

Effects of Manganese on the Microstructures, Mechanical Properties and Deformation Characteristics of Cu-29Zn Alloy

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Abstract. Deformation characteristics of brass alloy are still under discussion, particularly concerning the critical level of when the change of deformation mechanism occurs. Previous research showed that the addition of Mn on brass alloys resulted in grain refinement and mechanical properties alteration. However, the effects of Mn on the deformation characteristic of brass alloys have not been investigated. In this research, Cu-Zn-xMn alloys were manufactured by gravity casting process using pure Cu and Zn ingots, as well as Mn chips as the feeding materials. Mn addition was varied to 1.26, 3.48, and 5.83 wt.%. As-cast samples were homogenized at 800 °C for 2 h in a muffle furnace. The samples were then cold-rolled with the level of deformation of 20, 40, and 70 %. Samples characterization includes chemical composition analysis, microstructure observation, tensile and hardness testing. The results showed that addition of Mn for 5.83 wt.% and above created β' phase, which is richer in Mn compare to that in the matrix. This phase segregated in the grain and along the grain boundary with irregular forms. Significant increase in hardness, yield and tensile strengths was observed with addition of Mn. The maximum elongation was achieved by addition of 3.48 wt.% Mn, while further addition tended to decrease it. At 20 % deformation, slip dominated and its density reduced with addition of Mn. When the deformation level increased to 40 %, twinning replaced slip as the predominant mechanism. Twinning density is slightly increase with the presence of Mn. Further deformation at 70 % produced shear bands and flattened the β' phase. Greater Mn content led to formation of more shear band.

Introduction

Brass is an alloy containing Cu and Zn, in which Cu is the main component. The alloys are widely used for many applications due to their excellent properties such as high strength, good in ductility, hardness, thermal conductivity, machinability and corrosion resistant [1]. Brass with Zn content up to 35 wt. % has single phase of α , while higher Zn content of 35-45 wt. % results in duplex alloys with α and β' phases [2].

Addition of alloying element on brass was aimed to improve their physical and mechanical properties, at which they heavily depend on the base alloy composition, the amount and choice of elements. Previous research showed that the addition of 0.3-2.0 wt. % Si on Cu-10Zn and 0.1 wt. % Co on Cu-10Zn-1.5Si alloy refined the grain size, increased the strength and hardness, while reduced the elongation [3]. Similar grain refinement was found by adding 0.1 wt. % Bi to Cu-30Zn, however no significant effect was found on the mechanical properties [4-6]. Titarev [7] observed that the addition of 0.5 wt. % Mn increased the elongation of Cu-49Zn-1.1Pb-0.45Fe, and even Ovat et al. [8] declared that the addition of Mn up to 5 % on Cu-15Zn remained increase the elongation without sacrificing the elongation and hardness.

Deformation mechanism of brass alloy during cold rolling process has attracted a lot of attention due to complicated deformation process that involves slip, twinning, and shear band [9]. The mechanism are highly influenced by the level of Stacking Fault Energy (SFE) which materials with

lower SFE have higher tendency to take twinning mechanism during deformation, so then shear band is easier to form [10,11].

Higher content of alloying element lessened SFE, for example, the SFEs of Cu, Cu-10Zn, Cu-20Zn and Cu-30Zn are 78, 35, 18, 14 mJ/m², respectively [12,13]. The increase in Al content also reduced the SFE of Cu alloys [14]. However, Mn addition on Cu alloys up to 12 % has no significant effect on SFE although it tends to increase strength and ductility [15]. Deformation characteristics are also affected by the presence of second phases which act as pinning agent during dislocation movement that result in the formation of heterogeneous deformation (shear band) and local deformation zone around the particles [16]. This research was intended to comprehend the effect of Mn on the microstructures, mechanical properties and deformation characteristics of Cu-29Zn alloy.

Experimental Methods

The samples of Cu-29Zn-xMn (wt.%) alloys were produced by gravity casting at melting temperature of 1150 °C, by using pure Cu and Zn ingots, as well as Mn chips as feeding materials. Mn was varied to 1.26, 3.48 and 5.83 wt.%. The molten metal was poured into a 600 °C preheated metal mold with the dimension of 110x110x6 mm³. The as-cast samples were then homogenized at 800 °C for 2 h in a muffle furnace. The obtained composition of the alloys is shown in Table 1. Sections of the samples were then cold rolled with the level of deformation of 20, 40, and 70 % in multiple passes. Microstructure observation was carried out by using optical microscope and Scanning Electron Microscopes (SEM). Samples were mechanically ground and polished by 0.5 μm alumina, followed by etching with 10 % FeCl₃ in alcohol for 5-10 seconds. Hardness testing was conducted by Vickers method using 300 g of load in accordance with ASTM E387. The tensile test was employed based on the ASTM E8 standard. Slip and twinning densities were defined as the length of slip and twin boundary lines in unit area. The measurements were taken at an optical microscope image with the size of 880x680 μm².

Table 1. Nominal composition of the as-homogenized alloys (wt.%).

Samples	Zn	Mn	Pb	Fe	Si	Cr	Al	Co	Bi	Cu
Cu-29Zn	29.2	0.006	0.005	0.005	0.005	0.002	0.002	0.032	0.269	70.3
Cu-29Zn-2Mn	30.1	1.26	0.005	0.095	0.005	0.0051	0.002	0.025	0.173	68.2
Cu-29Zn-4Mn	29.1	3.48	0.005	0.063	0.005	0.0155	0.002	0.023	0.2	66.9
Cu-29Zn-6Mn	29.6	5.83	0.005	0.096	0.005	0.03	0.002	0.023	0.204	65.1

Results and Discussion

Microstructures

Fig. 1 (a-c) show the microstructures of as-homogenized Cu-29Zn alloys with Mn contents of 0.006, 1.26 and 3.48 wt.%. Meanwhile, Fig. 1 (d-f) describe the Cu-29Zn alloy with Mn content of 5.83 wt.% with different magnification. As shown in Fig. 1, the microstructures contain gas porosity due to contamination with hydrogen. As-homogenized samples possess large equiaxed grains (~ 600 μm) due to grain growth during homogenization at relatively high temperature of 800 °C. The Cu-29Zn alloys with Mn content up to 3.48 wt.% show single phase (α), meanwhile that with 5.83 wt.% Mn exhibits duplex phase of α and β'. The β' phase is richer in Mn compared to that in the matrix. They segregated in the grain and along the grain boundary with irregular forms. Diffusivity of Mn in Cu is lower than that of Zn [17], therefore Mn tends to segregate during solidification and leads to formation of β' phase.

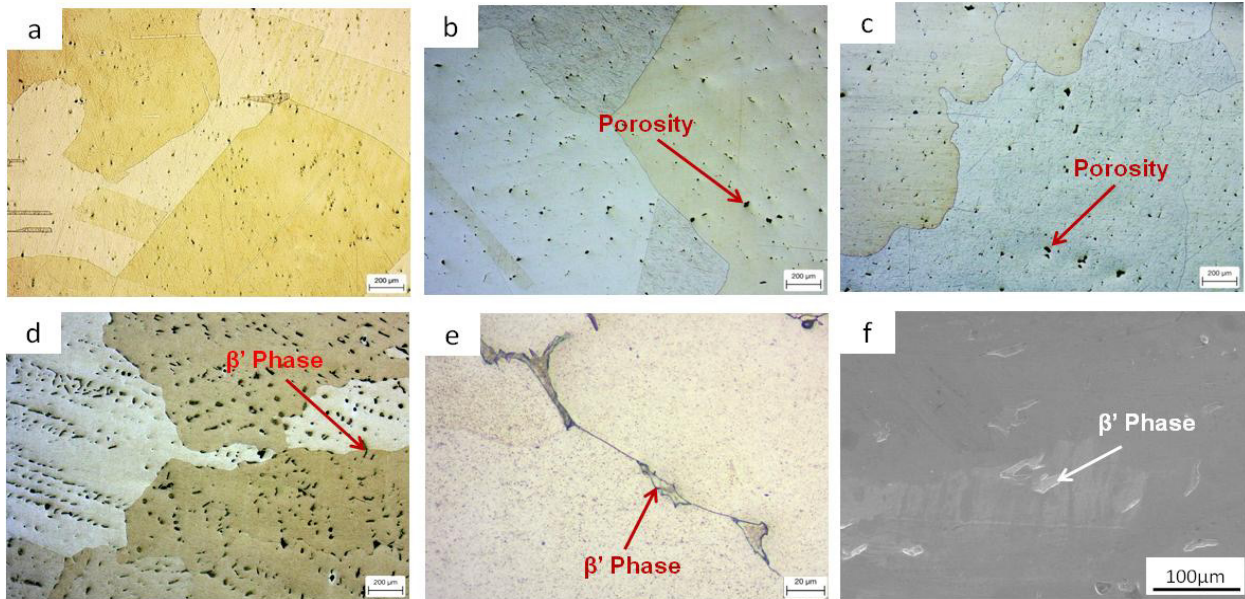


Fig. 1. Micrographs of the as-homogenized Cu-29Zn alloys with Mn content of (a) 0.006 (b) 1.26 (c) 3.48 (d-f) 5.83 wt.%.

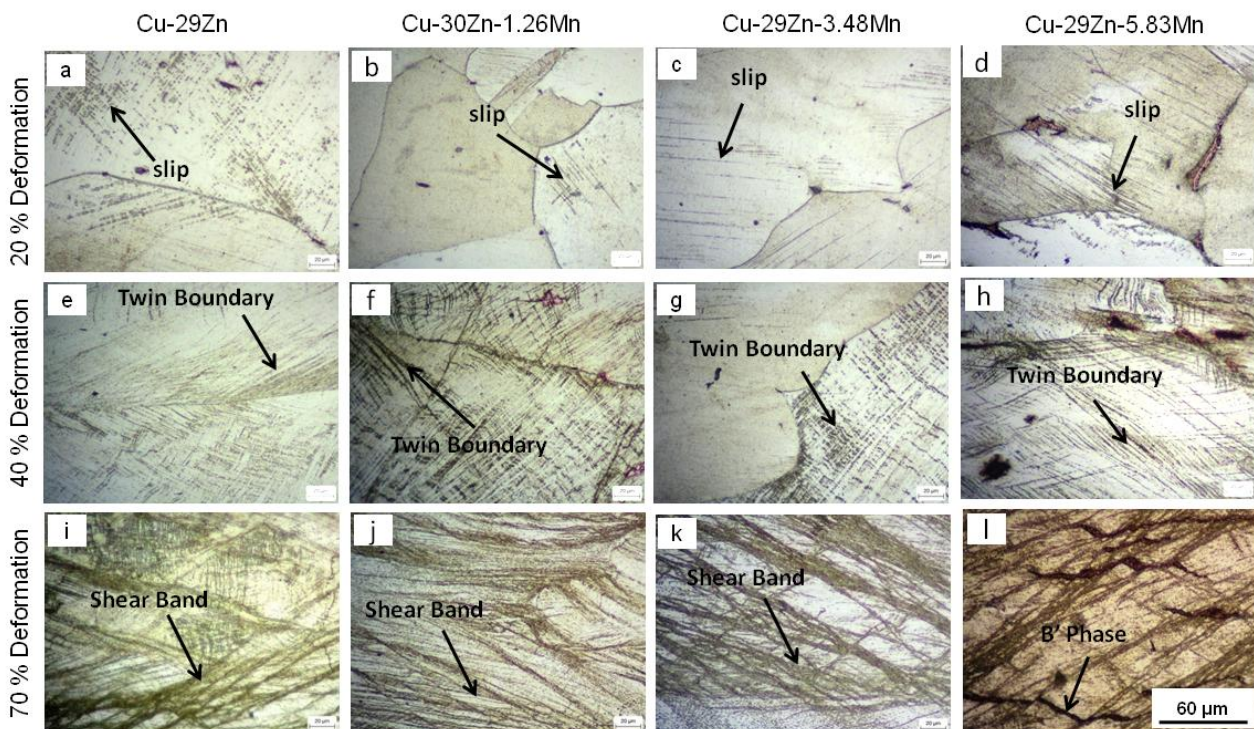


Fig. 2. Micrographs of Cu-29Zn alloy with the Mn content of (a) 0.006 (b) 1.26 (c) 3.48 (d) 5.83 wt.% after cold rolling for 20, 40, and 70 % thickness reduction.

Fig. 2 (a-l) illustrates the microstructure of Cu-29Zn, Cu-29-1.26Mn, Cu-29Zn-3.48Mn, and Cu-29Zn-5.83Mn alloys after cold rolling with deformation level of 20, 40, and 70 %. All micrographs have the same magnification as shown by the scale bar on the bottom right hand side. While the results of measurement of slip and twin density are provided in Fig. 3. At 20 % deformation, slip was dominant and the presence of Mn decreased the slip density. However the slip density remained the same with the increase in Mn content. The slip densities of Cu-29Zn alloy with the Mn contents of 0.006, 1.26, 3.48 and 5.83 wt.% are 33.1×10^{-3} , 6.8×10^{-3} , 12.4×10^{-3} and $8 \times 10^{-3} \mu\text{m}^{-1}$, respectively (Fig. 3). The presence of Mn atoms both as solid solution and as β' phase within the Mn matrix acts as the pinning agents that inhibit the movement of slip during homogeneous deformation. At 40 % deformation, twinning replaced slip as the predominant

mechanism and its density was slightly increased with the presence of Mn. However the increase of Mn content have no significant effect on the twinning density. The atomic size mismatch among Cu, Zn, and Mn led to atomic lattice strain and retarded the homogeneous deformation [16]. Further deformation at 70 % produced shear bands and flattened the β' phase. Greater Mn content led to formation of more shear band.

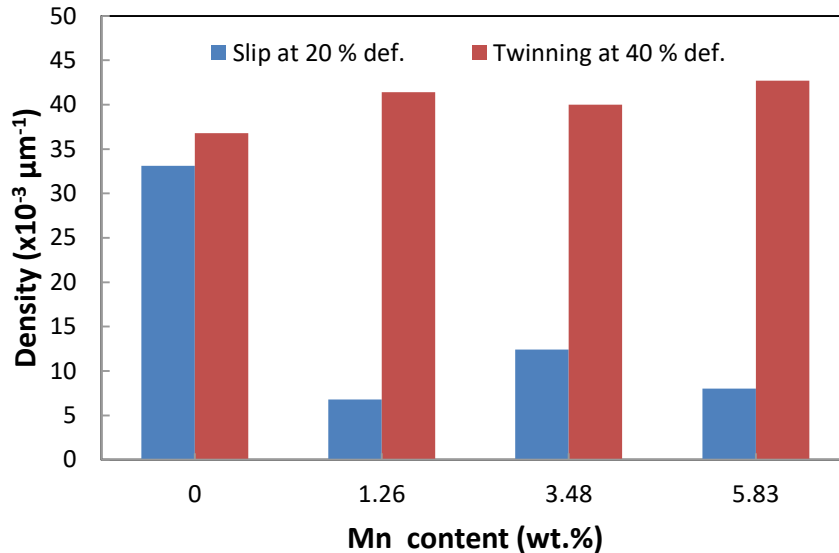


Fig. 3. The effects of Mn content on the slip and twinning density of Cu-29Zn alloy at the deformation levels of 20 and 40 %.

Mechanical Properties

Fig. 4a shows the hardness of Cu-29Zn alloys with different Mn content. The figure illustrates that increasing of Mn content followed by the increase in hardness. The highest hardness occurs at sample with Mn content of 5.83 wt. % due to the effect of both solid solution strengthening and the presence of β' phase (Fig. 1 (d-f)). The presence of Mn drives the substitutional solid solution which creates the atomic lattice strain and inhibits the dislocation movement and results in higher hardness. Furthermore, the β' phase also acts as pinning agent and inhibits the dislocation movement [16].

Fig. 4b and 4c describe the strength and elongation of Cu-29Zn alloy with different Mn content. From Fig. 4b, it is clear that the higher the Mn content, the higher the strength of alloys. However, unusual trend of elongation was observed. The increase in strength was followed by the increase in elongation up to 3.48 wt. % Mn, but then further addition to 5.83 wt. % reduced the elongation. The presence of second phase (β') at the Cu-29Zn-5.83Mn alloy acted as the pinning agent during deformation and led to the alloy brittleness.

Fig. 4d shows the effect of Mn content and deformation level on the hardness of Cu-29Zn alloys. The figure shows that the increase of Mn content promoted the increase of hardness due to solid solution and β' dispersion strengthening (Fig. 1 (d-f)). Furthermore, the hardness also increased with the increase in the level of deformation due to strain hardening. However, different mechanisms operated at different levels of deformation. At 20 % of deformation, slip was the major mechanism, while at 40 and 70 % of deformation, twinning and shear band was more dominant, respectively (Fig.2). When Mn is present in the alloy, it forms solid solution and β' phase, which act as the pinning agents for dislocation movement. Therefore, Mn-added alloys would undergo higher increase in hardness, when compared to the base alloy, at the same level of deformation.

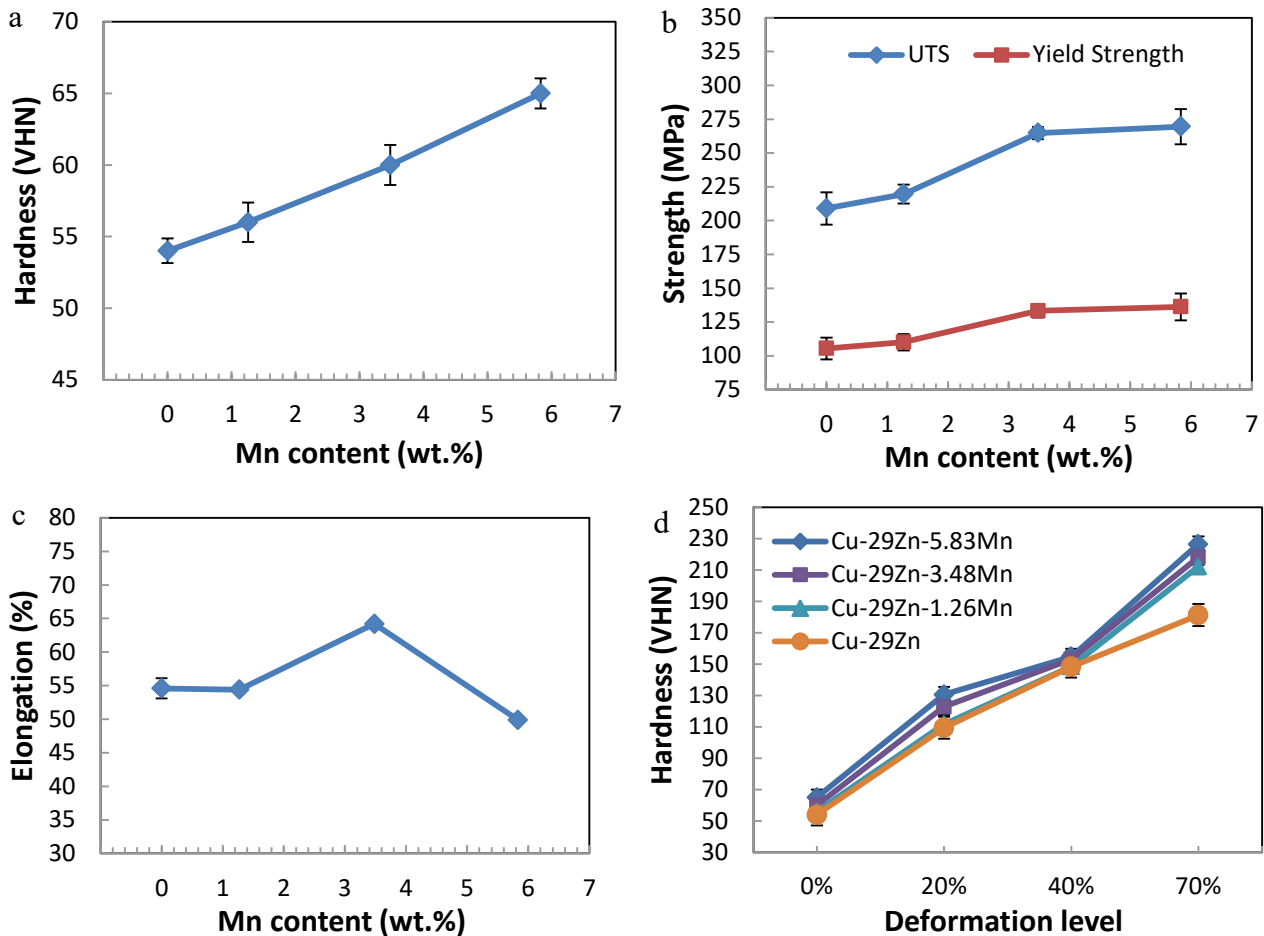


Fig. 4. The effects of Mn on (a) hardness (b) yield and tensile strength (c) elongation of Cu-29Zn alloy (d) Effect of Mn content and deformation level on hardness of Cu-29Zn alloy.

Conclusions

The results of the observation can be concluded as follows:

1. Addition of Mn up to 3.48 wt.% to Cu-29Zn alloy resulted in α single phase, meanwhile, further addition to 5.83 wt.% exhibited duplex phases of α and β' . The increase of Mn content promoted the increase of hardness, yield, and tensile strength of Cu-29Zn alloy due to the solid solution and β' dispersion strengthening. The highest elongation was achieved at the Mn content of 3.48 wt.% and tended to decrease with the content of 5.83 wt.%. The presence of β' phase acted as the pinning agent during deformation and led to the alloy brittleness.
2. At 20 % deformation, slip was dominant and the presence of Mn decreased the slip density. However the slip density remained the same with the increase in Mn content. The presence of Mn both as solid solution and as β' phase acts as the pinning agent that inhibit the movement of slip during homogeneous deformation.
3. At 40 % deformation, twinning replaced slip as the predominant mechanism and its density was slightly increased with the presence of Mn. However the increase of Mn content have no significant effect on the twinning density. The atomic size mismatch among Cu, Zn, and Mn led to atomic lattice strain and retarded the homogeneous deformation.
4. At 70 % deformation, shear band was dominant and β' phases are flattened and filled intergranular space.

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