Studying grain refinement in Al alloys using x-ray radiography and machine learning

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Although grain refinement by inoculation is the most widespread method to control grain size in Al alloys, its efficiency is low since only 1 % of the added particles nucleate a grain. This project aims to extend our knowledge of the factors controlling inoculant nucleation in order to learn how to manipulate conditions to increase efficiency, enhance grain refinement and to provide a basis for designing better grain refiners.

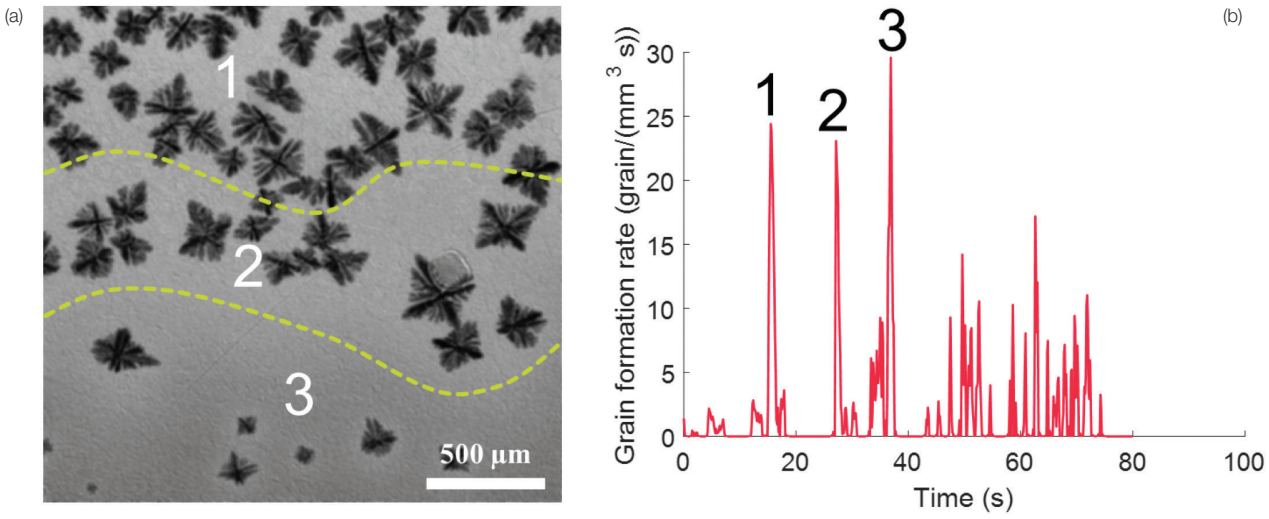

FIGURE 1. (a) Radiographic image of a solidifying Al-25wt%Cu alloy cooled at a constant cooling rate of 0.3 Ks^{-1}. Each equiaxed grain was detected the instant it formed, and then tracked using a machine learning algorithm. (b) Grain formation rate showing the three bursts of nucleation that appear as waves 1, 2 and 3 in (a).

A computer vision algorithm was trained using machine learning to analyse hundreds of thousands of X-ray radiography video frames for the solidification of Al-Cu alloys. The algorithm was capable of detecting every single grain as it appeared during cooling and to quantify its nucleation undercooling. The subsequent growth and movement of thousands of grains as a function of solidification conditions was also recorded. Figure 1a shows a typical frame of a semi-solid Al alloy in which three successive nucleation waves are highlighted. Figure 1b is a plot of the formation rate for the same sequence with peaks corresponding to bursts of nucleation.

The work provides novel, reliable quantitative data to be used to validate long-standing solidification theories as well as unveil new aspects of nucleation. These could lead to new approaches to grain refinement in the metal industry.

The data shows good agreement with the long-standing free growth model of nucleation but reveals new understanding that solute effects lead to both higher nucleation undercoolings and more efficient grain generation by bursts of nucleation.

Future efforts will focus on measuring the potency of different grain refiners and how to exploit solidification conditions to increase the efficiency of existing grain refiners.