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## Solidification characteristic of cu-20%sn bronze alloys casting process by using sand and metal molds

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# Solidification characteristic of cu-20%sn bronze alloys casting process by using sand and metal molds

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**Abstract.** Solidification is an essential part of casting process. This is a change process range from liquid phase into solid phase. Difference of solidification rate affects the needed time to change liquid phase into solid phase as well as the release of latent heat. This study aimed at reviewing solidification characteristic of Cu-20%Sn Bronze Alloys as Balinese gamelan materials during casting process by using sand and metal molds. Pure commercial copper (Cu) and white tin (Sn) were melted in crucible furnace until 1000°C. The melted metal was poured into sand and metal molds. History of solidification temperature was measured and recorded by using thermocouple type K which was directly connected to computer equipped with data acquisition system. The results of this study showed that the solidification rate of casting process in metal molds faster than solidification rate on using sand molds. Finer dendrites with multiple branches are formed on casting on metal molds than compared that dendrite forms that produced on castings by sand molds

## 1. Introduction

Bronze is commonly called as tin bronze because the main alloys of this alloy are copper (Cu) and white tin (Sn). Tin bronze is widely used as engine bearing, pump blade, ring piston, bell, gear, and some engine elements. This alloy has good mechanical characteristic to hold the weight and wear, so it is always used in as-cast condition without heat treatment. If this alloy is used in as-cast condition so the properties material is merely controlled by casting process [1].

Tin bronze with composition Cu - 20% Sn is generally used as music instruments such as bell, *gamelan*, because this alloy has good mechanical characteristic, stable in room temperature, good acoustic characteristic, i.e. it can produce low damping vibration [2,3].

Casting has some strengths, i.e. it can produce complex thing, produce big and small products, produce net shape in mass number with low cost. With this strength, most of the production process is done by casting process [4].

One of important parameters in casting process is solidification process, i.e. change process from liquid phase into solid phase. Two main things happen in solidification process are nucleation and crystal growth [4]. Nucleation is started by forming solid particle in liquid form. This solid particle is formed when energy in lower particle from liquid energy. These small cores are formed independently in random spots. These cores will be the center of further crystallization process. Nucleation rate is depended on metal natural characteristic, impurity, and solidification rate.

In metal solidification process, solidification temperature gradient mostly happens in solidification area of liquid cooling. Solidification in liquid and solid area (mushy zone) releases latent heat; the temperature change gradient is relatively small. After there is no latent heat, the solid cooling starts which is followed by re-raising gradient temperature [5].

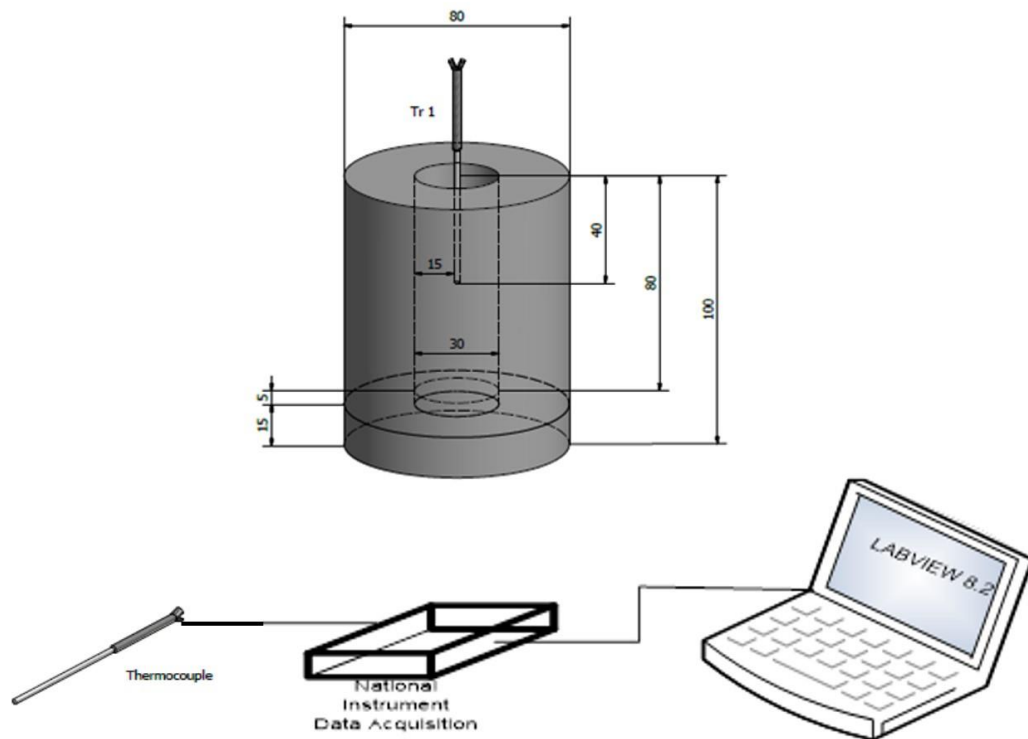
Solidification rate influences micro structure form such as grain size and dendrite arm spacing (DAS). The change of micro structure influences mechanical characteristic of the casting product. Some studies about solidification have been done previously such as solidification on alloy of binary system [6], solidification on bronze alloy Cu-8%Sn [7], fast solidification on tin solder alloy Sn-Cu [8], solidification rate on ductile cast iron [9], peritectic alloy Cu-Sn [10].



So far, a study about solidification of bronze casting with composition Cu -20%Sn on sand and metal molds has not been conducted yet. In this study, the effect of solidification rate on the formed micro structure and the mechanical characteristic as the result of casting process on both molds was reviewed.

## 2. Set - Up Experimental

Bronze alloy used in this study was alloy of copper (Cu) and white tin (Sn) with composition 80%Cu - 20%Sn. Commercial pure copper 99.99 wt.% and commercial pure tin 99.99 wt% were melted in crucible furnace until liquid temperature of 1000°C. This liquid metal was poured into sand and metal molds (permanent molding) with molding temperature of 400°C. the shape of the mold is cylinder with diameter 30 mm and height 80 mm. Measurement of solidification temperature used thermocouple type K which was directly connected to data acquisition system (National Instrument thermocouple system). Set-up of the solidification temperature measurement is showed in Figure 1.

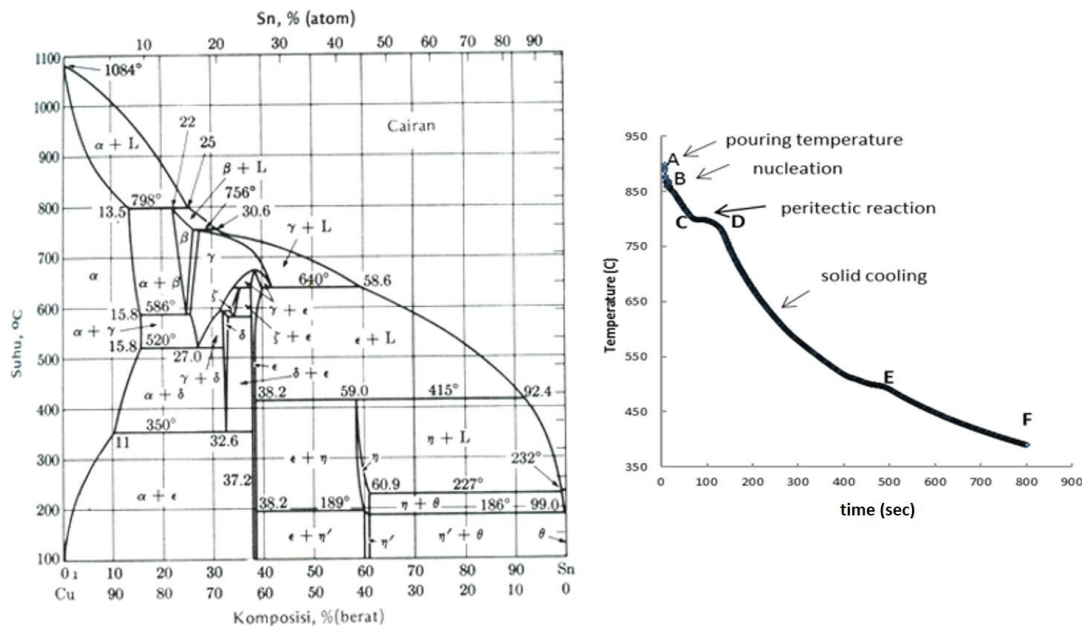


**Figure 1.** Set-up of the solidification temperature measurement

Characteristic of micro structure from the casting product was observed by using optical microscope. Specimen with diameter 30 mm and height 15 mm was prepared for micro structure investigation. The cut specimen was smoothed by using sandpaper respectively sized 240, 400, 600, 800, 1000, 2000, polished with diamond pasta, and finally processed with solution of 10% HNO<sub>3</sub> + 90 % alcohol. Tensile testing was done by using universal testing machine digital with capacity of 20 KN. The size of specimen followed the standard of JIS Z2201. No.7. Vickers hardness testing was used to test specimen hardness.

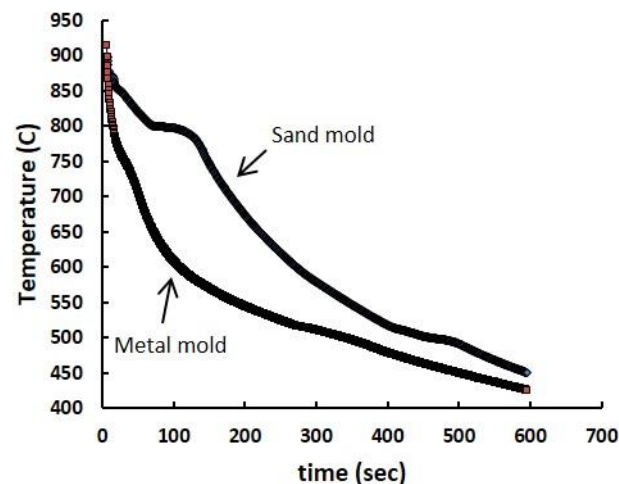
### 3. Results and Discussion

Figure 2 shows phase diagram and curve of solidification rate on casting process. From the solidification rate curve, it can be shown that liquid cooling happened along the A-B curve. In this area, the cooling rate is high, which is caused by high temperature difference between pouring temperature and molding temperature.



**Figure 2.** Phase diagram and Curve of solidification tin bronze alloy 80-20%Sn

Liquid metal which directly touched with the mold had earlier cooling, because the heat was absorbed by the mold which had lower temperature. Dendrite nucleation was started in 878°C (spot B) until temperature of 796.3°C in spot D. In this temperature range, there was alloy cooling (mushy zone), between liquid and solid phase  $\alpha$ . Cooling process in this area was ended with peritectic reaction, i.e. reaction of phase change  $L + \alpha \rightarrow \beta$ , happened along C-D line. In the cooling process of mushy zone, there was release of latent heat of the alloy so the freezing was complete in spot D. After there was no latent heat, solid cooling was started accompanied by the decrease of high temperature gradient (D-F line), cooling rate in area D-F was lower than liquid area because in this condition the mold had started to heat as consequence of the heat transfer of liquid metal into the mold so it produced low temperature gradient between wall temperature of the mold and casting metal. Figure 3 shows cooling curve between sand and metal molds. Both graphs show relation of temperature with cooling time in the cooling process.



**Figure 3.** Curve of cooling rate on sand and metal molds casting process.

Characteristic of cooling rate of both graphs is highly different. Characteristic of cooling rate on sand mold was slower than cooling rate by using metal mold. Cooling rate on sand mold was  $0.442^{\circ}\text{C/s}$  and cooling rate on metal mold was  $7.725^{\circ}\text{C/s}$ . The difference of cooling rate influenced the total time needed in cooling process, which was measured since pouring temperature until complete cooling [11]. Total time of solidification in sand mold casting was higher than using metal mold. When solidification process happened, both molds were heating, cooling gradient (cooling solid) of both molds was almost the same.

Cooling rate was influenced by the amount of heat transfer which happened between liquid metal into the mold. The occurred heat transfer was depended on heat conductivity ( $k$ ), density ( $\rho$ ) and specific heat ( $C_p$ ). Both molds in this casting process had different heat transfer characteristic so it produced different cooling rate curve. The ability of heat transfer on metal mold was higher than the ability of heat transfer on sand mold.

### 3.1. Microstructure Observation

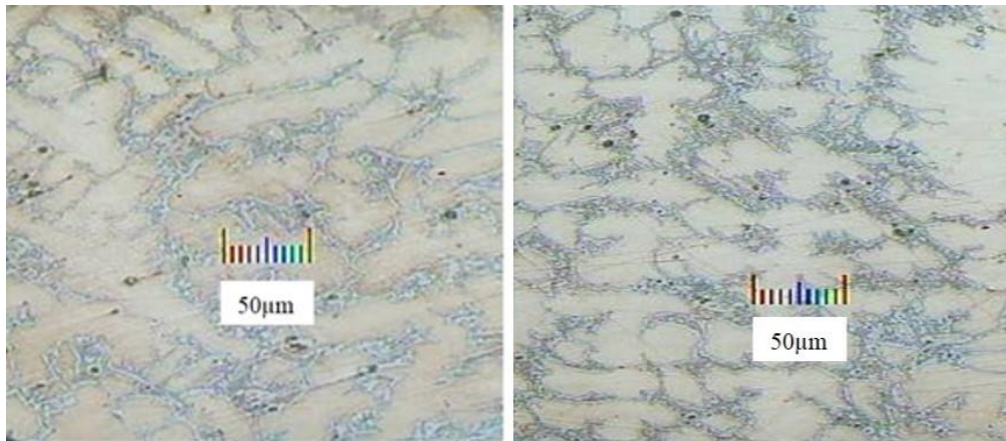
Figure 4 and 5 show the micro structure of castings materials on sand and metal molds casting process. The form of DAS (dendrite arm spacing) was smooth with many branches on metal mold casting. Bigger dendrite structure with few branch was found in sand mold. These differences were formed by cooling rate on the casting process.

In the gradient of molding and high liquid temperature, heat transfer is faster and  $\alpha$  dendrite primer became smoother and columnar with few branches (arms). Cooling time on sand mold is longer than on metal mold. Longer cooling time gave longer opportunity to diffusion process and crystal growth become bigger. Along the solidification process, the mold temperature raised so heat gradient decreased, solidification rate declined, primary dendrite grew, and DAS size raised up.

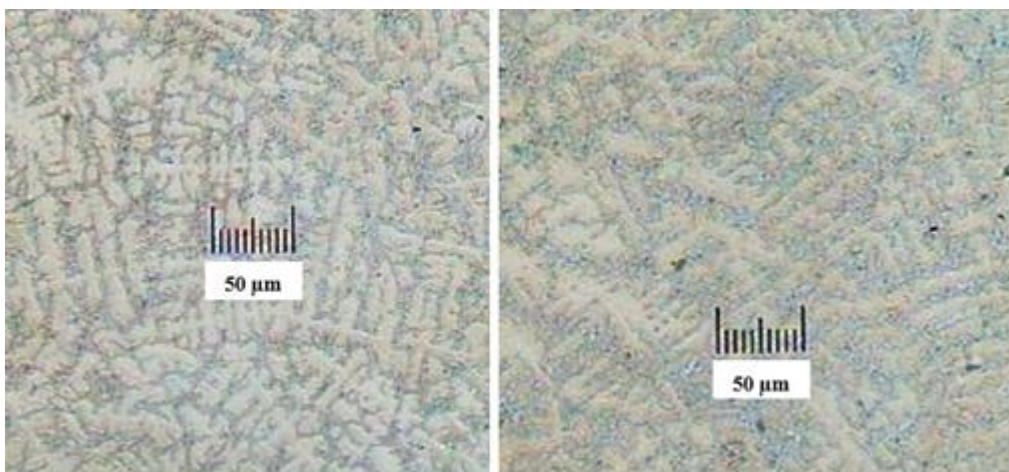
Variation of dendrite structure form was influenced by variation of solidification rate from the wall into the middle of the mold [12]. Metal solidification occurred on surface directly contacted with the mold and spread to the center of specimen diameter. Inner side of liquid metal had longer time for solidification compared to the liquid metal which directly contacted with the mold.

From Figure 3, it can be found that solidification rate on the metal mold casting is higher than on the sand mold. The effect of solidification rate is important to be found to design smoothing process from metal structure. It significantly influenced the mechanical characteristic.





**Figure 4.** Micro structure of tin bronze alloy Cu-20%Sn  
(Sand mold casting)

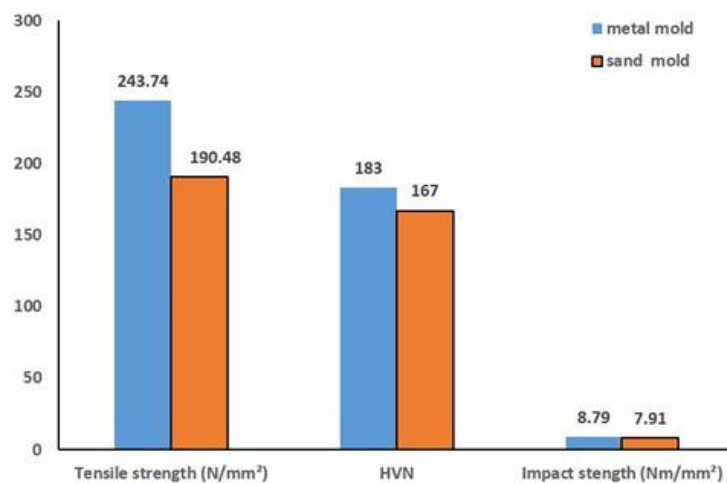


**Figure 5.** Micro structure of tin bronze alloy Cu-20%Sn  
(Permanent mold casting)

In high solidification rate, the needed total time is short, results smoother structure form and augments solute solubility [11]. The higher cooling rate, the micro structure is getting smoother and dendrite tip radius will be getting pointed [13].

### 3.2. Mechanical Properties

The difference of solidification rate resulted by the different use of mold influenced the mechanical properties. The mechanical properties resulted by casting of sand and metal molds is shown by Figure 6. It shows that mechanical properties, i.e. tensile strength, hardness and impact toughness from the metal mold was higher than using sand mold. The increase of solidification rate improved mechanical properties of the casting product.



**Figure 6.** Mechanical properties of tin bronze alloy Cu-20%Sn

High solidification rate results better mechanical properties compared to low solidification rate. Smoother structure was formed in high solidification rate. These fine grains form many grain boundaries which will be able to prevent dislocation movement so it will improve material strength [11].

#### 4. Conclusion

From the finding and data analysis of the casting using different molds, it shows that solidification rate influences micro structure and mechanical properties, i.e. tensile strength, hardness, and impact strength. Micro structure of the casting using metal mold is smoother than using sand mold. Higher solidification rate results higher mechanical properties compared to lower solidification rate.

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