**ABSTRACT** – This paper investigates the influences of brazing parameters (temperature and time) on microstructure and mechanical properties of pure copper brazed with porous copper using brazing filler metal (Cu-9.7Sn-5.7Ni-7P). Diffusion brazing was employed in a partial vacuum furnace in order to investigate the effects of brazing parameters on joint interface. The brazing temperature in this experiment was 700 °C and holding time was varied from 5 – 15 min. The microstructure and phase constitution of bonded joints were analyzed by SEM-EDX and XRD. The diffusion between Cu, Ni, Sn and P developed a strong reaction between each other. The EDS analysis revealed that Phosphorus is the main element contributing to the formation of microstructure. The element Sn completely diffuses from the filler metal into Cu plate due to lower melting temperature.

1. **INTRODUCTION**

Thermal management is a major issue for high power electronic devices facing serious challenges due to growing capacity. Cooling of electronic devices is very critical to promote runtime reliability, optimal performance and extended operational life span of the product. Porous metals have many potential applications in thermal management because of their huge internal surface area, high thermal conductivity and high permeability for fluids. The cooling system can be composed of porous copper to enhance heat transfer making it suitable for replacement as active cooling devices, such as heat exchangers and heat sinks [1-2].

Applications to electronics cooling of metal foam heat exchangers have been investigated by several researchers revealing promising advances in rate of heat removal. Zhang et al. [3] investigated experimentally on heat transfer performance of lotus-type porous copper heat sink. The authors fabricated a special kind of micro-channel heat sink using porous metal with long cylindrical pores. The results from the experiment show that lotus-type porous copper heat sink has excellent heat transfer performance compared to conventional type of heat sink. As compared to empty channel, the porous copper sample enhanced the heat transfer performance three times. Investigation by Boomsma et al. [4] revealed that the increased heat transfer comes at a large cost because there is a strong increase in pressure drop.

It can be highlighted that applying the brazing technique using porous Cu is a good selection to fabricate a heat sink. In this research, brazing is conducted to join porous Cu to Cu plate using single piece of filler metal to join the base and the top side to avoid filling cells entirely with brazing material. The focus of this research is to achieve a good quality joint and strength while minimizing brazing imperfections that will affect the flow of fluid passing through the material.

2. **METHODOLOGY**

In this research, pure solid Cu plate available commercially with a 99.9 (wt.%) composition and pure porous Cu of 15 PPI were cut using Electrical Discharge Machining (EDM) wire cutter to the dimension of 15 x 15 x 3 mm³ and 10 x 10 x 5 mm³, respectively. A piece of Cu-based filler metal known as MBF 2005 with compositions of Cu-9.7Sn-5.7Ni-7P (wt. %) and 50 μm thickness was prepared in approximate size of 13 x 13 mm². The items were stacked in sandwich configuration in a specific clamp system as shown in Figure 1.

![Figure 1 Schematic illustration of specimen arrangement in a specific clamp system.](image)

The brazing process was conducted in a tube furnace equipped with a heating controller and argon gas [5]. The brazing temperature was set at 700 °C and holding time was varied from 5 – 15 min. An average heating and cooling rate of 10°C/min were set for the experiment. The industrial grade argon gas was applied at a rate of 3.5 L/min. The microstructural characterization was conducted using Scanning Electron Microscopy (SEM) model Phenom Pro X Desktop equipped with Electron Dispersive X-ray Spectroscopy (EDS). An X-Ray Diffraction (XRD) model PANalytical Empyrean was employed for testing and analysis was done using HighScore software for identification of elements and phases. The Vickers microhardness test analysis was carried out using a test force of 980.7 mN with a duration time of 5 seconds. The model of the microhardness tester used was HMV 2T E, Shimadzu.

3. **RESULTS AND DISCUSSION**

For all the parameters tested, a successfully brazed joint was achieved. The cross-section of the brazed specimens was examined using a SEM with an EDS point...
analysis to examine the element distributions and phases. Figure 2, 3 and 4 show the SEM images for all samples presented in 2 categories; top and base. The diffusion of filler metal can be identified by different pattern in grey colour that can be observed in the SEM images.

![Figure 2: SEM image of joint cross section brazed at 700 °C for 5 min, (a) base and (b) top.](image)

![Figure 3: SEM image of joint cross section brazed at 700 °C for 10 min, (a) base and (b) top.](image)

![Figure 4: SEM image of joint cross section brazed at 700 °C for 15 min, (a) base and (b) top.](image)

The microstructure of the joint interface was analyzed by SEM to identify the existing filler metal elements. The EDS analysis revealed that Phosphorus is the main element contributing to the formation of microstructure. This is due to high amount of phosphorus element spotted during analysis of different parameters. Moreover, Nickel (Ni) is also spotted at the top joint interface at point 5 in Figure 3(a) contributing to microstructure formation. It was also observed that diffusion of filler metal into porous copper and top joint interface improved with increasing holding time. It can be perceived that the thickness of the reaction layer reduces at the base, flowing towards porous copper and the top after increasing the brazing time.

The element Phosphorus in filler metal has the function of accelerating dissolution of copper during brazing. It is known that the function of phosphorus is to act as a fluxing agent. As phosphorus has a deoxidizing effect, Cu-P filler metals tend to be self-fluxing. The addition of nominal P content (7 wt%) slightly affect on reducing the ductility of the joint while the addition of some amount of Ni and tin (Sn) is to improve glass forming ability during filler metal manufacturing process [6]. Moreover, Phosphorus can also improve the wettability and spreading ability of the filler metal [7]. The filler metal has high corrosion and wear resistance due to presence of Ni, Sn and P. The element Sn completely diffuses from the filler metal into copper due to lower melting temperature.

![Figure 5: XRD analysis of phase present on copper surface at 700 °C, 15 min.](image)

**Table 1 Composition of different points at 700 °C for 10 min marked in Figure 3(a).**

<table>
<thead>
<tr>
<th>Point</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>100</td>
<td>74.6</td>
<td>76.9</td>
<td>71.7</td>
<td>78.5</td>
</tr>
<tr>
<td>P</td>
<td>-</td>
<td>17.4</td>
<td>18.0</td>
<td>21.3</td>
<td>12.2</td>
</tr>
<tr>
<td>Ni</td>
<td>-</td>
<td>7.6</td>
<td>4.8</td>
<td>5.1</td>
<td>7.9</td>
</tr>
<tr>
<td>Sn</td>
<td>-</td>
<td>0.4</td>
<td>0.3</td>
<td>1.9</td>
<td>1.4</td>
</tr>
</tbody>
</table>

**Table 2 Composition of different points at 700 °C for 10 min marked in Figure 3(b).**

<table>
<thead>
<tr>
<th>Point</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>77.2</td>
<td>72.0</td>
<td>78.5</td>
<td>76.8</td>
<td>75.5</td>
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<tr>
<td>P</td>
<td>21.8</td>
<td>26.9</td>
<td>20.7</td>
<td>22.0</td>
<td>13.7</td>
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<tr>
<td>Ni</td>
<td>0.8</td>
<td>0.9</td>
<td>0.7</td>
<td>0.8</td>
<td>8.2</td>
</tr>
<tr>
<td>Sn</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>2.6</td>
</tr>
</tbody>
</table>

A further analysis was performed using XRD to confirm the results obtained in microstructure analysis using SEM. It was revealed that all sharp peaks are related to copper. The XRD analysis identified four phases that were present due to reaction of active filler metal. The existing phases were detected as Nickel Tin (Ni$_{17}$Sn$_1$), Copper Tin (Cu$_{13}$aSn$_{0.3}$), Copper Phosphorus (Cu$_{0.97}$P$_{0.03}$), and Copper Nickel (Cu$_{13}$ Ni$_{0.2}$) shown in figure 5 below. The mechanical properties of the porous copper after brazing were also tested using Vickers micro hardness test. The solid copper had a maximum value of 29.7 HV whereas the joint interface had a maximum value of 68.3 HV. It can be concluded that the rigidity of the porous copper tends to increase due to the effects of surface hardening. The rigidity of porous copper after brazing is important to ensure it will less deform during servicing of cooling devices; an important property for future product development.

**4. CONCLUSION**

For all parameters tested, a successfully brazed joint was achieved. The filler metal melted and filled the joint gap by capillary action to form joints. It was found by EDS analysis that phosphorus is the main element contributing to the microstructure of the joint. By increasing the holding time, better diffusion was noticed.
in overall bonded region and the top joint had better strength due to higher presence of filler metal elements.

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