Effect of Composition and Pouring Temperature of Cu-Sn on Fluidity, Density and Mechanical Properties by Investment Casting

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Abstract. Composition and pouring temperature are important parameters in the casting. Incorrect composition and pouring temperature settings can cause defects in cast product. Material used in Cu-(20-24)wt.%Sn. The pouring temperature was varied 1000°C and 1100°C. The mold was made using a wax pattern and coated in clay (SiO2). The mold has a length of 400 mm, width of 10 mm and thickness of the cavity varied from 1.5-5 mm. The length of the fluidity tends to decrease with the addition of the composition, while the increase in pouring temperature and the thickness of the mold cavity increases the length of the fluidity. The density increases with increasing composition and temperature of the pour. The high density indicates low porosity. Material hardness and bending decreases to increase composition and pouring temperature. Tensile strength decreases with the addition of composition, while the pouring temperature increases.

Keywords: investment casting, composition, pouring temperature, density, mechanical properties.

1 Introduction

Metal casting is a method of formation that is widely used to produce metal components. The advantages of metal casting are suitable for mass production, suitable for all types of metals, the process is simple and the production costs are relatively cheap. The weakness of metal casting is the surface of rough objects, shrinkage of products and porosity.

Investment casting is much developed in addition to sand casting. Investment casting is the oldest technology used for casting: tools, weapons, jewelry and ornaments in various forms. Casting investment is also known as lost wax process or precision casting [1]. The advantages of investment casting are suitable for thin-walled molds, having slopes and curvatures with small radius variations, smooth surfaces, accurate shapes and dimensions [1]–[3]. Investment casting produces cast products close to near net shape, decreases production time and without machining processes [4].The resulting product does not require final work on its surface and high product tolerance [3]. The weakness of investment casting is that it requires a long process step, the cost is relatively expensive, limited to small size cast objects and difficult to add core.

ICCSET 2018, October 25-26, Kudus, Indonesia

DOI 10.4108/eai.24-10-2018.2280525

The low bronze <17% Sn is widely used to make various engine components such as valves, bearings, pump impellers, piston rings, rifle components and other mechanical products [5], [6]. High tin bronze >17% is used to make various musical instruments. It was used to make church bells in the 11th century [7]–[9], trumpets and percussion instruments and gamelan as the main ingredients [10]–[12]. Tin bronze alloys have castability in a variety of molds, able to be forged, corrosion resistance and good acoustic properties.

The success of metal casting is influenced by the amount of alloy composition and pour temperature. Fluidity is the ability of liquid metal to flow and fill the mold cavity before freezing. The dewaxing and sintering process of the investment casting can reduce the temperature gradient between the mold and the pour temperature. Porosity due to gas release from water binders can also be reduced. Investment casting has a lower porosity than sand casting. The length of the fluidity in investment casting increases compared to sand casting.

Addition of tin composition to a certain extent will improve tin bronze mechanical properties. Alloys become easily poured, shrinkage is low, solubility of hydrogen decreases, corrosion resistance increases especially in single phase alloys. The hardness and tensile strength of Cu-Sn alloys increases in sand mold, while elongation decreases. The impact strength of Cu-Sn alloy increases until the tin content is around 5%, more than that will decrease. Tensile strength increases in tin content up to about 10% Sn, yield strength increases to a composition of about 20wt.% Sn [9].

This study aims to determine the effect of compositionCu-(20-24)wt.%Sn on pouring temperatures of 1000°C and 1100°C on fluidity, density and mechanical properties by investment casting.

2 Material and Methods

The material used in the research was tin bronze Cu-(20, 22, 24) wt.% Sn. Alloys made with melting Copper (99.99%) and tin 99.9% in the crucible furnace using wood charcoal. The composition of the alloy was calculated by weight ratio of Cu and Sn. Material composition was tested using spectrometry, as shown in Table 1.

Table 1. Materials composition.

Alloys	Composition (%)						
	Cu	Sn	Zn	Pb	Fe	Ni	Al
20wt.%Sn	79.77	20.06	0.08	0.02	0.04	0.00	<0.001
22wt.%Sn	78.16	21.39	0.03	0.14	0.13	0.10	<0.001
24wt.%Sn	75.13	23.86	0.14	0.20	0.48	0.14	<0.001

The wax pattern was coated with clay slurry which was a natural ceramic material. Clay composition was tested using SEM-EDS. The investment casting mold manufacturing process was through the following stages:

a. Stage 1, the wax pattern was dipped in clay slurry with 200 mesh and dried. This process was carried out many times to a thickness of 5 mm.
b. Stage 2, coated with clay slurry with 100 mesh, until the mold thickness reaches 600 x 250 x 220 mm.
c. The mold was dried under the sun to reduce its water content.
d. The mold was carried out by dewaxing and sintering at 600ºC.

The shape of the wax pattern, the investment casting mold and the dewaxing process were shown in Figure 1.

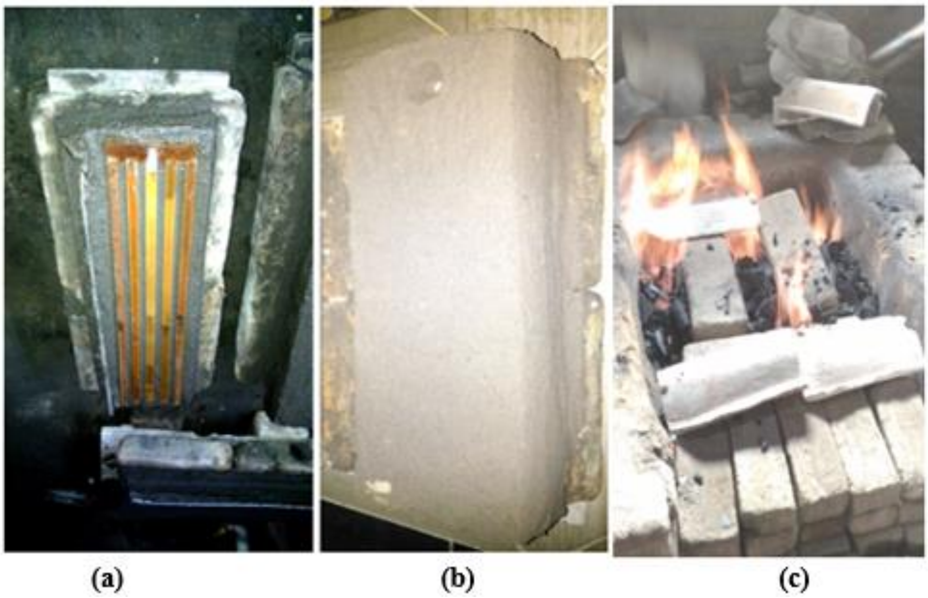


Fig. 1. Stages of investment casting (a) wax pattern (b) coating mold (c) dewaxing.

The wax pattern has a length of 400 mm, width of 10 mm and the thickness of the mold cavity varied by 1.5, 2, 3, 4, 5 mm, shown in Figure 2.

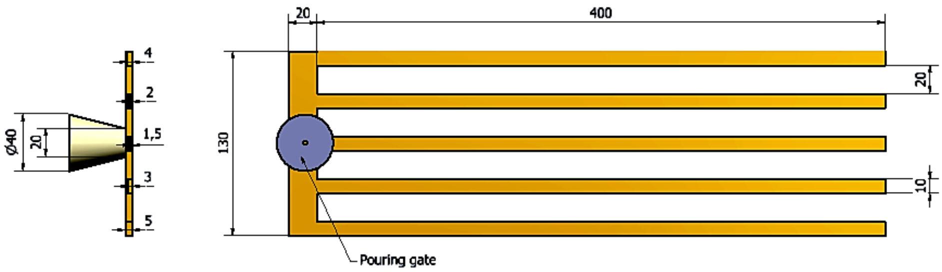


Fig. 2. Wax pattern design (unit: mm).

The pouring temperature was varied 1000ºC and 1100ºC. Tensile strength testing was tested using ASTM E-8, ASTM E-290 for bending test and hardness of VHN. Measurement of density using equation 1.

$$\rho_b = \frac{w_{air}}{w_{air} - w_{water}} \, x \, \rho_{water} \qquad (1)$$

Where :

ρ_b = Density actual (g/cm^3)

w_{air} = Mass in air (g)

w_{water} = Mass in water (g)
ρ_{water} = Density pure water (1 g/cm^3)

3 Result and Discusion

The material used to coat the wax pattern as a mold is clay. It has SiO_2 compound which is a type of traditional ceramic. Other ceramic compounds are Al_2O_3 and ZrO_2. SiO_2 and Al_2O_3 ceramic slurries have high heat resistance, are not reactive to cast metals compared to ZrO_2 [1]. SEM-EDS test results as shown in Figure 3.

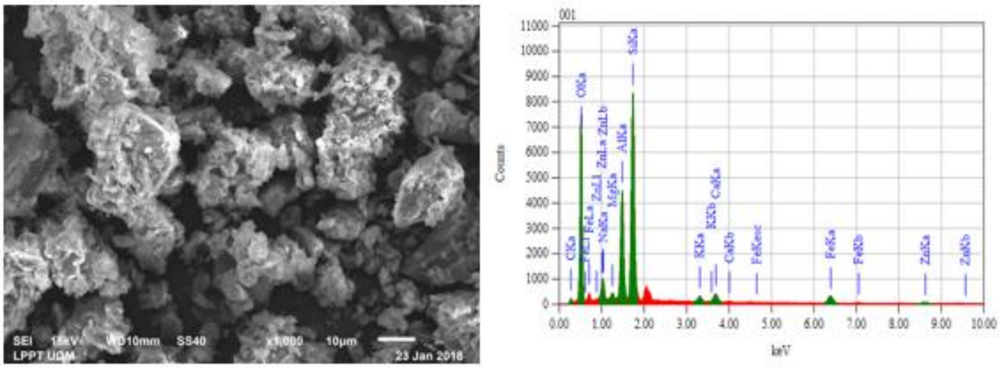


Fig. 3. Test of SEM-EDS of clay.

The addition of a composition of 20-22wt.% Sn decreases the fluidity length of the Cu-Sn alloy, while at 24wt.% Sn the fluidity length of the increases. The fluidity length of the Cu-Sn alloy decreases more due to increased viscosity [13]. The Cu-Sn phase diagram shows the phase α (10-22) wt.% Sn while it is right β (> 22-25) wt.% Sn. Phase α where the solubility of Cu is still dominant while the β phase shows the liquid metal is in the intermetallic phase. The fluidity length is also affected by the solidification rate and the amount of surface tension on the mold wall. Clay slurry with fine and uniform granules will increase the fluidity length, where the surface tension of the mold wall is relatively small. Increased pouring temperature and mold cavity also increase the fluidity length for alloy composition. Molds with large cavities and high pouring temperature will be able to reduce product defects, where all parts of the mold are easily filled. Figure 4. shows the fluidity length (a) Cu-20wt.% Sn (b) Cu-22wt.% Sn (c) Cu-24wt.% Sn.

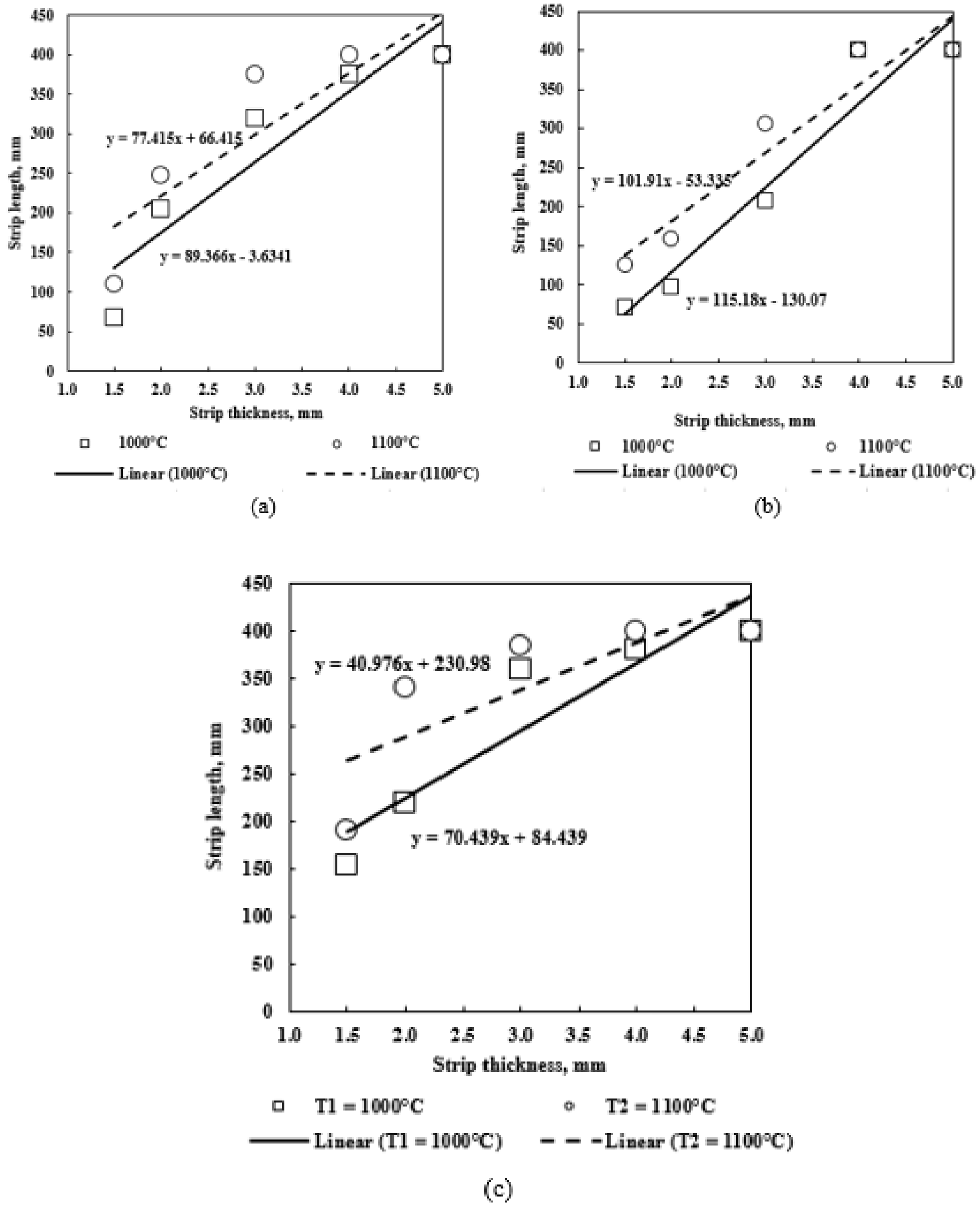
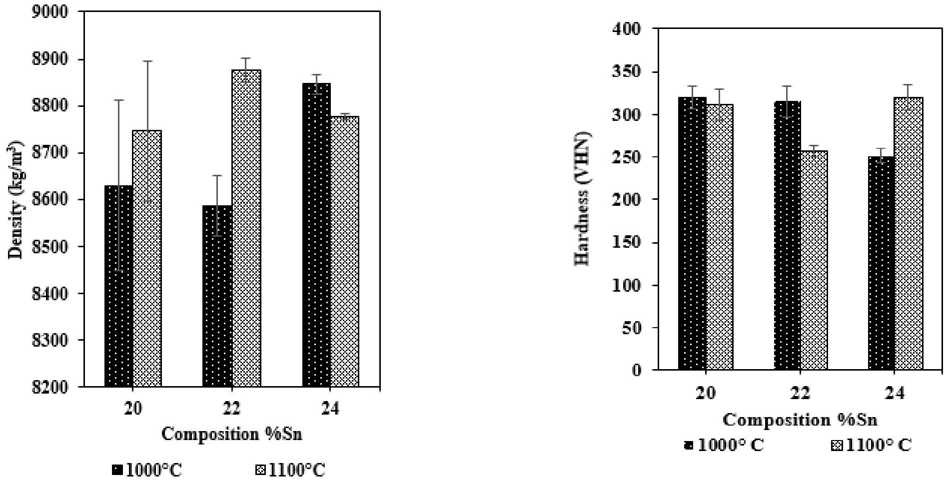


Fig. 4. Fluidity length of Cu-Sn (a)20wt.%Sn (b) 22wt.%Sn (c) 24wt.%Sn.

Increased pouring temperature and composition in the alloy can cause a decrease in density. Increasing pour temperature 1100°C at composition 22wt.% Sn does not cause a decrease in density. The decrease in density is mostly due to the formation of porosity. Density is strongly influenced by the conditions during the smelting process, including time, temperature and liquid treatment that can cause deoxidation. Dewaxing and sintering on investment casting will release water compounds (H_2O) which are used as binders of clay slurry while strengthening the mold walls. Dewaxing and sintering processes pay attention to time and temperature so that the mold does not crack due to thermal shock [3]. The decrease in porosity can also be reduced by adjusting the casting distance so as to avoid flow turbulence. The Cu-Sn density is shown in Figure 5.a.

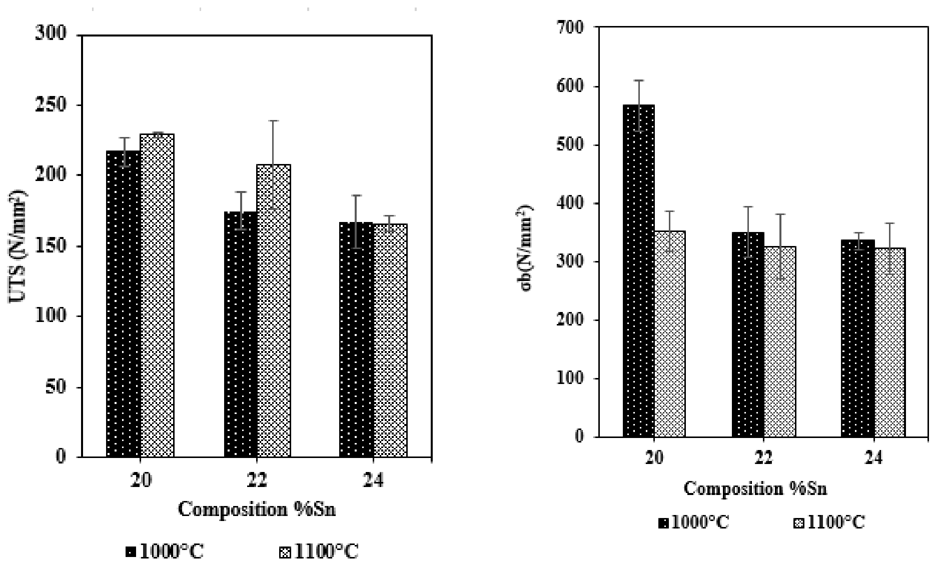


(a) **(b)**

Fig. 5. Mechanical properties Cu-Sn (a) Density (b) Hardness.

Increased pouring temperature and tin decrease the hardness of Cu-Sn alloys. Increasing tin will reduce hardness in the copper matrix. Dewaxing and sintering treatments on investment casting cause the mold temperature to increase. Increased mold temperature causes slow solidification rates. It can increase grain size and roughness which can reduce its mechanical properties. Fine grains cause a harder structure, not easy to crack, fatiq resistance, tensile strength and increased toughness compared to coarse grains [14], [15]. Figure 5.b shows the hardness of Cu-Sn alloys on the composition and pouring temperature.

Increased composition causes the tensile strength to decrease, while increasing the pouring temperature increases the tensile strength of the material. Addition of tin composition causes Cu-Sn alloy to tend to brittle. Tensile strength is directly proportional to alloy density, while material hardness value is inversely proportional to density. Figure 6.a and 6.b show the tensile strength and bending of Cu-Sn alloys.



(a) **(b)**

Fig.6. Mechanical properties Cu-Sn (a) tensile strength (b) Bending strength.

The decrease in tensile strength and hardness is caused by the formation of rough and large SDAS[6]. Increasing the pouring temperature causes the molten metal to bind a lot of air that enters together with the pouring process.

4 Conclusions

The results of Cu-(20,22,24) wt.% Sn research on fluidity and mechanical properties byinvestment casting techniques are as follows:

1) Increasing the length of the fluidity is at the composition of 20-22wt.% Sn through increasing the pour temperature and thickness of the mold cavity.
2) The addition of a composition of 20-22wt.% Sn to a temperature of 1100 ° C does not cause a decrease in density.
3) Tensile strength, hardness and bending strength decrease with the addition of composition and increase in pouring temperature.
4) Length of fluidity, density and mechanical properties show a decrease in composition > 22% which is the boundary between the phases α and β.

Acknowlegment

The research was carried out under dissertation grant by the Indonesian Ministry of Finance through *Lembaga Pengelola Dana Pendidikan* (LPDP).

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