with aluminium and magnesium alloys, but also with steel. In the case of magnesium alloys, processing in the semi-solid state reduces drastically the reactivity of the metal. The working conditions and the safety of the process is improved and the produced parts contain less oxide inclusions caused by a turbulent flow of the metal during the process. Magnesium can be cast into very long parts with thin walls. In some cases walls 0.5 mm thick have been achieved in series production.

SSM process

There are basically three routes to work magnesium alloys in the semi-solid state: Thixoforming, Rheoforming and Thixomoulding. Thixoforming is the best known of them. For Thixoforming a specially produced pre-material with a globular microstructure is necessary. At the Foundry Institute the so called RSCT (Rapid Slug Cooling Technology) was developed especially for the production of pre-material billets of magnesium alloys. Afterwards, the pre-material billets have to be reheated into the semisolid state, where a precise control of the solid fraction and temperature of the billet are for the process of great importance. The semi-solid billets are then shaped. Figure 1 shows the development of the microstructure after the different steps of the thixoforming process. Compared to aluminium alloys, the pre-material slugs do not present globular particles but globular dendrites. The arms of these dendrites grow and get rounder during the heating process. During shaping the arms break up in globular particles that give the material excellent thixotropic properties and are very well distributed through the cutetic matrix.

Colour etching techniques developed at the Foundry Institute enable to distinguish between individual grains in the microstructure of the samples. In the Rheoforming process, the number of steps is reduced. The melt is cooled into the semisolid state, in such a way that the microstructure becomes globular and the material acquires thixotropic properties. The material is then directly shaped without the need of the reheating process. The best known process is ‘New Rheocasting’ (NRC) from UBE Technologies, Japan. For this process, the melt is cast just above its liquidus temperature in a lightly heated metallic mould. The mould is cooled down with air and during the process a lot of solid embryos, which grow globulitic, are created. When the metal reaches the desired temperature, the mould is inductively heated for a short time to facilitate the extraction of the slug and its placement on the shot sleeve of a diecasting machine or a squeeze caster. The process enables the production of a very fine microstructure with good flow properties.

The third process is Thixomoulding from Thixomat, Ann Arbor, Michigan. For this process a modified injection casting machine for plastics was modified and adapted to be used with magnesium chips. The magnesium chips are charged through a funnel into the conveying screw of the machine, which pushes the material through the heating chamber. Here the metal reaches a semi-solid state and because of shearing caused by the screw, a globulitic microstructure is achieved. The semi-solid metal passes through a check valve and is gathered at the tip of the screw. When the desired volume is reached, the screw shoots the metal forward into a specially designed die. The biggest advantage of the process is that it does not require a magnesium melting furnace with all of its
hazards. The machine works with argon as a protective gas and SF₆ is not needed. A disadvantage is the need for chips or granules of magnesium alloys, which represent an extra cost for the process. Thixomoulded parts are successfully replacing plastic components, especially in the consumer electronics industry, the manufacture of cellular phones, laptops, cameras, etc.

**Rapid Slug Cooling Technology (RSCT)**

The driving force for the development of the RSCT process was the need to produce a cheap pre-material for the thixocasting process of magnesium alloys with a fine globular microstructure, without mechanical or inductive stirring of the melt.

Magnesium alloys are very sensitive to the cooling rate and a very fast quenching of the melt leads to a fine globular microstructure. For the process, the melt is poured close to liquidus in a permanent mould. After casting, the mould is immersed in cold water and the melt solidifies very fast. An homogeneous microstructure of fine globular dendrites is achieved (Figure 1). The process has proved useful for the processing of several magnesium alloys including AZ31, AZ61, AZ91, AM50, AM70 and MEZ (creep resistant alloy with rare earths from Magnesium Elektron, UK). Some high strength aluminium alloys like the AF48 and M59 can be also successfully produce using this method.

The RSCT billets are then inductively reheated into the semi-solid state and pressed into different test dies developed at the Foundry Institute to evaluate and investigate the SSM processing of metals. Figure 2 shows some of these test dies. The 'step die' is a modular design in which the mechanical properties and the microstructure of the parts can be tested as a function of the wall thickness, the metal velocity, different coatings, vacuum, etc. Cross sections from 25mm down to 0.5mm can be obtained. The 'meander die' has a total length of 2830mm with a cross section of 7mm. The flow properties of the semi-solid metals can be evaluated with this die as a function of the metal velocity, metal temperature, solid fraction, vacuum, etc. A third test die is a suspension part used to examine the behaviour of the alloys under 'real life' conditions. It presents a long flow length and the problem of metal flowing through two channels that meet again. The formation of cold spots after rejoining of the metal can be eliminated when the correct process parameters are applied. For the production of safety parts for the automobile industry, the ductility of the materials is besides the strength of capital importance. An elongation of above 10% is usually specified.

**Thixomoulding**

Interest in the thixomoulding process has grown steadily since its industrial introduction in the mid 1990s. As part of the research programs on SSM at the Foundry Institute, a comprehensive study of the whole process was undertaken, which includes the magnesium chips that serve as feedstock, the influence of the different process parameters on metallurgical properties of the parts and a process adapted mould designing is under way.

The feedstock material has been analysed for its homogeneity, particle size, size distribution, form factor and inflammability. When the particles are too small they present a very big surface susceptible to corrosion, that can result in Thixomoulded parts with non-metallic inclusions. A wide particle size distribution can also lead to separation of the material during transport and storage. Another consequence of the size distribution combined with a low form factor (long chips) is that the entanglement of the feedstock chips during the feeding into the Thixomoulding machine. A great concern regarding magnesium is the fire hazard. Experimental studies with magnesium chips showed, that even though they can be brought to ignition, it is under very severe circumstances, which include a very strong heat source over a relative long period of time. All the necessary safety measures have to be strictly followed through.

For a reliable operation of the Thixomoulding process, a lot of emphasis has been given to the development of a process window. This process window for the production of quality parts should include all the process parameters that influence the metallurgical properties of them. Parameters like the metal temperature, solid fraction, conveying screw rotation velocity, temperature of the melting chamber, injection velocity, pressure, vacuum, mould temperature, mould coatings have to be taken into account. As important as the process parameters is the design of the mould. The gatting system, the layout of the parts, the geometric relations and changes within the gatting system and the parts themselves have to be adapted to the new process, but still they have to comply with the metallurgical requirements of the semisolid magnesium alloys. Most of the commonly used mould designs for thixomoulding evolved from the injection mould design for thermoplastics and are therefore for the production of quality metallic parts not always adequate.

An important tool for the optimisation of the mould design is the numerical simulation. The numeric simulation program MAGMAsoft with a special module for thixotropic metals is used at the Foundry Institute for the designing of test moulds for the process. Figure 3 shows a simulation of the filling of a test die with four plates of different thickness. Turbulence and the entrainment of air are tried to be reduced by optimising the design of the mould.

In order to understand the behavior of metals in the semisolid state, a lot of research is to be done. Many questions have still to be answered, but the SSM processing of magnesium alloys is definitely a very good alternative to the conventional manufacturing processes that have to deal with highly reactive melts or materials that are difficult to shape in the solid state.

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**References**

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