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EFFECTS OF COLD ROLLING (CR) AND ANNEALING TIME ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AA 5052 ALUMINUM ALLOY

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In this paper, the influences of cold rolling and annealing time on the microstructure and mechanical behaviors of AA 5052 aluminum alloy were investigated. An aluminum sheet was cold-rolled at room temperature at 15, 30, and 45 % rolling reduction. The 45 % cold-rolled sample was subsequently annealed at 370 °C for 2, 4, and 6 h. The microstructure was observed using optical microscopy whereas the mechanical behaviors were evaluated through hardness and tensile tests. It was found that the equiaxed grains are severely elongated along the rolling direction with increased rolling reduction. The hardness and strength increase significantly with an increase of rolling reduction but the ductility decreases. The annealing treatment reduces hardness and strength but improves the ductility.

Keywords: AA 5052; cold rolling; annealing; microstructure; mechanical properties

INTRODUCTION

Due to its high strength-to-weight ratio, excellent corrosion resistance, toughness, and good weldability, the non-heat treatable AA 5052 aluminum alloy has been extensively used in various industries such as automotive, marine and construction industries [1]. However, this alloy is not strong enough for structural material applications [2]. It has been well- documented that there are two famous methods to enhance the strength of non-heat-treatable Al-Mg alloy, namely work hardening or strain hardening and micro-alloying [3]. Cold rolling is one of the most widely used strain hardening methods that improves the strength and hardness significantly but reduces the ductility of A-Mg alloy due to the increased dislocation density [4].

It is well-known that the annealing heat treatment is one of the most used methods to enhance the ductility of cold-rolled aluminum alloys [5]. Several factors play a role in the success of annealing such as temperature, holding time, and heating rate of annealing. Numerous studies have been conducted on enhancing the mechanical properties of non-heat treatable Al-Mg alloy using strain hardening methods followed by annealing. It was reported that strain hardening methods such as accumulative roll-bonding (ARB), cryogenic rolling [6], and warm rolling [7] subjected to the aluminum alloy can drastically improve strength and hardness but decrease ductility. So far, investigations on the mechanical properties of cold-rolled 5052 aluminum alloy followed by annealing were still limited.

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In this experiment, the AA 5052 aluminum alloy sheet was first cold-rolled under different rolling reductions, namely 15, 30, and 45 %. The 45 % reduction cold-rolled AA 5052 sheet was then annealed at 370 °C at various holding times: 2, 4, and 6 h. The influences of cold rolling and annealing time on the microstructure and mechanical properties of AA 5052 alloy are discussed in this article.

MATERIALS AND EXPERIMENTAL METHODS

A commercial AA 5052 alloy sheet with a thickness of 3 mm was used in this experiment. Its nominal composition was 2,37 % Mg, 0,31 % Fe, 0,22 % Cr, 0,08 % Mn, 0,11 % Si, and with the balance of Al (all in wt%). The sheet was first homogenized at 470 °C for 6 h with a heating rate of 5 °C/min and then cooled in air. The homogenized sheet was cold-rolled at room temperature with 15, 30, and 45 % rolling reductions. The 45 % cold-rolled sample was then annealed at 370 °C at various holding times of 2, 4, and 6 with the heating rate of 5 °/min.

The microstructures of as-received, cold-rolled, and annealed samples were examined using optical microscopy on the short transverse and longitudinal (rolling) directions. The specimens were made using the standard metallographic procedures such as grinding, polishing, and etching using Keller's reagent.

Mechanical behaviors of as-received, rolled, and annealed samples were determined through hardness and tensile tests. Vickers microhardness was measured using a Boehler Micromet hardness tester under a load of 50 g and a loading duration of 15 s. The strength and elongation were assessed through a tensile test using a servo-hydraulic universal testing machine. All hardness and tensile specimens were taken along the rolling direction.

RESULTS AND DISCUSSION

Three main directions in AA 5052 aluminum alloy with the appropriate microstructure are presented in Figure 1a. The microstructures of the α(Al) matrix and a large number of second phases dispersed within the grain are observed in all samples. Figure 1b shows the microstructure of the as-received sample in a longitudinal direction where large equiaxed grains with no preferred orientation can be observed. The elongated grain is exhibited in the microstructures of as-received and rolled samples in a short transverse direction indicating the characteristic of rolled alloy structure (Figure 1c-f). The cold-rolling reduces the grain size of the AA 5052 alloy. The fine-grain alloy after cold rolling may be attributed to the increased number of nucleation sites when the higher rolling reduction is applied [8].

The optical microstructures in the short transverse direction of the rolled sample with a reduction of 45 % and rolled samples subjected to annealing for 2, 4, and 6 h are shown in Figure 2. The elongated grains can still be dominantly observed in the rolled sample with a reduction of 45 % and rolled samples subjected to annealing for 2 and 4 h (Figure 2a, b, c). Moreover, severe equiaxed grains as a result of recrystallization during annealing are also shown in the structure of rolled samples followed by annealing for 2 and 4 h. On the other hand, more equiaxed grains are exhibited in the microstructure of the rolled sample followed by annealing for 6 h (Figure 2d). This indicates that annealing at 370 °C for 6 h has changed the elongated grain structures to become the equiaxed grains. This may be associated with the recrystallization phenomenon that occurred in the rolled AA 5052 alloy followed by annealing at 370 °C.

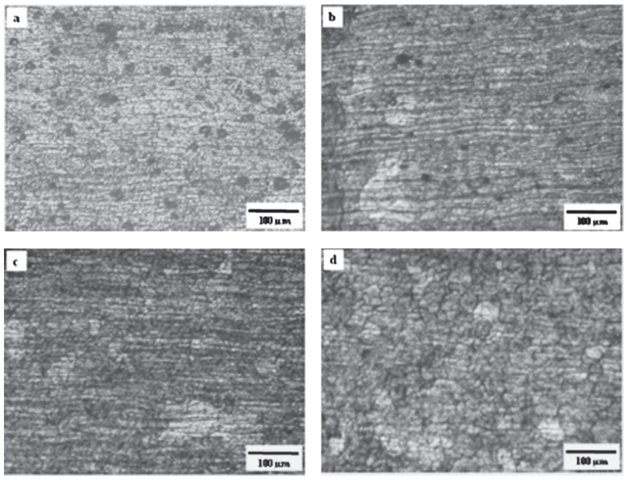

Figure 2 Optical micrographs of (a) rolled sample, (b) rolled sample followed by annealing for 2 h, (c) rolled sample followed by annealing for 4 h, (d) rolled sample followed by annealing for 6 h

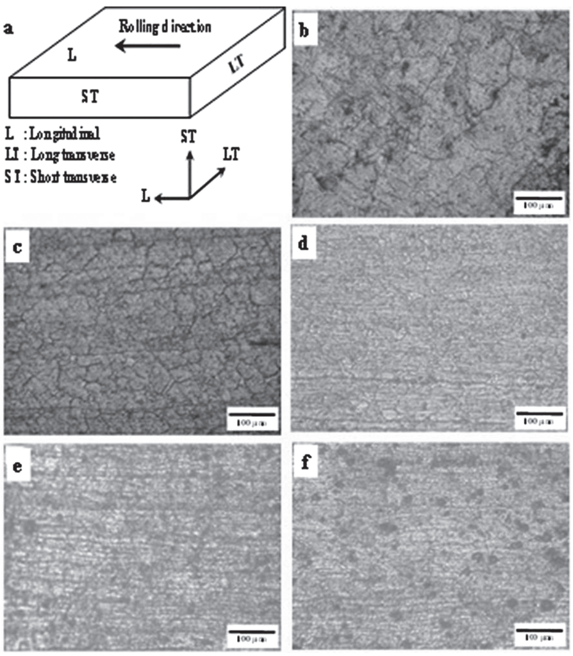

Figure 1 (a) Three main directions in AA 5052 sheet with corresponding microstructures:
(b) As-received sample in longitudinal direction
(c) As-received sample
(d) 15 % reduction rolled sample
(e) 30 % reduction rolled sample
(f) 45 % reduction rolled sample

The hardness values of as-received and rolled AA 5052 alloy at various rolling reductions are presented in Figure 3. It is obvious that the hardness was significantly increased with rolling reduction. This may be attributed to three reasons as follows [9,10]. Firstly, the cold rolling results in the decrease in grain size, and the grain boundary increases with an increase of rolling reduction. The smaller grain size is more effective at inhibiting the dislocation movement and multiplication resulting in enhanced hardness. Secondly, the density of dislocations was remarkably increased during cold rolling. Furthermore, the existing dislocations hinder the nucleation and movement of new dislocations leading to the increased hardness of this material. Thirdly, the development of texture orientation due to cold rolling has

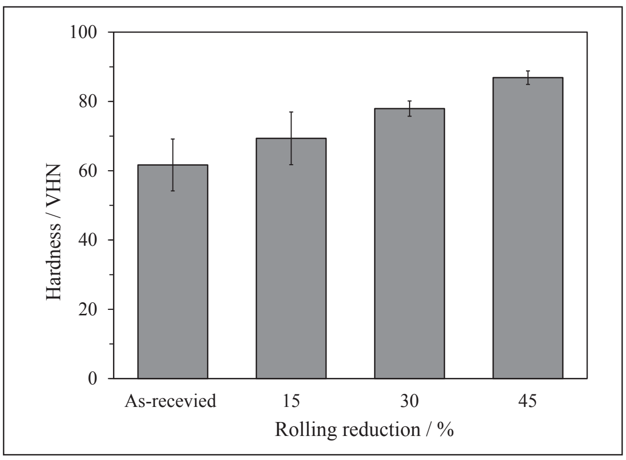

Figure 3 Variation of hardness with different rolling reduction

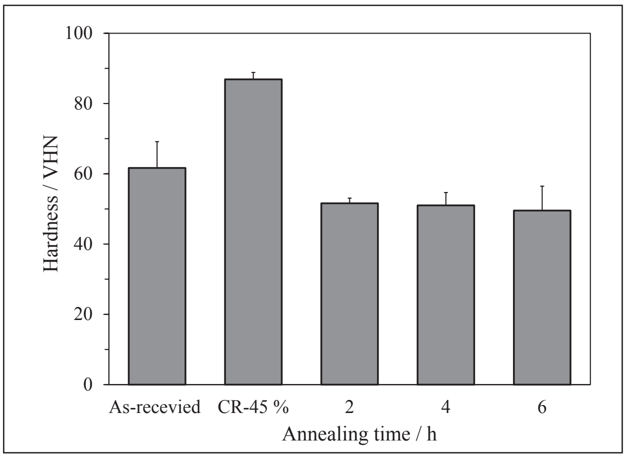

Figure 4 Variation of hardness with different annealing time

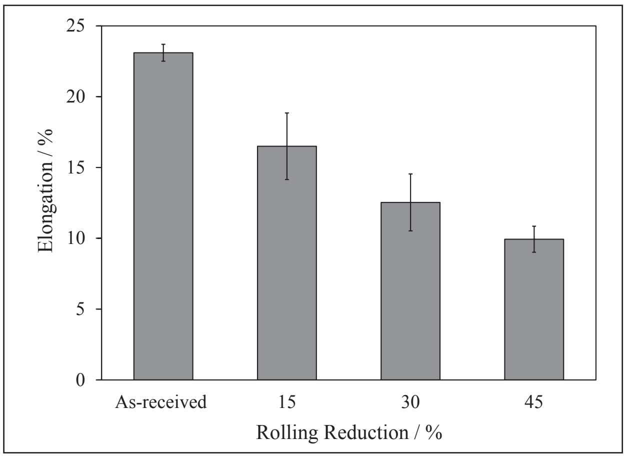

Figure 6 Variation of elongation with different rolling reduction

an effective role in improving the hardness and mechanical properties of AA 5052 alloy.

The influence of annealing time on the hardness of the 45 % rolled sample is presented in Figure 4. The hardness of all rolled and annealed samples is lower than both as-received and rolled samples. This means that the annealing treatment drastically reduces the hardness of rolled AA 5052 alloy. This is ascribed to recrystallization leading to coarsening and growth of grains [5,11]. The dislocation density decreased due to recrystallization during annealing resulting in the reduced hardness of rolled AA 5052 aluminum alloy. From Figure 4, it can be also observed that hardness is unchanged with an increase in annealing holding time. This means that an increase in annealing time did not influence the hardness. Full recrystallization of grains that occurred after an annealing time of 2 h may be responsible for the unchanged hardness with increasing annealing time.

Figure 5 displays the yield and tensile strength of as-received and rolled AA 5052 aluminum alloy under different rolling reductions. It was found that the yield and tensile strength of the rolled 5052 aluminum alloy were higher than as-received. This implies that cold rolling improved the strength of AA 5052 aluminum alloy. This is in agreement with the hardness results as demonstrated in Figure 3. Figure 6 presents the elongation of as-received and rolled AA 5052 aluminum alloy under different rolling reduction. The ductility was decreased by increasing annealing holding time. This is especially associated with the more obvious effect of work hardening and an increase in the dislocation density [12]. Besides, by increasing the rolling reduction, the grains become very elongated through the rolling direction, which forms the fiber texture and finally results in increased tensile strength and reduced ductility [5].

Figure 7 depicts the influence of annealing time on the yield and tensile strength of AA 5052 aluminum alloy. It is clear that the yield and tensile strength were drastically reduced after annealing at 370 °*C for 2 h. This reduction might be attributed to* a larger decrease in dislocation densities during annealing at 370 °*C for 2 h. However, the annealing holding time for 4 and 6 h* does not affect the strength. On the other hand, it can be observed in Figure 8 that elongation significantly increases after annealing for 2 h but further annealing time has no effect. The rearrangement of dislocation and reduction of dislocation densities during recrystal-

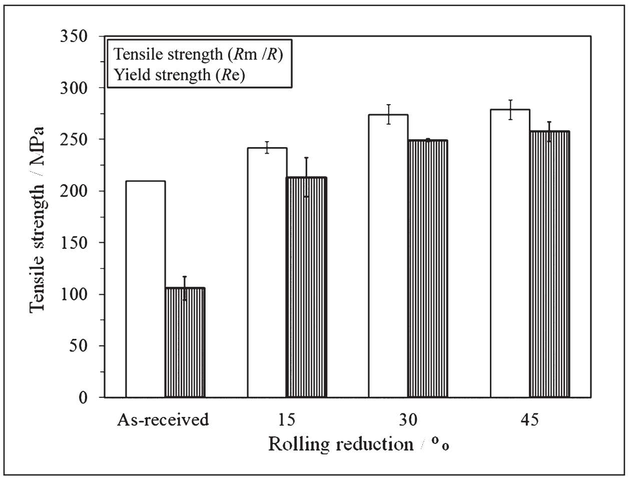

Figure 5 Variation of yield and tensile strength with different rolling reduction

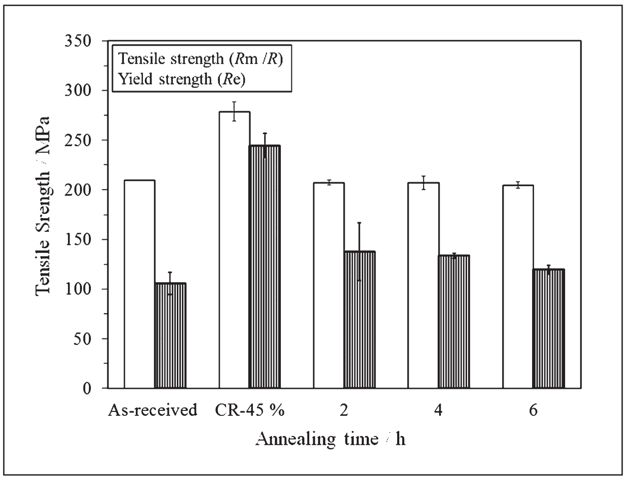

Figure 7 Variation of yield and tensile strength with different annealing time

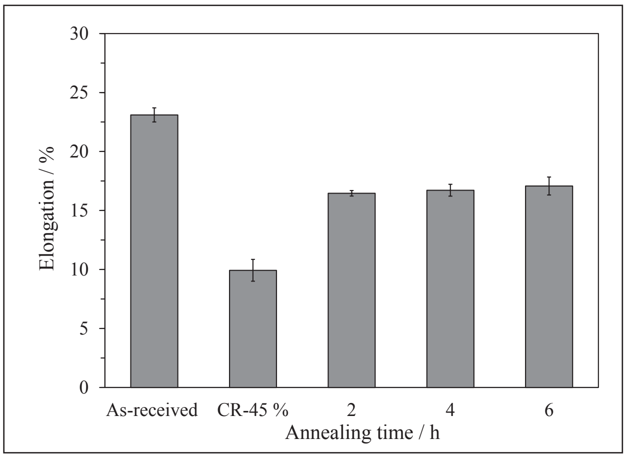

Figure 8 Variation of elongation with different annealing time

lization in annealing treatment might be responsible for the increase in elongation [13]. From Figures 7 and 8, it was found that the strength and ductility were unchanged with increasing annealing time.

CONCLUSIONS

The influences of cold rolling and annealing time on the microstructure and mechanical properties of AA 5052 aluminum alloy was studied. Results displayed the equiaxed grains are severely elongated along the rolling direction by increasing rolling reduction. The elongated microstructures are changed to equiaxial structures due to recrystallization after annealing for 6 h. With an increase in rolling reduction, the hardness and strength enhance significantly but the ductility decreases drastically. Annealing treatment leads to a reduction in the hardness and strength but enhances the ductility. Increasing annealing time does not affect the hardness and strength of AA aluminum alloy.

Acknowledgments

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Note: The responsible English translator is Emily Peterson - the Language Center, Syiah Kuala University, Indonesia