Effect of Adding Ag on Tensile and Microstructure Properties of Zinc Alloy

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Abstract: Silver additions between 0.03 wt.% to 0.50 wt.% were made to the Zn-20Sn (wt.%) in an attempt to develop Zinc based alloy for application and improvement in giftware industry. In this study, we investigated the effect of Ag addition on Zn based alloy and mechanical properties of Zn-Sn-Ag alloys with variation of Ag contents. The measured mechanical properties are tensile strength and percentage elongation. It was found that addition of Ag over the entire range of concentrations has a useful effect on tensile properties of the alloy. Furthermore, the percentage elongation and tensile strength of the samples also increases with further increase in Ag content. Alloy containing 0.50 wt.% showed the highest value in both tensile strength and percentage elongation. Thus, the mechanical properties of the alloy improved with increasing Ag percentage up to 0.50 wt. %. On the other hand, increasing Ag content also significantly affected the fracture surface of the alloys. The surface showed a mixed mode of fracture exhibiting ductile failure and brittle failure. Metallographic studies showed that the addition of Ag resulted in microstructure modifications of the alloy involving the formation of intermetallic compound identified as Ag₃Sn and AgZn which decrease the precipitation of Zn in Sn matrix. The microstructure results also affected the mechanical properties of alloy by the presence of the elements.

Keywords: zinc alloy, silver, giftware, mechanical properties, fracture
I. INTRODUCTION

Based on literature, Zinc-based alloys have been developed and are increasing in commercial value (Boyer and Gall, 2007). Zinc alloy is chosen as a replacement of pewter alloy in application of giftware industry. The selection of zinc alloy for alternative material is important in engineering applications to reduce the cost of production without sacrificing the functional requirements of the components. Arif et al., (2011) note that Zinc-based alloys offering a number of benefits over their conventional counterparts like aluminum casting alloys, copper-based alloys, bearing bronzes and cast iron in various engineering applications. These alloys feature clean, low-temperature, energy-saving melting, excellent castability, high strength and equivalent or often superior bearing and wear properties as compared to standard bronze bearing.

Zinc alloys possess a unique combination of properties that permit rapid and economic casting of accurate components. Zinc is cheap thus it has a distinct cost advantage over other alloys. These alloys exhibit mechanical properties equal to or exceed those of cast iron, aluminium, and copper alloys (Joseph et al., 1992). In addition, they have excellent bearing properties, machinability and wear resistance. The additional advantages include lower casting temperature, which translate into faster casting speeds, lower energy requirements and longer die life and superior as-cast surface qualities (Porter, 2003). They also have excellent mechanical and physical properties at ambient temperatures but problems may be cause by their low creep resistance (Anwar and Murphy, 2001). Zinc is a silvery white metal with relatively low melting point (419.5°C). When unalloyed, its strength and hardness is greater than that of tin or lead but appreciably less than that of aluminium or copper. Zinc is brittle at ordinary temperatures but malleable above 100°C (Morgan, 1985).

Nowadays, there are many variations of zinc alloys in the industry. Most of the alloys were developed for industrial application. The important characteristics for such alloys are, toughness, ability to cast, corrosion resistance and hardness. Among the important ones are Zinc-based alloys. In giftware industry, there are additional requirements which are resistance to acid, alkali and water which are mostly caused by the environment. The causes of materials degradation with the associated environmental variables have been well explained by Ekuma et al., (2007). Ekuma and Idenyi (2006) stated that the service life of most engineering materials depends on their ability to resist degradation. In addition, the alloy must be of low temperature, low viscosity and low hardness and easily soldered. It is contrary to alloy for industrial usage where higher hardness is desirable. The alloy must not contain any toxic metal elements such as lead, mercury and cadmium as the giftware products are used for food and dishes. The manufacturing of zinc alloys involves many processes such as pressure gravity die cast, spin cast and squeeze cast. Moreover, the colour of alloy must be maintained as raw zinc based alloy and resist to corrode. Zinc alloy can be improved by changing the composition. It has been suggested that the mechanical properties could be improved through alloying with different elements. Zinc shows poor corrosion resistance against acid and alkali (Nilsson et al., 2002), easily to oxidize and have poor corrosion resistance (Zhou et al., 1996). Tin is added at 20 wt. % to improve the corrosion resistance of the alloys (Vianco and Rejent, 1999). Ag is added between 0.03-0.50 wt. % for bright and shiny appearance (Song et al., 2005). The selection of Ag composition is for cost minimization. A numbers of author showed that some of the important trends have present regarding the relationship the relationship between mechanical properties and microstructure of Zinc-Aluminium alloy but it can be said that no information on Zinc-Tin alloy. In addition, there is sufficient information available on the effect of adding Ag on Zn alloy.

The Zn-Sn alloy has recently been considered as one of alloy that can replace the Pewter alloy in giftware industry. Zn-Sn alloy has greater mechanical properties and lower cost. However the tendency of oxidation of this alloy confines its application (Schweitzer, 2007).
The objective of this work is to investigate the effects of the addition of Ag on mechanical properties (tensile strength and elongation) and microstructure of Zinc-based alloy.

II. EXPERIMENTAL METHOD
Zinc-tin-silver ternary alloy were fabricated with the following compositions (wt. %): 79.97Zn-20Sn-0.03Ag, 79.73Zn-20Sn-0.27Ag, 79.50Zn-20Sn-0.50Ag

A measured weight of Zn was placed into a ceramic crucible and melted to a temperature of 420°C. The appropriate amount of Ag was then added. Although Ag melts at relatively high temperature (961°C), it dissolves very readily into the molten metal of Zn bath. Finally, the addition of Sn (Tmelt =231°C). Specimens were produced by casting the molten alloy of Zn-Sn-Ag into rubber mould of spin casting. The mould is designed based on ASTM standard A370 (Song et al., 2007).

Tensile tests were performed on five specimens of each alloy. Tensile tests were carried out on 25 mm gauge length specimens at the speed of 5mm/min using an INSTRON Universal Testing Machine. The tests were carried out to determine the tensile strength and percentage elongation and also the differences in stress-strain curve.

In addition to tensile test, Rockwell hardness tests were performed to measure the hardness of all specimens by using a ball indenter under an applied load of 100 kgf. A Mitutoyo Ark-600 Rockwell Hardness testing machine was used to measure the hardness of each specimen at ten different points to determine the mean value of hardness at different locations.

The standard metallographic techniques were used. Microstructure examination of the experimental alloys was carried out by grinding and polishing. The reagent for etching was a solution containing 5g CrO₃, 0.5g Na₂SO₃, and 100ml H₂O for 2 seconds (Hubert et al., 1985). A JEOL JSM-5600 scanning electron microscope (SEM) was also used for detailed fracture studies. Fracture surfaces of typical samples subjected to tensile tests were investigated.

III. RESULTS AND DISCUSSION

I. Mechanical Properties

Figure 1 shows the samples prepared for tensile test based on ASTM standard. Sample (a) is the original sample before the test while sample (b) and (c) are samples after tensile test. Sample (c) which contained 0.50 wt. % Ag shows the higher elongation, L₂ compared to (b).

Figure 2 shows the stress-strain diagram for different Ag content. The pattern of the curve is different in stress and strain. Alloy containing 0.50 wt. % Ag having relatively large tensile strains up to the point of rupture whereas for both alloy containing 0.27 wt. % Ag and 0.03 wt. % Ag shows small strain up to the point of rupture. Alloy of 0.50 wt. % Ag also shows the highest yield point and the yielding region take up the majority of stress strain curve. It can be concluded that alloy containing 0.05 wt. % Ag is more ductile than other alloys. By comparing the curve, it is observed that the alloy containing 0.50 wt. % Ag capable of absorbing much larger quantities of energy before failure which is similar to ductile materials characteristics (Umoru and Ige, 2007). Ductile materials exhibit large strains and yielding before they fail. On the other hand, Thornton and Colangelo (1985) stated that brittle fractures are correlated with cracks or other flaws in the material and in contrast to ductile behaviour, they are characterized by low energy absorption and lack of gross plastic deformation (cited in Tajally et al., 2009, p. 3891).

Fig. 1 Sample of tensile test (a) original (b) Zn-Sn-0.03Ag and (c) Zn-Sn-0.50Ag.
Figure 2 shows the effect of Ag contents on tensile strength. The experiment is conducted by preparing samples containing lowest and highest Ag contents with fixed Sn composition (20 wt. %). The graph obtained as functions of percentage of Ag content with tensile strength. By adding 0.03 wt. % Ag, the tensile strength is low (28MPa) compared to alloy containing 0.27 wt. % Ag (39 MPa) which is better than 0.03 wt. % Ag. The addition of 0.50 wt. % Ag tends to increase the tensile strength of the alloy and show the highest value (52MPa) among three alloys. It is approximately 4% difference than the reference alloy (50MPa). By comparing the values, the tensile strength became greater with an increasing Ag contents. The large increase in tensile strength is caused by the increasing Ag-Sn compound in the alloy.

Figure 3 shows the effect of Ag contents on percentage elongation of Zn alloys. The same content of alloys are used for this experiment. Alloy containing 0.03 wt. % Ag shows the lowest value (7%). By adding 0.27 wt. % Ag, the percentage elongation tends to increase to 13%. The percentage elongation continues to increase to 17% by adding 0.50 wt. % Ag and shows the highest value compares to another two alloys. It can be said that the alloy with addition of 0.50 wt. % has close value to percentage elongation of Pewter (18.07%) by 5.9%. Thus, the addition of Ag to the alloy system was marginally increased the elongation. On the other hand, the elongation and tensile strength of alloy containing 0.50 wt. % Ag shows highest value when the tensile test were performed at deformation rate of 7.8x10e-5 per seconds. The higher elongation indicates that the eutectic structure become to a hypoeutectic structure. The formation of an Ag-Sn compound occurs at the expense of the Sn phase. The variation in Zn content makes the eutectic structure into hypoeutectic structure. Addition of Ag into the Zn-20Sn alloy reduces the eutectic structure and Zn matrix. It is accompanied by coarsening of the microstructure matrix. The improvement in tensile strength and elongation could be ascribed by grain size increment.

II. Fractography Analysis
Pio (2011) reveals that the mechanical properties are reliant on the microstructures of the casting. The ways to develop the mechanical properties are grain refinement and modifications. Fractographic features of the experimental alloys after tensile tests can be seen in Figure 5. Figure 5 (a), (b), (c) and (d) represent tensile test fracture surface of alloy containing 0.50 wt. % Ag, 0.27 wt. % Ag and 0.03 wt. % Ag. It can be observed that the alloy containing 0.50 wt. % Ag...
showed a mixed mode of fracture exhibiting ductile failure while the rest showed brittle failure. Fracture surface of alloy containing 0.50 wt. % Ag shows the presence of more dimples indicating the occurrence of ductile mode of fracture (Fig. 5a). Increasing Ag content significantly affected the fracture surface of the alloys. In this context, alloys contained 0.27 wt. % Ag and 0.03 wt. % Ag showed brittle rupture and less ductile failure with dimples as shown in Figure 5b, 5c and 5d as compared to Figure 5a. It can be observed that both alloys possess a smooth flat surface, cleavage regions and absence of dimples. It also reveal more small cup and cone fracture size of 0.27 wt. % Ag and 0.03 wt. % Ag alloy. This phenomenon reflects a lowering in ductility of the alloy. The formation of intermetallic compounds cause the increasing in ductility of the alloy. The formation of Ag-Sn compound precipitate is also contributed to the high ductility of 0.50 wt. % Ag alloy (Hansen, 1958).

III. Fractography Analysis

Figure 6 shows the microstructure of Zn-Sn-Ag alloys. In the 0.03 wt. % Ag sample (Figure 6a), fine Ag particles (bright) can be observed. A few Ag particles (bright) with slightly larger size were found in Figure 6b which contain 0.27 wt. % Ag. In figure 6c illustrates that in sample of 0.50 wt. % Ag, the populations of irregular Ag and Zn-Sn grains were increased. Thus, the presence of Ag in the alloy resulted in increasing size of grains. The addition of Ag to the Zn-Sn alloy can result the formation of Ag3Sn precipitates. However, the Ag selectively combines with Sn, instead of Zn to form an Ag-Sn compound. The solubility of Sn in Zn is extremely restricted. The Ag particles of Ag3Sn and AgZn are intermingled with Sn (dark) in Zn matrix (yellow). The addition of
a small amount of Ag to Zn-20Sn alloy causes the zinc rich components of the eutectic to coarsen and lamellar structure to appear in large plates. The silver combines with Sn to form Ag3Sn and with Zn to form AgZn. Chen et al., (2005) reported that the standard Gibbs free energy of the formation for AgZn3 and Ag5Zn8 compounds are much lower than that of the Ag3Sn compounds. Thus, the alloy system will form Ag-Sn compounds rather than Ag-Zn compounds. Consequently, the compound formation between Ag and Zn reduces the Zn content of the matrix.

IV. CONCLUSION AND SUGGESTIONS

The addition of Ag improves the tensile properties, tensile strength and elongation of Zn alloy. The 0.50 wt.% Ag alloy had a greater elongation than that both 0.27 and 0.03 wt.% Ag. The 0.50 wt.% Ag alloy also exhibits best tensile strength and ductility of the other alloys. Thus, give benefits to machining process whereby rolling and bending will be easier and will reduce the time for machining.

Metallographic studies showed that Ag particles (Ag3Sn or AgZn) existed in the microstructure and the size of grain is increasing. Ag combines with Sn form an Ag-Sn compound. The 0.5 wt.% Ag addition to the Zn-20Sn alloy destroys the uniform eutectic structure and leads to formation of Ag-Sn compound, a hypoeutectic matrix, and increasing the elongation, tensile strength and ductility.

It is recommended in the future that further research on effect of Ag addition into Zinc alloy can be conducted in other aspects such as viscosity and compatibility to low pressure die cast, spin cast, squeeze cast and lathe profile.

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