Study on the microstructure and mechanical properties during cold rolling and annealing process of Cu-30Zn-1Al-1Mn Alloys

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Abstract. This research was conducted to determine the effect of cold rolling and annealing process on the microstructure and mechanical properties of the Cu-30Zn-1Al-1Mn brass alloy produced by gravity casting. Samples were cold rolled with deformation levels of 20%, 40% and 70% and followed by annealing process with temperature variations of 300°C, 400°C, 500°C, and 600°C for 30 minutes. Sample characterization includes chemical composition analysis, microstructure observation and hardness testing. The results illustrate that the Cu-30Zn-1Al-1Mn brass alloy shows the appearance of α and β phases. The cold rolling process with a deformation levels of 20% and 40% promote the formation of a slip and twinning mechanism. On the other hand, samples with a 70% deformation level are dominated by shear bands. The annealing process induces the phenomena of recovery, recrystallization and process of grain growth. The higher the deformation level, the faster the recrystallization process. Furthermore, the smaller the grain size, the higher the sample hardness.

1. Introduction

Munition is the sample of brass product in the defense industries. The munition cartridge case is made from cartridge brass alloy which has a composition about 30% Zn [1]. The mechanical properties of brass alloys have the significant effect on the deformation process during the manufacturing process. Previous studies by Sofyan et al [2] and Hajizadeh et al [3] declared that the brass alloys with the Zn content about 30% have good ductility and strength. These mechanical properties are very influenced by several factors such as crystal structure, texture, grain size and alloy composition.

Actually, the mechanical properties of brass alloys are not only depending on the composition of Zn, however it also depend on the other elements contained therein. The mechanical properties can be enhanced by adding other elements such as Pb, Se, Bi, Mn and Al [4-10]. The addition of others alloying elements to the brass alloy is the mechanism of strengthening metal as the solid solution strengthening. The alloying element can dissolve in the Cu metal by both of intertition and substitution mechanism. Previous research by Ovat et al [7] showed that the addition of Al or Mn about 1 to 10 wt.% on the Cu-15Zn alloy tended to increase the strength and ductility. Furthermore, the investigation by Basori et al [5] also stated that the addition of Mn to Cu-29Zn alloys also tended to increase strength and ductility.

The mechanical properties of brass alloys can also be improved by cold rolling. Cold rolling will cause a strain hardening process in brass alloy which increase the strength and hardness. On the other hand, the cold rolling process will reduce the ductility, however it can be recovered again by annealing
process [3]. The annealing process carried out on the brass alloy after the cold rolling process will promote the recovery, recrystallization and grain growth. These phenomena are also accompanied by changes in mechanical properties such as a decrease in the value of hardness. In this research, a cold rolling process will be carried out and followed by annealing to investigate the phenomena on the microstructure and mechanical properties of Cu-30Zn-1Al-1Mn alloys.

2. Methods
The samples of Cu-30Zn-1Al-1Mn alloys (wt.%) were produced by gravity die casting with dimensions of 100x100x6 mm$^3$. The raw material includes the pure Cu, Zn, Al and Mn. Then, the as-cast samples were homogenized at 800 °C for 2 h in a muffle furnace. The obtained alloy composition is shown in Table 1. Further, the samples were cold rolled with a deformation level of 20%, 40% and 70% followed by an annealing process at a temperature of 300, 400, 500, and 600 °C for 30 minutes. The samples testing includes chemical composition analysis, microstructure observation, hardness testing, and tensile test. The microstructure was observed using an optical microscope. Hardness tests were carried out by the Vickers method. Grain size measurement was used based on the interception method.

| Table 1. The nominal composition of the as-homogenized Cu-30Zn-1Al-1Mn alloys (wt.%). |
|------------------|--------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Zn               | Al           | Mn             | P              | Pb             | Fe             | Si             | Mg             | Cr             | Co             |
| 31.7             | 1.14         | 0.772          | 0.003          | 0.05           | 0.05           | 0.005          | 0.001          | 0.015          | 0.036          | 0.278          | 65.9           |

3. Results and discussion

3.1. Microstructures
Figure 1 shows the microstructure of Cu-30Zn-1Al-1Mn alloys after the casting process and also the homogenization process. The homogenization process is carried out to uniform the alloy composition and reduce the presence of segregation. From Figure 1 it can be seen that the homogenization process increases grain size and also clarifies the existence of the beta phase (β). The addition of 1 wt.% Al promotes and accelerates the formation of β phase in Cu-30Zn-1Mn alloys. The appearance of the β phase in the alloy will affect the hardness value. This phase is formed due to the content of the solute element has added over the solubility limit of base metal and then promote the formation of the second phase [5].

Figure 2 shows the microstructure of Cu-30Zn-1Al-1Mn alloys after the cold rolling process with deformation level of 20, 40 and 70%. The deformation process of 20% and 40% does not significantly influence the morphology of the grains wherein the deformation mechanism is still dominated by slip and twinning. While at the deformation level of 70%, the shape of the grain has changed significantly where the grain morphology tends to be elongated with the dominance of the shear band deformation mechanism. The deformation level of 70% also changes the morphology of β phase which is also elongated. At the deformation level of 70%, the dislocation density is very high so that the homogeneous deformation with slip and twinning mechanism in plane of (111) is more difficult [2].
Figure 1. Optical micrographs of Cu-30Zn-1Al-1Mn alloys (a) as-cast 10X (b) as-homogenized 10X (c) as-cast 20X (d) as-homogenized 20X.

Figure 2. Optical micrographs of Cu-30Zn-1Al-1Mn alloys after cold rolling process with thickness reduction of (a,d) 20% (b,e) 40% (c,f) 70 % with magnification of (a-c) 10X (d-f) 50X.
Figure 3. Optical micrographs of Cu-30Zn-1Al-1Mn alloys after cold roll for 20, 40 and 70 % thickness reduction, followed by annealing at (a-c) 300, (d-f) 400, (g-i) 500, and (j-l) 600 °C for 30 minutes.

Heat treatment process by annealing is carried out to restore the resilience of the alloy after cold rolling. The annealing process will recrystallize the alloy grains and make the grains be smoother with grain growth. Figure 3 shows the microstructure of the Cu-30Zn-1Al-1Mn alloy after the cold rolling process and continued by annealing. At annealing temperature of 300 °C, the microstructures of all samples have no show the significant changes. At this level, the samples just undergo the recovery and stress relief step.

At annealing temperature of 400 °C, specimens with 70% deformation level start to undergo the recrystallization process. This is clearly seen in Figure 3f with the formation of small grains around the shear bands. Meanwhile, at the same temperature, specimens with deformation rates of 20% and 40% have not showed the changes in the microstructure. At 70% deformation level, the deformation mechanism is dominated by shear band which is an area with a very high dislocation density so it has more energy for the recrystallization process. At annealing temperature of 500 °C, specimens with deformation level of 40% begin to undergo recrystallization. This is clearly seen in Figure 3h with the formation of small grains in the microstructure. Meanwhile specimens with 70% deformation level still continued to show significant recrystallization even though shear bands structure remained. At annealing temperature of 600 °C the specimen with deformation level of 20% showed recrystallization in it grains.
In Figures 3j and 3k, the microstructures show the appearance of an annealing twin structure. This structure occurs due to the alteration of the grain formation caused by an increase in temperature.

From the Figure 3, it was found that the recrystallization process began at 400 °C for the sample with 70% deformation level. While for the samples with the deformation level of 40% and 20%, the recrystallization process started to occur at temperatures of 500 °C and 600 °C, respectively. This phenomenon proves that the level of deformation affects the speed of recrystallization. The greater the level of deformation, the smaller the temperature required for recrystallization. The cold rolling and annealing process also influences the shape and size of the alloy grains. Cold rolling will promote the elongation grain. The higher the level deformation, the greater the length of the grains. At the deformation level of 20%, 40% and 70%, the average length of the grains is 200µm, 210µm and 250µm, respectively. On the other hand, at the same annealing temperature (600 °C), the greater the deformation level, the smaller the grain size (Figure 4).

![Figure 4](image_url)

Figure 4. The correlation between level of deformation and average grain size of Cu-30Zn-1Al-1Mn after annealing process at 600°C for 30 minutes.

### 3.2. Hardness

Figure 5 shows the hardness value of the samples for each level of deformation with different annealing temperature. The figure 5 show that the specimen with 70% cold rolling deformation has the highest hardness value of 254.8 HV. This proves that the higher the level of deformation, the higher the alloy hardness. On the other hand, Figure 5 also shows a decrease in hardness value on the samples due to an increase in annealing temperature. The higher the annealing temperature, the lower the hardness value of the brass alloy. Test specimens with a 20% deformation level have a hardness value of 156.2 VHN before annealing. At annealing temperature of 300 °C the hardness value dropped 6.8% to 145.56 VHN. At annealing temperature of 400 °C the hardness value dropped 8.5% to 142.8 VHN. At annealing temperature of 500 °C the hardness value dropped by 20.3% to 124.42 VHN. And finally, at annealing temperature of 600 °C, the hardness value dropped 36.7% to 98.74 HV. Based on the Figure 5, the decrease in the hardness value is not significant from annealing temperature of 300 °C to 500 °C. However, at a temperature of 600 °C the hardness of this specimen dropped dramatically. From the results obtained, it can be concluded that the significant decrease in the hardness of the alloy is related to the recrystallization of grains in the alloy. A drastic decrease in the value of hardness indicates that at that temperature the alloy grains begin to undergo recrystallization and grain growth.
Figure 5. The change of hardness of Cu-30Zn-1Al-1Mn alloy after cold deformation for 20, 40 and 70 %, followed by annealing at 300, 400, 500, and 600 °C for 30 minutes.

4. Conclusion
The results of the observation can be concluded as follow:

- The as-cast and the homogenized samples of Cu-30Zn-1Al-1Mn alloys showed the appearance of the formation of β phase.
- The deformation level of 20% and 40% did not significantly influence the morphology of alloy grains wherein the deformation mechanism was still dominated by slip and twinning. While at the deformation level of 70%, the grain shape has changed significantly where the grain morphology tended to be elongated and deformation mechanism was dominated by the shear band.
- The greater the level of deformation, the smaller the temperature required for recrystallization. On the other hand, at the same annealing temperature, the greater the deformation level, the smaller the grain size.
- The higher the deformation level followed by the higher hardness. On the other hand, at the same deformation level, the higher the annealing temperature, the lower the sample hardness.

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