Effect of fibre-lasers parameters on interfacial reaction and wetting angle of two different types of SAC305 solder fabrication on Cu pad

T J Nabila¹, S R A Idris¹* and M Ishak¹

¹Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
*Corresponding author: nabilatamarjaya@gmail.com

Abstract. This paper presents the effect of different parameters of fibre laser soldering on interfacial reaction of two types of lead-free solder fabrication on Cu pad. The objective of this paper is to study the intermetallic compound thickness (IMC) formation and wetting angle of two different types of solder fabrication when it was exposed to varies of laser power and scanning time. A fibre laser with 200W continues wave (CW) was used in this experiment to form a joining between SAC305 solder wire and printed copper board. A continuous laser power was ranged between 72W to 88W and scanning time of 1.5s and 2.5s were chosen to create joining. Flux was used in the laser soldering experiment in order to gain uniform heat distribution throughout the solders. The mechanical properties were observed by using optical and metallurgical microscope. Results showed that SAC305 solder powder performing good wetting angle with smallest value of 18.18° meanwhile, the smallest wetting angle for solder wire is 26.12° and in terms of IMC layer comparison, solder powder has more thinner IMC layer with value of 1.1 µm compared to SAC305 solder wire which is 2.9 µm. Thus, it is showed that solder powder improved the solder joint properties compared to conventional solder wire when exposed to laser soldering.

1. Introduction
Following Waste Electrical and Electronic Equipment (WEEE) and Restriction of the Use of Hazardous Substances in Electrical and Electronic Equipment (RoHS Directive) lead solders have been banned world widely due to its toxicity which have caused a lot of environmental and health problem issues [1-4]. Even though, lead solders have been known for its good low melting point, good wettability and reliability in electronic packaging industries, group of researchers still keep on continuing their studying in order to produce good lead-free solder alloys which then results in high quality solder joint [5, 6]. One of the potential substitutes that has highly accepted in electronic packaging industries is the Sn-Ag-Cu (SAC) solder alloy as it has low melting point, good wetting on different substrates, low cost [7-9].

Regardless that the electronic packaging industry has it favours in SAC solder alloy, there has been some debates on the preferable composition to use. Most commonly discussed composition in SAC solder alloy family are Sn96.5Ag3Cu0.5 (SAC305) and Sn4.0Ag0.5Cu (or also known as SAC405). SAC405 is commonly utilized in the North American and European industries region meanwhile in Asian industries, SAC305 is used as solder medium as it is classified under the JEITA recommendation for lead-free soldering and plus it is less expensive compared to SAC405 due to its lower silver (Ag)
content [10, 11]. Some studies stated that the extra additional silver content in alloys does not significantly improve the solder joint performance [12, 13].

Recently, fabricating composite solders through powder metallurgy (PM) method has becoming popular among researchers [14, 15]. Some of them even have claimed, that through this method the mechanical properties of a composite solder also could be enhanced [16]. Aside from knowing that PM method is an economically manufacturing process, the solder alloy that fabricated through PM method is reportedly to have a good solder reliability and hardness improvement [17-19].

The application of laser in soldering process has gained attention in electronics packaging industries. It is known for its advantages of precisely focused laser beam on the targeted area, rapid rise and fall in temperature [20, 21]. Its localized and non-contact heating giving laser soldering make it a better choice over reflow soldering as those sensitive electronic components are less damaged during soldering process and due to its short and high cooling rate, a good solder joint is formed thus producing a quality electrical conductivity for the circuits [22, 23]. Therefore, laser soldering technology clearly shows off its benefits more compared to conventional reflow soldering.

From the above barely introduction, in this paper laser soldering onto two types of lead-free solder fabrication was performed. This experiment was conducted in order to study its mechanical properties, mainly focused on the IMC thickness and wetting angle. In the experiment two types of Sn-3.0Ag0.5Cu (SAC305) solder were used, whereas one was fabricated through conventional method which was in solder wire form and another type of solder was fabricated through powder metallurgy (PM) method that it was in solder pellet form. Then, the discussion on the effects of different parameters on the wettability joint and the IMC thickness are explained in this paper.

2. Methodology
The experimental method covers on the preparation of SAC305 solder powder and the laser soldering on both types of solder fabrication with varies of laser power output and scanning time.

2.1. Preparation of SAC305 powder solder pellet.
The SAC305 powder solder pellet is made by through powder metallurgy method. The metal powder of Tin (96.5%), Ag (3.0%) and Cu (0.5%) are pre-weighed first by analytical balance, then it was mixed and milled by using ball milling machine (Model: Nian Hai Tianyang FM-2) with a fixed speed of 1400 rpm and 6 hours of continues duration. The mixed powder metal then is weighed again to a desired weight before it is compressed in the designated die and mold with 6.0 mm of tablet diameter size by using manually TOYO Hydraulic Press, 30C-model (30 Ton maximum capacity) with 5 ton of pressure. The SAC305 powder solder pellet had 1.0 mm of thickness and 6.0 mm of diameter in size.

2.2. Laser soldering
Solders used in the experiment are SAC305 solder wire that is brought from RedRing Solder with diameter of 1.0 mm and SAC305 powder solder pellet which was fabricated as stated before (Figure 1). The solder wire was coiled into a spiral-shaped with diameter of about 6mm (Figure 1 (a)).
The SAC305 solder in form of (a) wire and (b) powder pellet with each has thickness of 1.0 mm and diameter of 6.0 mm in size.

Before the solder was placed onto printed circuit board (PCB) a thin layer of SENJU Sparkle Flux WF-6317i no-clean flux was applied on the PCB first. After the solder wire was placed on the PCB, another thin layer of flux was lightly applied again on top of the solder wire. The solder was lasered by using a 200W continue wave (CW) IPG YLM 200/2000-QCW fibre laser machine. The parameters involved are the laser power and scanning time. The laser power output was ranged into 72W, 76 W, 80W, 84W and 88W meanwhile the scanning time was 1.5s and 2.5s respectively. The PCB then was placed on the x-y platform jig as shown in Figure 2. The steps were repeated for SAC305 powder solder pellet.

After laser soldering, the samples were cold-mounted. The samples were grinded, polished and etched by using a 100 mL mixed solution of 5% Hydrochloric acid (HCL) and 95% Ethanol and then were observed physically by metallurgical microscope. The mechanical properties that were observed were the intermetallic compound (IMC) formation thickness of the solder joint and its wetting angle.

3. Result and discussion

3.1. Intermetallic compound at interfacial
IMC thickness is a layer that formed at every solder joint as a result of chemical reaction that occurs between the solder and the substrate. This layer is vital in solder joint as it affects the strength of the
joint [24, 25] however it has a brittle characteristics where a too thick of IMC layer could deteriorates the solder joint [26, 27]. Meanwhile, IMC that forms through laser soldering is said to be more productive in order to reduce the formation of IMC at the solder joint and ensuring a reliability of the joint whereas usually the IMC layer formed is more thin compared to conventional reflow soldering [20].

Figure 3 below shows the pattern of IMC thickness between SAC305 solder powder and SAC305 solder wire. In this experiment, the scanning time is fixed to 1.5s and the power output is varied to 72W, 80W, 84W and 88W. Following the pattern of the graph, the IMC thickness for all solder powder have thickness of below than 3µm, whereas the lowest is at 72W of laser power output with 1.057656 µm and highest is at 88W laser power output with 2.71655 µm. Meanwhile, for the SAC305 solder wire, the IMC thickness is much higher compared to the solder powder. At the lowest laser power output (72W), the IMC thickness is 2.89133µm and at highest laser power output of 88W it gives out a 6.62159 µm IMC thickness. Thus, it shows that this study signified that by increasing the laser power output, a thicker intermetallic layer was formed [28].

![Figure 3](image_url)

**Figure 3.** The value of IMC thickness against the laser power output (72W, 80W and 88W) between SAC305 solder powder and SAC305 solder wire.

In Figure 4, from the optical microscope observation, when the laser power output of 72W, it is showed that the layer of IMC is much thinner for SAC305 solder powder (4.a) compared to the IMC layer of solder powder at laser power output of 88W (4.b). The same pattern also showed for solder wire, the IMC layer is much thinner at low laser power output (4.c) than at higher laser power output (4.d). Cu₆Sn₅ was formed at the interfacial surface between solder and Cu substrates with scallop-like shaped [29]. As to compared in between these two kinds of solder, solder powder showed a more fined IMC thickness than solder wire be it low or high laser power output. The solder powder that were fabricated through PM method, showed a well homogenous fine microstructure due to good heat distributed and rapid heat supplied through the volume [16].
Figure 4. The figure shows the differences of IMC thickness when the irradiation time is fixed to 1.5s and laser power output is varied to between SAC305 solder powder and SAC305 solder wire. (a) is the IMC layer for solder powder and (c) is for solder wire at 72W. (b) is the IMC layer for solder powder and (d) is for solder wire at 88W.

3.2 Wetting angle

Wettability of solder is the measurement ability for the molten solder to make interconnection between solder and substrate and it is one of the important properties to test the strength of a solder joint [14, 30]. The latest acceptable contact angle range should be below 45° and the smaller the contact angle, the better is it’s wettability joint [31].

In Figure 5 shows the wetting angle of SAC305 solder powder and SAC305 solder wire. The scanning time is fixed to 2.5s and the laser power is varied to 72W, 76 W, 80W, 84W and 88W. It shows that both types of solder have wetting angle range below 90° where it is still under acceptance range and shows a high wettability [32]. SAC305 solder powder shows a decreasing in number of wetting angles as the power increases from 72 W to 80W, however it increases slightly at laser power of 84W (36.015°) and lastly performed a very a good wetting angle at 88W laser power output with 18.18°. The same trend pattern of graph also showed for the wettability result of SAC305 solder wire but only differs in terms of the values. For SAC305 solder wire, a decreasing in number of wetting angles is showed as the power increases from 72 W to 80W, but then there is a slightly increment at laser power of 84W (52.04°) and then it decreasing again at 88W laser power output with 26.12°. Overall, all the SAC305 solder powders shows a better wettability by having wetting angle below 45° SAC305 solder powder. Therefore, it is proved that through wetting angle of solder powder which are made through ball milling process is said to have a convenient wettability [33].
Figure 5. The wetting angle between SAC305 solder powder and SAC305 solder wire with scanning time of 2.5s.

4. Conclusions
In this study, it can be concluded that:

i. The soldering by using laser technology has results in a thin layer of IMC thickness which is good for solder joint. The increment of laser power output also gives out a much thicker IMC at the interfacial as it is showed in the pattern of the graph. The SAC305 solder powder has thinner IMC layer with value of 1.1 µm as to compared to SAC305 solder wire which is 2.9 µm.

ii. The increases of power output, increases the wettability joint of solder. Even though, both types of solder are in acceptable wettability angle, SAC305 solder powder has a good wetting angle which is less than 45 as to compared to SAC305 solder wire with result of 18.18° meanwhile, the smallest wetting angle for solder wire is 26.12°.

iii. Thus, it is showed that solder powder improved the solder joint properties compared to conventional solder wire when exposed to laser soldering.

iv. The applicable of PM method in solder fabrication could save cost in solder alloy electronic packaging manufactured industries.

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