Introduction

Semisolid metal (SSM) processing has been a promising technique for the rheocasting or thixocasting of aluminium alloys for more than 30 years. Extensive effort has been expended to take SSM based casting of aluminium alloys to full scale commercial exploitation with very limited success. Unfortunately, this now acts as a barrier to the advance of new rheocasting technologies that can overcome both the technical and cost issues of the earlier SSM casting processes.

In order to develop the new rheocasting process for aluminium it was realised that the key step to provide ideal semi-solid slurry was to subject the alloy melt to extreme conditions of shear and turbulence as can be achieved in a twin screw mechanism of the type originally developed for polymer processing. Under the conditions of high shear and turbulence in the twin screw slurry maker near ideal SSM slurry is produced in a short processing time that is typically 20 seconds. An ideal SSM slurry has a perfect dispersion and uniform distribution of fine spherical particles. Unlike all conventional casting processes high shear rheocasting ensures a high survival rate of nuclei and the generation of fine grained uniform as cast microstructures with no entrapped gas to cause porosity or macroscopic oxide film defects to devalue mechanical properties.

This means that aluminium alloys can be produced with fine uniform microstructures from the cast state and that subsequent thermomechanical processing can be minimised to provide cost effective high performance semi-fabricated forms and components.

The Twin Screw Slurry Maker

The design of the twin screw slurry maker (Figure 1) is now in its fourth generation. The twin-screw slurry maker has a pair of co-rotating, fully intermeshing and self-wiping screws rotating inside a barrel. The screws have specially designed profiles to achieve high shear rate and high intensity of turbulence. In the slurry maker liquid alloy is rapidly cooled to the required SSM processing temperature while being mechanically sheared by a pair of closely intermeshing screws converting the liquid into semisolid slurry with fine and spherical particles of a given volume fraction dictated by the barrel temperature. The barrel temperature is closely controlled. This high shear processing ensures that the solidifying metal grows into spherical particles, rather than dendrites or rosettes. With increasing shear rate and intensity of turbulence growth morphology changes from dendrites to spheres due to changes in diffusion geometry in the liquid around the growing solid phase.

The major challenge was to find a suitable material for the construction of the screws and the barrel that would survive exposure to highly reactive aluminium melts. Initial efforts to find non-reactive materials or to use coatings were unsuccessful until the concept was changed to sourcing a material that would react to provide a protective layer. Having found and extensively tested this material the twin screw slurry maker can now be readily fabricated and can survive prolonged exposure to turbulent aluminium alloy melts.

By Geoff Scamans and Zhongyun Fan, Innoval Technology Limited and Brunel University, UK

Figure 1
Schematic of the high shear slurry maker
Since slurry making is essentially a batch process, the second key component in the slurry delivery system is the accumulator that acts as a reservoir until a sufficient volume of slurry is available to feed into the casting system. For example, a 16kg casting shot will require a 8kg slurry maker to operate twice in order to provide enough semisolid slurry in the accumulator for a single shot. A blade type stirrer is fitted in the accumulator to prevent particle agglomeration and to maintain the slurry uniformity.

The metal delivery system based on the slurry maker and accumulator is sized to fit the demand of the specific casting system that can be a high pressure diecaster (Figure 2), a direct chill (DC) caster, a twin roll caster or a continuous extruder to provide bar or tube. There is no need to make thicker cast sections than necessary as thermomechanical processing to ameliorate casting defects and microstructural inhomogeneity is no longer essential. The casting system also reduces or minimises the need for liquid metal filtration systems and formal additions of grain refiners.

Collectively the family of casting technologies based on the new high shear melt conditioning and delivery process are known as rheoforming technologies.

**High Shear Rheo-diecasting**

The most developed rheoforming technology is rheo-diecasting (RDC) that feeds conditioned slurry into conventional cold chamber high pressure die casting (HPDC) equipment. HPDC is a mature, high volume production, low cost casting process which has been extensively used by the metal processing industry for more than 100 years. However, the quality of components manufactured by the HPDC process is limited by the presence of a substantial amount of porosity, which not only excludes the application of HPDC components in high-safety and airtight systems, but also denies the opportunity for further property enhancement by heat treatment. These limitations are overcome by high shear rheo-diecasting.

It is most important to achieve laminar mould filling to avoid gas entrapment while maintaining adequate fluidity for complete mould filling. Rheo-diecast components have a fine and uniform microstructure, porosity below 0.5 vol% and incorporated oxide is dispersed as fine particles. This leads to a significant improvement in mechanical properties as is shown in Figure 3 for a cast component made with a conventional aluminium silicon casting alloy (A357 Al 7%Si 0.6%Mg). Typically there is a 15% increase in strength together with a 100% increase in elongation. Specific process improvements are longer die life, lower scrap rate, shorter cycle time and higher materials yield and potentially a 25% lower overall component production cost.

The RDC process blurs the conventional boundaries between cast and wrought aluminium products and the division between cast and wrought alloys. Figure 4 shows the as cast microstructures of AA2014 and AA7075 aerospace alloys that can’t be cast by conventional HPDC. In both cases the microstructures show the typical 50µm diameter spherical particles formed in the slurry maker and the refined microstructure of the alloy that solidified in the die.
chamber. This too has a spherical non-dendritic microstructure because the remaining liquid in the SSM slurry solidifies under high cooling rate.

The process can also be used to cast alloys that are essentially immiscible and/or have an exceptionally wide freezing range. Such alloys with low melting point additions like lead, bismuth and tin of are of interest for use as bearings. Figure 5 shows an alloy where 6% lead has been incorporated without macro-segregation as fine dispersed particles of the order of 50µm in diameter. For tin containing alloys like Al241 (Al 12%Sn 4%Si 1%Cu) the tin-rich phase is uniformly distributed with no macro-segregation of tin.

There is significant interest in hypereutectic aluminium silicon alloys and alloys that contain high levels of iron in both cases way beyond conventional alloy ranges. Preliminary work has shown that aluminium alloys with 20% silicon and 2% iron are readily castable with fine uniform microstructures as is shown for a high iron alloy in Figure 6. These alloys will find application in a range of high performance applications where resistance to high temperatures and/or wear are important. Tolerance of increased or higher levels of iron in aluminium is of considerable importance for the future incorporation of higher levels of recycled scrap into aluminium products. In addition to the low porosity levels and dispersed oxides these alloys have advantages in that primary intermetallic particles are uniformly distributed, are refined in size and are equiaxed in morphology. The needles or plates found in HPDC microstructures are completely eliminated.

The Rheoforming Technologies

The range of rheoforming technologies is shown in the roadmap in Figure 8 and shows that high shear slurry casting can potentially provide the aluminium structural materials sector with a new generation of high performance, high quality products that are cost competitive with existing products.

For DC rheocasting (Figure 9) there is considerable scope for process innovation as the rheoformed slurry can be fed into either thin or horizontal variants of the standard DC casting process or alternatively the slurry can be cast onto the surface of an aluminium block to make novel clad products.

The advantages of the twin roll rheocasting (TRRC shown in Figure 10) technology include a step change in quality and uniformity of the roll cast sheet that will result in sheet products with a fine and uniform microstructure over the entire cross-section. In addition twin roll casting of a wider range of alloys will be possible which should make some of the higher performance automotive and aerospace alloys amenable to lower cost production. This has the potential to greatly facilitate the penetration of such eco-friendly materials into the transportation industries for reduction of fuel consumption and CO2 emissions.

Continuous extrusion of aluminium through the Conform process is well established and provides a
wide range of profiles and co-axial products. The combination of a high shear slurry maker with an accumulator and a continuous extruder (Figure 11) could provide an efficient route to manufacture conventional alloys with enhanced mechanical properties but also to directly fabricate alloys that have only been made to date by powder processing and compaction.

**Summary**

High shear rheocasting can provide a range of benefits and opportunities that include:

- The effective commercialisation of a SSM casting process for the first time
- Refined and uniform cast microstructures without shell zones, columnar grains, porosity, oxide film defects and macroscopic segregation
- Castings with enhanced mechanical properties that can be heat treated as required.
- Wrought products that require minimal thermomechanical processing to final product form
- A route to high performance alloys and composites that have not been considered to be conventionally castable.
- Twin roll casting of sheet for automotive and aerospace applications
- A family of aluminium rheoforming technologies to provide both shape cast components and a wide range of semi-fabricated forms APT

**Biographies**

Geoff Scamans is presently Chief Scientific Officer for Innoval Technology Limited an independent technology provider based in Banbury, Oxfordshire serving aluminium companies and end-users of aluminium.

Professor Zhongyun Fan is the founder and current Director of BCAST (Brunel Centre for Advanced Solidification Technology) at Brunel University that is now the largest centre for solidification research in the UK.