INFLUENCE OF RECRYSTALLISATION ON PROPERTIES OF AA7010 THICK PLATE

N-E. Andersson and S. Johansson

Division of Engineering Materials
Department of Mechanical Engineering
Linköping University, S-581 83 Linköping, Sweden

Abstract The variations in structure and mechanical properties of AA7010 thick plate have been investigated. The studied plate thicknesses were 100-200 mm and the material was overaged and stress relieved. The material studied is frequently used to produce load-carrying airframe components. The focus of this paper is the influence of recrystallisation. The degree of recrystallisation was determined as a function of position in the mid width of the plates by using optical microscopy and image analysis. The crystallographic orientation of recrystallised grains were determined from EBSP maps. Hardness measurements on subgrain areas and on recrystallised grains were done by micro hardness indentations in order to reveal the effect of recrystallisation on yield strength. The fracture toughness at different positions of the plates are discussed in terms of influence from recrystallisation. The paper also discusses the mechanisms behind the recrystallisation and its influence on mechanical properties such as yield strength and fracture toughness. The suggested influence of recrystallisation on the mechanical properties are compared to the influence seen from other parameters such as chemical composition, quench rate, texture, grain size, distribution and sizes of inclusions, dispersoids and ageing precipitates.

Keywords: *recrystallisation, yield strength, EBSP, quench rate and hardness.*

1. Introduction

AA7010 Al alloy was developed in the seventies to among other things have high static strength over a wide range of plate thicknesses with a reduced quench sensitivity [1]. Properties throughout plates are anisotropic [2-4]. Variations of properties according to position are more or less caused by differences in chemical composition, quench path, size and distribution of inclusions, dispersoids and ageing precipitates, texture, grain size and degree of recrystallisation. Interaction effects of mentioned structural features are also possible [2,5]. AA7010-T7451/52 thick plate is used for airframe components, which are machined in NC-machines. For better reproducibility an isotropic material is desirable. Fracture toughness is a property of great interest for designers. It has been stated in the literature that recrystallisation has a negative effect on plane stress fracture toughness of 7xxx series aluminium alloys [6], on the other hand it has also been stated that it doesn't have any influence [7] or that the influence is in interaction with quench rate [5]. Information about the influence of recrystallisation on yield strength of hot rolled and overaged 7xxx series aluminium alloys is not very common in the literature.

This study has been undertaken to investigate the influence of recrystallisation on fracture toughness and yield strength in thick plate A7010-T7451/52.

2. Experimental details

The AA7010-T7451/52 plates were manufactured by hot rolling of ingots about 410 x 1100 mm in cross section and with a length of a few meters after some machining. After hot rolling with a reduction from about 410mm to 100, 150 and 200 mm, the plates were solution treated, stretched or cold compressed and artificially aged.

Centre blocks were cut through the thickness, (T). The blocks were centred in width and cut out about 2 meters from the beginning of the plates, i.e. where the ingots first solidified. From these blocks tensile specimen, samples for X-ray texture measurements, EBSP and optical microscopy studies were machined out. The tensile specimen had a flat shape. They were cut out parallel to the rolling surface in directions 0°, 45° and 90° to the rolling direction at four different depths (T/8, T/4, 3T/8 and T/2). The flat shape of the specimens allow the yield strength to be determined locally through the thickness. The thickness of the flat specimen was 3mm and the other dimensions are found in Swedish standard 112116.

The tensile testing was performed using an Alwetron TCT 50 screw machine together with an external MTS extensometer sometimes together with strain gauges directly attached to the specimen surface in order to increase the accuracy of testing, or on a MTS screw machine with extensometers on both sides of the specimens. X-ray measurements of texture were performed at the four different depths and at the surface of the plates. The measurements were performed with a Seifert X-ray diffractometer. The {111}, {200}, {220} and {311} pole figures were determined with maximum tilting angle 75°. The microstructure through the thickness was observed with optical microscopy, mappings of the microstructure by using automatic indexed EBSP measurements have been performed. Micro Vickers hardness indentation was performed on cross sections perpendicular to the rolling direction. The indentations were done in recrystallised grains and in recovered grains. The equipment used was a LECO M-400, and the loads were 10 and 25 g. The specimens were etched with Barker's reagent in order to reveal recrystallised and recovered grains. Macro Vickers hardness indentation through the thickness of the plates were done using a LECO V-100A hardness tester with a load of 10 kg on the Vickers diamond. K_{IC} fracture toughness were measured by the manufacturer of the plate material by using standard specimens. Reheattreatment of tensile specimens and samples for hardness indentation were done in a salt bath oven and a silicon bath using standard times and temperatures. The EBSP specimens were ground, polished and electropolished and investigated in a JEOL WinSEM 6400 SEM with a standard EBSP equipment.

3. Results and discussion

The fracture toughness of the different plates at mid width position in the three different orientations, L-T, T-L and S-L, at different depths are shown in Fig. 1a-c). The result of the fracture toughness tests show that there is a clear tendency for increasing K_{IC} at increasing depths. The thicker the plate, the less significant is the toughness increase towards mid thickness.

The results of an investigation of degree of recrystallisation as a function of depth are shown in Fig. 1d). These results were obtained using optical microscopy and image analysis [8]. The measurements are done on planes of different depths parallel to the rolling plane. The through thickness variation of recrystallisation of the 100 and 150mm plates, is in agreement with EBSP mappings and with earlier [9] and later manually qualitative estimations using optical microscopy. The result of the 200mm plate is more difficult to verify. The EBSP mappings show grains with relatively large angle misorientations without showing clear subgrain boundaries. The grains of the 200mm plate were extremely flat and elongated. These pancake shaped grains are probably not recrystallised. Only very few recrystallised grains are observed on the EBSP mappings, these grains are often very small. Fig. 2a) shows a mapping of a section perpendicular to the rolling direction from mid thickness of the 200mm plate. It has been shown that the recrystallisation mechanism of this material is due to particle stimulated nucleation (PSN) around the iron and silicon rich inclusions [10]. This mechanism results in a near random orientation distribution of the recrystallised grains. An earlier estimation of the crystallographic orientation of the recrystallised grains in the 100mm plate of this investigation, showed a high fraction of cube or rotated cube orientation [11]. In [12] it was shown that the starting texture is important. The starting texture for the three different plates are equal because they were rolled starting from the same kind of ingot. The 200mm plate did not show much recrystallisation, but the intensity of the cube component is fairly high. If the cube component of the ingot is strong and still exists to some extent after the hot rolling, then the preferred cube orientation could be explained. When the mapped recrystallised grains are not completely surrounded by a high angle grain boundary, the mechanism behind the recrystallisation could be due to subgrain growth in PFZs close to grain boundaries followed by Strain Induced grain Boundary Migration (SIBM) as proposed by[13].

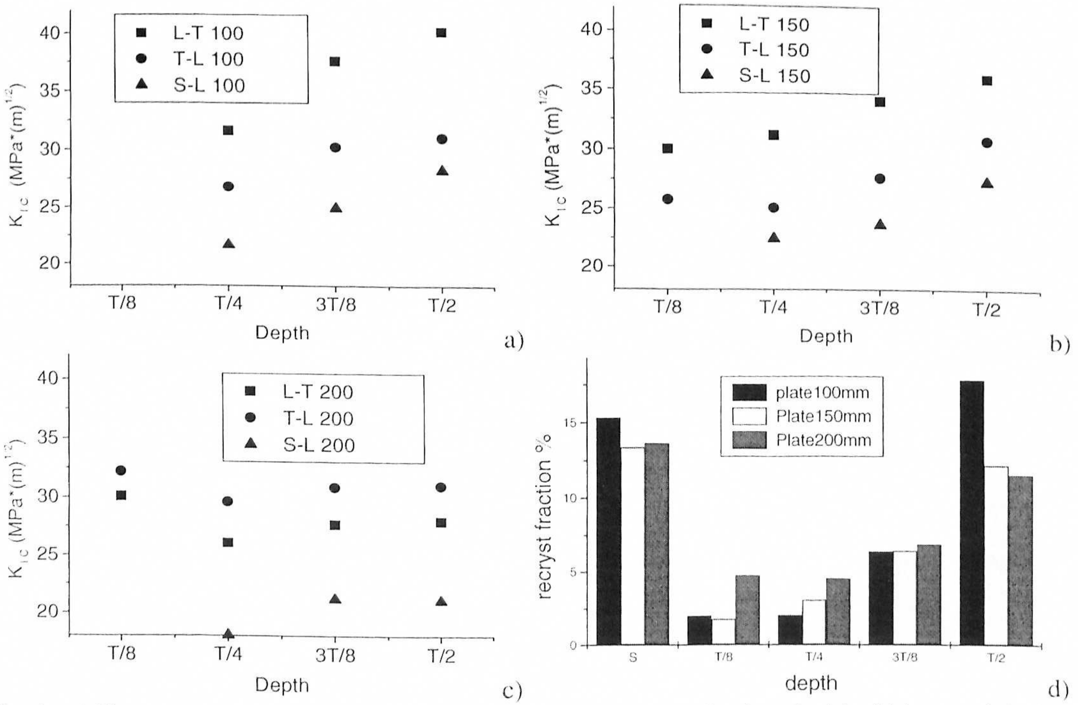

Fig. 1a-c) Fracture toughness for different directions at different depths of mid width material of the three plates. a) 100mm plate, b) 150mm plate and c) 200mm plate. Fig. 1d). Degree of recrystallisation as a function of depth for the different plates [8].

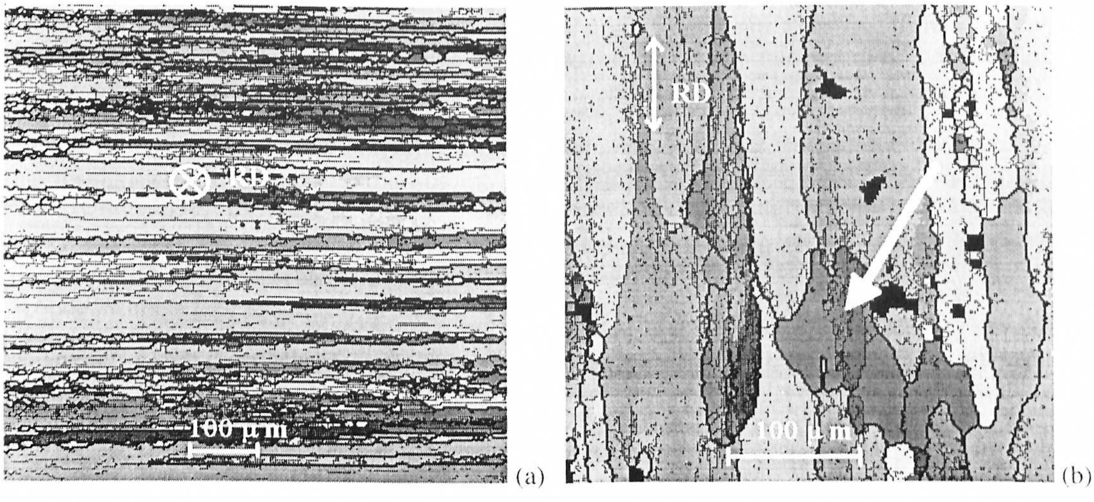

Fig. 2. EBSP mapping of 7010 thick plate, mid thickness position. (a) 200 mm, the transversal direction lies horizontally and the normal direction lies vertically in the figure. (b) 150 mm, the rolling direction lies vertically and the normal direction lies horizontally in the figure.

This last mechanism would work to maintain the texture developed during hot rolling. A study of the fraction of recrystallised grains containing low angle grain boundaries as part of the surrounding grainboundary, proposing the SIBM mechanism, gave a rough estimation of 15%. A typical site of this kind is shown in Fig. 2b). The white arrow points at the area where recrystallisation has started by subgrain growth followed by SIBM. The subgrain boundaries appear as a fine black network on the maps and the clean area is recrystallised.

The results from the tensile testing are shown in Fig. 3a-c). The filled symbols show result for as received material, while hollow symbols show result from reheattreated specimens. The difference in quench rate of the as received material was removed through reheattreatment of the specimens.

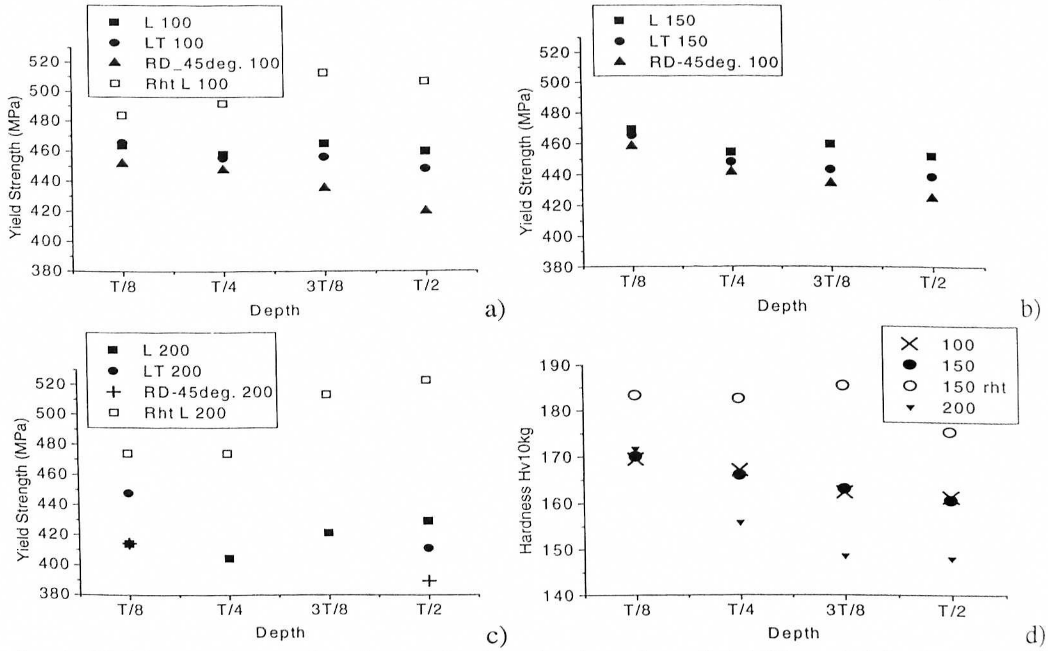

Fig. 3a-c). Yield strength as a function of depth and orientation of a) 100mm thick plate, b) 150mm thick plate and c) 200mm thick plate. Fig. 3d). Hardness as a function of depth in the plates. The open symbols represent reheattreated material.

Tensile specimens, orthogonal and 45 degrees, to the rolling direction were only taken from T/8 and T/2 for the 200mm plate. No significant difference of micro hardness between recrystallised and recovered grains was measured. Comparisons of micro hardness between recrystallised and recovered grains were carried out on three different depths, surface, T/4 and T/2, in order to see differences in micro hardness and if difference in quench rate accentuated eventual differences in micro hardness. Two different loads, 25g and 10g, were used in order to involve different number of subgrains in the plastic flow during indentation. This could show if interaction between plastic flow and subgrain boundaries was of any significance. The result suggests that the influence of recrystallisation on yield strength, as compared to the well recovered structure, is of no significance. No significant effect on the difference in micro hardness as a function of quench rate was observed. The use of different loads did not point at any hardening effect from subgrain boundaries. The general decrease of fracture toughness with increasing yield strength is due to larger plastic zone. Since the plate material is highly textured close to mid thickness, the yield strength is anisotropic. Therefore the macro hardness is used as a measure of the influence from the size of the plastic zone ahead of a crack. Plots of toughness versus macro hardness are shown in Fig. 4a-c). Fig. 3d) shows hardness as a function of depth for the plates. The open symbols represent the hardness of the 150mm plate after a reheattreatment in order to remove the influence from difference in quench rate. Fig. 4d-f) show plots of fracture toughness as a function of macro hardness, but here the different plates are compared with each other. The influence from hardness on the fracture toughness is stronger the thinner the plate. The plates are slightly overaged and intergranular fracture occurs

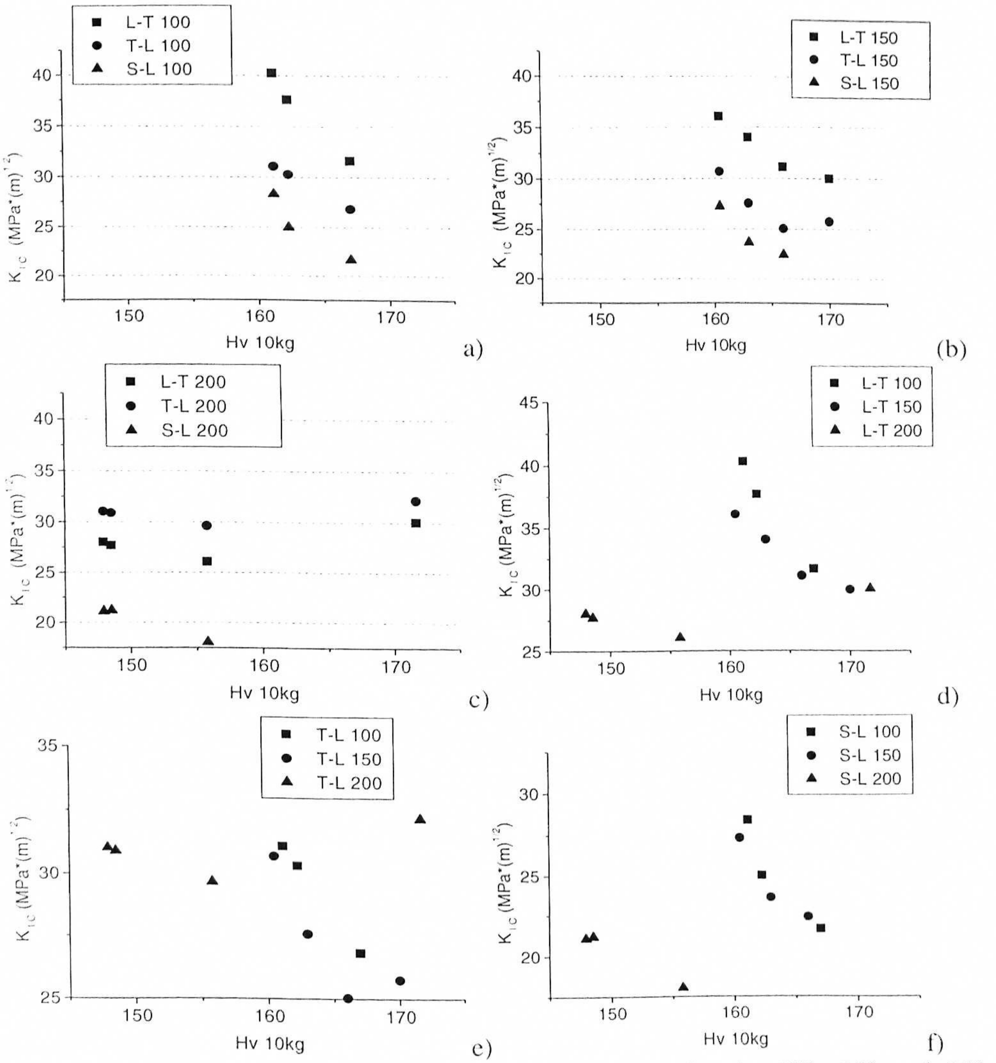

Fig. 4a-c) Fracture toughness as a function of hardness for the 100, 150 and 200mm plates respectively. Fig. 4d-f). (d) Fracture toughness in the L-T direction, (e) fracture toughness in the T-L direction, (f) fracture toughness in the S-L direction.

Thicker gauges leads to lower quench rates, which promotes precipitation in the grain boundaries. Also, the more flattened grain shape increase the ratio between ground boundary and grain volume. This increase in ratio should increase the effect of quench rate.

The lower hardness of material from the mid thickness of the 150mm plate after reheattreatment should then be due to the drop in amount of main alloying elements near the mid thickness, this drop in chemical composition of alloying elements was measured in [9] and is also supported by measurements from the plate manufacturer. The higher degree of recrystallisation at this depth are not believed to have any influence due to the micro hardness observations. A varying distribution of inclusions through the thickness should affect the fracture toughness. No significant variations were observed through the thickness in the 150mm plate [14]. The only observation with significance was that the iron rich inclusions were smaller in size and more frequent close to the surface. They were thought to have been crushed during the hot rolling due to larger shear deformation closer to the rolls. All plates show relatively weak texture at the intermediate thicknesses, T/8 and T/4. Here the strongest texture components are cube and various forms of cube rotated around the normal of the rolling plane. Typical rolling texture components are found in the depths closer to mid thickness. At 3T/8, copper, brass and S are present in all plates, cube texture at a lower level is also found. At mid thickness brass becomes dominant in all the three plates. The dominance of brass is larger for the 100 and the 200mm plate compared to the 150mm plate. The strongest texture is found in the 200mm plate. This suggests that the yield strength anisotropy is pronounced in the 200mm plate. This seems true for the through thickness variation, but not for the planar anisotropy, see Fig. 3c). The grain morphology differs between the plates. The 100 and 150mm plates show similarities. The grains are flat and elongated, their mean sizes are smaller close to the surface. Grain size in the intermediate layers are slightly larger compared to the size at the centre depth [11]. It is also shown in the same reference that the size of the grains in the more reduced plate are slightly smaller compared to the grains in the 150mm plate. However the grain morphology of the 200mm plate is different from the less thick plates. Here the grains are extremely pancake shaped, as could be seen in Fig. 2a). For sheet material this elongated, unrecrystallised grain structure is known to be beneficial for fracture toughness properties [6].

4. Conclusions

- Micro hardness of recrystallised grains compared to recovered grains did not show any significant differences. Properties of flow stress was not significantly affected by subgrain boundaries.
- Recrystallisation did not show any detrimental effect on fracture toughness.
- EBSP mappings showed that recrystallisation not only took place through PSN, but also probably through subgrain growth at grainboundaries within PFZs with sequential SIBM.

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