Improving the Quality of Magnesium Castings using Modelling and 3-Dimensional Imaging

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Magnesium alloys are increasingly being considered for critical structural parts in aerospace and automotive applications due to the weight saving potential associated with their use in place of aluminium or steel. Key to realizing this potential is the development of processing methods that reliably produce components that are free from internal defects that could produce premature failure. The magnesium industry is increasingly making use of non-destructive testing methods such as ultrasonic inspection to ensure that as-cast magnesium billets can meet the stringent requirements demanded by aerospace industry regulation. At present this results in scrapping a large number of defect containing billets, which adds a significant and undesirable penalty to the alloy production cost. A key difficulty is that little is understood about the nature and source of the defects that lead to failure during ultrasonic inspection.

The purpose of this work was to use 3-dimensional imaging methods such as X-ray tomography and serial sectioning to understand in detail the nature of the defects that form in magnesium alloy castings, and then use modelling and targetted experiments to improve the processing to reduce the incidence of such defects.

Material containing defects, as identified by ultrasonic inspection, was isolated and examined using 3-dimensional X-ray tomography across a range of length scales. A tomography image of one of the larger defects inspected is shown in Figure 1. It was found that these defects consisted of two main features; an entrained oxide film surrounded by an agglomeration of large intermetallic particles which were identified by EDX analysis as insoluble Al-Mn phase (Al8Mn5). Serial sectioning using focussed ion beam milling (FIB) revealed further details, showing that the oxide films contained trapped pockets of gas (Figure 2); it is these trapped pockets that lead to a strong signal response in ultrasonic inspection.

A study of the liquid metal filtering used in the casting process and a simulation of the metal flow (Figure 3) and intermetallic evolution was used to understand the origins of the defects during casting. It was demonstrated that the agglomeration of the oxide and coarse intermetallics, which is particularly undesirable, was produced by a trawling effect as the oxide circulates in the melt pool. The model was used to develop a better casting procedure that provided an improved metal flow path. This was tested and demonstrated to greatly reduce the incidence of oxide becoming trapped, and thus significantly reduce failure rates at ultrasonic inspection.

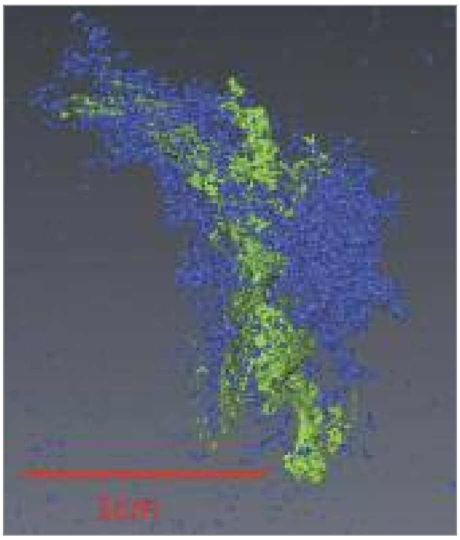

Fig. 1 X-ray tomography image showing a large defect in a magnesium alloy casting. Green regions indicate entrained oxide film, blue indicates large Al8Mn5 intermetallic particles

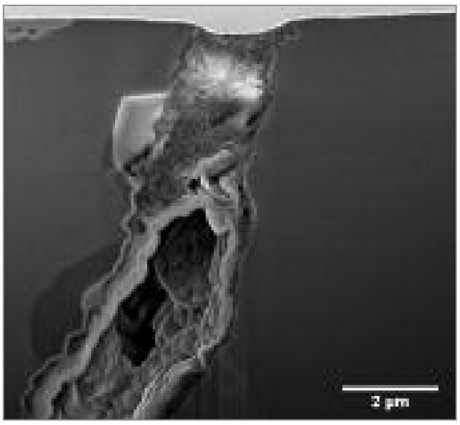

Fig. 2 Slice from serial sectioning experiment revealing a gas pocket trapped between oxide films in a magnesium casting

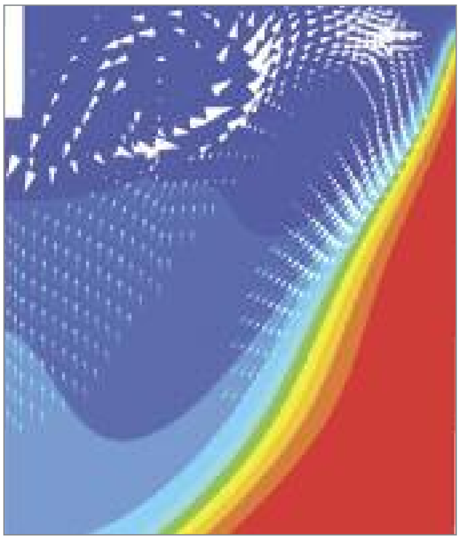

Fig. 3 Simulation of liquid metal circulation in the sump during casting showing velocity vectors

Acknowledgements: This LATEST2 associated project was performed through the EngD centre for advanced manufacturing and processing with support from Magnesium Elektron.

Publications D. Mackie, J. D. Robson, P. J. Withers, and M. Turski, Analysis of Casting Defects in Magnesium-Aluminium-Zinc Direct Chill Castings by X-Ray Tomography, Proc. Magnesium Alloys and their Applications, TMS, 2012

D. Mackie, J. D. Robson, P. J. Withers, M. Turski, T. Wilks, Study of Defects in Direct Chill Magnesium Castings Using X-Ray Tomography, EuroMat 2011, Montpellier, France, 12-15th September 2011