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To cite this article: Nur Nadiah 'Izzati Binti Zulkifli *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **551** 012091

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## Fabrication of Novel Geopolymer Reinforced Tin Copper Solder in Suppressing Intermetallic Layer Growth

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**Abstract.** Currently, lead-free composite solder technology system is the new approach that have been considered as a promising replacement for toxic SnPb solder alloy. Sn-0.7Cu was used as matrix solder alloy while fly ash geopolymer and kaolin geopolymer with different compositions (0.5 wt.%, 1.0 wt.%, and 1.5 wt.%) was added as a reinforcement to increase the properties of solder alloy. The solder composite was prepared by using powder metallurgy method which consist of mixing, compaction, and sintering process via microwave oven. Microwave sintering approach results in more uniform heating, lower pore coarsening with cost-effective and energy efficiency. The chemical composition and morphology of geopolymer reinforcement was analysed by using X-ray Fluorescence and Scanning Electron Microscope. The influences of the geopolymer particulates in the monolithic matrix solder on the interfacial intermetallic compound thickness and wettability were investigated by using optical microscope, while the specific value was measured by using J-image software. The melting point temperature were investigated by using differential scanning calorimeter (DSC). The influences of adding types of geopolymer particulates into Sn-0.7Cu lead free solder were investigated in terms of interfacial intermetallic compounds (IMCs) and thermal properties. It is noted that several addition of fly ash geopolymer and kaolin geopolymer particles can remarkably suppressed the thickness of intermetallic layer between composite solder and the substrate and thus gives higher melting temperature but somehow certain composition resulted low in mechanical properties. Overall, the addition of 0.5 wt.% of kaolin geopolymer reinforcements into Sn-0.7Cu lead-free improved all the listed properties of the solder materials.

### 1. Introduction

Nowadays, electronic packaging industries has become one of the most famous in the field of electrical engineering among the electronic industries and has grown rapidly becoming more sophisticated and advance in producing electrical device [1]. Some of the process occur in electronic packaging consist of soldering process which bond the solder materials together with the substrate forming one or more electrical connection by melting it at a controlled temperature. Two functions of soldering process are as electrically support; giving required electrical connection within the solder and circuit and mechanically support; holding the components to provide assembly together.

Over the past few years, Pb is typically used in soldering industries but nowadays, the uses of Pb as the solder alloy has been banned and restricted due to environmental issues. Therefore, other



alternatives is used to provide more safe and low cost with great performances effectiveness materials alloy such as Tin silver (SnAg), tin bismuth (SnBi), tin copper (SnCu), tin zinc (SnZn), tin rhenium (SnRE), tin zinc aluminium (SnZnAl), tin silver copper indium (SnAgCuIn), tin silver copper (SAC) etc to lower the consumption of Pb usage. Besides, the addition of other reinforcement such as from ceramic based are widely acknowledge by the researchers as it can increase the mechanical and thermal properties of the solder joint. Recently, many investigation about Sn-0.7Cu/Si<sub>3</sub>N<sub>4</sub>, Sn-0.7Cu-0.05Ni/TiO<sub>2</sub>, Sn-3.0Ag-0.5Cu/ SiC, Sn-3.0Ag-0.5Cu/ NiO and other related to this study has been observe to have various properties for the matrix alloy solder [3,4].

Currently, some researchers had found that the addition of nano-ceramic particles will increase the mechanical and thermal behaviour of the solder joint. Since geopolymers powder is one of a type of reinforcement came from rare earth elements which also can be called as ceramic based, it can be added into the matrix of solder alloy. Geopolymer is getting a worldwide interest due to its low carbon dioxide emission [5]. Geopolymer materials come from polymerization process which produce a chemical reaction between aluminosilicate materials such as alumina, silicon, fly ash, kaolin, slag with alkaline activators such as NaOH based, KOH based, or a mixture of Na<sub>2</sub>O with SiO<sub>2</sub> based (Na<sub>2</sub>SiO<sub>3</sub>) forming a paste or binder. M. Albitar et. al. elucidates that fly ash geopolymer can withstand sulphate attack, corrosion and acid attack and therefore easy to get with a low cost. Fly ash geopolymer could give some advantages over metakaolin due to it is waste resource produced in huge quantities by coal-fired power stations making them environmentally friendly feedstock [6]. Previous research shows that NaOH solution above 12 M are more risky to handle compared to 12 M NaOH solution [7]. It also has high chance for the alkaline activator to undergo solidification faster compared to 12 M of NaOH solution. Mustafa Al Bakri et. al, 2011 also elucidate that fly ash geopolymer with 12 M NaOH concentration shows excellent result in compressive strength until 94.59 MPa when testing for seven days. This is because the microstructures appear to be homogenous and contains proportion of unreacted fly ash microspheres with continuous matrices of aluminosilicate and microcracks [8].

Nmiri et. al, also investigated the effect of different concentration of KOH and NaOH towards the compressive strength where they found that 13 M gives the highest compressive strength which is 33.5 MPa for KOH and 36.7 MPa for NaOH. Meanwhile, increasing molarity up to 15 M of NaOH and KOH concentration makes the compressive strength become lower. A new improved solders were fabricated by incorporating nanosized of geopolymer can suppress the grain growth and therefore contribute to small intermetallic layer growth which can give high surface energy to the solder-substrate [7].

## 2. Experimental

### 2.1. SnCu

In general, lead free solder cost almost two to three times higher than SnPb itself but Sn-0.7Cu solder usually cost only about 1.3 times higher than SnPb solder which explain why SnCu has been used in this study [9]. SnCu powder used was Sn-0.7Cu and was supplied by Nihon Superior, Japan with size range 25-40µm which act as the matrix alloy in the geopolymer particulates. Previous research elucidate that SnCu solder alloy can performed as the same level as SnPb solder alloy as they can give good fatigue, creep resistance, high melting point [10].

### 2.2. Fly Ash Geopolymer

Chemical composition analysis was undergoes to investigate the ASTM C618 standard. Based on ASTM C618 standard, there are two classes of fly ash which is Type C and Type F. In this study, the fly ash type F was used as the reinforcement in Sn-0.7Cu/fly ash geopolymer was obtained from Manjung Power Plant, Lumut, Perak, Malaysia. The alkaline activator used in this study was prepared by mixing 12M of NaOH solution with Na<sub>2</sub>SiO<sub>3</sub> solution. The alkaline activator with the weight ratio

( $\text{Na}_2\text{SiO}_3/\text{NaOH}$ ) 2.5 was blended together with fly ash into weight ratio of S/L is 2.0. The solid/liquid which can be categorized as fly ash/alkaline activator and  $\text{NaSiO}_3/\text{NaOH}$  ratio also influenced the workability of the mixture where less workability caused failure in providing good flexural properties. Some researcher agreed that 2.0 fly ash/alkaline activator ratio and 2.5  $\text{NaSiO}_3/\text{NaOH}$  ratio give the maximum strength up to 71 MPa [8]. Some of the researchers stated that the best flexural strength can be obtained when the ratio of fly ash/alkaline activator and  $\text{NaSiO}_3/\text{NaOH}$  were 2.0 and 2.5 [11]. The mixture was then poured in a flat mould to make it easier during milling process to produce powdery reinforcement. After that, fly ash geopolymer was cured for 24 hours in ambient temperature. Huseien et. al, 2016 investigates that most fly ash geopolymer samples cured at ambient temperature shows lower water absorption compare when curing in oven and has resulted excellent compressive strength with low percentage of water absorption when curing fly ash geopolymer at ambient temperature [12]. Final fly ash geopolymer was milled to obtain powder reinforcement by using ball milling machine until achieve  $63\mu\text{m}$  in size.

### 2.3. Kaolin Geopolymer

Kaolin refers to a family of kaolinitic clays that consist of 1:1-type clay mineral with one tetrahedral sheet and one octahedral sheet depending on the weathering and geological condition [13]. In this study, kaolin was obtained by Manjung Power Plant, Lumut, Perak, Malaysia. The same molarity of 12M NaOH was used with a ratio of alkaline activator ( $\text{Na}_2\text{SiO}_3/\text{NaOH}$ ) 0.24. In terms of S/L, Heah et. al observed that kaolin geopolymer with S/L ratio of 0.60 disintegrated in water at 7 days while S/L 1.0 does not disintegrated in water even after 180 days [14]. The same observation was obtained when using  $\text{NaSiO}_3/\text{NaOH}$  with ratio 0.16 and 0.32. Heah et. al (2012), concluded that as S/L and  $\text{NaSiO}_3/\text{NaOH}$  ratio increase, the workability will decrease. As S/L ratio increase, the mix become stiffer where more solid content then fluid medium within the mixes. While as  $\text{NaSiO}_3/\text{NaOH}$  ratio increase, viscous property of sodium silicate become higher than NaOH solution. Workability of kaolin geopolymers decreased when the ratio of solid/liquid and  $\text{NaSiO}_3/\text{NaOH}$  increase. Therefore, workability decrease due to inter-particle friction and highly viscous properties [14]. In this study, the kaolin was then blended with alkaline activator with a ratio S/L is 0.8. After the mixture was well blend, the mixture was then poured in a flat mould and been cured in the oven temperature of  $60^\circ\text{C}$ . It was found that  $60^\circ\text{C}$  curing temperature gives the highest compressive strength [8]. Based on Joshi and Kadu, 2012, curing in the oven temperature of  $60^\circ\text{C}$  to  $75^\circ\text{C}$  for 24 hour can increase the strength as compared to room temperature [15]. Final kaolin geopolymer was milled to obtain powder reinforcement by using ball milling machine and sieve until achieve  $63\mu\text{m}$  in size.

### 2.4. Sample Fabrication

Precise weighing of the solder alloy or solder material elements and the reinforcement materials are performed. Tin copper and geopolymer powder were weighted following the composition for 2 gram per sample. Several composition (0.5 wt.%, 1.0 wt.%, and 1.5 wt.%) of fly ash geopolymer and kaolin geopolymer were weighted. Sn-0.7Cu/fly ash geopolymer and Sn-0.7Cu/kaolin geopolymer powder were mixed together in a roller blender at speed of 250 rpm for 1 hour to ensure that the mixture were mixed homogenously. The compaction technique via powder metallurgy was used in the laboratory for this study was uniaxial compaction (hand press). The mould used was 12 mm diameter which the size consist of body base, two small plungers and main plungers. Then, the mixed powder were inserted into the mould and were compacted under pressure 4.5 ton for 1 minute. The mould was cleaned first by using WD40 liquid before undergo compaction process to ensure the mould clean from any contaminations.

The sintering of green body process was done by using a microwave oven. The temperature was set up to  $175^\circ\text{C}$  for 2 minutes. The sample were placed inside a ceramic crucible to make sure that the heat fully absorbed into the sample.

### 2.5. Analysis and Characterization

The microstructural elemental analysis of the metallographically polished samples of the composite materials were examined using optical microscope (OM model Olympus Optical Co. Ltd BX41RF) and SEM was utilized to determine the surface structure, thickness of intermetallic compound, and wettability formed in the solder matrix. This was aimed to investigate morphology, presence of intermetallic compounds (IMCs) formation of the solder-substrate and contact angle between solder and substrate from the cross-section area of the sample. Before the samples were observed under OM, the samples were mounted using a mixture of epoxy and hardener to make it easy to grind and polished the samples since the size of the sample is small and thin.

After the mounted samples solidify, the mounted part was removed from the mold. The surface area of the mounted samples were cleaned to remove foreign matters or unbalanced mounted part. The surface of the mounted sample were then grind and polished to ensure smooth and shining surface area so that their microstructure can be view under a microscope.

Solder reflow process was the last process in soldering process where the solder paste was melted on the Cu substrate, mixed with active flux and wet the surfaces to be joined. This process produce the connection to form intermetallic compound when the matrix alloy was melted on Cu substrate. At the end, the solder solidified and form a strong metallurgical bond between them. F4N reflow oven used in solder reflow process. There are four zones involved in this process which are thermal soak zone, preheat zone, reflow zone and cooling zone. Thickness of intermetallic compound layer (IMC) and their wettability were determined by using OM. The IMC that formed at the Cu substrate layer of the cross-sectioned samples was measured by using J-Image software to obtain average result of IMCs thickness.

Differential scanning calorimeter (DSC model TA Instruments DSQ-10) was used to determine the melting point of the materials. The samples were weighed below 5 mg and were placed on aluminium pan and heated up to temperature 250°C with a heating rate 10°C/min under a protective nitrogen atmosphere. The solder samples were coated with small amount of rosin flux and attached on the Cu sheet before placed into aluminium pan.

## 3. Results and Discussions

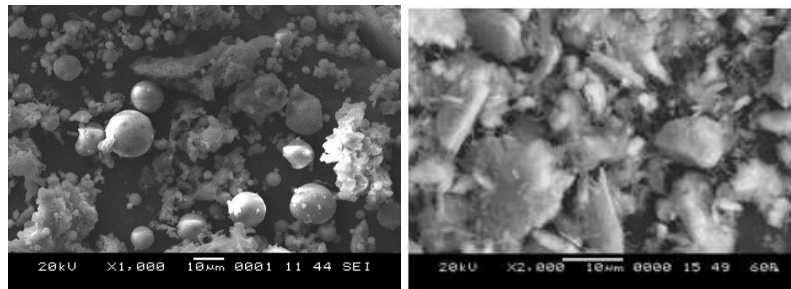
### 3.1. Surface Microstructure

Microstructure of fly ash and kaolin powder, distribution of particles, and homogeneity degree were examined by using SEM and OM. There are several magnification involved in this analysis which are two magnification for SEM; 2000x and 5000x and three magnification for OM; 50x. SEM analysis revealed morphological of pure crystal in magnification 2000x and 5000x as in Figure 3.1. Figure 3.1 shows that fly ash are generally in glassy solid or hollow, spherical and finer in shape [16]. The micrograph image can be seen from the figure that fly ash consist of a series of spherical vitreous particles of different sizes. While usually hollow in shaped, some of the spheres almost appear within other interior small size sphere.

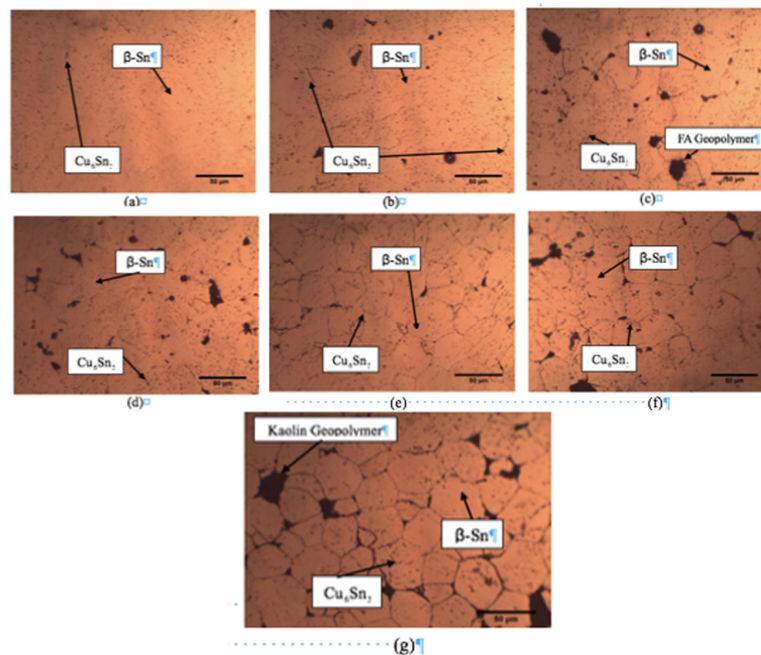
Generally, kaolin structure was flaky-like as can be observed on the surface of kaolin particles. Besides that, systematically arranged layered structure forming stacks of books can also revealed due to kaolin geopolymer composed sheets of silica and alumina held together by Van Der Waals and hydrogen bonding [17]. The nature kaolin structure contributed smaller surface area for geopolymerization process compared to materials with spherical-shaped particles such as fly ash. This will act as barrier that caused only minimum dissolution by alkaline solution and hence the geopolymerization reaction [17].

Based on Figure 3.2, clear grain boundary of Sn-0.7Cu without the addition of any geopolymer reinforcement can be observed. Increasing in weight percentage of fly ash geopolymer reinforcement making the black area become more obvious. By the addition of 0.5 wt.% and 1.0 wt.% fly ash geopolymer reinforcement, it shows that the fly ash particles does not uniformly distributed between the grain boundaries where at certain part the fly ash geopolymer particles agglomerate with each

other compare to 1.5 wt.%. This shows that the fly ash geopolymer and the monolithic Sn-0.7Cu does not homogenously mixed during mixing process. Addition of kaolin geopolymer into the matrix alloy shows the grain boundary region had fairly distribution of kaolin geopolymer. As the weight percentage of kaolin geopolymer increases to 1.5 wt.%, the kaolin geopolymer particles which distributed along the grain boundaries of the bulk solder (black area) increases and produced a few agglomeration of kaolin geopolymer particles between the grain boundaries. This happened due to non-homogenous distribution of the Sn-0.7Cu/kaolin geopolymer between the grain boundaries during mixing process.



**Figure 3.1:** SEM analysis of a) fly ash, b) kaolin



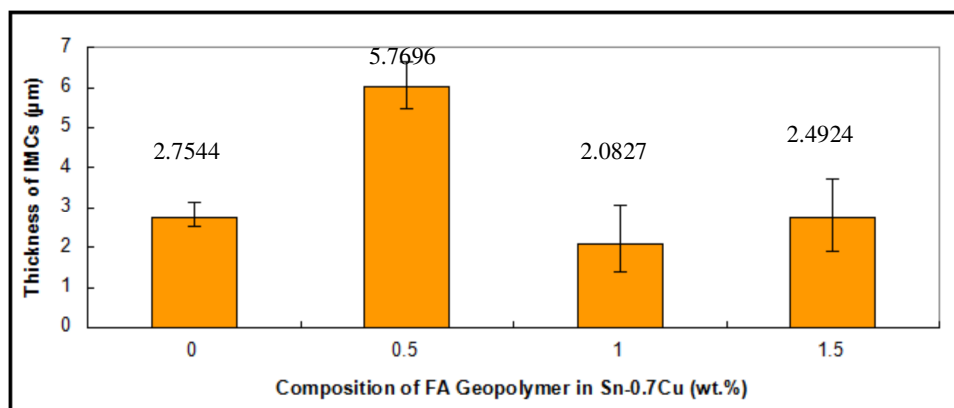
**Figure 3.2:** Optical micrographs of Sn-0.7Cu + geopolymer grains structure at 50x magnification with a) 0 wt.%, b) 0.5 wt.% FA geopolymer, c) 1.0 wt.% FA geopolymer, d) 1.5 wt.% FA geopolymer, e) 0.5 wt.% kaolin geopolymer, f) 1.0 wt.% kaolin geopolymer, g) 1.5 wt.% kaolin geopolymer.

Typically, microstructure of Sn-0.7Cu solder alloy that forms on the substrate consist of primary  $\beta$ -Sn cells or dendrites that surrounded by eutectic which is combination of  $\beta$ -Sn and intermetallic  $\text{Cu}_6\text{Sn}_5$  [18]. Based on the figure above, the pure Sn-0.7Cu solder alloy consist of large number of primary  $\beta$ -Sn cells with small intermetallic compound  $\text{Cu}_6\text{Sn}_5$ . Besides, it also has uniform eutectic structure phase microstructure. Addition of 0.5 wt.% fly ash geopolymer and kaolin geopolymer reinforcement into Sn-0.7Cu solder shows that the primary  $\beta$ -Sn cells are still present in the microstructure and the microstructure become uniform with small  $\beta$ -Sn dendrites and small number of intermetallic compound  $\text{Cu}_6\text{Sn}_5$ . The microstructure of  $\beta$ -Sn dendrites was refined and has smaller intermetallic compound  $\text{Cu}_6\text{Sn}_5$ . Addition of 1.0 wt.% and 1.5 wt.% geopolymer reinforcement, the microstructure become non-uniform because of large  $\beta$ -Sn cells with larger number of intermetallic  $\text{Cu}_6\text{Sn}_5$ . This can be concluded that fly ash geopolymer did not completely dissolved homogenously in Sn-0.7Cu solder alloy.

The small changes in composition of reinforcement can affect the formation and properties of  $\text{Cu}_6\text{Sn}_5$  while it involve actively during interface reaction [19]. According to Chellvarajoo et. al, many researchers proved that addition of ceramic reinforcement can affected the formation and properties of  $\text{Cu}_6\text{Sn}_5$  while it involve in the interface reaction actively [20]. Ng et. al, elucidate that  $\beta$ -Sn dendrites are still present in the microstructure but the eutectic has been modified with the incorporation of Zn into the  $\text{Cu}_6\text{Sn}_5$  crystals. The microstructures of the bulk alloys can be refines by added a small amount of Zn [19].

### 3.2. Intermetallic Compound Layer (IMC)

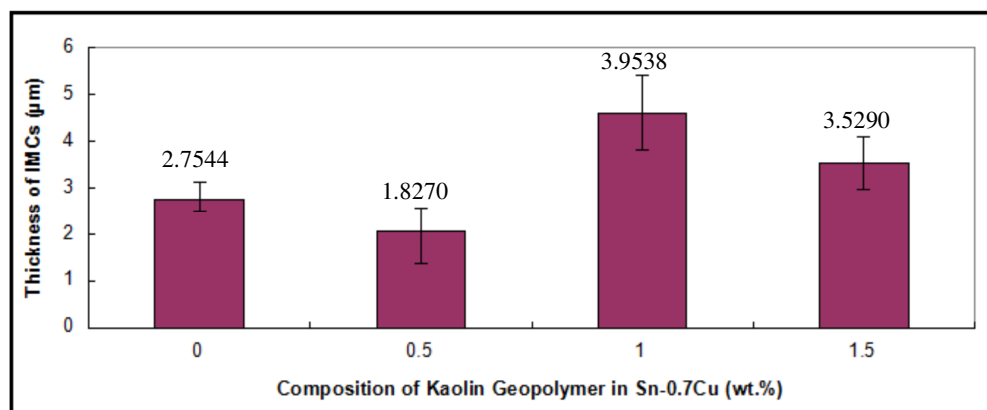
From the observation, the presence of fly ash geopolymer as reinforcement in Sn-0.7Cu solder alloy helped to change the thickness of IMC. By referring to Figure 3.3, the bar graph shows that 0.5 wt.% of fly ash geopolymer particles caused the intermetallic layer increases compared to pure Sn-0.7Cu solder. 1.0 wt.% of fly ash addition gives the best result in retarding the thickness of IMCs layer. It is noted that when fly ash geopolymer particles was added into solder and reflowed, the particles remain as stable solid particles. This shows that 1.0 wt.% was the optimum composition for Sn-0.7Cu/fly ash geopolymer to obtain good metallurgical bond for solder-substrate. While solder with 1.5 wt.% fly ash geopolymer begin to increase the thickness of IMCs near the value of pure Sn-0.7Cu IMCs. Figure 3.4 shows the bar graph of IMCs thickness for each composition of kaolin geopolymer added to Sn-0.7Cu solder. By adding 0.5 wt.% kaolin geopolymer can suppress the intermetallic layer growth thus producing better performing of solder substrate. Addition of 1.0 wt.% kaolin geopolymer shows the highest IMCs thickness compare to pure Sn-0.7Cu and addition of 1.5 wt.% kaolin geopolymer.



**Figure 3.3:** Thickness of IMCs with different composition of fly ash geopolymer

During reflow soldering process, the mobility of geopolymer particles caused the respective particles to embed in Sn-0.7Cu grain structure and Cu substrate [21]. Therefore, the free movements of Cu atoms from the Cu substrate and solder matrix slowly inhibited by the accumulation of these particles. IMC thickness will slowly reduce when a limited number of Cu atoms presence during IMC formation [18]. Previous researchers investigated that the pure Sn-0.7Cu solder indicated that the interfacial  $\text{Cu}_6\text{Sn}_5$  were in needle like and scalloped structure compare to the shorter and more faceted structure when adding  $\text{TiO}_2$  reinforcement [22].

The presence of other reinforcing elements appear to limit the growth of neighbouring grains making the IMC layer more stable [22]. But addition of 0.5 wt.% fly ash geopolymer resulted in more higher in thickness (5.7696  $\mu\text{m}$ ) compare to pure Sn-0.7Cu matrix solder (2.7544  $\mu\text{m}$ ) which is opposite from previous research [21]. This phenomenon occur due to addition of 0.5 wt.% cannot act as heterogenous nucleating agent to suppress the IMC layer growth [23]. It also might occur due to too small of addition in the Sn-0.7Cu composite solder cannot be detected in the phase and therefore disturbed the IMCs formation [23].



**Figure 3.4:** Thickness of IMCs with different composition of kaolin geopolymer.

But as soon as the kaolin geopolymer being increased, the thickness of IMCs increased more higher up to 3.9538 $\mu\text{m}$  and 3.5920 $\mu\text{m}$  compare to pure Sn-0.7Cu. Previous study by Kotadia et. al (2014), stated that reinforcing ceramic-based in matrix solder might be risk as the high amount of ceramic particles might contribute to brittleness of the solder joint. Besides that, an increasing IMCs layer also might cause by the difficulties to achieve homogeneous distribution of ceramic particles since ceramic is a hard particles [10]. Humidity in environment also can cause ceramic especially kaolin geopolymer to agglomerate again even after sieving.

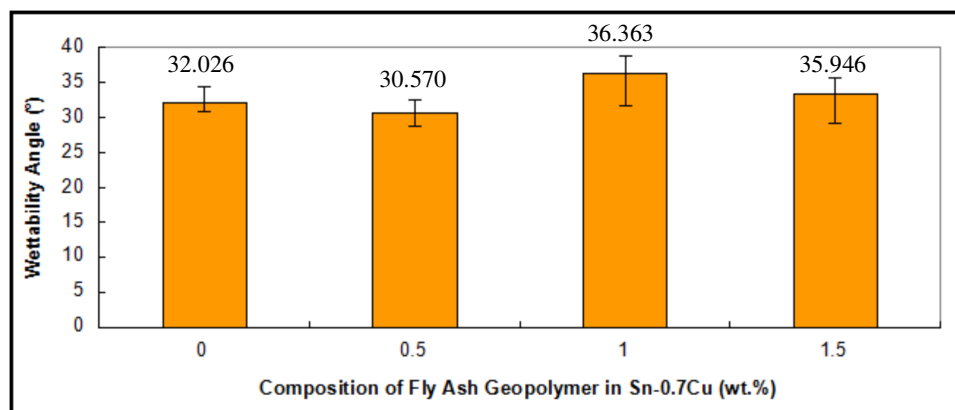
### 3.3. Wettability

Figure 3.5 observed that contact angle for 0.5 wt.% fly ash geopolymer decrease until 30.57° from pure Sn-0.7Cu solder (32.026°) and increase to 36.363° after 1.0 wt.% addition of fly ash geopolymer. Addition of fly ash geopolymer more than 1.0 wt.% shows the contact angle decrease back to 35.946°. This shows that optimum composition of 0.5 wt.% is the optimum composition of geopolymer reinforcement can be added to increase the wettability. Wettability of solder alloys depends on surface properties and also solder alloy proportion. Generally, the smaller the contact angle, the better wettability of the interconnections. An acceptable range of contact angle should be below 45° [24]. Figure 3.6 shows average contact angle for each composition of kaolin geopolymer addition in monolithic Sn-0.7Cu solder alloy. The wettability shows at the best when 1.5 wt.% kaolin geopolymer was used in Sn-0.7Cu which it can obtained until 27.946°. The trend shows in the bar graph starting

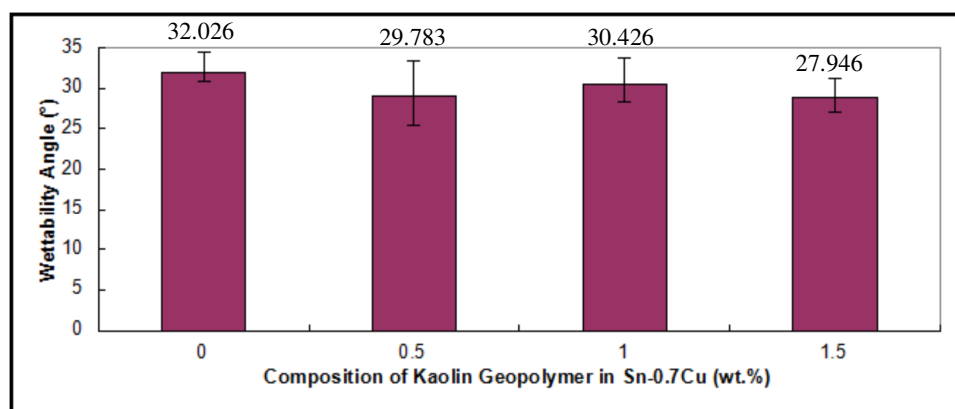


with high wettability angle which is pure Sn-0.7Cu up to 32.026°. But the addition of kaolin geopolymer contribute to lower the contact angle between the solder and substrate. The wettability of 1.0 wt.% kaolin geopolymer as a reinforcement in Sn-0.7Cu solder increased but it is still low than pure Sn-0.7Cu wetting angle.

Wetting can be relate with the thickness of intermetallic layer growth of the solder-substrate. When there is intermetallic formation, it means that there are contact angle (wetting) occurs between solder alloy and the substrate [25]. Some researchers stated that wettability angle of solder-substrate related to the formation of intermetallic compound where addition of 1.0 wt.% and 1.5 wt.% reinforcements resulted higher IMC thickness thus contributed to higher wetting angle [13]. As seen in Figure 3.5 above, 0.5 wt.% addition gives better contact angle. Generally, as composition of reinforcement in solder alloy increase, contact angle can be reduced [25]. But as the percentage of fly ash geopolymer increased up to 1.0 wt.% and 1.5 wt.%, the contact angle become larger. Based on Salleh et. al (2011), addition of reinforcement particulates will only improve the wettability until the optimum composition is achieved. Too higher of reinforcement percentage will further degrade the wettability of composite solder which can be worse than monolithic Sn-0.7Cu alloy since ceramic-based reinforcement gives brittle properties in nature [24].



**Figure 3.5:** Wettability angle with different composition of fly ash geopolymer



**Figure 3.6:** Wettability angle with different composition of kaolin geopolymer

Previous study state that formation of intermetallic layer can influenced the wettability of the solder (Zang et. al, 2009). When comparing with the IMC layer growth produced in Figure 3.6, the wettability of Sn-0.7Cu/0.5 wt.% kaolin geopolymer increased when the IMCs thickness decreased. This phenomenon has been supported by previous studies which agreed that addition  $\text{Si}_3\text{N}_4$  particulates in molten Sn-0.7Cu solder act as an agent to increase the wettability between Cu substrate [24].

#### 3.4. Melting Point

As seen in the Table 3.1, the result shows the reduction in melting temperature, TL of Sn-0.7Cu solder from 229.67°C to 228.15°C after addition of 0.5 wt.% fly ash geopolymer which is lower than the monolithic melting temperature of Sn-0.7Cu. This showed fly ash geopolymer particles has just slightly altered the melting temperature. But as the composition of fly ash geopolymer increase to 1.5 wt.%, the melting temperature start to slightly increase to 228.99°C but still lower than the monolithic solder alloy. Besides, the solidous temperature of pure Sn-0.7Cu solder and Sn-0.7Cu/fly ash geopolymer particles range from 225.09°C to 225.83°C shows increasing reading with increasing fly ash geopolymer content. Meanwhile, addition of kaolin geopolymer powder, the monolithic Sn-0.7Cu obtained up to 229.67°C while slowly decrease the melting point when 0.5 wt.% kaolin geopolymer particles is added. DSC results shows that increasing in composition of kaolin geopolymer up to 1.5 wt.% created low melting temperature until 228.83°C. The mixing of 1.5 wt.% kaolin geopolymer composite solder absorbs less amount of heat (228.83°C) compared than 0.5 wt.% kaolin geopolymer (228.99°C). Besides, the solidous temperature of pure Sn-0.7Cu solder and Sn-0.7Cu/kaolin geopolymer particles range from 225.09 to 226.47 shows increasing reading with increasing kaolin geopolymer content.

**Table 3.1:** Melting temperature of Sn-0.7Cu/geopolymer solder.

Materials	Solidous temperature, $T_s$ (°C)	Liquidous temperature, $T_L$ (°C)	$\Delta T$ (°C)
Sn-0.7Cu	225.09	229.67	4.58
Sn-0.7Cu/0.5FA geopolymer	225.83	228.15	2.32
Sn-0.7Cu/1.5FA geopolymer	225.79	228.99	3.20
Sn-0.7Cu/0.5Kaolin geopolymer	225.98	229.02	3.03
Sn-0.7Cu/1.5Kaolin geopolymer	226.47	228.83	2.36

If the melting temperature is higher, it can lead to several damage to the solder part in electronic components in packaging due to higher soldering temperature [12]. The reduction in melting temperature of Sn-0.7Cu/0.5 wt.% fly ash geopolymer was due to the addition of non-alloying element particles has just slightly altered the melting temperature [20]. More addition of fly ash ceramic reinforcement can cause increasing in melting temperature since geopolymer is highly resistance to high temperature [22]. This statement has been proved by this experiment since the addition of 1.5 wt.% fly ash geopolymer resulted increasing in melting temperature from 228.15° to 228.99°. Liu et. al (2008), explained higher addition of Bi particles in solder alloys could increase the melting range and therefore lead to initiation of solidification crack of the solder joints. This prove that addition of 0.5 wt.% of fly ash geopolymer reinforcement is the optimum composition which can produce better melting point [26].

Table 3.1 shows the melting range decreased from 4.58°C to 2.36°C. Chellvarajoo and Abdullah observed that addition of 0.5 wt.% NiO particles caused the melting range become lower than plain solder. This result indirectly saves the cost for thermal application for the composite solder to melt during reflow soldering process since high melting temperature increase the usage of energy [21].

#### 4. Conclusions

The comparison between morphological, growth of interfacial intermetallic compound formation, wettability angle, and thermal properties of Sn-0.7Cu solder using different types and compositions of geopolymer reinforcement was examined through this project. The influences of adding fly ash geopolymer and kaolin geopolymer powder into Sn-0.7Cu solder alloy can refine the microstructures and IMCs as long as the Sn-0.7Cu/geopolymer reinforcement were homogeneously mixed.

Based on this study, the addition of 1.0 wt.% fly ash geopolymer reinforcement into monolithic solder alloy Sn-0.7Cu can retard the formation of IMCs layer. In case for kaolin geopolymer reinforcement, thickness of IMCs layer become thinner at 0.5 wt.% kaolin geopolymer addition. Between both geopolymer, addition of 0.5 wt.% kaolin geopolymer reinforcement gives good result in IMCs thickness (1.827 $\mu$ m) compare to fly ash geopolymer reinforcement at composition 1.0 wt.% (2.0827 $\mu$ m).

The melting temperature become lower with the addition of geopolymer reinforcement. Addition of 0.5 wt.% fly ash geopolymer gives low melting temperature until 228.15°C while addition of 1.5 wt.% kaolin geopolymer can decrease until 228.83°C. Wettability of solder-substrate improves with the addition of 0.5 wt.% fly ash geopolymer reinforcement and 1.5 wt.% kaolin geopolymer reinforcement. It should be the same observation with IMCs but the result were different. It can be concluded that solder substrate experience less wetting time or due to Tombstoning effect during reflow solder. Therefore, when the IMCs of the solder increases, the wettability also decreases. Overall, it can be concluded that 0.5 wt.% kaolin geopolymer reinforcement gives better properties in terms of interfacial intermetallic compound, wettability, and melting temperature compare to addition of fly ash geopolymer which shows inbalanced result.

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