Discussion

Discussion of “On the Refinement Mechanism of Silicon in Al-Si-Cu-Zn Alloy with Addition of Bismuth”*

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The authors describe the refining action of Bi on the silicon phase in their Al-Si alloy, attributing it to the reduction in surface tension of the liquid alloy, and the enhanced wetting of the silicon.^[1]

Despite having been proposed many times, with respect, it is not easy to see the logic underlying this approach. The surface tension of the liquid alloy (a liquid/gas interface) bears no clear relation to the mechanisms of the growth of the silicon phase (on a liquid/solid interface). Nor is it clear that any enhanced ‘wetting’ of the liquid alloy on the Al dendrites occurs, and whether this would in fact aid the formation of silicon.

The authors seem unaware that a new theory of ‘modification’ of Si in Al-Si alloys has been proposed which appears to have been completely successful to explain all the features observed so far concerning this complex process.^[2] It is based on the fact that during the casting of most alloys, the turbulence of the pouring action entrains the surface oxide on the liquid in the form of fragments of doubled-over oxide films, which have been called bifilms. Al-Si alloys are usually full of a suspension of bifilms. X-ray radiographs reveal snow-storm-like conditions.^[3]

It seems that silicon nuclei, AIP, precipitate on either side of the bifilms, initiating the growth of Si on the bifilms and straightening them during the lateral growth of the silicon flakes. The unbonded central interface in the bifilm forms the familiar crack often seen down the center of silicon flakes, and minor folds in the bifilm create the often-seen transverse cracks. In this way, the silicon particles appear to be brittle, and their content of cracks, incorporated during their growth, contributes to the impairment of properties. This coarse morphology is the so-called ‘unmodified’ structure.

The addition of ‘modifiers’ such as Sr appears to deactivate the bifilms as favored substrates, probably by deactivating the AIP nucleant. Thus, now the easy nucleation and growth of Si flakes in the liquid cannot take place. The alloy now has to cool to a lower temperature to nucleate the silicon phase, which now grows as a classical coupled eutectic. The high twin density of this silicon is suggested to be the result of the particle continually being forced to change growth direction as a result of proximity to its neighbors. (The freely floating unmodified primary silicon had no such problems, and so grew with little constraint, and consequently relatively few internal twins.) There are many other aspects of the form of silicon in Al alloys for which the bifilm theory can provide clear and accurate explanations. A review is available.^[3]

Turning now to the interesting observations by the authors, it seems that bismuth also deactivates the AIP nuclei to some extent, although some limited growth still continues on the bifilms as suggested by the ‘refined lamellar’ morphology of the silicon. This origin predicts a growth surrounded by liquid and, therefore, unconstrained and stress free, which would explain the relative perfection of the crystals and their consequential low twin density. The lower temperature at which this occurs indicates the inhibition of the AIP nucleant and/or growth conditions on the bifilms.

The ‘modification’ effect of Bi is probably similar to that observed for other heavy elements such as Sb and Yb, but is not as complete as that observed for elements such as Na and Sr, in which the undercooling is substantial, and growth of Si adopts a fine coral morphology and a high density of twin defects. It may be that the modification by Y (adjacent to Sr in the periodic table of the elements) is an intermediate case. The bifilm theory is consistent with a spectrum of modification effectiveness of different chemical elements. It appears that a fascinating opportunity remains open for future rationalization of modification phenomena.

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