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Microstructure and micro-texture evolution during large strain deformation of aluminium alloy AA 2219

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ABSTRACT

Aluminium alloy AA2219 is widely used in the fabrication of propellant tanks of cryogenic stages of satellite launch vehicles. These propellant tanks are welded structures and a fine grained microstructure is usually preferred for sheets/plates and ring rolled rings used in their fabrication. In order to study the effect of large strain deformation on the microstructural evolution, hot isothermal plane strain compression (PSC) tests were conducted on AA 2219 in the temperature range of 250 °C–400 °C and at strain rates of 0.01 s^{-1} and 1 s^{-1}. Flow curves obtained at different temperatures and strain rates exhibited two types of behavior; one with a clear stress peak followed by softening, occurring below Z=2.5E+15 and steady state flow behavior above it. Electron Back-Scatter Diffraction (EBSD) analysis of the PSC tested samples at the location of maximum strain revealed the presence of lamellar microstructures with very low fraction of transverse high angle boundaries (HABs). The loss of HABs during large strain deformation is attributed to the occurrence of dynamic recovery (DRV) as the ratio of calculated to measured lamellar boundary width is less than unity. Based on detailed microstructure and micro texture analysis, it was concluded that it is very difficult to obtain large fraction of HABs through uniaxial large strain deformation. Therefore, to obtain fine grain microstructure in thermo-mechanically processed AA2219 products, multi-axial deformation is essential.

1. Introduction

Precipitation hardenable aluminium alloys of 2XXX and 7XXX series find extensive applications in the aerospace industry in view of their good combination of strength, toughness and stress corrosion cracking resistance [1–3]. Al-Cu-Mn (AA 2219) and Al-Cu-Mg (AA 2014/AA 2024) are important commercial alloys of 2XXX series which find application in aircraft structures, propellant tanks and inter-stage rings of satellite launch vehicles. The design of structural members is based on strength and any improvement in yield strength of these alloys will reduce mass of structural hardware. Further, fine grained microstructures will improve the weldability of aluminium alloys by reducing the tendency for crack propagation [4,5]. Therefore, there are continuous efforts in improving the strength of aluminium alloys by controlling the microstructure, by changing composition and by introduction of newer tempers.

Thermo-mechanical processing is an important step in the manufacture of industrial components which is used not only to give the required shape and size changes but also is used to impart the desired microstructural changes in the material. Among the known strengthening mechanisms, grain refinement is the only technique by which strength can be improved without loss of ductility. Therefore, refinement of grain size is one of the important topics of thermo-mechanical processing research. Ultra-fine grained materials processed by large plastic deformation processes such as Equi-Channel Angular Processing (ECAP), High Pressure Torsion (HPT), Accumulative Roll Bonding (ARB) etc. are being studied worldwide. Significant improvements were reported in the mechanical properties of ultra-fine grained steels [6,7], Ti alloys [8,9], Mg alloys [10,11] etc. over their coarse grained counterparts.

Aluminium being a high stacking fault energy (SFE) material, dislocation climb and cross-slip occur readily during hot deformation [12]. The occurrence of dynamic recovery during working of aluminium alloys at room and higher temperatures decreases the density of crystalline defects. This in turn reduces the driving force for recrystallization. Hence, grain refinement in bulk aluminium alloys through the conventional route is very difficult owing to its high SFE. In view of this limitation of conventional processing, Severe Plastic Deformation (SPD) techniques

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have been widely acknowledged to realize fine grained materials by imparting large strains. SPD of various aluminium alloys such as 1XXX, 2XXX, 6XXX and 7XXX has been reported by various researchers [13–20].

However due to complicated nature of strain and strain rate distribution in work pieces processed by ECAP, HPT and ARB it is difficult to understand the relationship between the processing variables and microstructure evolution precisely. In order to understand the microstructure evolution during large strain deformation, it is essential to use a simple and reliable testing technique. Some authors of this paper have successfully developed a [21–24] single hit compressive testing technique in which the heating and cooling rates, deformation temperature, imposed strain and strain rate can be accurately controlled. They previously studied the large strain warm deformation leading to the formation of ultra-fine grained steels [21,22] aluminium alloys [23] and super-alloys [24].

In view of the above, it is very interesting to study the effect of strain rate and temperature on the microstructural evolution in aluminium subjected to very large strains under controlled conditions. Therefore, the aims of the present investigation were two-fold; (a) to study the large strain deformation behavior by conducting hot isothermal single hit plane strain compression tests on aluminium alloy AA 2219 and study the stress-strain behavior under large strain conditions; and (b) to evaluate the microstructure and microtexture of the deformed specimens to understand the mechanisms of deformation under plane strain conditions.

2. Experimental procedures

In the present study, a simple compression technique has been used for conducting the hot deformation studies. In contrast to the other large plastic deformation techniques where high strains are achieved by multi-pass deformation steps, the present technique is a single hit deformation process. This procedure eliminates the possibility of the sample undergoing structural changes during static holding/reheating cycles between the passes. In the plane strain compression test used in the present study, strain gets accumulated at the centre of the specimen and it varies in the range of 0–4 from surface to centre of the specimen [21,22]. This strain distribution facilitates the observation of regions deformed to different strain regions in a single test specimen.

Test specimens having dimensions of 15 mm long × 13 mm wide × 12 mm thick were extracted from a hot rolled plate of aluminium alloy AA 2219-T87 having composition (6.3Cu-0.3Mn-0.3Fe-0.2Si-0.18Zr-0.06Ti-0.1 V and balance aluminium, all in weight %). The T87 temper corresponds to solution treatment at 535 °C for 1 h followed by water quenching. Subsequently this plate was subjected to 7% cold deformation with a final ageing step at 163 °C for 24 h. The test specimens were machined such that the compression axis is perpendicular to the rolling direction. Fig. 1 shows optical photomicrograph of the initial microstructure of AA 2219-T87 plate used in the present study. The plate rolling and normal directions are shown in Fig. 1. The microstructure consists of grains with clear grain boundaries that are slightly elongated in the direction of rolling. Primary $CuAl_2$ particles are uniformly distributed throughout the matrix and are seen as bright particles.

Using a Gleeble-3800 thermo-mechanical simulator capable of controlling specimen temperature, strain and strain rate, the specimens were heated in the temperature range of 250–400 °C. Specimens were heated at 5 °C/s to their specified deformation temperatures and were soaked for 60 s to achieve uniform temperature distribution and were subsequently compressed in a single stroke to impose a reduction of 75% in thickness. The compressive deformation was carried out in the durations of 1.38 s and 138 s so as to impose apparent nominal strain rates of 1 s^{-1} and 0.01 s^{-1} respectively. Immediately after the deformation the specimens were in-situ water quenched. Fig. 2 shows the schematic of the experimental plan which includes specimen heating, soaking, deformation followed by water quenching adopted in the present study. The plane strain compressed specimens were then subjected to ageing at 175 °C for 6, 12, 18 and 24 h to check for any

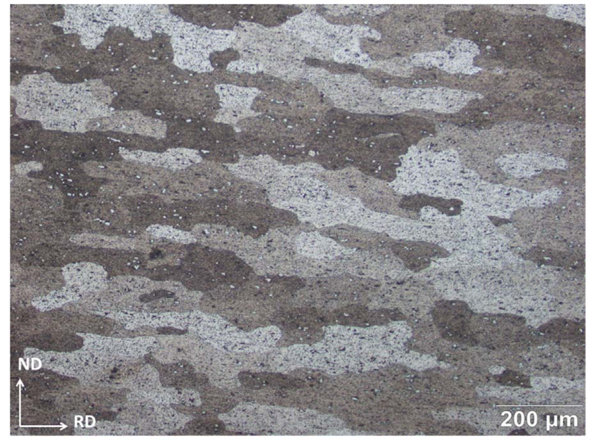

Fig. 1. Optical photomicrograph of the initial microstructure of AA 2219-T87 plate used in the present study. The plate rolling and normal directions are shown. The microstructure consists of grains with clear grain boundaries that are slightly elongated in the direction of rolling. Bright particles seen in the microstructure are primary $CuAl_2$ particles uniformly distributed throughout.

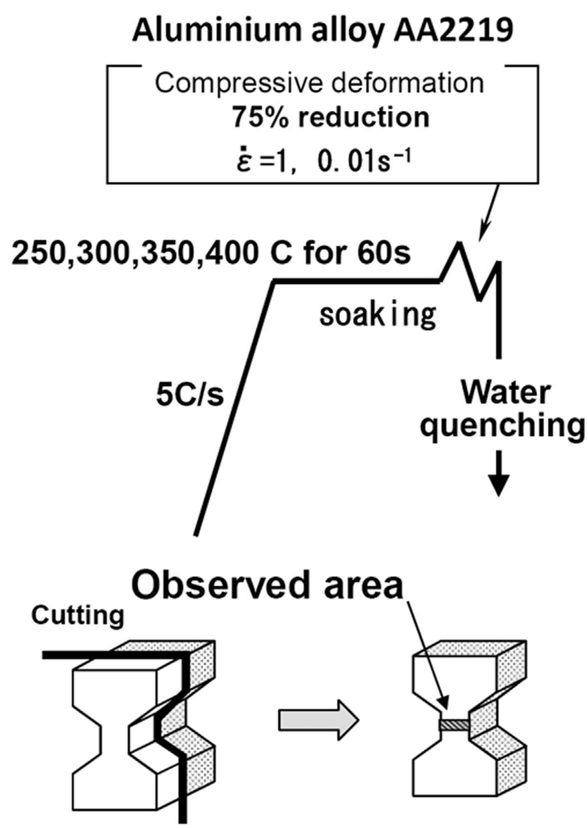

Fig. 2. Schematic of the experimental plan (with heating, soaking, deformation and cooling sequence) adopted in the present study. The sectioning plan for microstructural observation is also shown.