An OIM™ Study of Five-fold Branched Si Particles Produced by Laser Cladding of an Al-Si Alloy*

Introduction

Laser surface processing of aluminum alloys has attracted considerable interest because of its ability to enhance the mechanical and chemical resistance of Al-alloy components. Various laser surface processing methodologies are available including laser transformation, surface melting, laser surface alloying and laser surface cladding. Laser surface alloying can form hard phases at the sample surface which reinforce and enhance the properties of the treated component. This is generally done with transition metals which react with the Al to form intermetallic aluminides. However, this technique often creates thermal distortion which results in severe residual stresses. Laser surface cladding overcomes some of these obstacles, as only a thin surface layer of the substrate melts during the process and combines with the additive material to form the coating. Thus, the desired coating properties are achieved with minimal effect to the Al-alloy substrate. In order to better understand laser cladding, Orientation Imaging Microscopy (OIM™) was applied to the study of the surface coating produced when laser cladding a cast Al-alloy substrate with 40 weight percent silicon. The resulting coating produced a fascinating structure composed of many five-fold branched Si particles (Sip) approximately 25 to 30 microns in size [1, 2].

Figure 1 shows a typical Sip that was partially etched to exhibit its three dimensional structure. Five flat faces are on the top of the particle and together five ridges are formed. The re-entrant growth groove at the branch tips is clearly demonstrated by the three-dimensional view, which intersects with the ridge at the center of the branches. It is interesting to note that the five-fold Si particle not only grows along the branched tips, but also thickens in the perpendicular direction, i.e. along the common [110] axis of the branches, pointing to the so-called twin plane re-entrant edge (TPRE) growth mechanism [3, 4].

The crystallographic nature of these multiple twinned structures is notable because there is a 7.5° mismatch between the twinning structure and the five-fold branched structure. The accommodation of this mismatch can be accomplished in two ways: 1) at a single twin boundary and 2) distributed among multiple constituent twin boundaries. OIM™ is an ideal tool for understanding the role of crystallography in the formation of these particles.

Single Twin Mismatch

An orientation map of a Sip is presented in Figure 2b. The particle consists of five twins that are represented by different colors, which are assigned on the basis of lattice orientation as indicated by the color-coded inverse pole figure (IPF). In the pole figure depicted in Figure 2c, <110> poles of all the five twins are plotted on the projection plane of the sample coordinates TD and RD, with corresponding colors to that of the twins in Figure 2b. Similarly, <111> poles are plotted in Figure 2d. It can be concluded from Figures 2c and 2d that the five twins share a common <110> axis and join through five <111> twinning planes, which are located at the center of each branch. Such a configuration results in an angular mismatch of 7.5° because the angle between each pair of twinning planes is 70.5° and the total angle is summed to 352.5°.

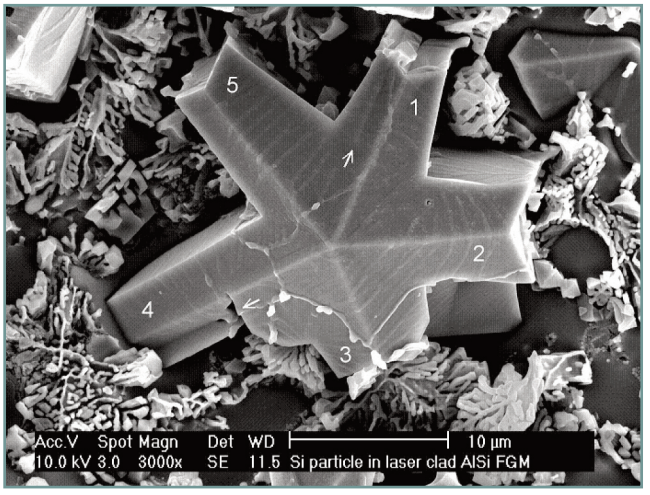

Figure 1. SEM micrograph of a five-fold branched Si particle in a laser clad AlSi40 FGM layer. The twins are numbered clockwise and the arrows mark extra re-entrant grooves.

**Extracted from an application note by Yutao Pei and Jeff Th.M. De Hosson, Department of Applied Physics, Materials Science Center and the Netherlands Institute for Metals Research, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands*

To answer the question how the 7.5° mismatch is accommodated in a five-fold twinned particle, we concentrated on the misorientation distribution over all the twins of a particle. The first possibility is identified with the particle displayed in Figure 2 where a single twin contributes nearly to the entire 7.5° mismatch. As one may note in Figure 2b, twin No. 4 shows two parts with a slight difference in color, i.e. one in red and the other in red-orange.

These two parts are distinguished from each other by a small angle grain boundary (SAGB) of about 7.1° misorientation (indicated with an arrow). This small angle misorientation can be more easily recognized from Figure 2c where the two corresponding groups of <110> poles rotate 7.1° about their common <110> axis.

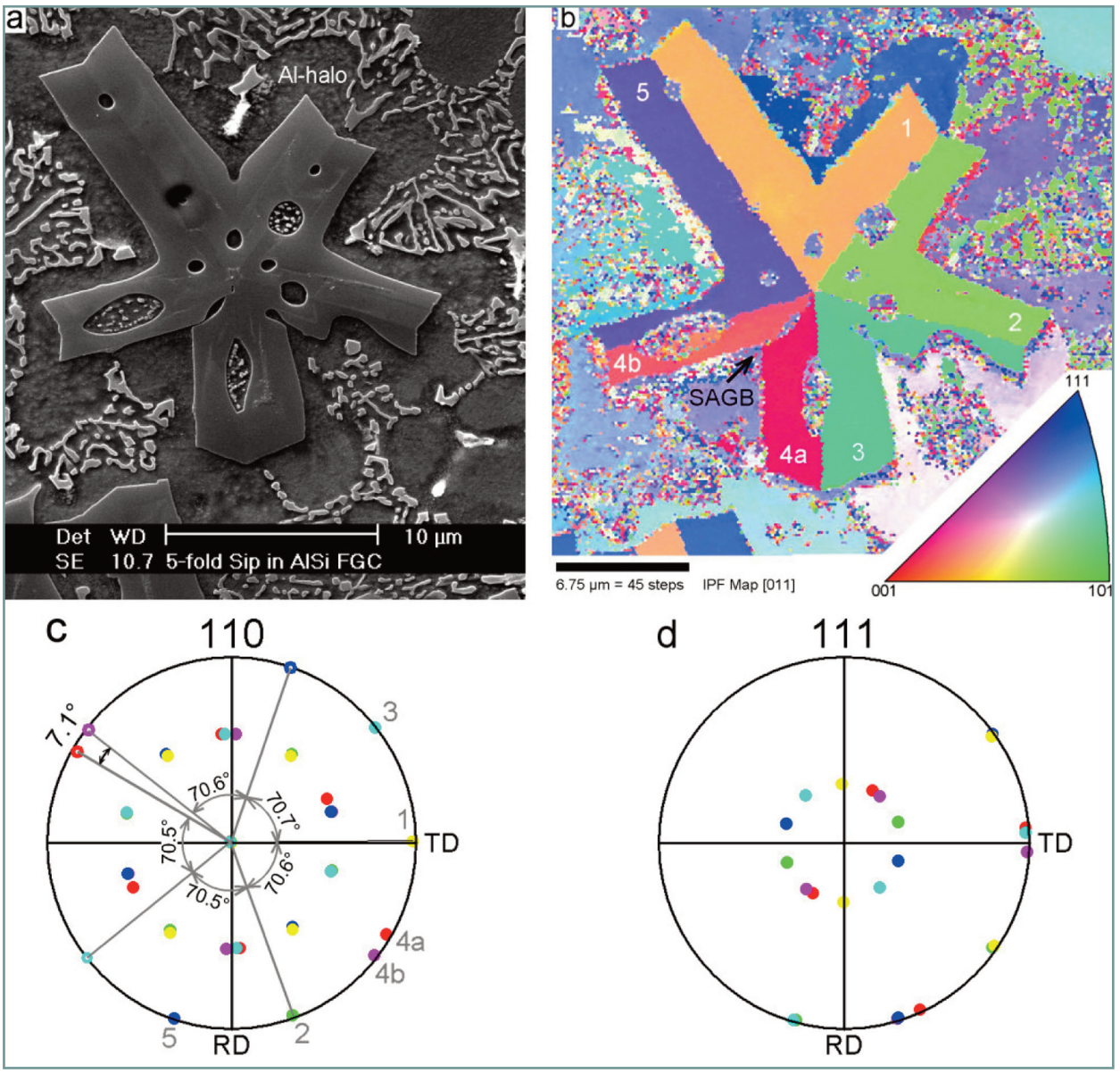

Figure 2. OIM™ result of a five-fold branched Si particle: (a) SEM micrograph. (b) [011] inverse pole figure (IPF) map showing the configuration of its five twins numbered clockwise. An arrow points to a single SAGB in the twin No. 4. The inserted unit triangle of IPF indicates the color shading assigned to local orientation of the lattice and is valid for the following IPF map. (c) <110> pole figure showing the 7.1° tilt angle of the SAGB and the coincided <110> poles among all the twins aligned to the normal direction (ND) of the sample by rotating the scan data. The gray numbers indicate the corresponding twins. (d) <111> pole figure showing pairs of coincident <111> poles between two neighboring twins.

Distributed Twin Mismatch

Other examples of accommodation where the 7.5° mismatch is divided into two or more twins of a particle are more frequently observed. Figure 3 shows a particle exhibiting four SAGBs in four different twins and a further twinning in the twin No. 5. The detailed misorientation distribution over each twin is visualized in Figure 3c by mapping the misorientation of all scanning points on a twin with respect to a definite reference point nearest to the twin boundary. Except for twin No. 2, all the twins show the misorientation distribution in two parts such that, the part containing the reference point exhibits an average misorientation in the range 0.48° to 0.74° and the other part possesses an average misorientation between 1.78° and 3.05°. The misorientation difference between these two parts indicates that there is a SAGB, which can be directly seen from the color difference inside the twins. The SAGBs originate from the center of the particle where the common <110> axis is located and terminate at the fork of the branched twins. The average tilt angles of the SAGB in twin No. 1, 3, 4 and 5 are 1.30°, 1.92°, 1.70° and 2.31°, respectively. These four SAGBs contribute to a total deformation of about 7.2° and the rest of the mismatch is assumed to be elastic deformation.

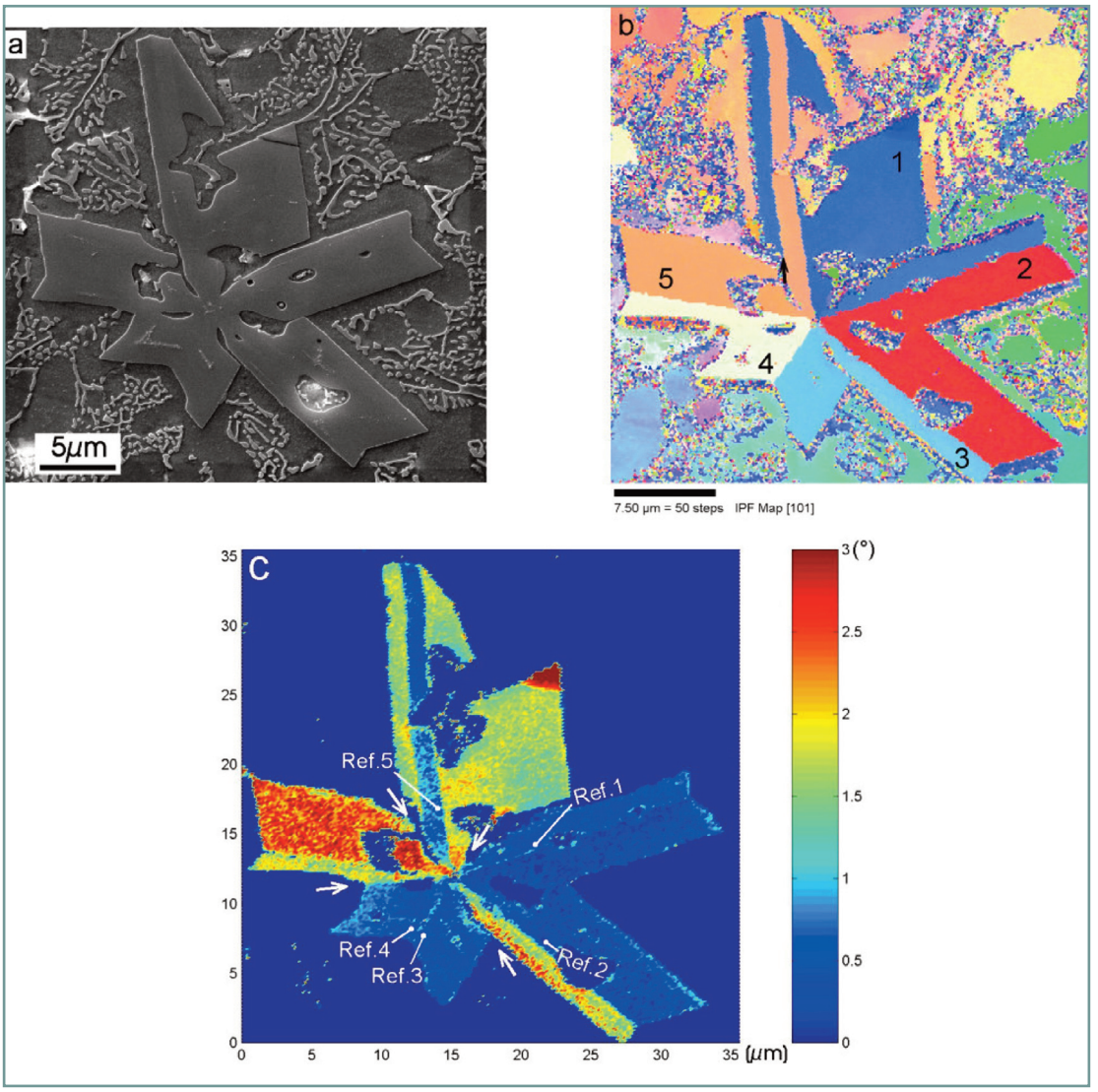

Figure 3. Combined microstructure and crystallography analysis of a five-fold Si particle: (a) SEM micrograph of the particle. (b) [101] IPF map showing the five twins numbered clockwise and a further twinning in the twin No. 5 indicated by an arrow. (c) Misorientation distribution of each twin drawn with respect to a definite reference point marked by a white circle. Arrows indicate the SAGBs in four different twins. The color-shading bar on right scales the misorientation angles.

Conclusion

The OIM™ results show that the 7.5° mismatch that arises when arranging five tetrahedrons around a common <110> axis is accommodated by SAGBs. The mismatch is most frequently accommodated by multiple SAGBs as opposed to a single SAGB. The situation in which all five twins of a particle contained an SAGB was never observed. The SAGBs may disturb the progress of growth steps, causing the particles to branch. The examples of a single SAGB reported previously [5] are just a special case of the SAGB mechanism. OIM™ is an ideal tool for examining the role of crystallographic orientation on surfaces modified by laser processing.

Bibliography

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