RESEARCH PAPER

CHARACTERISTIC OF INTERFACE BIMETAL ALUMINUM-COPPER FOR BI-METAL BUSHING PRODUCED BY CENTRIFUGAL CASTING

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ABSTRACT

Bimetallic is a type of metal composite that combines two metals that form a metallurgical bond. The manufacture of bimetallic bushings by centrifugal casting has not been developed much. Recently, there is no recommendation yet for optimum temperature and speed of rotation to produce bimetallic bushings. The research was conducted to determine the rotation of the mold in centrifugal casting so as to produce a well-integrated interface. The materials used for the manufacture of bimetallic bushings are aluminum and copper. Aluminum was melted at a temperature of 750 °C, while copper was melted at 1200 °C. Molten metal was pouring alternately. First, aluminum was poured into the mold, and then after the aluminum temperature reached 400 °C, copper was poured into the mold to form a bushing aluminum-copper bimetallic. The molten metal was poured into a rotating sand mold with a constant filling speed of about 0.15 kg s^{-1}. The variations of the rotational speed of the mold were 250, 300, and 350 rpm. The result shows that the interface's width increases as the mold rotation increases during the pouring process. Interface hardness and wear are increased compared to the base metal. Hence, centrifugal casting with 350 rpm is recommended for aluminum-copper bimetal bushing applications.

Keywords: Bushing bimetal; Centrifugal casting; Aluminum-Copper; Interface

INTRODUCTION

The centrifugal casting principle applies forces generated from the centripetal acceleration of a rotating mold [1]. Centrifugal casting produces a product with accurate dimensions and limited gas porosity [1,2]. These characteristics are caused by the distribution of molten metal into the mold cavity, which uses forces resulted from the centripetal acceleration of a mold rotation. The centrifugal force is influenced by the rotational speed, radius, metal density [1], and gating system [3]. The non-pressurized system, with reduced turbulence and the increasing cross-sectional area towards the mold cavity, can increase the mechanical properties [4]. Moreover, to improve the average bending strength can be done by enlarging the vortex runner diameter in the gating system [5]. The pressure distribution controlled by rotational speed affects the porosity, which can be reduced by the rotational speed of more than 180 rpm [6]. Furthermore, the quality of casting products depends on the combination of the rotational speed, runner design, and gating system [7, 8].

Bimetallic is a type of metal composite that combines two metals that form a metallurgical bond (metal bond) [9]. The purpose of bimetallic production is to make an integrated component consisting of two metals, but each metal still has its unique properties [10]. The presence of metal bonds on the surface of the two metals increases the components' mechanical properties. The two metals complement each other in mechanical, chemical, and physical properties [11].

Bimetallic composites can be made by gravity casting [12] or centrifugal casting [10]. The manufacture of bimetallic composites by casting produces a cohesive compound and diffusion of the metal interface during pouring, resulting in a high bond strength [13]. One of the current developments of bimetal is to manufacture bushing products. Making bushings using the gravity casting method will produce low-density products with cast defects [12]. Meanwhile, the manufacture of bushing by centrifugal casting will create products with accurate dimensions, smooth surface, less gas porosities, and faster freezing [2].

Centrifugal casting utilizes the force generated by the centripetal acceleration of a rotating mold to distribute molten metal into the mold [1]. High rotation reduces the number of product defects [14]. Castings with high temperatures require higher rotational speeds to avoid sliding. Meanwhile, the low casting temperature will cause the casting surface to be rough, and the gas porosity appears. Casting temperature affects the rate of freezing and the amount of segregation that occurs [10].

Evaluation of the copper-aluminum bimetallic interface shows that the primary layer's freezing time is calculated based on the Chornief equation [10]. The pouring of the second metal liquid after a different time will change the components' interface temperature. Interfacial diffusion capability and hardness depend on the temperature of the copper and aluminum when casting in the mold. The intermetallic structure, which is brittle, will decrease if the pouring temperature is low. Metallurgical bonds will become strong if the pouring temperature is suitable and reduced impurities or metal oxides [10]. Defects that form in the bimetallic are due to a delay when pouring molten copper after solidification of the aluminum. This causes the formation of metallurgical bonds at the interface to improperly formed [9].

The strength of the aluminum-copper bond at the interface has resulted from bonding the intermolecular and intermetallic compounds of the two metals being held together. The higher the

casting temperature will increase the bond strength of the two metals interface. However, if the temperature is too high, it will result in the emergence of a new phase, which is brittle and lower strength [10].

The interface bond between metals in centrifugal casting is influenced by rotation speed [9]. One of the bonds formed at the interface is the quasicrystalline and intermetallic phases, which are embedded in the Al-FCC matrix. This phase has stability and high mechanical strength (4-7 times from before) [15]. The mechanical, physical, and chemical properties of the intermetallic phase are very different from those of the two constituent metals. The development of bimetal bushings with centrifugal casting continues, but there is no recommendation yet for suitable temperature and speed to produce a sound product. Analysis and evaluation are carried out on product and interface defects to have high hardness and wear resistance. The research is conducted to determine the rotation of the mold in the centrifugal casting in order to produce appropriate integration at the interface.

MATERIAL AND METHODS

The materials used in this research were aluminum and copper. The main compositions of aluminum and copper were shown at **Table 1** (tested by a spectrometer with IK 5.4-1-1 method).

Table 1 Chemical composition of materials (wt.%)

Alloy	Composition (wt.%)						
	Al	Cu	Si	Fe	Mn	Zn	Ni
Al	92.33	0.48	4.93	0.68	0.21	0.98	0.03
Cu	0.09	99.63	0.02	0.01	0.01	0.12	0.06

Aluminum-copper bimetallic bushing was produced by vertical centrifugal casting. Aluminum was melted at a temperature of 750 ºC, while copper was melted at a temperature of 1200 ºC. The molten metal was poured into a rotating sand mold with a constant filling speed of about 0.15 kg s^{-1}. First, aluminum was poured into the mold, and then after the aluminum temperature was 400 ºC, copper was poured into the mold to form aluminum-copper bimetallic in the form of a bushing. Molten metal pouring was carried out alternately. The variations of the rotational speed of the centrifugal casting mold were 250, 300, and 350 rpm. The schematic product of bushing can be seen in **Fig. 1**. Bushings had 35 mm and 25 mm diameters for outer and inner, respectively, with a height of 30 mm. The thickness of aluminum and copper is 2.5 mm each.
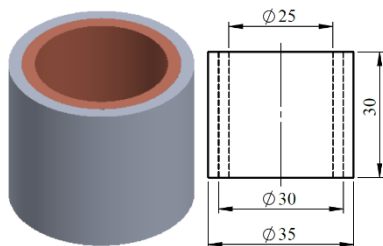

Fig. 1 The schematic product of bushing

The observations carried out in this research included microstructures in the interface of bimetal. The microstructure characterization was analyzed using a metallurgical microscope (PME 3, Olympus, Japan) and SEM-EDS (Quanta x50 SEM Series). Preparation was done with #180 to #1000 sandpapers to obtain a smooth surface, then metal polished. While to uncover the microstructure (etching process), a hidroflouride (HF) was used in aluminum, while an HNO$_3$ 60% was used in copper.

The tests done in this research included hardness and wear tests. The hardness was obtained in the interface between aluminum and copper samples using a hardness micro Vickers tester (HMV-M3, Shimadzu, Japan). The distance among each test point of the hardness test was 50 µm with a load of 50 gf, which is hold for 5s. The wear test was carried out on the interface between aluminum and copper samples using universal wear (Riken Ogoshi's, Tokyo, Japan) with a load of 6.36 kgf as far as 15 m.

RESULTS AND DISCUSSION

Results

Fig. 2 shows the microstructure at the bimetal interface with variations in rpm.
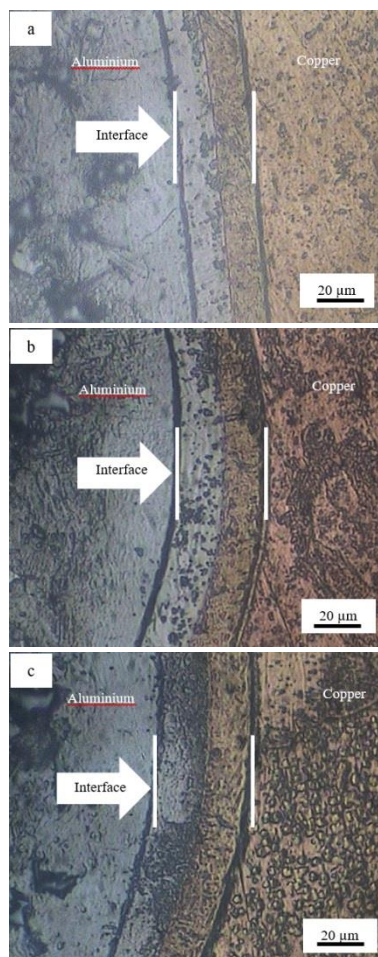

Fig. 2 The microstructure at the bimetal interface of Al-Cu, produced with 250 rpm (a); 300 rpm (b); and 350 rpm (c)

Based on the observations, it can be seen that all products with variations in rpm occur Al-Cu intermetallic compounds (IMCs). It is similar with previous research [10, 16]. The thickness of IMCs increases in line with the increase of the mold rotation.

The thicknesses of IMCs for the products with the rotation of 250, 300, and 350 rpm were 33, 37, and 41 µm, respectively.
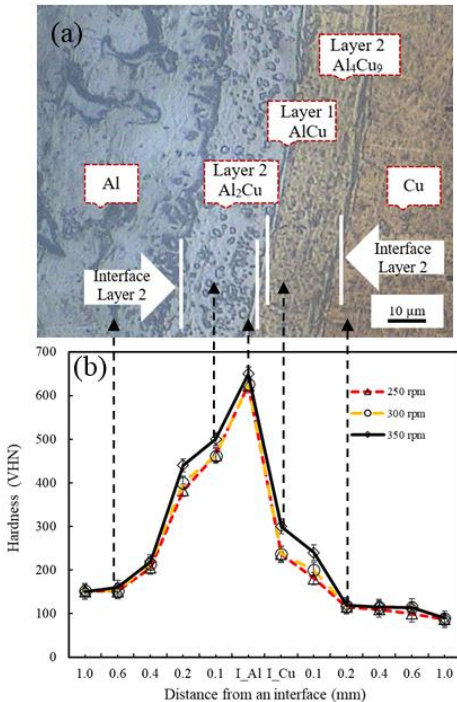

Fig. 3 (a) Microstructure at the interface with inference component, (b) the hardness of each interface

The microstructure at the interface with the inference component (based on SEM-EDS) can be seen in **Fig. 3(a).** Based on the observation, in the Al_2Cu interface (layer 2) and Al_4Cu_9 are formed, while at the AlCu interface (layer 1) is formed. The results of this observation are similar to previous studies [16]. The width of interface layer 2 of Al_2Cu and Al_4Cu_9 regions is almost the same for about 20 µm. While the width of the interface layer 1 is about 2 µm.

The hardness test results in the interface area can be seen in **Fig. 3 (b).** The hardness at interface layer 2 and layer 1 is increased compared to the hardness of the base metal. The hardness of aluminum (150 VHN), which is made at 350 rpm, increases at the Al_2Cu interface layer (500 VHN) then reaches the highest hardness at the AlCu interface layer (624 VHN). The hardness drops on the interface layer Al_4Cu_9 (300 VHN), then decreases again in the copper area (114 VHN). The trend of hardness looks similar between specimens with variations in rpm. The hardness is particularly affected by the kind of phase of the microstructure [17].

Fig. 4 shows the wear of the bimetal interface. The wear of aluminum, Al_2Cu, Al_4Cu_9 interface and copper are 1.7E-07, 9.7E-08, 1.3E-07, and 6.6E-07 mm³kg⁻¹m⁻¹ respectively. The wear interface is 1.7 times higher than aluminum and 6.8 times higher than copper.
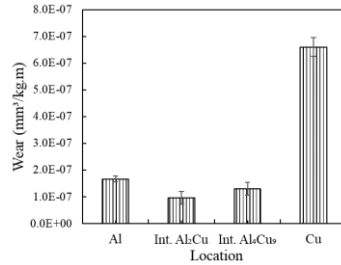

Fig. 4 The wear of bimetallic interface

Discussion

The aluminum-copper bimetallic of interface bonding made by centrifugal casting in variations of rpm occurs well. The interface width increases in line with the increase of mold rotation. The bimetallic interface widths made with rpm 250, 300, and 350 are 33, 37, and 41 µm, respectively. The molten metal pressure increases due to the centrifugal and tangential force acting on molten metal when entering the mold [3,18]. The high rotation during pouring increases the driving force of the molten metal into the mold. This condition results in better bonding at the interface. Interfaces are formed because of the bonds between atoms so that no new phases are formed [10].

From the microstructure observations in several places, it was seen that there were impurities in the interface area caused by metal oxides and protective oxides of the two materials. Based on observations, there are more impurities in the Al_4Cu_9 interface. There are correlations between the microstructure with the mechanical properties [19]. The pressure of the molten metal cannot remove the metal oxide, so that there is no special bond at the interface. If there are impurities, the two metals separate, and a diffusion bond does not form between them. The least impurities at the interface occur in bushings made at 350 rpm. The rotational speed of the mold when pouring increases the liquid pressure distributed into the mold [1]. This reduces the number of product defects [14], one of which is oxide impurities. The hardness of the interface area is higher than that of the constituent metals. The hardness of aluminum and copper at a distance of 0.4 mm is the same as the hardness of the base metal. The hardness of the interface increased up to 650 VHN (≥ 4 times base metal). The higher the rotation of the mold when pouring causes the hardness at the interface to be higher. Increased hardness happens due to the formation of hard aluminum carbides.

The increase of wear on the interface area (layer 2) is caused by the formation of hard Al_2Cu, AlCu, and Al_4Cu_9. However, higher hardness does not always lead to better wear resistance. Hardness is should not necessarily be considered the most critical factor in assessing the wear resistance of a material [20]. There is a correlation between wear behavior with surface topography [20]. However, because the surface topography is prepared in similar conditions, hardness is a major factor in wear resistance.

CONCLUSION

The conclusions of this research are:
1. The width of the interface increases as the mold rotation increases during the pouring process.
2. The interface hardness and wear are increased compared to the base metal.
3. Centrifugal casting with 350 rpm is recommended for aluminum-copper bimetal bushing applications.

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