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A 3-D EBSD investigation of dynamic recrystallization in a Cu-Sn bronze

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Cu-Sn alloys are single-phase fcc alloys with a low stacking fault energy. This means that during deformation, recovery processes are very slow and the accumulation of a large dislocation density results in dynamic recrystallization. Solute pinning of the grain boundaries restricts growth of the new grains, resulting, at deformation temperatures of ~400^{o}C in strings of grains of diameter 1-2µm at the prior grain boundaries [1]. Using conventional metallography and EBSD of plane sections as seen in fig.1, no orientation relationship between the old and new grains is detected. However, it is likely that the new grains will have originated with some crystallographic relationship to the old grains, and therefore it is necessary to examine 3-D sections so as to study the relationship between the old grains and the three dimensional sheet of new grains, and we have undertaken this by progressive FIB sectioning coupled with EBSD analysis.

The work was undertaken with an FEI dual beam NOVA600i FIB instrument equipped with an Oxford Instruments HKL EBSD system. Typical operating conditions were for FIB 30kV and EBSD 20kV and about 1 to 2nA probe current for both EBSD and FIB. The regions examined were typically 30x30µm in area, with lateral and depth pixel steps of 0.1-0.2 µm. Runs of up to 100 slices were carried out, resulting in penetration of the microstructure to a depth of 10 µm or more depending on the step size.

Fig. 2 is a 3-D EBSD map, showing a sheet of dynamically recrystallized grains formed at the boundary of two prior grains. It is found that the sheets of dynamically recrystallized grains contain many Σ3 twins, but because the material has been deformed as the grains are formed, the Σ3 relationship is no longer exact in some regions, and it is necessary to relax the Brandon criterion in order to identify the "twin" boundaries. It is found that significant lattice rotations are formed adjacent to the prior boundaries, and that new grains are often associated with such regions. Fig.3 shows a prior boundary, which was originally a Σ3 twin. However, the grain reorientations during deformation have substantially altered the nature of the boundary, where the misorientations are in places, up to 20^{o} from the Σ3 relationship, and the misorientation profile from point A to point B is shown in fig. 3b. At point C, a new small grain has formed. The 3-D sections show that this is an isolated grain. This grain is misoriented ~18^{o} from A and has regained the 60^{o} <111> Σ3 relationship with the right hand grain. It is possible that the driving force to form a low energy Σ3 boundary may be a factor in nucleating dynamic recrystallization.

Our preliminary conclusions are that dynamical recrystallization usually starts in regions where plastic deformation has resulted in significant lattice rotations adjacent to the grain boundaries. Once such a new grain has formed, dynamic recrystallization is propagated by successive twinning from the new grain, along the prior grain boundary, resulting in families of several hundred twin-related dynamically recrystallized grains.

[1] D.T. McDonald, F.J. Humphreys, P.S. Bate and I. Brough. Mats. Sci. Forum. 558-559, (2007), 449.

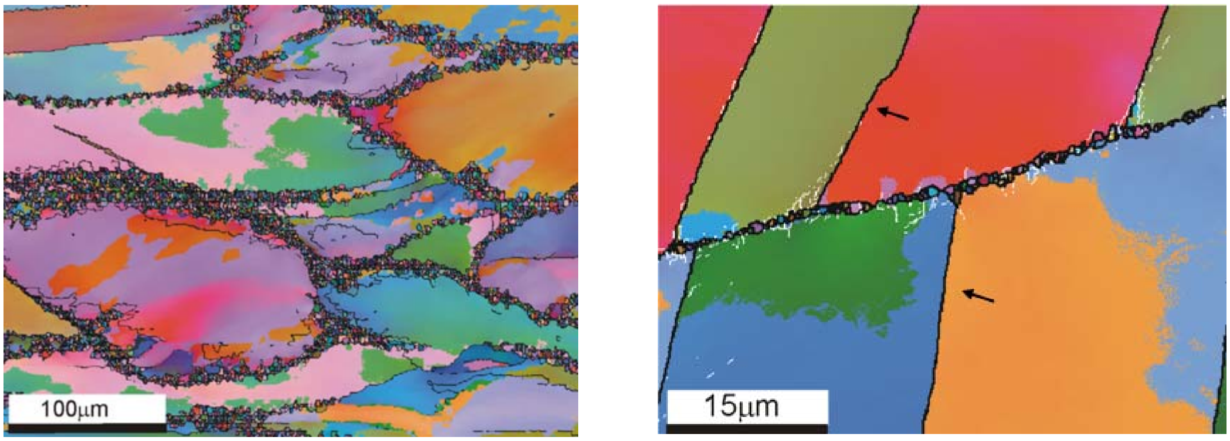


Fig.1. EBSD maps of conventional plane sections of Cu-4.5%Sn deformed to a) ε=0.36 and b) ε=0.22 at 400°C showing small dynamically recrystallized grains. There are less grains formed at the arrowed Σ3 boundaries in (b)

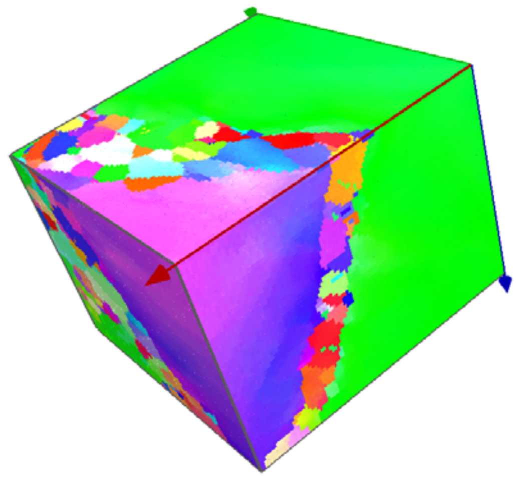
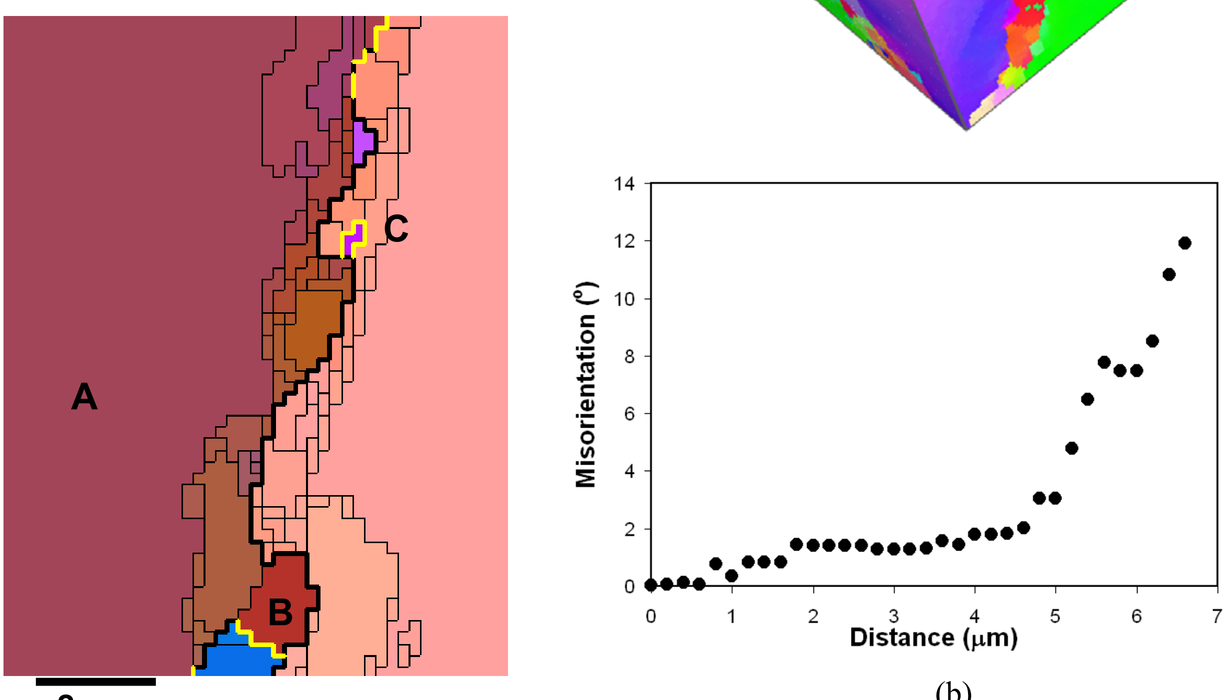


Figure 2. 3-D EBSD map with dimensions of 12 μm x 12 μm x 8.5 μm and 0.1 μm resolution in x, y and 0.15 μm resolution in z directions.(ε=0.22 at 400°C)



(a) (b)

Fig.3.a) Misoriented regions at a grain boundary showing a small twinned grain at C
b) Misorientation profile from A to B. (HAGBs are thick black and Σ3 boundaries yellow)

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