INVESTIGATION OF ASYMMETRIC ROLLING APPLIED TO TWIN-ROLL CAST Al-Mn ALLOY

POKOVÁ Michaela[1], ZIMINA Mariia[1], CIESLAR Miroslav[1], GRYDIN Olexandr[2]

[1]*Charles University in Prague, Faculty of Mathematics and Physics, Department of Physics of Materials, Prague, Czech Republic, EU, pokova@karlov.mff.cuni.cz*
[2]*University Paderborn, Faculty of Mechanical Engineering, Lehrstuhl für Werkstoffkunde Microscopy, Paderborn, Germany, EU*

Abstract

Twin-roll cast AA3003 series aluminum alloy was subjected to several passes of asymmetric rolling at room temperature. This process is more effective in the grain refinement than conventional cold-rolling. During subsequent annealing at elevated temperatures the deformed grains are replaced by new ones by static recrystallization, which starts near the surfaces of strips. Higher strain imposed by rolling results in a decrease in recrystallization temperature. Nevertheless, the rolling direction remains apparent even after full recrystallization.

Keywords: Twin-roll casting, asymmetric rolling, microhardness, recrystallization

1. INTRODUCTION

Twin-roll casting (TRC) is an alternative method to direct-chill casting techniques for the production of aluminum alloys. Among the advantages of twin-roll casting are mainly high casting speed and more economical production [1]. Recently, many works were devoted to investigations of microstructure evolution in TRC alloys, eg. [2, 3]. However, new methods how to further improve strength of TRC sheets are under an intensive research. Main possibilities are modification of chemical composition and application of severe plastic deformation [4, 5].

Asymmetric rolling (ASR) is a method of severe plastic deformation (SPD), the aim of which is to reduce grain size to submicron range and thus increase the strength of the material. Asymmetric rolling has greater economic efficiency than other SPD techniques such as accumulative roll bonding and equal channel angular pressing, since it produces large volumes of deformed material and can easily be implemented on industrial rolling mills [6].

Asymmetric rolling with different angular velocities of rolls gives rise to intense plastic shear strains, which result in grain refinement and hence improvement of mechanical properties. The most common implementation of different angular velocities is the use of rolls with the same diameter but different speed [7, 8]. The ASR gives rise to a simple shear and compressive strains and develops a shear texture [9].

The aim of the present study is to evaluate the microstructural changes during asymmetrical rolling and subsequent isochronal annealing of modern twin-roll cast AA3003 aluminum alloy.

2. EXPERIMENTAL

An AA3003 series aluminum alloy was studied. The amount of main alloying elements is as follows: 1.02 wt.% Mn, 0.20 wt.% Fe, 0.53 wt.% Si and 0.17 wt.% Zr. This alloy was manufactured by twin-roll casting in industrial conditions to thickness 8.5 mm. Afterwards the sheet was ASR treated in laboratory conditions with higher speed of the upper roll and speed ratio 4. After each step the sheet was rotated by 180° around the rolling direction. First step led to the thickness reduction to 5.3 mm, second one to 3.5 mm, third to 2.5 mm, fourth to 1.9 mm and the final thickness after fifth asymmetric rolling pass was 1.4 mm.

Mechanical properties of ASR sheets were tested by Vickers microhardness (HV) measurement with a load of 100 g at QNess A10+ microhardness tester. Microstructure changes were observed in polarized light by light optical microscope Olympus GX51 after electrochemical polishing by Barker solution [10]. The recrystallization process was monitored during isochronal annealing in an air furnace with the step 50 K/50 min.

3. RESULTS AND DISCUSSION

3.1. Asymmetric rolling

The initial state of the studied alloy after twin-roll casting consists of grains elongated in the rolling direction (RD) and inclined towards the sheet surface, with their length of approximately 200 μm. The grain structure is inhomogeneous through the sheet thickness - the grains are more flat near both the sheet surfaces and a macro-segregation of particles of α-Al(Mn,Fe)Si phase [11] is present in the central part of the sheet (**Fig. 1a**).

During asymmetric rolling the thickness of the sheet is reduced and grains are flattened and elongated. The microhardness gradually increases with the number of ASR passes (**Fig. 2**). From the initial value of 55 HV0.1 the microhardness rises to 80 HV0.1 after the first pass and reaches 95 HV0.1 after five passes. The evolution of the microhardness is similar in both planes perpendicular to the rolling direction and to the transverse direction (TD).

The microhardness distribution is inhomogeneous through the sheet thickness, which is demonstrated on **Fig. 3**. This figure represents microhardness distribution in the plane perpendicular to the transverse direction in the sheet after three passes of ASR. Microhardness is higher near sheet surfaces, where grains are more flattened and also in the central part of the sheet, where the macro-segregation of primary phases occurs. The non-uniformity of microstructure after ASR is connected with the heterogeneous structure of the TRC sheet. This heterogeneity is demonstrated on the grain structure of the sheet deformed by one pass of ASR on **Fig. 1b**).

After further rolling to the thickness 1.4 mm the differences in the grain shape within the sheet thickness become less distinct, pancake grain structure develops and the grain length reaches several mm (**Fig. 1d**).

3.2. Isochronal annealing

The high temperature stability of the asymmetrically rolled sheets is examined during isochronal annealing with heating rate 50 K / 50 min from room temperature to 600 °C. The evolution of microhardness for different number of ASR passes during the annealing is shown on **Fig. 4**.

At annealing temperatures below 200 °C slight increase of microhardness is observed. Such an increase in microhardness was described by Huang et al. [12] in severely deformed aluminum and is attributed to depletion of the aluminum matrix from dislocations and formation of dislocation cells. In such materials with reduced dislocation density new dislocation sources have to be activated to enable further deformation; thus, a higher stress is required. Similar behavior was observed on the same alloy processed by equal channel angular pressing [13] and on similar material deformed by accumulative roll bonding [14]. This effect gets more significant with increasing deformation.

Microhadness starts to decrease in the course of annealing above 200 °C. The higher was the implied deformation, the more pronounced is the microhardness drop between 200 and 400 °C. At 400 °C the microhardness is the same for all sheets regardless the number of undergone asymmetric rolling passes and reaches value around 80 HV0.1. At this stage the grains are still heavily elongated in the rolling direction.

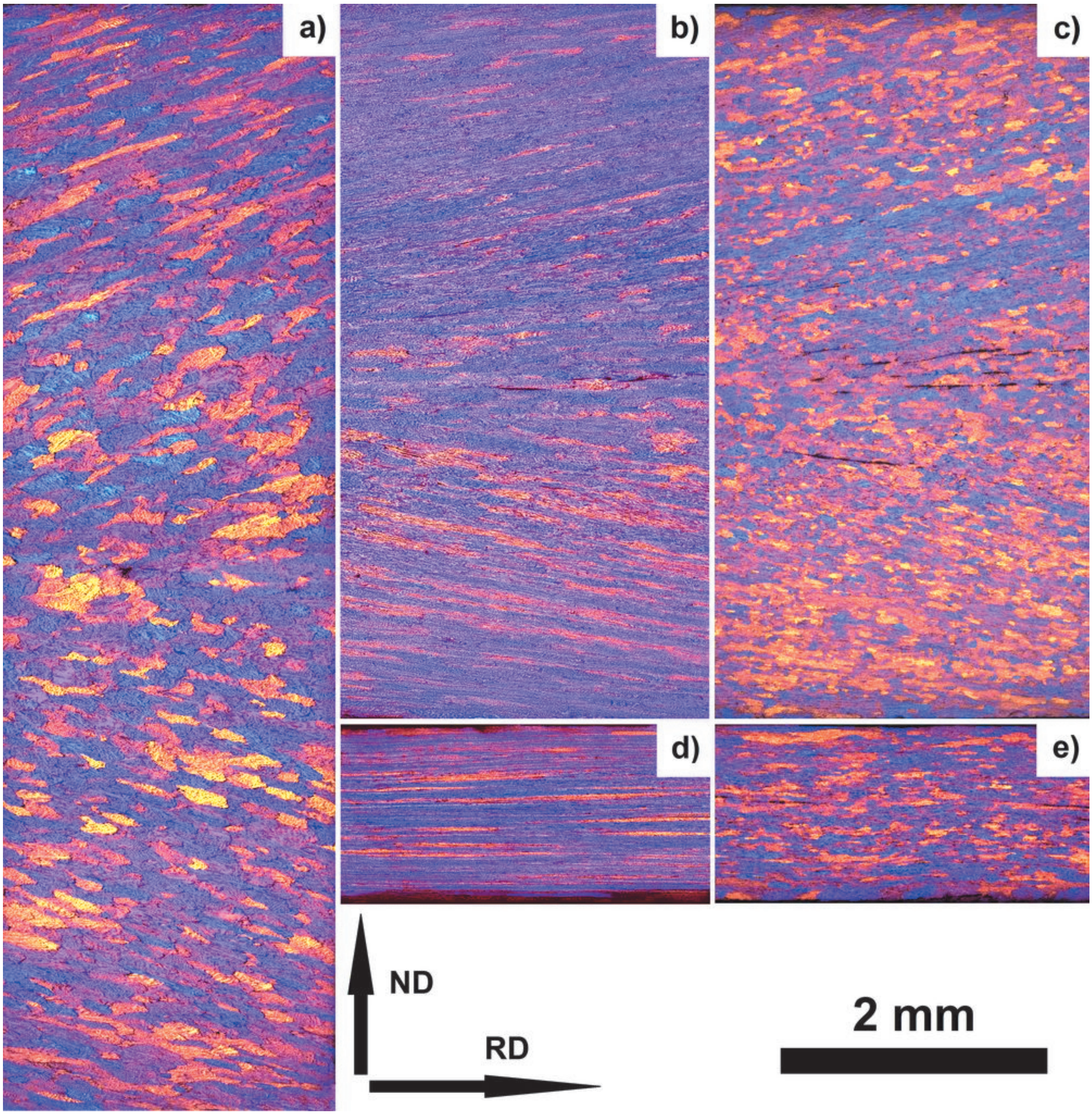

Fig. 1 Light optical micrograph of grain structure of twin-roll cast alloy (a). Elongated grain structure after one (b) and five (d) passes of asymmetric rolling. Recrystallized grains after annealing to 600 °C of ASR sheets deformed by one pass (c) and after annealing to 450 °C of sheet deformed by five ASR passes (e)

Above 400 °C significant drop of microhardness takes place and recrystallization occurs in all the sheets. Recrystallization starts near the sheet surface. The original grains are finer near the surface than in the central part and also the microhardness is higher, which is connected with higher stored deformation energy. Thus, driving force for recrystallization is higher in these areas and recrystallization starts there. Some fractions of grains near the surface grow to a larger size as compared to the central part of the sheet.

The temperature of recrystallization is highly dependent on the sheet thickness, which is closely connected with the stored deformation energy in the matrix. At 450 °C the sheet deformed by five passes of ASR is fully recrystallized (**Fig. 1e**). The newly formed grains are much shorter; however, the rolling direction is still apparent. The average size of recrystallized grains is 70 μm in the rolling direction and 25 μm in the normal direction and is not significantly influenced by the number of ASR passes (**Fig. 5**).

Recrystallization of sheets deformed to lower extent begins at higher annealing temperatures. Example of a partially recrystallized structure is given in **Fig. 6a**. Materials deformed by 2, 3 and 4 passes of ASR are fully recrystallized at 550 °C (**Fig. 6b**), material deformed by only one pass with the lowest stored deformation energy is fully recrystallized after annealing up to 600 °C (**Fig. 1c**).

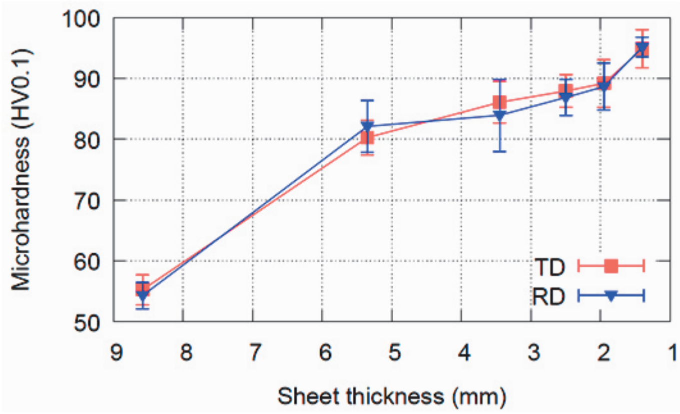

Fig. 2 Microhardness evolution with decreasing sheet thickness during asymmetric rolling; values are measured in planes perpendicular to transverse direction (TD) and rolling direction (RD)

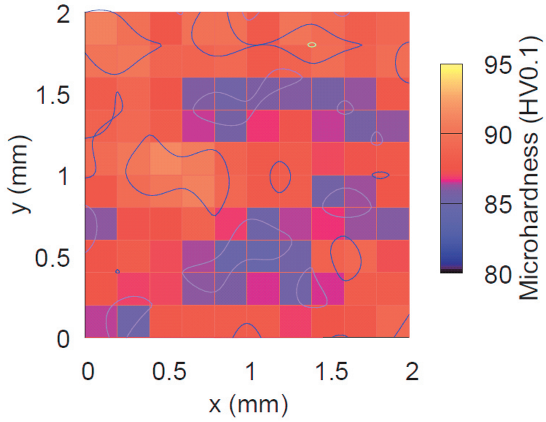

Fig. 3 Microhardness distribution after 3 asymmetric rolling passes measured in the plane perpendicular to the transverse direction

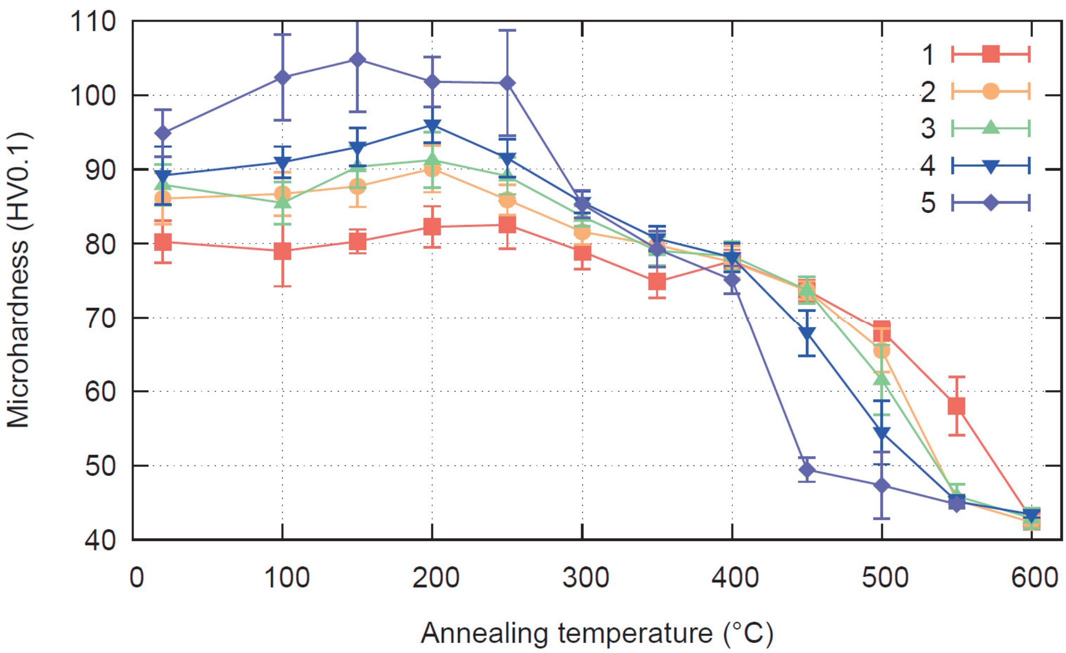

Fig. 4 The evolution of Vickers microhardness in sheets asymmetrically rolled to various thicknesses during isochronal annealing with 50 K / 50 min rate

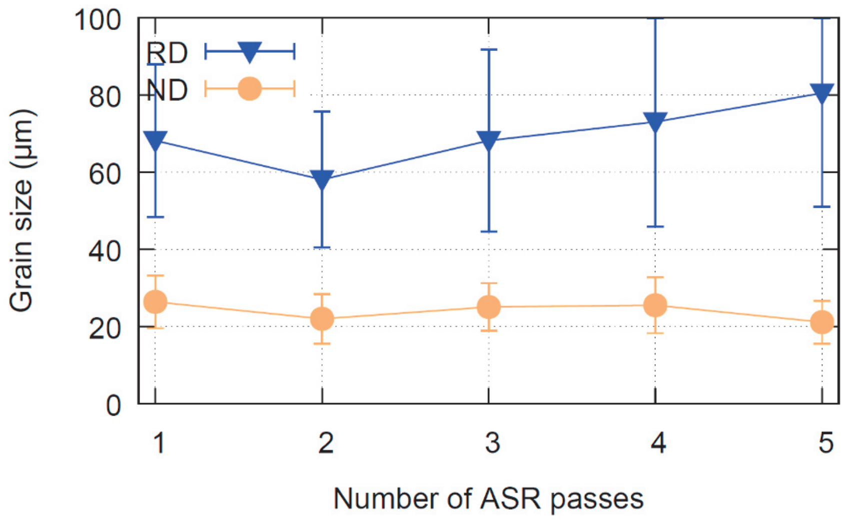

Fig. 5 Recrystallized grain size after annealing up to 600 °C in normal (ND) and rolling direction (RD) for sheets after different number of asymmetric rolling passes

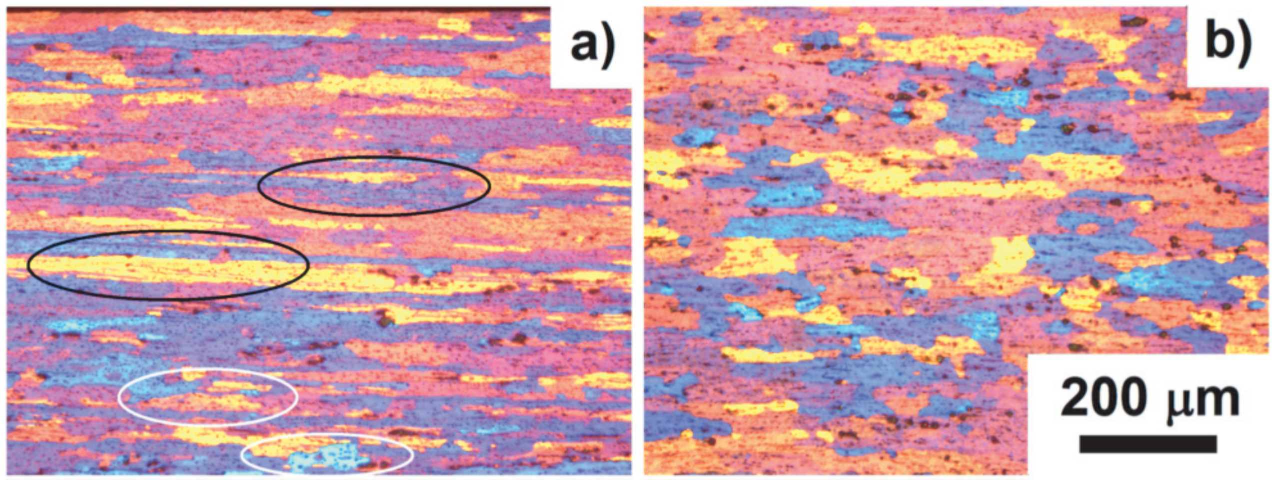

Fig. 6 Grain microstructure of sheets processed by three ASR passes and annealed to 500 °C (a) and 550 °C (b). Deformed parts in (a) are marked by black ellipses, recrystallized by white ones

4. CONCLUSION

Twin-roll cast aluminum alloy was subjected to severe plastic deformation by several passes of asymmetric rolling with the speed ratio of rolls equal to 4. ASR leads to formation of pancake grain structure and substantial increase in microhardness.

The higher is the stored deformation energy induced into the material during ASR, the lower is the thermal stability at elevated temperatures and sheets recrystallize at lower temperatures. The grain structure remained inhomogeneous after recrystallization with the average grain size 70 μm, which is lower than in twin-roll cast sheet.

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