Interfacial Microstructure and Bonding Area of Sn-based Alloy-GG25 Gray Iron Bimetallic Material Using Flux, Sn, and Sn-Zn Interlayer Compound Casting

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Abstract—A bimetallic casting consisting of GG25 gray iron substrate and Sn-based alloy using the liquid-solid technique has been studied in this paper. Three different pretreatment processes of gray iron surface substrates including flux only, flux and Sn powder, and flux and Sn-8.8% Zn powder eutectic alloy surface treatment were adopted for the aim of improving the quality of tinning, the interfacial structure, and the bonding area of the Sn-based alloy/gray iron bimetallic composite in order to promote the bonding quality of bimetallic castings. Microstructure characterization on the bonding interface was conducted. The novel tinning material for gray cast iron substrate comprising of Sn-8.8% Zn eutectic alloy powder in combination with flux interlayer improved the bonding area, the interfacial bimetal structure, and the shear stress. This improvement is due to the higher interface reaction of Zn with Fe that leads to the formation of a very thin layer of Fe-Zn and Fe-Sn intermetallic phases.

Keywords—Sn-based alloy; GG25 gray iron; flux; Sn-Zn; bimetal; interface

I. INTRODUCTION

Nowadays, manufacturing techniques are more focused on fabricating materials of superior properties and the facilitation of their fabrication techniques. Despite the intensive development of cast metal’s structure and properties, the possibilities of the existing monometallic alloys are practically exhausted for fabricating new materials of superior properties [1-3]. Liquid-solid compound casting has been used to fabricate different ferrous and nonferrous functionally graded materials, and is considered the most economical fabrication process, which allows the fabrication of bimetal materials directly [4-8]. For bimetallic bearing materials, higher bonding strength is still required to meet the industrial application demands. More effort on the enhancements of the bimetallic composites interfacial structures and bonding area should be considered. The tin-based SnSb$_3$Cu$_3$ alloy is one of the most common bimetallic bearing materials used in thrust bearings with substrate shells. Carbon steel alloys are commonly used as shell substrates in liquid-solid compound casting techniques [8-12]. Although the gray cast iron has unique mechanical properties, it has limited applications in the liquid-solid compound casting as solid shells due to its free graphite flacks. Gray iron is well known as flack graphite iron in which the graphite is present in a matrix of ferrite, pearlitic, or ferrite-pearlitic. Compared with carbon steel substrates, the relatively higher silicon and carbon content, as well as the production processing parameters of gray iron, make eutectic graphite separate from the molten iron. As solid bimetal shells, grey irons have been used in liquid-solid configuration casting [13, 14]. The interfacial bonding strength of Sn-based alloy/grey iron was investigated for bimetal composites fabricated by centrifugal casting process in [13]. In addition, Al-Si alloy/grey iron bimetal composite has been fabricated. The optimum shear strength was achieved with the assist of hot dipping of the solid iron in a Zn–0.2 wt. % Bi melt [14].

In the current study, the Sn-Zn eutectic alloy was used due to its physical and mechanical properties. The Sn-Zn eutectic system is a promising candidate for the replacement of Sn-Pb solders due to its melting temperature (198°C), which is very close to the Sn-Pb eutectic alloy melting temperature (183°C), so it is suitable for electronic components without major modifications [15]. In addition, the Sn-8.8% Zn eutectic lower melting temperature is favorable and the cost of production is relatively low compared with other Sn-Ag and Sn-In soldering materials [16]. For the aim of improving the interfacial structure and bonding area of Sn-based alloy/grey iron bimetallic composite, the gray iron surface substrate is prepared using three pretreatment processes. Gray iron surface substrates are treated with flux only, flux + Sn powder, and flux + powder Sn-8.8% Zn eutectic alloy. The proposed Sn-Zn...
interlayer of Sn-based alloy/GG25 gray iron bimetallic material using the tinning process is considered as an alternative new interlayer material designed for fast, easy, high bonding interface and low-cost surface improvement of the gray iron solid substrate. This newly designed Sn-based alloy/GG25 gray iron with Sn-Zn interlayer is more suitable for bimetallic materials of flat and horizontal solid substrates.

II. EXPERIMENTAL WORK

The Sn-based alloy/GG25 gray iron bimetallic composite specimens were prepared using the liquid-solid compound casting technique. Sn-8.8% Zn interlayer alloy samples were prepared by melting pure Sn (99.97%), and pure Zn (99.95%) in graphite crucibles using an electrical muffle furnace. The alloys were melted 2 times to ensure uniform mixing of the elements. Table I shows the chemical compositions of the Sn-based alloy and the GG25 gray iron substrate used for the Sn-based alloy/GG25 gray iron bimetallic composite fabrication.

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cu</th>
<th>Pb</th>
<th>Sb</th>
<th>Sn</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sn-based alloy-ASTM B-23-Grade2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.0-4.0</td>
<td>0.0-0.35</td>
<td>7.0-8.0</td>
<td>Bal</td>
<td>-</td>
</tr>
<tr>
<td>GG25 gray iron substrate</td>
<td>3.0-3.25</td>
<td>1.85-2.10</td>
<td>0.4-0.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Bal</td>
<td>-</td>
</tr>
</tbody>
</table>

Gray iron substrate specimens of solid cylindrical shape of 25.4mm diameter and 5.5mm thickness were cut and ground with up to 800 grades emery papers. The specimens were tinned with pure Sn and with Sn-8.8% Zn alloy. The direct pretinning process of the gray iron substrate that involves Sn powder or Sn-Zn alloy and flux mixture has been explained in detail in [17–18]. The current flux is fabricated with a mixture of chemicals listed in Table II mixed with the pure tin or Sn-Zn powders. The Sn to flux ratio is 1:10 (1g of Sn and 10g of flux). The necessity of using flux in the tinning process during bimetal fabrication is to remove the oxides for the sake of allowing the Sn or Sn-Zn to stick directly to the gray iron surface.

<table>
<thead>
<tr>
<th>Flux chemical composition wt.% ml.</th>
<th>ZnCl2</th>
<th>NaCl</th>
<th>NH4Cl</th>
<th>HCl</th>
<th>H2O</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 gm</td>
<td>6 gm</td>
<td>3 gm</td>
<td>1 ml</td>
<td>1 ml</td>
<td></td>
</tr>
</tbody>
</table>

In order to study the effect of different pretreatments of gray iron surface on the quality of tinning, the interfacial structure and the bonding area of the Sn-based alloy/gray iron bimetal, three groups of specimens were fabricated.

- The first group of Sn-based alloy/gray iron bimetal was produced by pretreated gray iron substrate with flux only.
- The second group was produced by pretreated gray iron substrate with flux + Sn (1g of Sn powder and 8g of flux).
- The third group was produced by pretreated gray iron substrate with flux + Sn -8.8% Zn (1g of Sn-8.8% Zn powder,8g of flux).

During the tinning process, 0.2gm/cm² of flux and Sn or Sn-Zn mixture was distributed on the gray iron shell substrate. Then the substrate was placed on a preheated hot plate of 360°C for 3min. After heating, the gray iron was removed from the hotplate and the tinned surface as cleaned using a towel and tap water and left to cool to room temperature. Sn-based alloy with the chemical composition shown in Table I was melted on a hotplate at 370°C and after 30min the crucible of molten metal was removed from the hotplate and was poured onto a ceramic mold that contained a preheated (370°C for 3min) tinned gray iron substrate. The volume of liquid Sn-based alloy to gray iron substrate ratio was kept to 3:1 for all casting groups.

![Fig. 1. Sn-based alloy/GG25 gray iron bimetall casting:](image)

The microstructure of the Sn-based alloy/gray iron bimetal, especially the interfaces region between the alloy and the gray iron substrate was examined with an Olympus optical microscope with a maximum magnification of 1000X. The optical examination was conducted after grinding, polishing, and etching with 4% nital to define interlayers, lack of bonding, and voids. Measurements of the as-cast specimens of the three groups of the Sn-based alloy/gray iron bimetal composites were taken.

III. RESULTS AND DISCUSSION

A. Macro-and Micro-structures of Base Bimetallic Materials

Figure 2 shows photographs of the Sn-based alloy/GG25 gray iron bimetal composite specimens and the cross section of the three fabricated specimens. Clear and regular bimetal interface for gray iron substrate treated with pure Sn and Sn-8.8% Zn alloy and an irregular bimetal interface for the gray iron substrate treated with flux only were monitored.

Microstructures of the materials used in the fabrication of tin-based alloy/gray cast iron bimetal composite are shown in Figure 3. Figure 3(a) shows the optical microstructure of Sn-
Based alloy revealing Cu6Sn5 and SnSb phases reinforced in the solid solution of the Sn matrix. The Cu6Sn5 phase has the shape of asterisks. The microstructure of a matrix of solid solution with hard-embedded phases of Cu6Sn5 and SnSb make a metal matrix composite possessing fatigue-resistant properties [19–21].

Previous studies [22–24] reported that the variation in the chemical composition of tin-based alloy modifies the microstructure. Tin-based alloys containing less than 8% Sb are characterized by a solid solution with distributed asterisks and needles of Cu6Sn5, copper-rich constituents, and fine precipitates of SbSn. On the contrary, the tin-based alloys containing greater than 8% Sb exhibit a primary cuboid phase of SbSn. The microstructure of Sn-based Babbitt alloy acquired in the present study is in good agreement with those available in the literature [22–24]. The microstructure of gray cast iron substrate (Figure 3(b)) shows the three common phases of ferrite, pearlite, and free graphite. The higher percentage of the pearlite verifies the Mn and Cu content in the gray cast iron chemical composition.

B. Microstructures of Interfacial Sn-based Alloy/Gray Cast Iron Bimetallic Composites

The microstructures of the interfaces of bimetallic composites containing tin-based alloy/gray cast iron substrate with different surface pre-treatments of gray cast iron solid substrates are shown in Figure 4. Visual observation of the interfacial microstructures of the bimetallic interface fabricated using flux only shows poor bonding between the two metallic parts (Figure 4(a)). Some small voids were observed in the interface area of bimetal composites fabricated using flux + Sn interlayer (Figure 4(b)). A uniform interfacial bonding free of defects is observed in bimetallic composites fabricated using flux + Sn-8.8% Zn alloy (Figure 4(c)). Tin-based alloy/gray cast iron composites fabricated with flux + Sn-8.8% Zn alloy revealed a good quality of interfacial bonding compared with other previous gray cast iron pre-treatment conditions. Figure 5 shows the interfacial bonded areas of the three fabricated Sn-based alloy/gray cast iron bimetallic composites with three different surface pre-treatments of gray cast iron solid substrate. It can be seen that substrate treated with flux only has the lowest value, while the substrate treated with flux + Sn shows comparable results. Gray cast iron substrate treated with flux + Sn-8.8% Zn exhibited a comparatively higher value. Both FeSn2 and FeSn Intermetallic Compounds (IMCs) could be formed in temperatures ranging from 300 to 500°C. Fe-Zn coating grows because of a rather complicated process of atomic diffusion of both metals with the formation of elementary intermetallic bonds and subsequent phase transformations. Layers consisting of these compounds have different compositions and thicknesses. They are usually marked with Greek alphabet letters, i.e. gamma (Γ), gamma1 (Γ1), delta (δ), zeta (ζ), and sometimes eta (η). Individual phases differ significantly not only by composition and morphology of the grain but also by mechanical characteristics. The formation of individual phases in the coating is ruled by the binary phase diagram Fe – Zn shown in [25–27].
C. Mechanical Properties of Sn-based Alloy/Gray Cast Iron Bimetallic Composites

The shear strengths of the Sn-based alloy/GG25 gray iron bimetallic composites with Sn and Sn-8.8% Zn interlayer compositions are shown in Figure 6. The shear strength of the bimetal fabricated with Sn-8.8% Zn interlayers is significantly more by 20% than the one fabricated with Sn interlayer, which is mainly due to the improvements of the interface bond area of Sn-8.8% Zn interlayers.

IV. CONCLUSION

In this paper, bimetallic specimens of Sn-based alloy/gray cast iron were successfully prepared by liquid-solid compound casting after depositing the molten Sn-based alloy on the solid gray cast iron substrate. A novel tinning material for gray cast iron substrate comprising of the Sn-8.8% Zn eutectic alloy powder in combination with flux was performed.

Sn-8.8% Zn eutectic alloy interlayer improved the bonded area and interfacial bimetal structure, due to the higher interface reaction of Zn with Fe that led to the formation of very thin Fe-Zn and Fe-Sn intermetallic phases.

Higher shear stress was achieved using Sn-8.8% Zn interlayer as tinning material. The optimum Zn content in Sn-Zn alloy interlayer should be considered for future work in order to optimize the fabrication of Sn-based alloy/gray cast iron bimetallic composite with high quality and long life bimetal bonding.

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