



## EFFECTS OF DEFORMATION AND ANNEALING TEMPERATURE ON THE MICROSTRUCTURES AND MECHANICAL PROPERTIES OF CU-32%ZN BRASS

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### ABSTRACT

Rolling and subsequent annealing are common processes to produce brass sheet. Cold rolling has attracted a lot of attention due to complicated deformation process that involves shear band and twinning. Debate remains on the level of deformation at which change in deformation mechanism occurs. Subsequent annealing process results in dynamic recrystallization, which is able to produce grain sizes and properties as required. Deterioration of formability and ductility during cold rolling may be recovered during annealing. This research studied change of microstructure and mechanical properties of Cu-32%Zn (wt. %) brass during cold rolling and annealing processes. The Cu-32%Zn alloy was produced by gravity casting in a metal mold with the dimension of 110x110x6 mm<sup>3</sup>. The cast plate was homogenized at 800 °C for 5 h in an muffle furnace. The plate was then cold rolled with the level of deformation of 20, 40 and 70 % in multiple passes. Annealing of the cold rolled plate was conducted at 150, 200, 300, 400 and 500 °C for 30 minutes. The cooling of samples was performed in water. Characterization included Vickers hardness measurement and microstructural observation by using optical microscope. The results showed that slip was clearly observed at the level of deformation of 20 % together with few twinning. When the deformation was increased to 40 %, the twinning is major and some shear band started to form. Further increase of deformation to 70 %, the twinning was mostly replaced by shear band. The change in mode of deformation was followed by the increase in hardness of the materials. The annealing process after cold rolling resulted in recovery, recrystallization and grain growth. The higher the temperature of the annealing process, the speedier the recrystallization process that followed by grain growth and reduction in hardness.

**Keywords:** deformation, twinning, twin boundary, shear band, recrystallization.

### INTRODUCTION

Brass is metal alloy which contains copper and zinc, where copper is the main element. This material is widely use for piping, tube, musical instrument and cartridge case for ammunition. The common manufacturing process of brass is casting [1]. Brass with zinc content up to 37 % has a single phase, which is  $\alpha$  solid solution. This alloy is good in strength, ductility, corrosion resistant, formability and cold workable. The strength and hardness of brass increases with addition of zinc content up to 37% [2].

Formability of material is affected by many factors, such as crystal structure, stacking fault energy (SFE), composition and grain size [3-5]. Brass possesses FCC crystal structure. Deformation mechanism in FCC materials is interesting because it depends on the SFE. Sheet with high SFE, such as pure copper, tends to have homogeneous deformation by slip mechanism, which results in copper texture with major orientation of  $\{111\}\langle 112 \rangle$ . Addition of Zn for 2.5 to 30 % into Cu systematically reduces SFE and drives the formation of twinning, that inhibits slip to occur at the major orientation, therefore inhomogeneous deformation (shear bands) forms and result in different texture, which is known as brass texture  $\{110\}\langle 112 \rangle$  [6-7]. The transition

of deformation mechanism may also be due to degree of deformation. At larger deformation, a dense population of twins occurs in  $\{111\}$  oriented grains that are approximately parallel to the rolling plane. This makes homogeneous slip on these planes is extremely difficult, and leads to inhomogeneous deformation (shear bands) [6-7].

Salari *et al* [8] found that in Cu-10Zn, heavy cold reduction resulted in inhomogeneous deformation (shear bands), which led to large misorientations between adjacent subgrains, so that strong texture was produced. In general, higher degrees of cold reduction increased the inhomogeneities and reducing the subgrains size before annealing. Debate remains on the level of deformation at which change in deformation mechanism occurs. In cold rolling of thin sheet, the thickness of the sheet as well as the grain size will affect the flow stress of the material. When the grain size is almost the same, decreasing thickness of sheet will decrease the flow stress. Because in a very thin sheet, the volume ratio of surface grains to inner grains is high. The surface grains are easier to deform than the inner grains, so that lower the resistance to deformation and hence decrease the flow stress [9].

Subsequent annealing process after cold deformation results in dynamic recrystallization, which is



able to produce grain sizes and properties as required [10]. Deterioration of formability and ductility during cold rolling may be recovered during annealing. Stretchability of brass increases at higher annealing temperatures at the range of 400-600 °C [11, 12].

This research studied the deformation behaviour of Cu-32% Zn alloy at various degree of cold reduction, as well as the change of microstructures after subsequent annealing process. It was intended to understand when the inhomogeneous deformation starts to form, and how it affected the recrystallization processes during annealing.

## EXPERIMENTAL METHODS

The Cu-32%Zn alloy was produced by gravity casting at melting temperature of 1000 °C, by using pure Cu and pure Zn ingots as feeding materials. The molten metal was poured into a 600 °C preheated metal mold with the dimension of 110x110x6 mm<sup>3</sup>. The chemical composition of the as-cast alloy is shown in Table-1. The as-cast plate was homogenized at 800 °C for 5 h in a muffle furnace. The plate was then cold rolled with the level of deformation of 20, 40 and 70 % in multiple passes. Subsequent annealing was conducted at 150, 200, 300, 400 and 500 °C for 30 minutes. The samples were water quenched within 5 second after the annealing process. Observation of microstructure was conducted by using optical microscope. Standard sample preparation included polishing with 0.5 µm alumina and etching with 10 % FeCl<sub>3</sub> in alcohol for 7-10 seconds. Quantitative measurement of grain size used intercept method. Hardness testing was performed with Vickers method by using 300 g of load in accordance with ASTM E384. Five indentation was made for each measurement.

**Table-1.** Chemical composition of as-cast Cu-32%Zn.

Zn	Pb	Mn	Fe	Si	Cr	Al	Co	Bi	Cu
32.1	0.005	0.002	0.005	0.005	0.001	0.002	0.027	0.188	67.6

## RESULTS AND DISCUSSIONS

### Microstructures

Figure-1 (ar) illustrate microstructures of cold-rolled Cu-32 % Zn samples with the level of deformation 20, 40 and 70%, followed by annealing at the temperatures of 150, 200, 300, 400 and 500 °C for 30 minutes. At the level of deformation of 20 % (Figure-1 (a)), only few twinning was observed in the microstructures, which indicated that slip mechanism is more dominant than twinning. When the deformation was increased to 40 %, twinning became more visible and more dominant, while at 70 % of thickness reduction, shear band were detected in a significant amount. The increase in level of deformation was also followed by the change in the

morphology of grains, from equiaxed to elongated structure.

After annealing at 150 and 200 °C (Figures 1 (d-i)), no change of microstructure was observed. The temperature may only provide energy for recovery and stress relieve. At the annealing temperature of 300 °C, the sample with 70 % deformation had shown to start recrystallization process (Figure-7 (i)). Stress-free new grains were formed around the shear band. While samples with lower deformation level had not shown any changes. When the annealing temperature was increased to 400 °C, recrystallization started in the 40 % deformed samples at the grain boundaries. The 70 % deformed samples had shown significant progress of the recrystallization process, although some shear band remains visible in the microstructure. And finally at 500 °C, all microstructures with 20, 40 and 70 % of deformation have small grains, indicating that the recrystallization process completed and the grains grew. The grains of the 20 % deformed samples were bigger than the 40 and 70 % ones. From Figure-1, it is clear that that deformation level affects the recrystallization process. The higher the deformation level, the lower the recrystallization temperature. In Cu-32%Zn, the recrystallization process starts at 300 and 400 °C for deformation level of 70 and 40 %, respectively. Higher deformation level resulted in higher internal stress as the driving force for recrystallization process. Detailed observation is needed to clarify the role of shear band in recrystallization process.

Deformation level also affects the final grain size after annealing process. Figure-2 shows the correlation between degree of deformation and the average grain size after annealing process at 500°C for 30 minutes. The higher the deformation level, the finer the grain size after annealing process. The deformation process introduces dislocations and texture in the microstructure. Subgrains in between shear bands and twinning may act as nucleation sites for new grains. Therefore, higher deformation leads to higher grain nucleation rate that ends as finer grains after annealing process.

### Hardness

Figure-3 shows the hardness of the Cu-32%Zn alloy after deformation at various levels, followed by annealing at various temperatures. It is clear from the figure that the higher the deformation level, the higher the hardness of the material. This is due to strain hardening occurs in the samples. The strain hardening is resulted from the formation of dislocation that moves along the slip planes. At 40 % degree of deformation, the twinning was more dominant than slip, so that slip was difficult to homogeneously occur on the {111} planes, resulted in higher hardness (171 VHN). Further increase in hardness (192 VHN) was found in 70 % deformed samples, because slip became more difficult due to the formation of shear band, or is known as inhomogeneous deformation. .

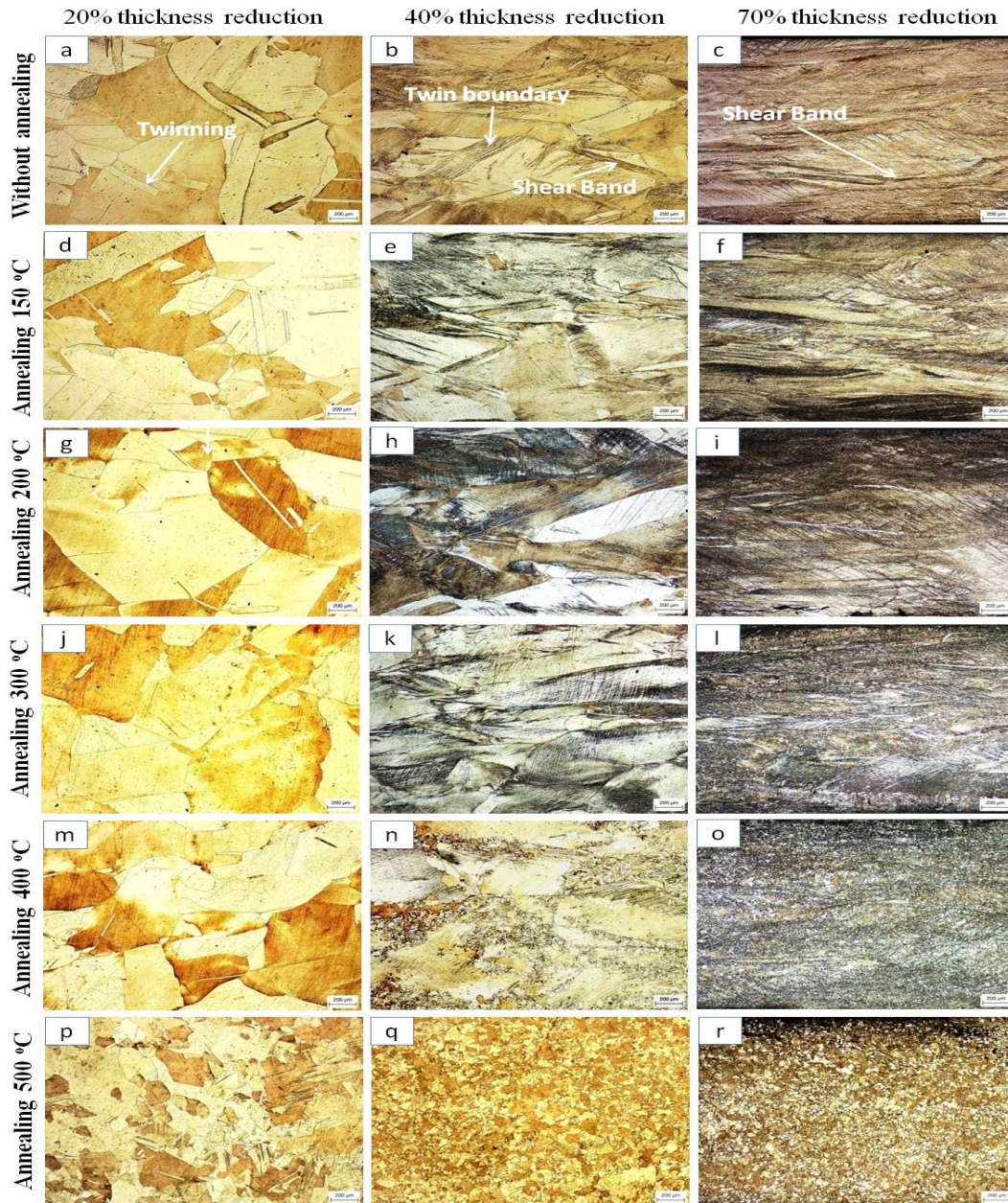
Annealing process applied after the cold deformation reduced the hardness of the material. At the



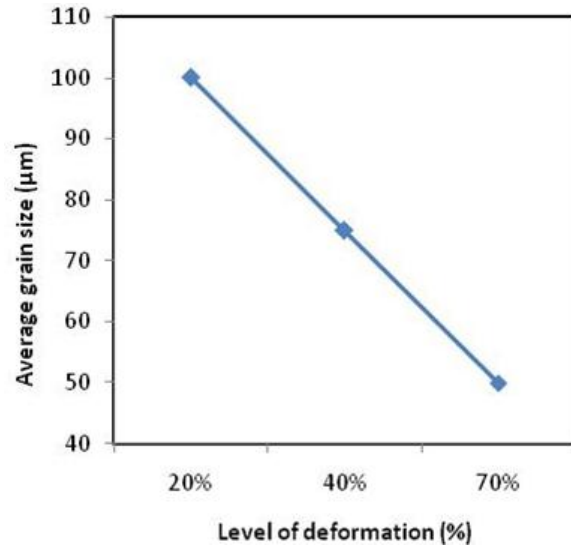


level of deformation of 20 %, the hardness of the material did not change after annealing unless the temperature is 500 °C or above. When this is correlated to Figure-1, it is clear that almost no change in microstructure is apparent after annealing at temperatures below 500 °C for samples deformed at 20 %. The 20 % deformation did not provide sufficient driving force for recovery and recrystallization to occur. Deformation for 40 and 70 % resulted in great amount of twinning and shear band, which drives the recovery and recrystallization process. In these samples, annealing at low temperatures, such as 150 and 200 °C,

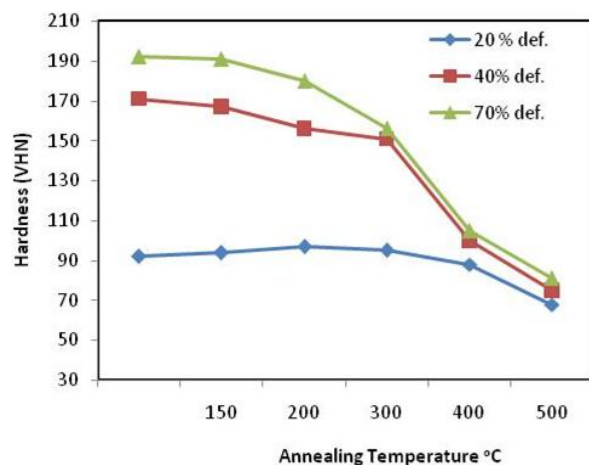
has caused reduction in hardness although the change is not significant yet. It suggests that these temperatures are below the recovery temperature of brass (~ 200 °C) [13]. Annealing temperatures of 300 °C and above substantially reduced the hardness of the samples. Overall, Figure-3 shows that the higher the annealing temperatures, the greater the reduction in hardness. The effect of temperatures is strengthened by degree of deformation. At the same annealing temperature, the decrease in hardness is more significant in higher deformed samples.



**Figure-1.** Optical micrographs of Cu-32%Zn alloy (a-c) after cold roll for 20, 40 and 70 % thickness reduction, followed by annealing at (d-f) 150, (g-i) 200, (j-l) 300, (m-o) 400, and (p-r) 500 °C for 30 minutes.



**Figure-2.** The correlation between level of deformation and average grain size of Cu-32%Zn after annealing process at 500 °C for 30 minutes.



**Figure-3.** The change of hardness of Cu-32%Zn alloy after cold deformation for 20, 40 and 70 %, followed by annealing at 150, 200, 300, 400 and 500 °C for 30 minutes.

## CONCLUSIONS

The results of the observation on Cu-32%Zn can be concluded as follows:

1. The level of deformation of 20 % majorly occurred through slip mechanism. When the deformation was increased to 40 %, the mechanism was dominated by twinning and some shear band started to form. Further increase of deformation to 70 %, reduced twinning, which was replaced by shear band, and this followed by change of grain morphology from equiaxed to elongated structure.
2. The annealing process after cold rolling resulted in recovery, recrystallization and grain growth. The higher

the annealing temperature, the speedier the recrystallization process that followed by grain growth and reduction in hardness. Higher deformation level accelerated the recrystallization process.

3. The hardness of material increased with the increase in level of deformation and decreased with higher annealing temperature.

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