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Cryorolling of Al 5083 Alloy: Microstructure and Mechanical Properties at Various Post Annealing Temperatures

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ABSTRACT. The present work discusses the effect of post annealing at different temperatures on cryorolled Al 5083 alloy. A new method called cryorolling has been widely studied among the researchers due to its potential of obtaining ultrafine grained which contributed to the enhancement of mechanical properties of metal alloys. The samples were immersed in liquid nitrogen followed by cryorolling and then the samples were annealed at various temperatures (150 °C, 200 °C, 250 °C, 300 °C). The hardness and tensile values decreased with increasing post annealing temperatures. The microstructure also showed some coarsening of subgrains after post annealing.

***Keywords**: Cryorolling, Post annealing, Ultrafine grain, Microstructure, Dislocation;*

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1. INTRODUCTION

Cryorolling has been considered as one of the potential route in producing ultrafine grained structure in metal working. It is basically a rolling process carried out in a cryogenic condition (liquid nitrogen temperature), hence giving the name cryorolling [1]. It has been receiving many attentions among researchers due to its likely formation of ultrafine grained structure and also improvement in mechanical properties. In cryorolling, the strain hardened metals is preserved as a result of the suppression of the dynamic recovery [2]. Rolling under cryogenic temperature has been widely used to improve the materials properties especially the strength and hardness. The grain refinement from cryorolling is what makes the method so famous for achieving ultrafine grained structure (UFG) structure in bulk metals. A comparatively lower plastic deformation is sufficient to produce strain for UFG formation in cryorolling than the existing SPD techniques.

The major problem with high strength UFG materials is the low ductility which might limit their usage in practical application. Annealing treatment after cryorolling process had been claimed to be an effective method to improve the ductility. The combination of strength and ductility would give a better range of the application for this alloy. Among Al alloy, the post annealing effect of Al-Cu based alloy has been studied in details and less work is focused on Al-Mg alloy [3]. Thus, Al-Mg based Al 5083 alloy was chosen for the investigation due to its special characteristics such as moderate strength, good corrosion resistance and high formability with reasonable price [4]. Moreover, the alloy also contains a small percentage of magnesium (Mg) which helps to influence the dislocation mechanism in the alloy. This work was carried out to focus on the effect of post annealing behavior on microstructure and mechanical properties of cryorolled Al 5083 alloy.

2. MATERIALS AND METHODS

The commercial Al 5083 alloy sheets of 15 mm × 50 mm size were used for the present investigation. The starting material was first characterized using X-ray fluorescence (XRF) to identify the elemental composition. In order to do so, the samples were grinded and polished for a mirror-like condition. The sample then underwent pre-heat treatment at annealing temperature of 300 °C. The 5 mm thick alloy then was dipped in liquid nitrogen for 1 hour to keep it at cryogenic condition and immediately rolled using a two high rolling mill with 50% reduction. The dipping interval for each rolling passes was set to be 5 min. The final sheet produced having 2.5 mm thickness. After rolling, the samples were post-annealed for 2 hours at four different temperatures; 150 °C, 200 °C, 250 °C, 300 °C. The sample then was characterized for microstructure, hardness value and tensile strength using optical microscope equipped with image analyser, Leco Microhardness Tester Machine LM248AT and Universal Instron 5567.

3. RESULTS AND DISCUSSION

3.1 Material selection. The XRF results showed the elemental composition of as-received Al alloy which consisted of 97.68% Al, 1.47% Mg and a few traces of Fe and Si of 0.37% and 0.17% respectively. The amount of aluminium and magnesium in the sample was comparable with the theoretical composition as shown in Table 1.

Table 1 Chemical composition of Al 5083 alloy

Elements	Wt.%
Al	97.68
Mg	1.47
Fe	0.37
Si	0.16
Cr	0.17
Mn	0.09
Cu	0.02

3.2 Hardness Test. The average hardness value of cryorolled sample with different annealing temperatures is shown in Fig. 1. The hardness value of cryorolled sample without post annealled was 128.6 HV. The hardness values continuously decreased with increasing annealing temperature as a result of stress relieved. This might be due to the rearrangement of dislocations including some loss of dislocations, as the recovery proceeded [5].

The hardness decreased slightly up to 200 °C and dropped rapidly to 87 HV at 250 °C. The rapid decrease showed that at 250 °C the sample underwent recrystallization process. Since the rate of recrystallization is mainly influenced by the amount of deformation, it shows that the samples received larger deformation which indicates that the softening rate during annealing would be closely related to the volume fraction of recrystallized grains [6,7].

In addition, the lower hardness value of the samples annealed at 200-250 °C indicates the presence of larger fraction recrystallized grains with minimum residual dislocations. These phenomenons showed that the hardness in annealed sample was influenced by the fraction of recrystallized grains.

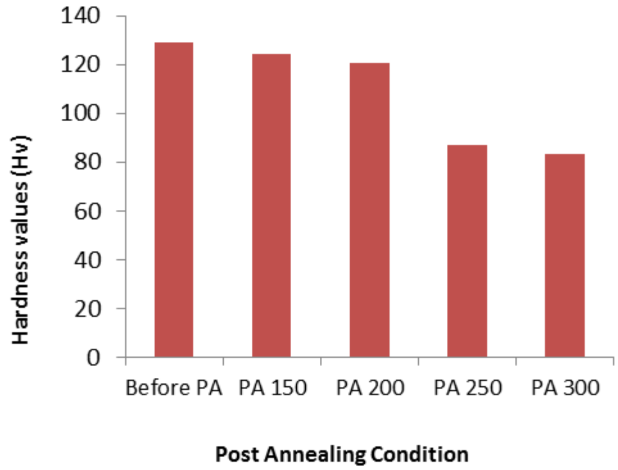

Fig. 1 Hardness values of cryorolled sample at different post annealing temperatures

3.3 Tensile test. The average tensile strength of cryorolled samples with different post annealing temperatures is shown in Fig. 2. Tensile test was performed under controlled condition at the crosshead speed of 2.5 mm/ min. The tensile strength showed similar trend to that of hardness in Fig. 1, where it dropped uniformly as annealing temperature increases. At annealing 150 °C, the tensile strength decreased about 4% from 435 MPa to 417 MPa due to small change in the dislocation densities during post annealing. Large decrease of strength follows afterward at 200-250 °C could be attributed to the changes of dislocation substructures dimension during post annealing [6]. The significant change occurs at annealing temperatures of 200-250 °C where the uniform elongation shows a rapid increase from 19% to 33%. This indicates the rearrangement of the dislocations during recovery. The yield strength of the annealed samples also showed the same decreasing pattern with 4-6% reduction. Annealing above 250 °C has kept the tensile and yield strength value on the same level while the uniform elongation has no significant change. Cryorolled sample with subsequent annealing showed about 5-7% of improvement as compared to un-annealed sample. These results are quite consistent with Lin et al. [8] who have reported the similar trend in the tensile properties due to changes of dislocation densities during recovery process.

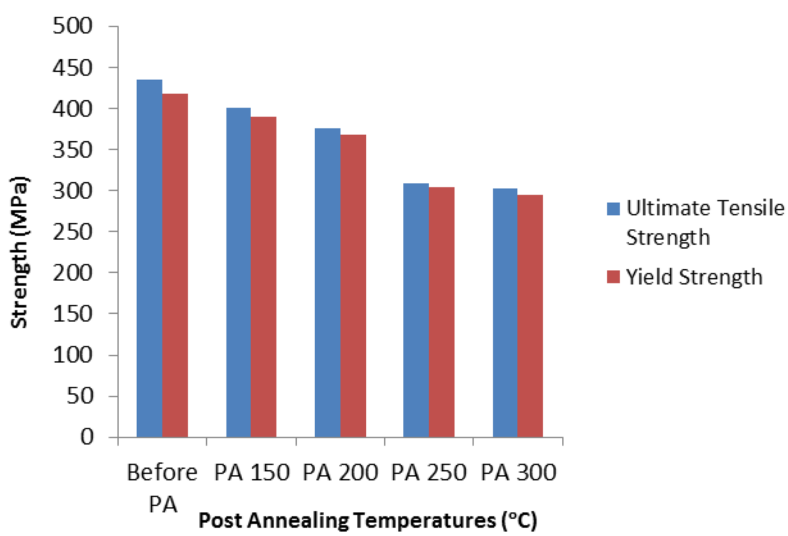

Fig. 2 Strength of cryorolled sample at different post annealing temperatures

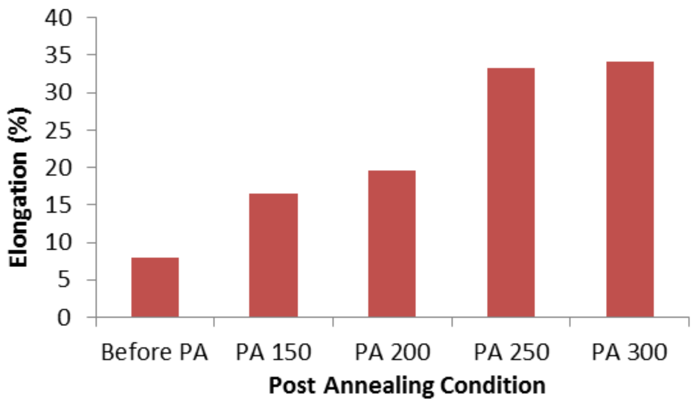

Fig. 3 Elongation of cryorolled sample at different post annealing temperatures

3.4 Microstructure. Fig. 3 shows the microstructural observation of cryorolled samples at different post annealing temperatures. The cryorolled sample showed severely elongated grain along the rolling direction. There were no observable changes in the microstructure below 200 °C (Fig. 5b and 5c) which would be expected to have little effect as boundary mobilities are very low [8]. As the annealing temperatures increases, the subgrain formation and rearrangement of dislocation takes place. Elongated grains recovered into subgrain boundaries as recovery proceed. The subgrain width simultaneously increases which resulted in the reduction of the subgrain aspect ratio [6].

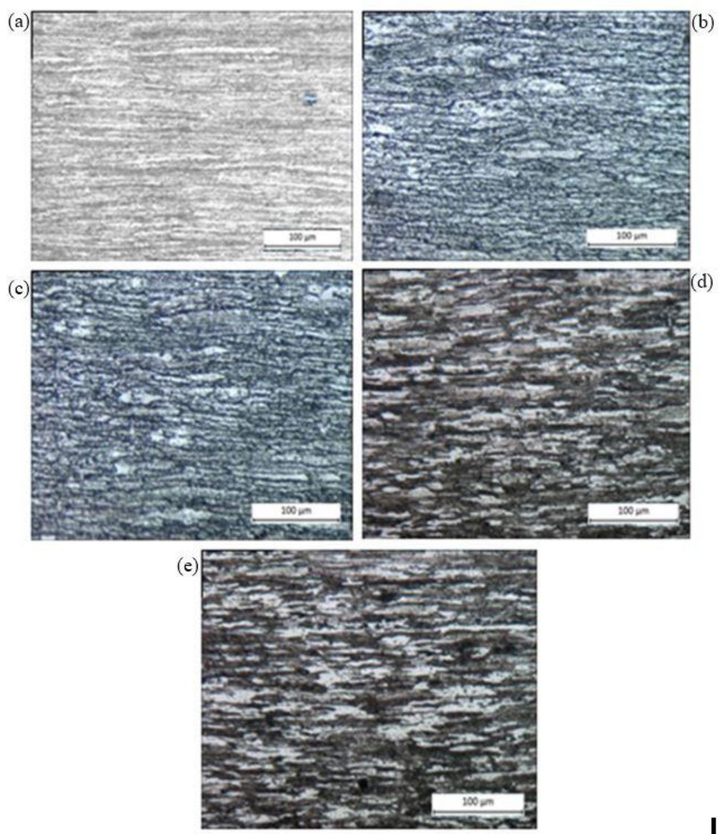

Fig. 4 Microstructure of (a) cryorolled sample without annealing, (b-d) cryorolled samples at post annealing temperatures of 150 °C, 200 °C, 250 °C and 300 °C

4. SUMMARY

The effect of post annealing temperatures on cryorolling samples is indeed important as it gives changes to the mechanical properties and microstructure. The mechanical properties of the cryorolled Al 5083 alloy and subsequently annealed at temperatures 200-250 °C were mainly influenced by the volume fraction of recrystallized grains. It can be concluded that at this particular temperature the grains recrystallized best compared with the other temperatures. Post annealing also effected the microstructure by recovered the elongated grains into subgrain boundaries. Although the results of hardness and tensile strength after post annealing is slightly decreasing, it is important to choose the best alloy that can meet the standard of any applications of good strength and adequate toughness.

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