Alloys and Intermetallics

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Softening processes in accumulative roll-bonding processed twin-roll cast aluminium sheets studied by light and transmission electron microscopy.

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Mechanical properties of metallic materials are very sensitive to the grain size. A reduction of the mean grain size increases the yield stress and the tensile strengths according to the Hall-Petch relationship. Severe plastic deformation (SPD) is frequently used for the grain refinement of metals and alloys [1]. The basic principle of the SPD process consists in inducing the extremely high plastic strain into the material resulting in a substantial grain refinement and improved strengths. Accumulative roll-bonding (ARB) is one of the most popular SPD techniques which does not require any special equipment [2]. The homogeneity and final thermal stability of the grain structure in aluminium alloys depends on the processing temperature, number of ARB cycles but also on the grain size of the initial material and the size and distribution of coarse primary particles which are generally present in the ingot cast and cold-rolled sheets. Therefore the thermal stability and homogeneity is improved in materials with fine particles and small grain size which is typical for continuously twin-roll cast (TRC) aluminium alloys. A commercial TRC AA8006 type alloy (0.40 Mn, 0.16 Si, 1.51 Fe in wt.%) was used in the study. Supplied 2 mm thick sheets were homogenized for 18 h at 610°C and then annealed at 450°C for 30 min in order to obtain fine-grained and fully recrystallized material (F0). Specimens with three (specimen F3) and five ARB cycles were prepared. Vickers microhardness measurements were carried out on the recrystallized material F0 and ARB processed specimens F3 and F5 annealed at different temperatures (Figure 1). In the initial state, the hardness of the F3 and F5 specimens is higher than the one observed in the F0 sheet. Above 100°C the microhardness increases in both deformed materials. The maximum of the microhardness is reached at 160°C. On the other hand the microhardness of the F0 specimen, which is fully recrystallized, remains constant within the experimental error during the whole annealing cycle. Between 160°C and 300°C, F3 and F5 hardness drops until the value similar to the F0 final hardness was reached. The examples of initial structures and the evolution of microstructure during annealing are given in Figures 2, 3 and 4. The microstructure of the F0 material was not modified by the thermal treatment because this specimen was already annealed at high temperature which results in the formation of uniform recrystallized structure with stable phase composition. The significant increase of microhardness which takes place in the ARB processed materials is in accordance with the LOM and TEM results due to the microstructure refinement occurring during ARB process. The F3 and the F5 specimens contain very small and elongated subgrains, nevertheless the higher number of ARB cycles, does not visibly increase the microhardness. Huang et al. [3] have shown that in heavily deformed aluminium materials like the materials after the ARB process the partial recovery of the dislocation substructure which is coupled with the dislocation density decrease and changes in the low subgrain boundary fraction may result in a surprising increase of the strength of the material. Such behaviour was observed also in material F5 and F3 where the microhardness increases until a maximal value at 160°C. A subgrain growth which is observed around 160°C is a concurrent process which finally prevails above the strengthening of the material and the microhardness starts to decrease again at higher annealing temperatures. Between 160°C and 200°C the microhardness decreases slightly then rapidly drops between 200°C and 300°C. The TEM observations show that the beginning of the softening can be explained by the subgrains coarsening and by the first creation of nuclei in the vicinity of coarse particles. Between 300°C and 440°C the microhardness varies only modestly because the microstructure is almost fully recrystallized at 300°C and only a recrystallization finalization and a moderate coarsening of grains occur at higher annealing temperatures. The TEM observations also reveal the presence of larger grains close to the coarse particles and smaller grains in other places during the recrystallization. This effect is caused by the creation of deformed zones with a high stored energy in the vicinity of the particles during the ARB process. This process is known as a particlestimulated nucleation which often results in the so called continuous recrystallization and abnormal grain growth [4].

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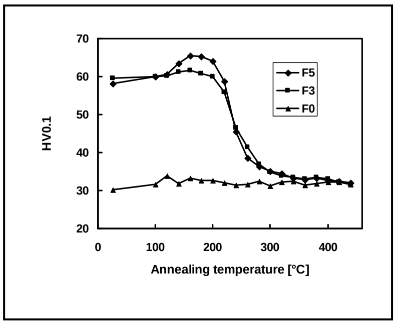

Figure 1. Evolution of microhardness in material after 0, 3 and 5 ARB passes.

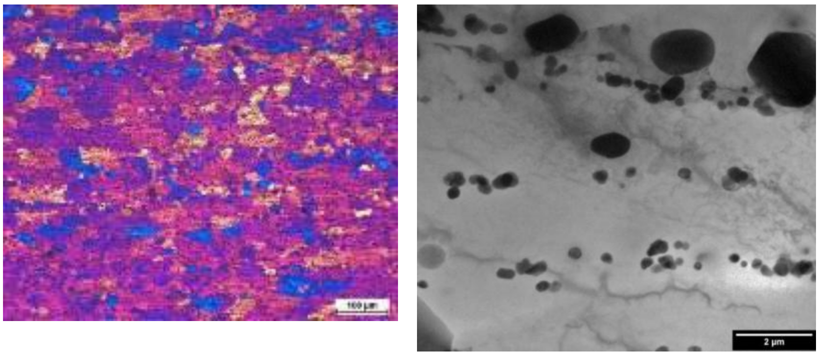

Figure 2. The microstructure of the F0 specimen (LOM left and TEM right).

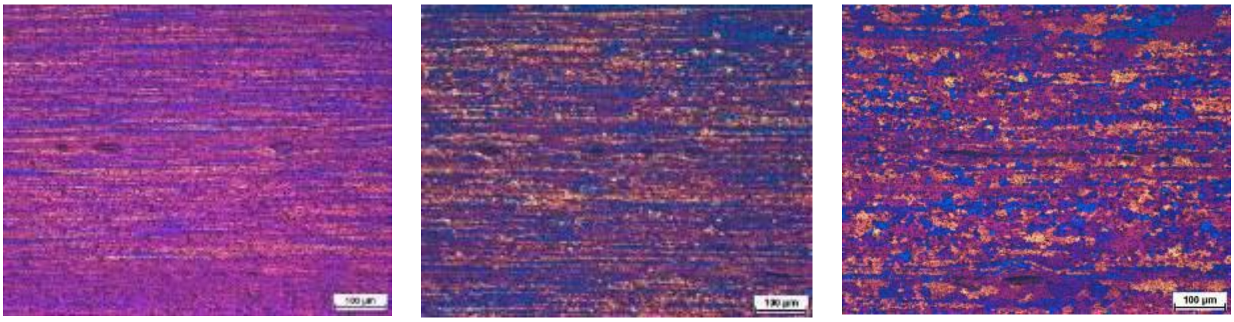

Figure 3. LOM of F3 material in the initial (left) state and after annealing up to 280 (middle) and 440°C (right).

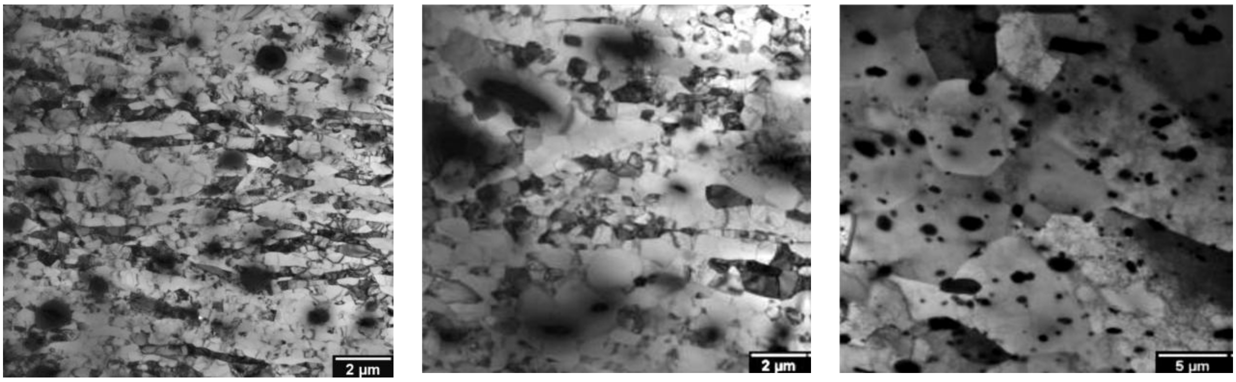

Figure 4. TEM of F3 material in the initial (left) state and after annealing up to 260 (middle) and 440°C (right).