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# Effect of Cold Rolling and Annealing Temperature on the Characteristics of Cu-28Zn-3.2Mn Alloy

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# Effect of Cold Rolling and Annealing Temperature on the Characteristics of Cu-28Zn-3.2Mn Alloy

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**Abstract.** Common material for bullet shell is cartridge brass which contains 26-32 wt. % Zn. In the deep drawing process, problems are typically found, such as cracking and tearing, due to low ductility. Therefore, manganese is added to cartridge brass to increase its ductility. In this study, Cu-28Zn alloy with addition of 3.2 wt. % Mn was fabricated by gravity casting. As cast samples were homogenized at 800 °C for 2 hours. Afterwards, the specimens were cold-rolled with deformation of 20, 40, and 70 %. The 70 % cold-rolled samples were subsequently annealed at 350, 400, and 450 ℃ for 15 minutes. Samples underwent characterizations by microstructure analysis using optical microscope and Scanning Electron Microscope (SEM) - Energy Dispersive Spectroscopy (EDS), and Vickers microhardness testing. The results showed that higher degree of deformation led to more elongated grains with increasing values of L/D ratio, and higher hardness. Annealing at 350 ℃ for 15 min did not change the deformed microstructures which indicated the stage of recovery and stress relieve. Meanwhile, higher annealing temperatures of 400 and 450 ℃ led to recrystallization and grain growth, respectively. Hardness declined with the increase in annealing temperature. Mn increases the hardness and recrystallization temperature.

## 1. Introduction

Cartridge shell for small caliber ammunition is commonly fabricated using cartridge brass that contains 26-32 wt. % Zn, due to its excellent properties such as yield strength, tensile strength, ductility, hardness. Cartridge brass is produced by a series of processes, such as casting, rolling, and deep drawing, wherein deep drawing process, cracking and tearing are typically found [1]. To minimize these problems, addition of manganese was found to be essential because it enhances ductility. Increased strength and ductility are necessary to produce good and flawless cartridge shell [2].

In a study conducted by Ovat, et al.[2], the addition of Mn to Cu-28Zn alloy improved the mechanical properties and the crystallographic texture by the grain refining mechanism. The addition of Mn up to 5 % increased formability at high temperatures. However, if the Mn was added more than 5 %, there will be a phenomenon of embrittlement. In addition, studies conducted by Sofyan and Basori [3] on the microstructure and mechanical properties of the annealing and process of the Cu-32Zn alloys were carried out with deformation variations of 20, 40, and 70 % resulted the change of deformation mechanism as increasing deformation degree. The deformation mechanism started with slip at the level of deformation of 20 %, followed by twinning at 40 % deformation, and shear band started to be dominant at 70 % deformation. The mechanisms are affected by Stacking Fault Energy (SFE). Materials with high SFE tend to have homogenous deformation by slip mechanism at major orientation. Whereas,

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materials with lower SFE tend to take twinning mechanism that lead inhomogeneous deformation by shear band to form [3].

In the study of Mazancova and Mazanec [4] about SFE of high manganese alloys indicated that carbon and iron do not significantly affect the SFE, in contrast to manganese and aluminum content, where with an increase in Mn, SFE values also increase, which will affect the deformation mechanism of the alloys. The annealing process after cold rolling will yield properties and microstructure as required. Moreover, formability and ductility that declined during cold rolling may be recovered during annealing process [3]. Therefore, this study was carried out to investigate the characteristics of Cu-28Zn-3.2Mn alloys that are subjected to cold-rolling with deformation of 20, 40, and 70 %. Furthermore, the effects of annealing process with temperatures of 350, 400, and 450 $^oC$ were also observed.

## 2. Experimental Method

The samples used in this research are Cu-28Zn alloy with addition of 3.2 wt.% Mn fabricated by gravity casting at melting temperature of 1150 $^oC$, by using pure Cu and Zn ingots, as well as Mn flakes. The molten metal was poured into a 800 $^oC$ preheated metal mold with the dimension of 110x110x6 $mm^3$. In this casting process, borax flux was used to remove scale. Degassing process is not required since Zn would boil away and would bring out trapped gas. The as-cast alloys were then homogenized at 800 $^oC$ for 2 hours, and followed by air cooling. The section of samples were then cold rolled at level of deformation of 20, 40, and 70 % in multiple passes. The samples with 70 % deformation were then annealed at 350, 400, and 450 $^oC$ for 15 minutes, followed by water quenching.

Microstructures were observed by using optical microscope and SEM/EDS. Standard metallographic preparation was conducted by polishing with 0.5 µm $Al_2O_3$ and etching with 10 % of $FeCl_3$ + alcohol for 3-6 seconds. Microvickers hardness was performed using 300 g of load in accordance with ASTM E384. Five indentation was made for each measurement.

## 3. Results and Discussion

### *3.1. Effects of Deformation*

Fig. 1 shows the microstructures of Cu-28Zn-3.2Mn alloy in as-homogenized condition and after a series of deformation. The corresponding hardness values are showed in Fig. 2(a). The as-homogenized microstructure possesses equiaxed large grains with L/d (length to diameter) ratio of ~ 0.7 (Fig. 1a). Some gas porosities were observed due to hydrogen contamination. This microstructure correlates to the hardness value of 56 HV (Fig. 2), which is higher than Cu-32Zn base alloy, 54 HV [3]. The increased hardness is due to the presence of Mn that fully dissolves in α matrix and creates solid solution strengthening [5]. Deformation for 20 % (Fig. 1 (c-d)) significantly increases the grain elongation to L/d ratio to 2.2. Some slip bands are clearly visible, as portrayed by arrows in Fig. 1(d). The hardness of the Mn-added alloy at this stage is 127 HV (Fig. 2), which significantly higher than that of the Cu-32Zn (92 HV) base alloy [3]. This indicates solid solution strengthening mechanism works together with strain hardening.

At 40 % deformation (Fig. 1 (e-f)), the grain elongation increased to L/d 7.7. In FCC crystal, the dislocations move on {111} plane, meaning that they can switch from a plane to another within the same family. It is called cross slips which are shown by arrow in Fig. 1(f) as the dominant deformation. It occurred when perpendicular slip cross one to another. The hardness at this stage is 145 HV (Fig. 2). Further deformation at 70 % (Fig. 1 (g-h)) produced shear bands as shown in Fig. 1(h) with hardness value of 207 HV (Fig. 2). This hardness value still remains higher than that of the Cu-32Zn (192 HV) [3].

Furthermore, Fig. 1(b) shows the microstructure of the as-homogenized sample consists of insoluble dispersoids within the α matrix. However, the EDS micro analysis (Table 1) shows that the particles are $Al_2O_3$ coming from polishing substances that were not perfectly cleaned. Points 2-3 on small white particles scattered on α matrix are found not much different from the surrounding matrix, the α brass phase.

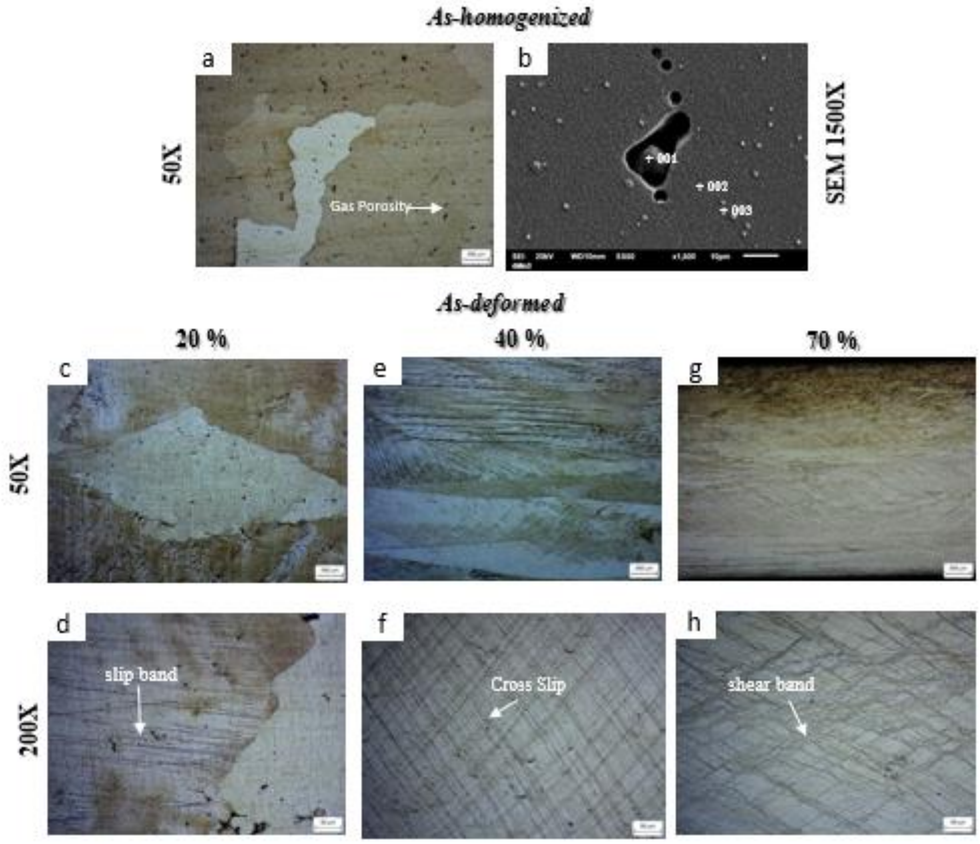


**Figure 1.** Micrographs of Cu-28Zn-3.2Mn in (a-b) as-homogenized condition, and after deformation for (c-d) 20 % (e-f) 30 % and (g-h) 70 %.

**Table 1.** Results of EDS microanalysis on Cu-28Zn-3.2Mn alloy before cold rolled at positions as shown in Fig. 1(b)

| Point | Composition (%) | | | | | Phase |
|---|---|---|---|---|---|---|
| | Cu | Zn | Mn | Al | O | |
| 001 | 0.52 | - | - | 40.53 | 58.95 | $Al_2O_3$ |
| 002 | 68.34 | 27.76 | 3.89 | - | - | α brass |
| 003 | 68.73 | 27.54 | 3.73 | - | - | α brass |

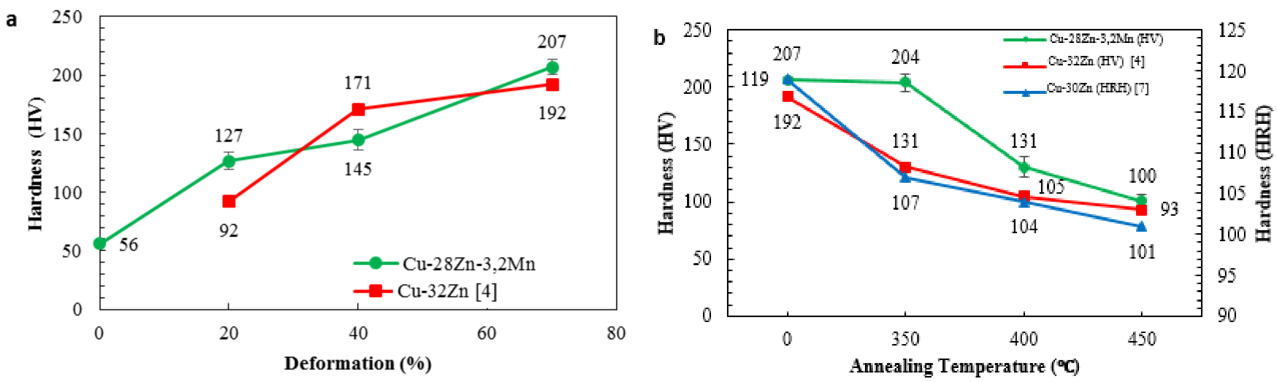


**Figure 2.** after annealed at 350, 400, 450 °C for 15 min.

### *3.2. Effects of Annealing Temperature*

Fig. 3 illustrates the microstructures after annealing at different temperatures. The corresponding hardness values are showed in Fig. 2(b). Annealing process reduced the hardness of the material. At 350 ℃, there was no new nucleation of grains and the existence of the shear band remains visible with a slight decline in hardness to 204 HV (Fig. 2(b)). This reflects the occurrence of recovery where some of the stored strain energy is released by climbing of dislocations [6]. At an increased annealing temperature of 400 °C, the hardness drops to 131 HV (Fig. 2(b)). It can be ascertained that is some parts of the shear band region turned into partial recrystallization as shown in Fig. 3(e-f). The growth of new strain-free granules and equiaxed grain with driving force derived from the internal energy due to deformation [6]. At this stage, the state of the material is similar with that of prior to deformation. Lastly, increasing annealing temperature to 450 ℃ resulting in a decrease in hardness to 100 HV (Fig. 2(b)). The microstructures (Fig. 3(g-h)) show that the entire shear band region has been replaced by new grains through the recrystallization phenomenon. Some grain growth was observed, in which larger grains tend to make small grains shrunk and seem to be ingested by larger grains (cannibalism) [6]. Larger grain size means less grain boundaries, thus providing more room for the movement of dislocations that leads to decreased hardness and increased ductility. The annealing temperature to achieve complete recrystallization is predicted to be in the range of 400-450 $^{o}$C.
By comparing the results of this study to previous research by Sofyan and Basori [3] as well as Walker [7] on the annealing treatment of Cu-32Zn, it is noted that addition of 3.2 wt.% increased the recrystallization temperature from 350 ℃ to 400 ℃. Mn atoms induce lattice distortion that may delay movement of dislocation to the grain boundary so that slowing down the recrystallization phenomenon. Therefore higher annealing temperature is needed to achieve perfect recrystallization.

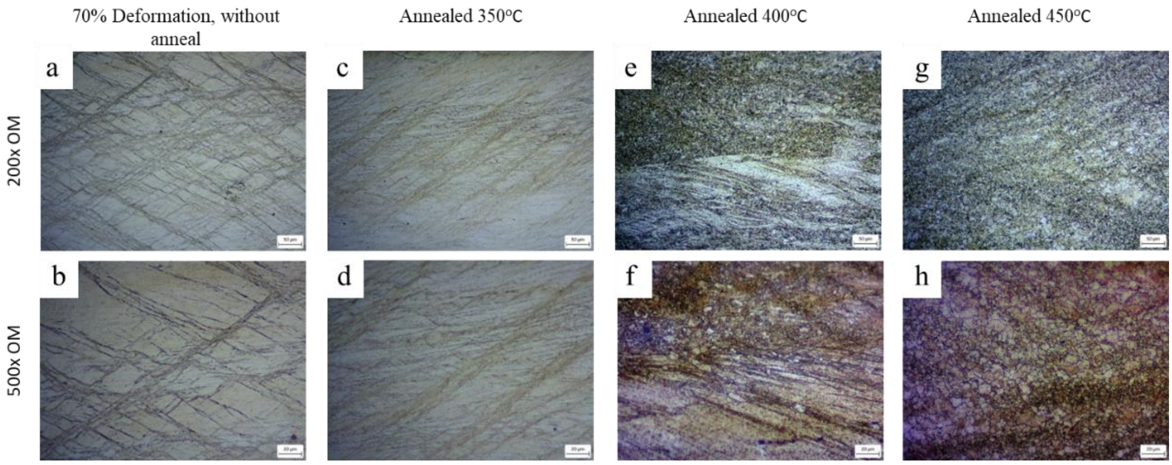


**Figure 3.** Micrographs of Cu-28Zn-3.2Mn after (a-b) 70 % deformation, and after subsequent annealing at (c-d) 350 $^{o}$C, (e-f) 400 $^{o}$C, and (g-h) 450 $^{o}$C for 15 min.

## 4. Conclusions

The results of the observation on Cu-28Zn-3.2Mn alloys can be concluded as follows:

1. Addition of 3.2 wt.% Mn resulted in a α single phase with higher hardness due to solid solution strengthening.
2. Mechanism works at 20 % deformation was slip, while higher deformation at 40 % produced cross-slip. Further deformation of 70 % was dominated by shear bands.
3. Increased level of deformation of 20, 40 and 70 % led to higher elongated grains with L/d ratios of ~2.2, ~7.7, and ~14.1 as well as higher hardness values of 127, 145, and 207 HV, respectively.
4. Increased temperatures of the annealing process of 350, 400, and 450 $^{o}$C decreased the hardness due to the mechanism of recovery and stress relieve, recrystallization, and grain growth, respectively.
5. Addition of Mn increased the recrystallization temperatures, which was found in the range of 400 $^{o}$C.

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