Dilatant Shear Bands in Solidifying Light Alloys

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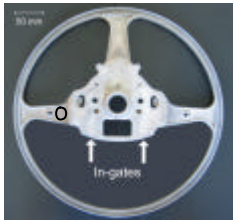
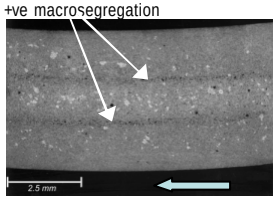
Industrial Context

Narrow bands of positive macrosegregation and porosity commonly follow the surface contour of high pressure die cast (HPDC) components.

Examples of defect bands in a commercial automotive steering wheel cast from AM50

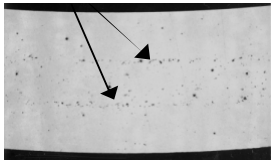


+ve macrosegregation



Bulk flow direction

Concentrated porosity



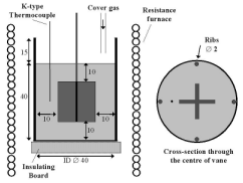
Why study defect bands?

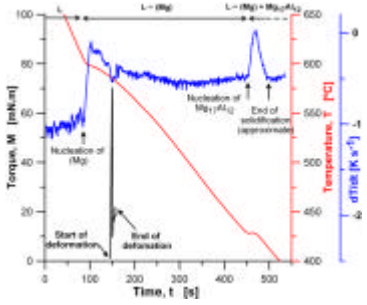
- Defect bands can play a partial role in determining the mechanical properties of HPDC components.
- Understanding defect bands will improve our understanding of the behaviour of solidifying alloys during the HPDC process.

Creating defect bands in the laboratory

Vane Rheometry

A four-bladed vane is rotated at 5rpm for one vane rotation during equiaxed solidification at a solid fraction $f_s=f(T)$

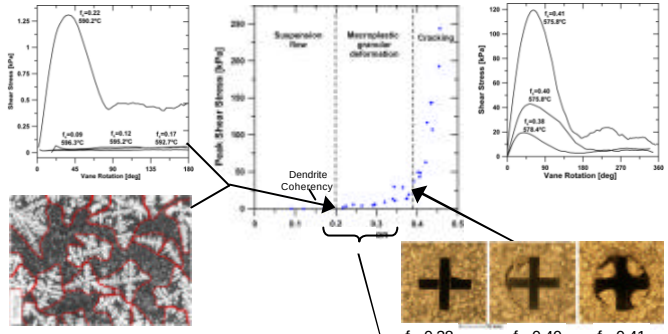




The sequence of events in a typical vane rheometry experiment

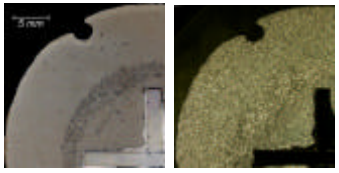
Alloys investigated: A356 (Al-7Si-0.3Mg) and AZ91 (Mg-9Al-0.7Zn)

Rheology of AZ91 cooled at 1K.s^{-1} and deformed in the range $0<f_s<0.5$

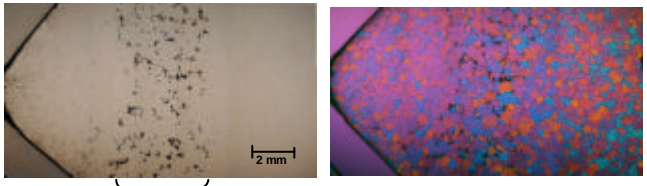


Typical microstructure at dendrite coherency. Dendrite envelopes are indicated in red. Example is for A356

f_s=0.38 f_s=0.40 f_s=0.41

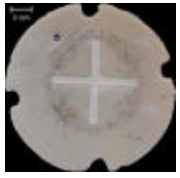


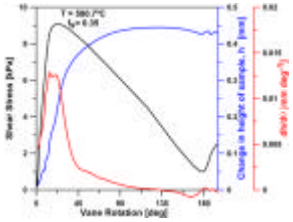
Between dendrite coherency and the cracking transition, bands of porosity form at the vane path.



Pore band

Volumetric changes during vane tests in which pore bands form



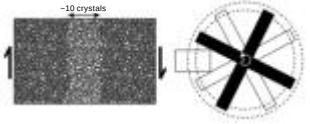


As the vane rotates, the material expands. A maximum in $dh/d\theta$ occurs at ~ the peak stress. The material then expands more gradually during strain softening until an approximately constant volume is reached. **This behaviour is characteristic of a compacted, cohesionless granular material such as dense sand.**

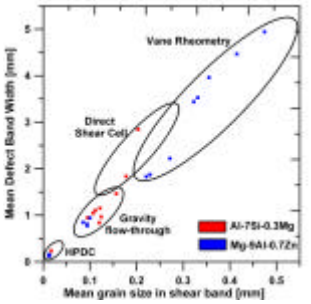
When defect bands form, the dominant deformation mechanism is Reynolds' dilatancy-enabled crystal rearrangement.

Reynolds' dilatancy principle: In order to initiate shear in a compacted assembly of particles by a rearrangement mechanism, it is necessary for the assembly to expand. The angle of dilatancy is defined as Ψ.

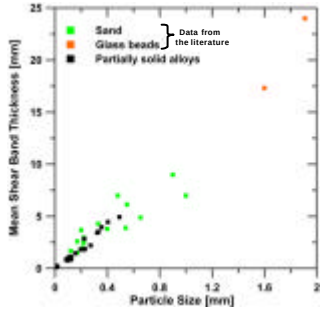
Dilatant shear band formation



Reynolds' dilatancy is unstable because it weakens the region in which it occurs. Thus, both dilatancy and deformation tend to localise during granular deformation. A shear band is fully developed when it has a local f_s that deforms without further expansion and at constant shear stress



In both A356 and AZ91, defect bands are 7-18 mean grains thick in HPDC and various rheometry techniques.



Dilatant shear bands in solidifying alloys are similar to those in other compacted granular materials

Conclusions

1. **When equiaxed solidifying alloys are deformed after the crystals have impinged, they behave as compacted granular materials.**
2. **Deformation then localises into dilatant shear bands 7-18 mean grains thick, similar to dense sand or glass beads.**
3. **The narrow bands of positive macrosegregation and porosity in HPDC components are dilatant shear bands.**