Reynold's Dilatancy in Al-10Cu during Equiaxed Solidification

B. Meylan[1,2], C.M. Gourlay[1,2], A.K. Dahle[1,2]

1 The University of Queensland, Australia

2 ARC Centre of Excellence for Design in Light Metals

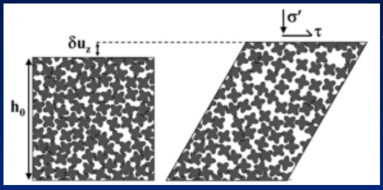
Introduction

Recent work from Gourlay and Dahle has shown that the behaviour of the semi-solid metal, after dendrite coherency solid fraction, is similar to the behaviour of a cohesionless compact granular material, which deform by crystal rearrangement and exhibits Reynolds dilatancy. It has been shown that this deformation mechanism is unstable and leads to concentration of the deformation in shear bands, which are responsible for defects observed in HPDC.

Gourlay and Dahle made observations on AZ91 Magnesium alloy and concluded that this behaviour is valid for all alloys during equiaxed solidification. This study brings more proofs that all alloys exhibit granular behaviour during solidification.

Reynold's Dilatancy

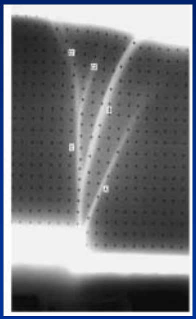
Granular materials when subjected to shear have to increase their volume in order to accommodate the deformation. This occurs by particles rearrangement as illustrated below.



Gourlay *et al*.
Acta Materialia
2008 Vol56 p.3403

Reynold's dilatancy is unstable and weaker regions of the material tend to become even weaker and the increase of volume is concentrated in these areas. These regions are called in granular science dilatant shear bands.

On the left x-ray radiography of sand during shear deformation. Shear bands appear in light colours as they are region of lower densities due to the Reynold's dilatancy. The lead beads in black show that deformation is concentrated in the shear bands.

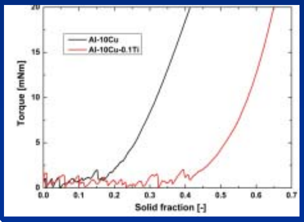


Wood
International Journal of Solids and Structures
2002 Vol39 p.3429

Dendrite Coherency Solid Fraction

During equiaxed solidification, the dendrite coherency point marks a transition from a liquid-like behaviour to a solid-like behaviour. Indeed, dendrite coherency is defined as the point were the dendrite tips of the growing crystals begins to impinge and form a solid network. Which means that before this point crystals can move freely and the semisolid behaves like a suspension. After this point the solid-solid interactions become predominant, resulting in an sharp increase of the shear strength of the semisolid.

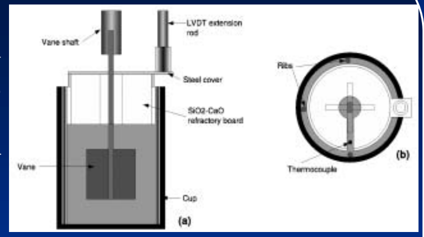
The dendrite coherency marks also the transition between mass-feeding and interdendritic-feeding. The later being much more difficult to achieve, defects can occur due to feeding difficulties (e.g. porosity, hot tearing, macrosegregation). It has now been shown by Gourlay *et al.* that dendrite coherency solid fraction is the onset of Reynold' dilatancy.



Denrite coherency measurement for Al-10Cu with and without grain refiner. The dendrite coherency is greatly affected by the morphology and grain size of the crystals.

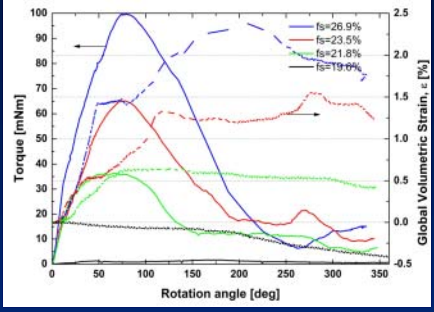
Experimental Method

The sample is first heated 100°C above the melting point of the alloy. Then a steel vane covered with BN is lowered in the middle of the sample. The vane is controlled by a rheometre. Torque and rotation are obtained from the rheometre

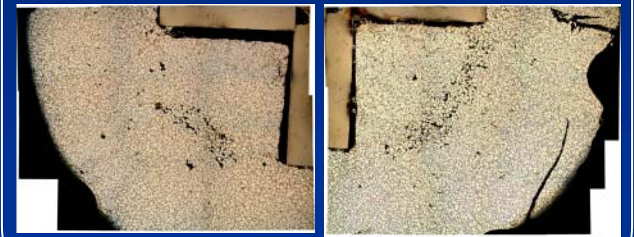


controller. A type K thermocouple is added in the melt in order to obtain a measure of the temperature during solidification. Finally a floating ceramic board is added to the top surface of the sample, this board is connected to a displacement transducer (LVDT) in order to measure the volume change during the vane rotation. The sample is let to cool down in air and the rotation of the vane is initiated at he desired temperature. The vane rotation lasts for 12s at 5rpm in order to produce a complete turn.

Results



Vane experiments with Al-10Cu show some Reynold's dilatancy when shear occur after coherency (Curves blue red and green above). On the other hand when deformed before coherency, no increase of volume is recorded. In fact the volume decrease due to solidification shrinkage and thermal contraction. The global volumetric strain increases with the solid fraction and can reach significant values.



Optical microscopy observation of the quench microstructure shows a band of porosity and positive macrosegreagtion in the path of the vane.

Summary

❖ This work has confirmed that Aluminium alloys also exhibit Reynold's Dilatancy during equiaxed solidification

❖ The use of aluminium alloys instead of magnesium alloys eases the experimentation as it does not require cover gas

❖ Some difference between Al-10Cu and AZ91 were observed in the as-cast microstucture. In many aluminium samples shear bands were hardly visible. Some more work is needed to show the incidence of the feeding properties on the visibility of the bands in the as-cast