Effect of solution treatment on Al 1100 cryorolled sheet alloy

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Abstract. Influence of cryorolling (CR) on Al 1100 alloy was investigated. Prior to cryorolling process, samples were solution treated at various temperatures (500ºC, 540ºC and 580ºC) and times (2, 4, 6 hrs) to study the effect of solution treatment on the percentage reduction and microhardness of cryorolled samples. Sample solution treated at 540ºC for 2 hrs showed the highest hardness of 69.74 Hv and the highest percentage reduction of 32%.

1. Introduction

Nowadays, various research works are being conducted to replace heavy steel body constructions with lighter aluminium ones in order to meet stronger energy consumption and environmental standards. The most important technical obstacle in achieving this goal is the inferior ductility properties of most aluminium sheet alloys [1]. It has been reported that control of the microstructures and the texture of materials is essential for improvement of their mechanical properties [1,2]. Hence, for automobile body applications, low-carbon steel sheets were widely used in the past year. But now aluminium alloys are most commonly used in light weight applications in the aerospace, automotive, marine and other industries applications [2,3]. They represent the highest volume (90%) of extruded aluminium products in the western countries [4].

Aluminium-based-alloys, such as Al 1000 series and 6000 series, have been widely used as structural components because of their desirable attributes, such as high strength-to-mass ratio, easy formability, good weldability, high corrosion resistance and low cost compared to other materials [5]. The mechanical properties of these aluminium alloys can be enhanced further by refining the grain structures as the maximum property limit has been achieved in its bulk form. The processing and development of strain-hardened and submicron materials have gained significant importance in recent times due to the superior mechanical properties achievable in these materials due to the grain size effect proposed by the Hall-Petch relationship [6].
Recently, submicron materials have been studied extensively and received considerable research interest due to their superior mechanical properties such as higher strength and ductility as compare to that of its bulk materials [7] and provide high strength without the degradation of toughness [8]. The demand for higher strength, toughness, and strength to weight ratio of aluminum alloys for structural applications is ever growing owing to the increasing importance of achieving longer life time and cost effectiveness of the materials [9]. This is due to the ever-growing demand for superior mechanical properties of Al alloys, a new processing route, namely severe plastic deformation technique (SPD) has been used extensively to produce this alloy [1,2,6].

SPD techniques such as equal channel angular pressing, accumulative roll bonding, multiple compression and high pressure torsion are increasingly being studied for the production of bulk ultra-fine grained metals and alloys [8,9]. Many researchers investigated the microstructural features of the rolled face-centered cubic metals, with medium to high stacking faults energies such as Cu and Al. However, the processing of bulk aluminum alloys to ultrafine grain sizes especially in Al, through the conventional route is very difficult due to its high stacking fault energy [2] and the reduced driving force available for recrystallization [9]. Hence, to obviate these difficulties, cryorolling has been identified as a viable route to produce ultrafine grained materials, as it requires less plastic deformations with strains much larger than unity 4]. The aim of this study was to perform the cryorolling process to an Al Al1100 aluminum alloy sheet and to investigate the effect on microstructural evolution as well as microhardness of the processed sheets.

2. Experimental Procedure

The 1100 Al sheets with 1mm thickness having the compositions of 0.57% Fe, 0.12% Cu, 0.13% Si, 0.03% Ti, 0.02% Mg, 0.013% Mn, 0.017% Ni, 0.01% Zn and 99.09% Al were purchased from Lian Giap & Co (Penang), Sdn. Bhd. The sheets were cut to into dimension of 25 mm x 15 mm x 1 mm using hydraulic cutter. The sheets were solutionised at three different temperature 500˚C, 540˚C and 580˚C for 2,4 and 6 hours followed by water quenching. The solutionised sample was subjected to cryorolling by dipping the samples in liquid nitrogen for 30 minutes before first pass and 5 minute for each subsequent pass until 100 passes. Microhardness test was carried out using Leco Microhardness Tester Machine LM248AT to determine the hardness value of all the cryorolled samples. The microstructures of the selected samples were examined under Metallurgical Microscope Olympus BX51M.

3. Results and Discussion

3.1 Effect of cryorolling on hardness of Al 1100 alloy.

Table 1 present the sample description and sample condition to study the effect of cryorolling on mechanical properties of Al 1100 alloy and the results are shown in Figure 1.

| Sample Discription | Sample Condition                  |
|---------------------|-----------------------------------|
| Sample 1            | Raw Material                      |
| Sample 2            | Raw Material + Dipped in liquid nitrogen |
| Sample 3            | Raw Material + Rolled             |
| Sample 4            | Raw Material + Dipped in liquid + Rolled |
The hardness of raw sample increases from 46.1 Hv to 48.2 Hv after dipped in liquid nitrogen for 30 min as shown in Figure 2. The increment of hardness is about 4.6%. The rolled sample have increased about 9.5% compared to raw material. The highest hardness value of 52.10 Hv was achieved for sample underwent both dipping and rolling process with a total of 13% increment. During dipping in liquid nitrogen, the volume of material contracted due to cryogenic temperature. The volume contraction released great compression deformation energy that served as the driving force for the formation and movement of dislocations. The improvement in dislocation density played a significant role in enhancing mechanical properties [10]. In addition, the compressive residual stresses of the material were higher after cryogenic treatment compared to before the cryogenic treatment. Both of these effects can enhance the hardness of the Al 1100 alloy. Apart from that, the cryogenic condition of liquid nitrogen helps in producing smaller grains by providing shrinkage to the void during dipping period. This behavior showed the significant effect of liquid nitrogen which is supposed to help in increasing the hardness value [11, 12].

3.2 Effect of solution treatment on cryorolled samples.

The percentage reduction for 500°C, 540°C and 580°C at different soaking times 2, 4 and 6 hours after cryorolled are shown in Figure 2, Figure 3 and Figure 4. The highest percentage of reduction for solution treated sample at 500°C was achieved at the 6 hours soaking time with a total reduction of 33%, then followed by 4 hours soaking time with a 29% reduction and 2 hours sample with a 27% reduction. At 4 hours soaking time, the percentage of reduction seems to increase much slower compared to the other soaking times. Due to the lower solution treatment temperature of 500°C, it requires more soaking time to completely become solid solution. Shorter soaking time resulted in a lower percentage of reduction because the alloying elements were not fully dispersed into the aluminium matrix [13].

For sample solution treated at 540°C, the highest percentage of reduction achieved at 2 hours soaking time with 32% reduction. The sample with 6 hours soaking time has the lowest percentage of reduction with 24% and it produced lesser reduction due to higher dissolution rate at which the soluble particles dissolve. The sample solution treated at 540°C have a higher reduction rate at lowest soaking time compared with sample solution treated at 500°C. This is due to the effect of solution treatment temperature which gave different effects on the solid solution production for each sample. Higher solution
treatment temperature tends to yield a solid solution faster than the lower temperature. Therefore, shortest soaking time can produce a higher reduction rate.

From Figure 4, it showed that the sample soaking for 2 hours possessed the highest percentage of reduction (38%) followed by 4 hours and 6 hours sample with (35%) and (29%) respectively. Much lower reduction was showed by sample soaked for 6 hours. This may be due to high rate of dissolution of strengthening elements when soaking time is longer. The sample solution treated at 580°C required lesser soaking time of 2 hours because the solid solution form faster at high temperature.

Figure 2: Percentage of reduction for Al 1100 alloy solution treated at 500°C

Figure 3: Percentage of reduction for Al 1100 alloy solution treated at 540°C
Microhardness of Al 1100 alloy after solution treatment is shown in Figure 5. The microhardness of the solution treated samples were lower compared with the starting material. The decreased in solution treated sample is due to a homogenous solid solution which produces a single phase during solution treatment, thus producing soft alloy with a lower hardness.

Microhardness of Al 1100 alloy after solution treated and cryorolled is shown in Figure 6. The microhardness of the samples after cryorolled were higher than the solution treated samples. Samples solution treated at 540°C and 580°C and cryorolled showed a decrease in microhardness as soaking time increased. On the other hand samples solution treated at 500°C and cryorolled showed increased in hardness as soaking time increased from 2 to 6 hours. Both samples solution treated at 540°C and 580°C and cryorolled achieved the highest hardness at 2 hours soaking time compared to the sample solution treated at 500°C and cryorolled which achieved the highest hardness at 6 hours soaking time. This is due to the effect of the solution treatment temperature where dislocations tend to rearrange faster at higher temperatures in shorter time [14]. Overall, sample solution treated at 540°C and cryorolled has the highest hardness of 69.74 Hv at 2 hours soaking time with 53% increment. The rapid increase of hardness for cryorolled samples seems to be attributed to strain hardening as a result of the subgrain boundary formation rather than grain refinement [15].

The hardness result was matched with the percentage of reduction achieved at a particular temperature and soaking time. The enhancement in hardness is mainly attributed to the generation and accumulation of dislocations density in the samples during rolling at liquid nitrogen temperature as reported by [16]. High dislocation density increases the strength by work hardening mechanism. Moreover according to [17] suppression of dynamic recovery during deformation at cryogenic temperature has been found to be the reason for enhanced in hardness due to the high density of defects generated by deformation process.
4.0 Conclusion

Cryorolling has successfully produced the Al 1100 sheet alloy with improved hardness. Solution treatment temperatures and soaking times play a vital role to ensure all the solute atom dissolve in the matrix Al which help to suppress the dynamic recovery during cryorolled. Solution treatment at 540 °C for 2 hrs showed the high percentage reduction in sample for 100 pass and the highest hardness.
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