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Microstructure Study of Diffusion Bonding of Centrifuged Structural Steel-Bronze

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Abstract

One of the methods to prevent unsuitable lubrication of moving components of devices and machinery is using bi-metal and three-metal bearings. Centrifugal casting process is one of the manufacturing methods that is used for such bearings. In this study, the purpose is microstructure evaluation of the bonding location and length determination of diffusion bond in structural steel-bronze. A mold made of structural steel with inner diameter of 240mm, length of 300mm and thickness of 10mm was coated by a 6mm film of bronze under centrifugal casting process. At first, a bronze ingot with dimension of 5mm×10mm×20mm is located inside of the hollow cylindrical mold and then the two ends of it will be sealed. During mold rotation with the rate of 800 rpm, two high power flames are used for heating the mold under Ar gas atmosphere to melt the bronze ingot at 1000˚C. After 15minutes, the system is cooled rapidly. Results showed that the diffusion bonding of bronze in structural steel to depth of 1.2µm from the bonding line was obtained. In this bonding, copper element was diffused to 50% of its initial concentration.

Keywords: Diffusion Bonding, Line Scan, Horizontal Centrifugal Casting

1 Introduction

Solid state welding procedure refers to those methods of welding processes that connection of two or several materials is performed lower than melting point of the materials. In this process, plastic deformation and/or diffusion along with plastic deformation are used. This process is used for welding of two or several similar or even dissimilar materials. The process that diffusion in it will be done with plastic deformation, is called diffusion welding or diffusion bonding. Solid state welding processes provide welding of metals and dissimilar alloys with minimum metallurgical destructions. The main problem in solid state processes is the absence of melt and low temperature. In such processes even with the presence of melt, it is highly limited and local melting is located on the vicinity of the interface [1]. Actually, diffusion bonding is a kind of solid state bonding that welding of surfaces together is done by combination of high pressure and temperature and longtime [2]. Therefore, this process is used for bonding of dissimilar materials with completely different physical and mechanical properties as well as manufacturing and repairing devices with least distortion and dimensional tolerances in different industries.

Diffusion welding of dissimilar materials is performed directly or using inter-layer. Welding often is not possible directly and using of one or several inter-layers is necessary. This inter-layer prevents diffusion of incompatible materials and/or act as an antioxidant agent. Bonding of copper to steel without inter-layers is not desired because in the contact surface of copper, copper oxide film will be formed even in oxygen-free atmospheres and suitable vacuums. Using of nickel inter-layer in bonding of copper-steel is a conventional method. This inter-layer avoids copper oxide formation on one hand and includes a good bonding with steel on the other hand. It is due to complete solution of nickel in copper. On the other hand, with increasing temperature, the released oxygen content at the interface of copper-steel increases and decreases the bond strength [3-6]. However with increasing of pressure, voids arising from different inherent diffusion coefficient at interface (Kirkendall voids) decreases [7-8]. Generally, increasing of pressure leads to plastic deformation of surfaces and forms a more suitable bonding. The bond strength of copper-steel increases by increase of pressure and bonding time, arising from volume increase in formed solid solutions and plastic deformation at interface [9-10]. Therefore, factors affecting the diffusion welding process include:

Temperature: temperature is a very important factor, because better diffusion occurs at high temperatures [6]. In this study, process temperature is 1000 ˚C. It means that connecting metal is melted and the diffusion bonding will be done in molten state.

Pressure: the amount of pressure is directly related to bonding quality. Higher pressures give more bond strength [6-8]. In the present study, centrifugal force along with small amount of Ar gas pressure is used for pressure applying.

Time: diffusion welding is time consuming. With increasing time, diffusion will increase but grain coarsening and surface oxidation should be considered too [9-10]. In this study, time of process is 15 min.

Quality of contact surface: the quality of contact surface is significant. Rough surface provides many problems and increases the time of process [11]. Hence, it is better to keep the surfaces roughness as low as possible. In this study, inner surface of the mold is machined carefully; in addition Ar gas atmosphere is used to prevent surface oxidation.

In the present article, bronze (bonding metal) is melted inside the mold made of structural steel and after applying centrifugal force by 15min, bonding is obtained. The base metal is a hollow cylinder with diameter of 240mm, length of 300mm, and thickness of 10mm that its inside is coated by a 6mm thick layer of bronze that contains small amounts of Pb, Zn and Sb without using inter-layer. The purpose is microstructure evaluation of the bonding location of these two metals.

2 Experimental

Hollow cylinder with diameter of 240mm, length of 300mm and thickness of 10mm made of structural steel was used as a mold and its chemical composition is presented in Table 1. The inside of mold was coated by a 6mm thick layer of bronze with chemical composition according to Table 2 using centrifugal force. To provide the required bonding, bronze ingot with dimension of 5mm×10mm×20mm was located inside of the mold and then two ends of it was sealed completely. Then, during mold rotation, the cylinder is heated by two high power flames to melt the bronze ingot. The temperature of mold reaches to 1000˚C. Inert Ar gas is injected to prevent oxidation and formation of slag and inclusions inside the mold. The mold is rotated with the rate 800 rpm. By this way due to heating, bronze melts and a film of molten bronze forms inside the mold under centrifugal force. Heating and rotation of the mold takes about 15min until the required diffusion obtains well. Finally the system cools rapidly. Microstructure evaluation and length determination of bonding is done by ion field scanning electron microscope of Razi Metallurgical Research Center (RMRC).

Table 1.
Chemical composition of outer cylinder made of structural steel

Element	**C**	**Si**	**S**	**P**	**Mn**	**Ni**	**Cr**	**V**
Content Wt%	0.12	0.05	0.011	0.025	0.70	0.001	0.004	0.003
Element	**Ti**	**As**	**Sn**	**Co**	**Al**	**Cu**	**W**	**Fe**
Content Wt%	0.001	0.008	0.02	0.05	0.006	0.11	0.003	Base

Table 2.
Chemical composition of inner cylinder made of bronze

Element	Cu	Sn	Pb	Sb	Zn
Content Wt%	Base	4.5	3.0	1.0	1.5

3. Result and discussion

According to Figure 1, diffusion of Cu in Fe (to 50% concentration of Cu) to 1.2 μm from the bonding line has been performed. So with considering of constant diffusion to half of initial concentration, bonding length is 1.2 μm.

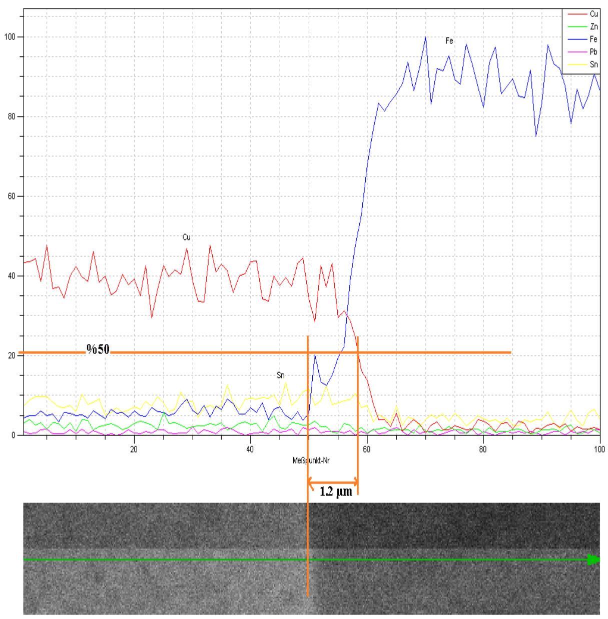

Fig. 1. Distribution of elements at bonding line and determination of bonding line to 50% of initial copper concentration using line scan

Figure 2 and Figure 3 show bonding locations at different magnifications. Density of steel is lower than bronze so it seems darker in the scanning electron microscope. Density of the bonding location is between the density of steel and bronze so it is observed with the length of 1.2μm in both figures as a dimmed layer (a little bit darker than bronze and lighter than steel). In this way, elemental distribution at the bonding location using line scan shows that Fe hasn't diffused to Cu matrix but Cu and to some extent Sn has diffused to Fe matrix.

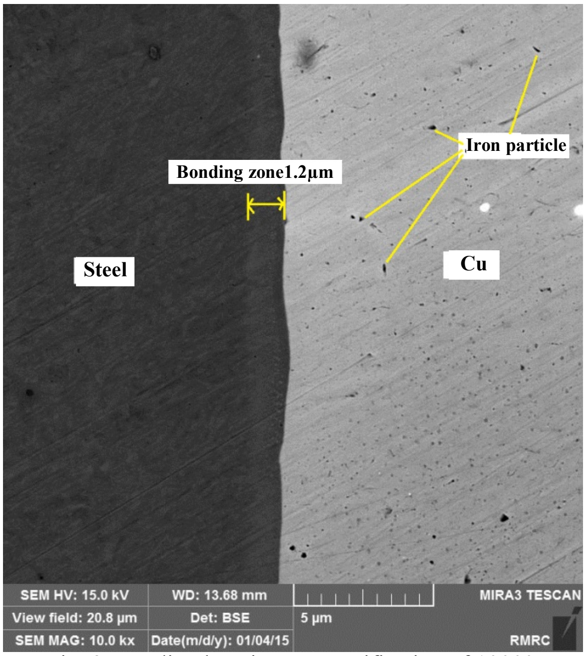

Fig. 2. Bonding location at magnification of 10000

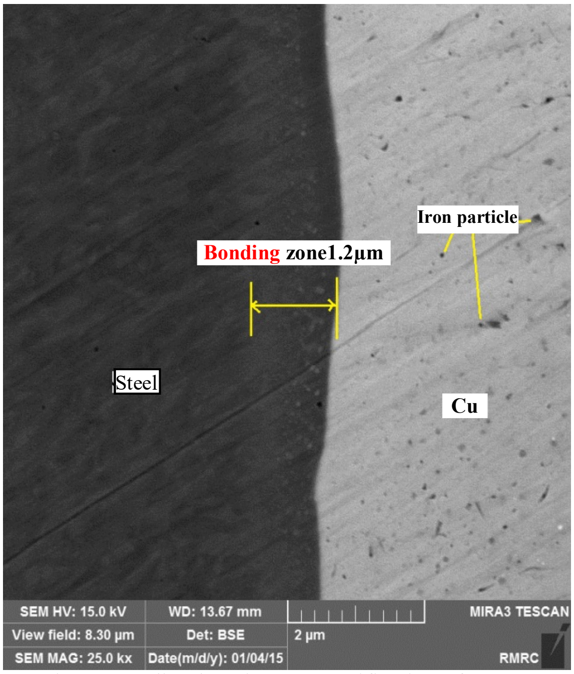

Fig. 3. Bonding location at magnification of 25000

EDS analysis of the dark grey phase according to Figure 4, shows that it contains 88 At% copper and 12 At% of Sn. According to Cu-Sn phase diagram (Figure 5), it is solid solution of Cu-Sn.

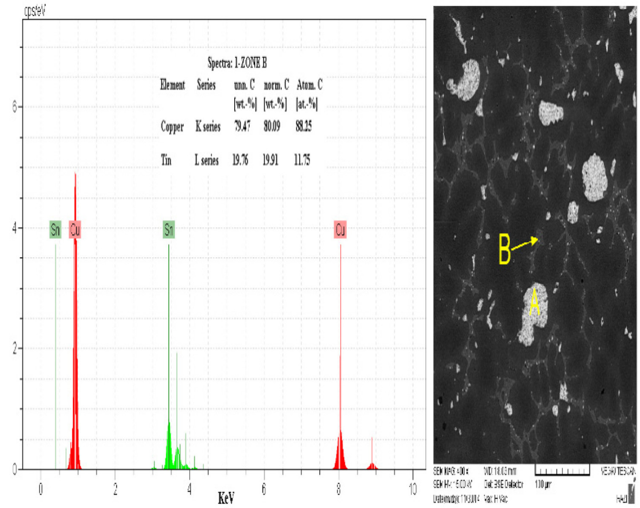

Fig. 4. EDS analysis of the dark grey phase

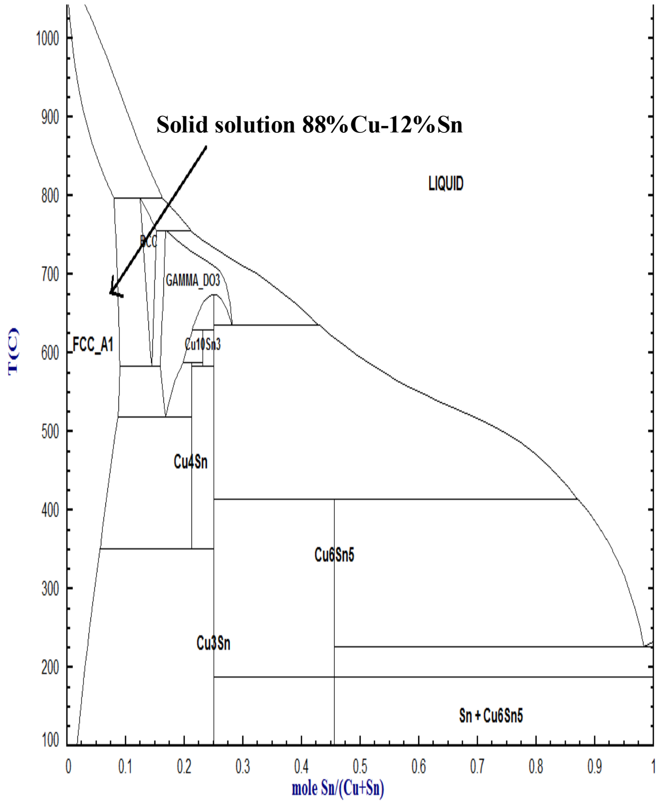

Fig. 5. Phase diagram of Cu-Sn

Based on EDS analysis in Figure 6, the black phase is Fe particles but copper spectrum relates to matrix, because according to phase diagram of Fe-Cu (Figure 7), these two metals do not generate solid solution or any special composition. Fe particles with size of 5-20µm at different depth of copper matrix are observed. As diffusion of Fe particles in to copper matrix is impossible, so presence of Fe particles in the copper matrix can be expressed as:

1- Fe particles exist in copper ingots as inclusions.

2- During rotation of the cylinder, due to impacts of copper ingots to iron body, Fe particles dislodge and immerse in the molten metal and retain at different depths after solidification.

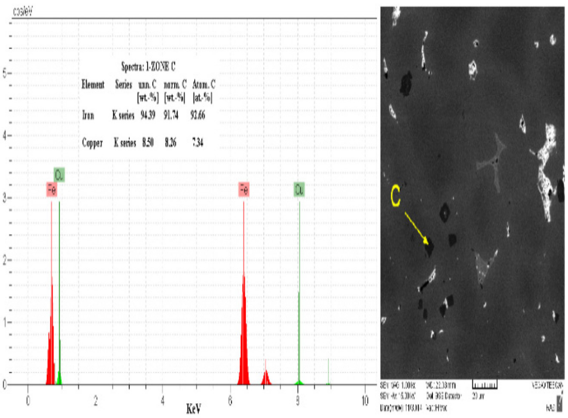

Fig. 6. EDS analysis of black phase

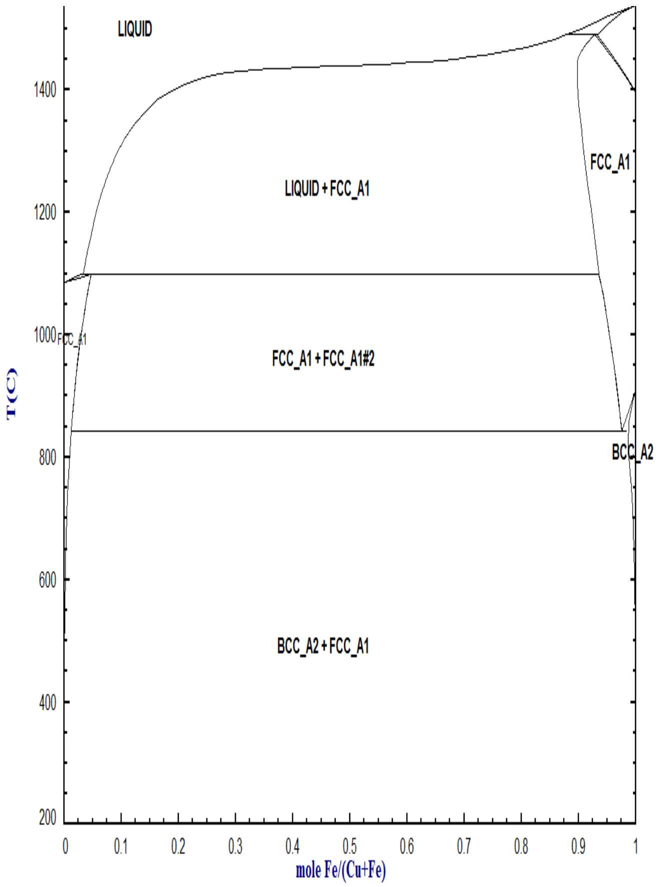

Fig. 7. Phase diagram of Fe-Cu

According to Figure 8, EDS analysis of withe phase correspond to lead metal (Pb). While at the phase diagram of Pb-Cu (Figure 9), solid solution does not form, so the available copper spectrum in Figure 8 arises from matrix.

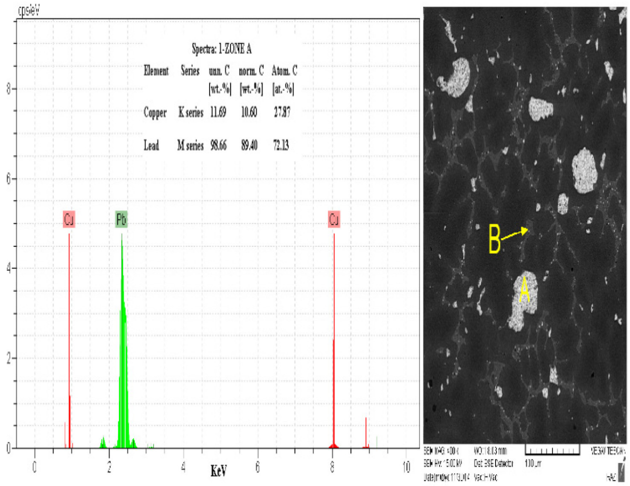

Fig. 8. EDS analysis of white phase

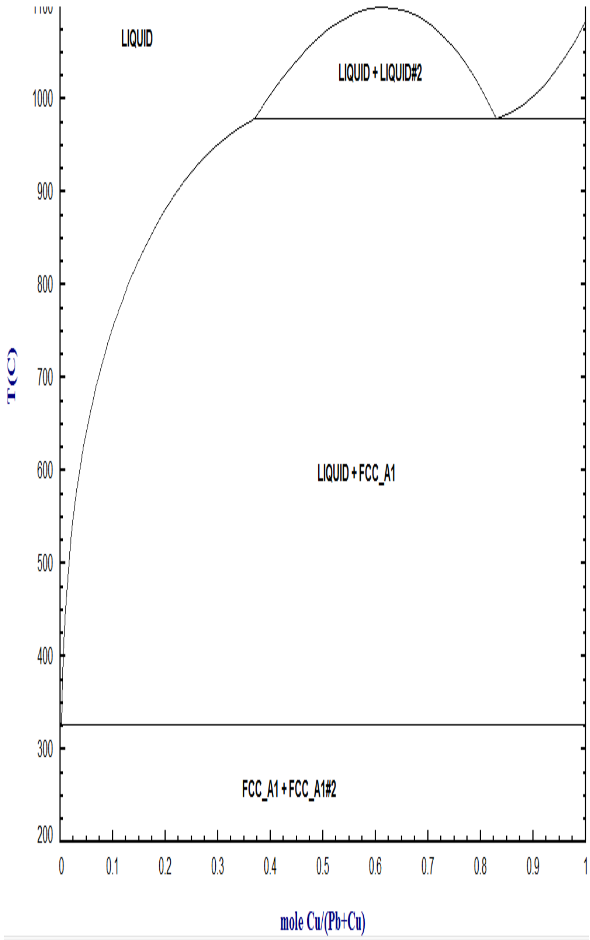

Fig. 9. Phase diagram of Cu-Pb

According to EDS analysis shown in Figure 10, the matrix contains 95 At% Cu, 2 At% Sn, 1.3 At% Zn and 1.7 At% Fe.

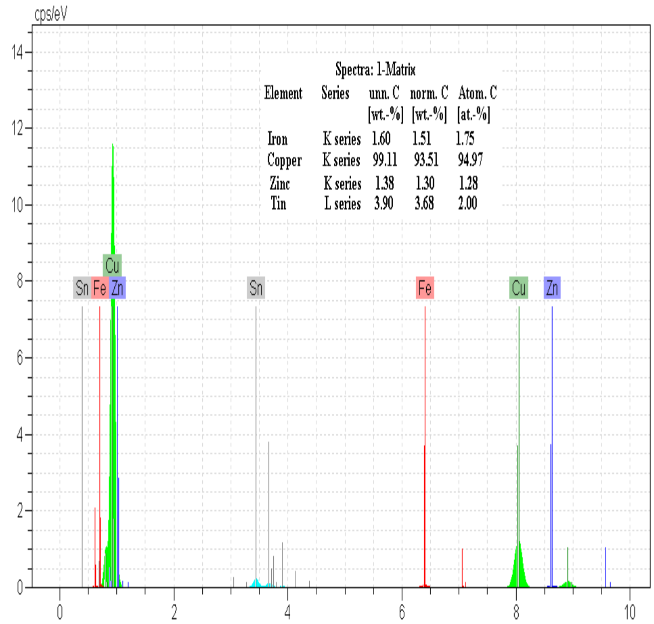

Fig. 10. EDS analysis of bronze matrix

Figure 11 shows broad distribution of two phases, Pb in white color and solid solution of Cu-Sn as dark grey color in the copper matrix.

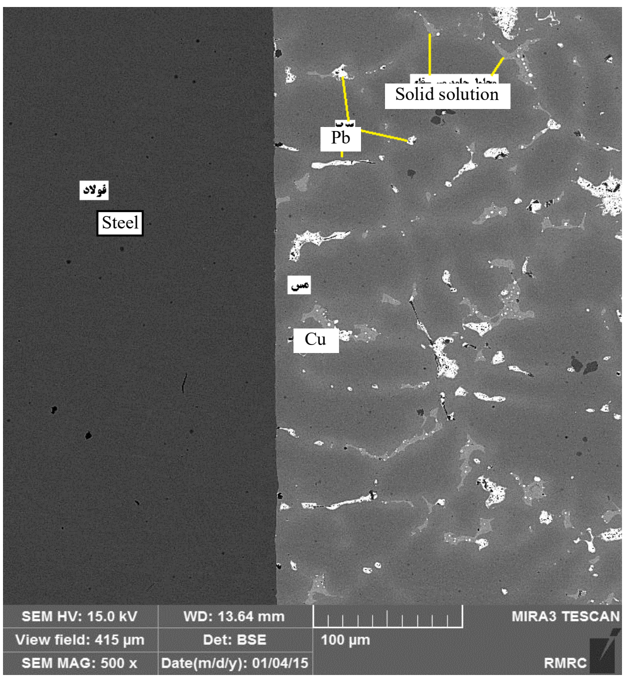

Fig. 11. Distribution of phases, Pb in white color and solid solution of Cu-Sn as dark grey color in the copper matrix

4. Conclusions

The purpose of this study has been microstructure evaluation of the bonding location and length determination of diffusion bond in structural steel-bronze. So, a structural steel mold was selected that inside of it, was coated by a film of bronze. First, bronze ingot was located inside of the mold. Then, two ends of the mold were sealed. During rotation of the mold, it was heated to melt the bronze ingot under Ar gas atmosphere. After several minutes, the system cooled rapidly. Results showed that without using any inter-layer, diffusion bonding in structural steel-bronze was obtained. In addition, to reduce the presence of Fe particles, it is better to melt the bronze at first and then pour it in to the mold.

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