Effect of Composition and Pouring Temperature of Cu-Sn Alloys on The Fluidity and Microstructure by Investment Casting

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Abstract. The alloy composition and the pouring temperature are main parameters to avoid cast defects in the metal casting process. The aim of this study was to investigate the effect of tin composition and pouring temperature on the fluidity and microstructure of Cu-Sn alloys to minimize product failure. The material used in this study was Cu with the addition of tin composition (20-25)% Sn by melting Cu = 99.9% and Sn = 99.9%. The pouring temperatures were varied T₁=1000°C and T₂=1100°C. Mold for fluidity test was used the wax pattern with investment casting method. The wax pattern for mold of fluidity test shaped bars with a length of 400 mm, the width of 10 mm and cavity thickness varies from 1.5-5 mm. The mold material was used natural ceramic such as clay (SiO₂). Increased of the tin composition decreases the length of fluidity, while the increased pouring temperature and the cavity thickness of the mold increase the length of fluidity. Increasing tin composition and pouring temperature increases the phase microstructure α and triggers the formation of columnar dendrites. The high rate of cast metal fluidity and the thickness of the mold cavity greatly affect the microstructure of the alloy.

1. Introduction

The tin bronze is an important alloy that the industry needs. These alloys are widely used to manufacture various engine components such as valves, bearings, pump impellers, piston rings, weapon components, gears and other [1]. The bronze alloys are more easily poured and shaped, compared to pure copper and brass [2]. The low tin bronze alloys <17wt.% Sn is used to make various machine components while high tin bronze alloys >17wt.% Sn is used to make various musical instruments. The tin bronze alloys are used to make church bells since the 11th century [3,4], musical instruments of trumpet, percussion, and gamelan [5–7]. The tin bronze alloys can be poured in various molds, forgeable, corrosion resistant and have good acoustic properties.

The casting is one of metal forming techniques that has long been used to produce various metal products. One of the most widely used metal casting techniques is Investment casting. It is also known as lost wax process or precision casting [8]. The advantage of investment casting is able to produce thin-walled cast products, having a slope and curvature with small radius variations, smooth surface, accurate shape and dimensions [8,9]. The investment casting produces a cast product approaching the end product, lowering production time and without machining process [10]. The resulting investment casting product does not require final work on its surface and high product tolerance [11]. The disadvantage of
investment casting is it requires long process stages, relatively expensive cost, limited to small cast objects and difficult to add core.

The Fluidity is one of the main parameters for the success of casting. Poor fluidity makes it difficult for cast metals to flow and fill the mold cavity and can cause cast defects [12]. Fluidity is the ability of the molten metal to flow and fill every part of the mold [13]. The fluidity length is measured from the pour point to the soli
dity point and is the maximum distance of liquid metal flows in the mold [14]. Fluidity is influenced by several parameters such as composition, pouring temperature, viscosity, flow rate and surface tension between a liquid metal with the mold wall.

The increased composition can reduce the fluidity rate to a certain extent from the alloy composition. The increases of composition to the limit of 25wt.% Sn increases the viscosity Cu-Sn alloy [15,16]. Increased viscosity of Cu-Sn alloys occurs in the 20-30wt.% Sn composition in the β and γ intermetallic phases [17].

Increasing pouring temperatures significantly increase the length of fluidity for all types of mold material [18]. The high pouring temperature gives a long time on the molten metal until it is finally solid. The cooling rate at investment casting is slower compared sand casting [19]. High temperature gradients between mold walls and cast metals cause the solidification rate to run fast. The low solidification rates produce larger dendrite α, decrease the mechanical properties of hardness and tensile strength. The increase of the pouring temperatures 1000°C to 1200°C decreases the density and mechanical properties of 20wt.%Sn alloy [20].

The microstructure growth during the solidification process is strongly influenced by several factors, such as temperature gradients between liquids (GL), growth rate (VL) and alloy composition (CO) [21]. The growth of microstructure of dendrite arm spacing (DAS) tends to be greater in the α + δ phase in CuSn alloys [22]. The addition of the tin composition and the increase of pouring temperature results in the change of equiaxed microstructure to dendrite columnar, secondary dendrite arm spacing growth and increased α + δ phase in Cu-Sn alloys. The fluidity length and pouring temperature can reduce product defects where cast metal is able to flow and fill the entire mold cavity. The length of fluidity in cast metal is very necessary as a reference for casting, especially in thin-walled molds. The aim of this research is to investigate the influence of the addition of tin composition in the Cu(20-25)wt.%Sn and pouring temperatures of T1=1000°C and T2=1100°C to fluidity length and microstructure by investment casting method.

2. Materials and Methods

The materials used in the study were tin bronze Cu(20-25)wt.%Sn. The alloy compositions were prepared using Cu = 99.9% and Sn = 99.9% in weight ratio respectively. The alloy was melted in a crucible furnace with uses charcoal wood fuel. The composition of Cu-Sn alloys was shown in Table 1.

| Alloys       | Cu     | Sn   | Zn    | Pb    | Fe   | Ni   | Al     |
|--------------|--------|------|-------|-------|------|------|--------|
| Cu-20wt.%Sn  | 79.77  | 20.06| 0.08  | 0.02  | 0.04 | 0.00 | <0.001 |
| Cu-22wt.%Sn  | 78.16  | 21.39| 0.03  | 0.14  | 0.13 | 0.10 | <0.001 |
| Cu-24wt.%Sn  | 75.13  | 23.86| 0.14  | 0.20  | 0.48 | 0.14 | <0.001 |
| Cu-25wt.%Sn  | 70.71  | 24.90| 0.05  | 3.51  | 0.59 | 0.02 | 0.041  |

The method used was investment casting. The pattern for fluidity test mold was made using wax. Furthermore, the wax pattern was coated with a natural ceramic material in the form of a mixture of clay, sand and water. The wax pattern for the fluidity test mold was gradually coated with clay slurry: 200 mesh for the inner surface followed by 100 mesh for the outer surface. The dewaxing and sintering treatment of the mold was carried out until it reaches the temperature of 600°C. The wax pattern for the
mold of fluidity test shaped bars with a length of 400 mm, the width of 10 mm and cavity thickness varies from 1.5, 2, 3, 4, and 5 mm. The fluidity test mold and fluidity product as shown in Figure 1.

![Figure 1. Wax pattern design (unit: mm)](image)

The natural ceramic material in the form of clay to manufacture molds has been tested using SEM-EDS. The composition of a natural ceramic material was contained SiO$_2$ compound, as shown in Figure 2.

![Figure 2. Composition of natural ceramic material by SEM-EDS](image)

The stages of investment casting were started from pattern preparation, coating with clay slurry, dewaxing process and fluidity product as shown in Figure 3.

![Figure 3. Fluidity test (a) wax pattern (b) mold investment casting (c) dewaxing (d) fluidity product](image)
The temperature of the casting is varied at superheat temperatures with the initials T1 and T2. It was the highest temperatures above the Cu alloy liquid point (20-25)wt.%Sn, where T1 =1000°C and T2 =1100°C. The length of fluidity is measured from the base of the inlet to the end of the cast metal. The microstructure observation using an optical microscope with 100X magnification. The etching was done with a mixed solution between HNO₃ and H₂O (50%:50%) ratio dipped for 5 seconds.

3. Results and Discussion

The addition of tin composition to Cu (20-25) wt.% Sn decreases the length of fluidity. The decrease in fluidity length is caused by increasing solidification rate and viscosity of the cast metal. The Cu-Sn phase diagram shows that the composition Cu(22-25) wt.%Sn is the transition phase, where the transition limit is at the composition of 22wt.%Sn. The composition (13.5-22)wt.%Sn is in the phase of α + L hypoperitectic and composition (22-25.5)wt.%Sn is in phase β + L hyperperitectic. The results of the measurement of fluidity length with the investment casting method on the tin bronze of Cu-20wt.%Sn, Cu-22wt.%Sn, Cu-24wt.%Sn and Cu-25wt.%Sn are shown in Figure 4.

![Figure 4. Fluidity of Cu-Sn alloys](image)
The increased pouring temperature and thickness of the mold cavity increase the length of fluidity for all compositions. A high pouring temperature in the superheat area can extend the distance between the melting point and solidus point. This will increase nucleation growth in cast metals during the solidification process. The superheat temperature increases the fluidity length of all alloy compositions [23]. The investment casting method has a relatively low solidification rate.

One of the factors that influence the high solidification rate is the temperature gradient between cast metal and mold wall. The alloy composition and pouring temperature are the main factors that determine success in the casting process in molds that have thin cavities. Increased the pouring temperature and mold cavity can improve the length of fluidity. The process of dewaxing and sintering besides removing wax material from the mold also serves to reduce water content (H₂O) and increase the temperature of the mold.

**Figure 5.** Microstructure Cu-Sn at 1000°C (a) 20wt.%Sn (b) 22wt.%Sn (c) 24wt.%Sn (d) 25wt.%Sn
Increasing of the tin composition and pouring temperature affect the microstructure of Cu-Sn alloys. The results of microstructural observation show that the growth of the α phase decreases with equiaxed grains morphology to dendritic columnar grains. The increase of the tin composition and the pouring temperatures increased the morphology of columnar dendritic grains and dendrite arm spacing (DAS). The increase of the tin composition and pouring temperatures increases the formation of α + δ eutectoid phase [22]. The microstructure of Cu-20wt.%Sn, Cu-22wt.%Sn, Cu-24wt.%Sn and Cu-25wt.%Sn at pouring temperature 1000°C is shown in Figure 5. Increased of the tin composition in the Cu(20-25)wt.% Sn triggers a change in equiaxed microstructure into columnar dendrites in the matrix [24]. Figure 6. shows the microstructures at pouring temperature at 1100°C.

4. Conclusions
This research can be concluded that: The increase of the pouring temperatures and cavity thickness of the mold will increase the length of fluidity Cu-Sn alloys. Increased of tin composition in the Cu(20-25)wt.%Sn decreases the fluidity length of Cu-Sn alloys. The increase of tin composition and pouring temperatures causes the change of fine equiaxed to the coarse columnar dendrite structure of the matrix and increase the α + δ eutectoid phase.

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