THE EFFECT OF REFLOW ON WETTABILITY OF Sn 96.5 Ag 3 Cu 0.5 SOLDER

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Resume

Surface conditions on Printed Circuit Board (PCB) final finishes have an important impact on the wetting behavior with lead-free solder. The improvement of the wettability in liquid Sn 96.5 Ag 3 Cu 0.5 Solder alloy on PCB substrate was measured with a sessile drop method at 523 K temperature. Wetting properties were determined in normal atmospheric air and inert atmosphere. The wetting angles increasing with the number of reflows both atmosphere. The effect of the atmosphere has a huge importance of the oxidation which manifests itself of the measured wetting angles. One of the most important factors affecting the wetting properties is the amount of oxygen in the soldering atmosphere. Using the inert atmosphere is crucial in case of Pb-free solders, particularly after reflows.

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1. Introduction

Soldering is the most popular joint technique in microelectronic and optoelectronic industries which technologies are widely used in the vehicle industry [1 ÷ 4].

Increasing global customer demand for miniaturised, hand-held and pocket electronic products has been a key driver in the design, development and wide application of high-density area array package format [5]. Electronics manufacturing industries have utilised advanced Integrated Circuits (ICs) packages such as Micro-Ball Grid Arrays (MBGA), Chip Scale Packages (CSP), Flip Chip (FC) technology and Surface Mount Device (SMD) to be able to achieve the manufacture of smaller, lighter, faster and cheaper products. However, the assembly of these surfaces mounts packages and the reliability of the products are challenged by crucial manufacturing process steps. The use of ultra fine pitch packages makes the stencil printing process more critical to produce a reliable solder joint [6]. The most important step in the SMT (Surface Mount Technology) production process besides paste printing is the reflow soldering process [7]. The solder reflow profile is one of the key variables in the electronics manufacturing process that significantly impacts product yields [8]. The manufacturing challenges associated with both solder paste printing and reflow soldering increases as electronic device size decreases. The increasing manufacturing difficulties are because at very small aperture sizes, the rheological dominancy of surface tension over paste viscosity impacts negatively on the printing process. The outcome may include overfill of stencil cavity with solder paste. The consequence of this outcome may lead to printing defects such as solder slumping and bridging. A vital key to achieving urgent customer satisfaction on further miniaturisation of electronics with good solder joint reliability is the in-depth understanding of the solder paste transfer efficiency [9].

Due to worldwide environmental concerns, public sentiments and market strategies, as well as governmental regulations on the use of toxic Pb in the electronic products, the conventional Sn–Pb solders are under strict scrutiny. Therefore, many Sn-rich alloy systems have been developed as alternative candidate Pb-free solders, which have attracted much research and trial applications in recent years [10]. With a combination of process attributes (modest melting point and reasonable solderability), comparable electrical performances and good mechanical properties, the Sn–Ag–Cu system is one of the potential choices [11].

Although great effort has been made for more than 10 years to get the Pb out of electronic industry, until now, there are still some tough barriers needed to override for a widespread and uniform industrial acceptance of favourable solder alloys and matched materials plus processes [12-13]. Besides the lack of legislation, the high cost and insufficient backup data of Pb-free operation (compared to the well–established Sn–Pb soldering system) are cautious consideration nowadays [11].

In the soldering process, the molten solder wets the substrates, and the interfacial reaction occurs at the solder–substrate interfaces, thus forming the soldering joints. Therefore, the wetting property between solders and substrates is crucial to the reliability of the soldering joints [14 ÷ 15].

This study experimentally determines the wetting properties using the sessile drop method at normal atmosphere and at inert gas atmosphere, and determined the effect of the reflow at both atmospheres.

2. Experimental conditions

The investigated solder was Senju M705-GRN360-KV Lead-free Solder Paste, which:

- Very stable solder paste viscosity over a longer period
- Clear flux residues combined with excellent joint cosmetics
- Excellent wettability
- Reduced flux residue cracking and occurrence of side balling.

Fig. 1 shows the investigated solderind paste optimal solderind temperature profile.

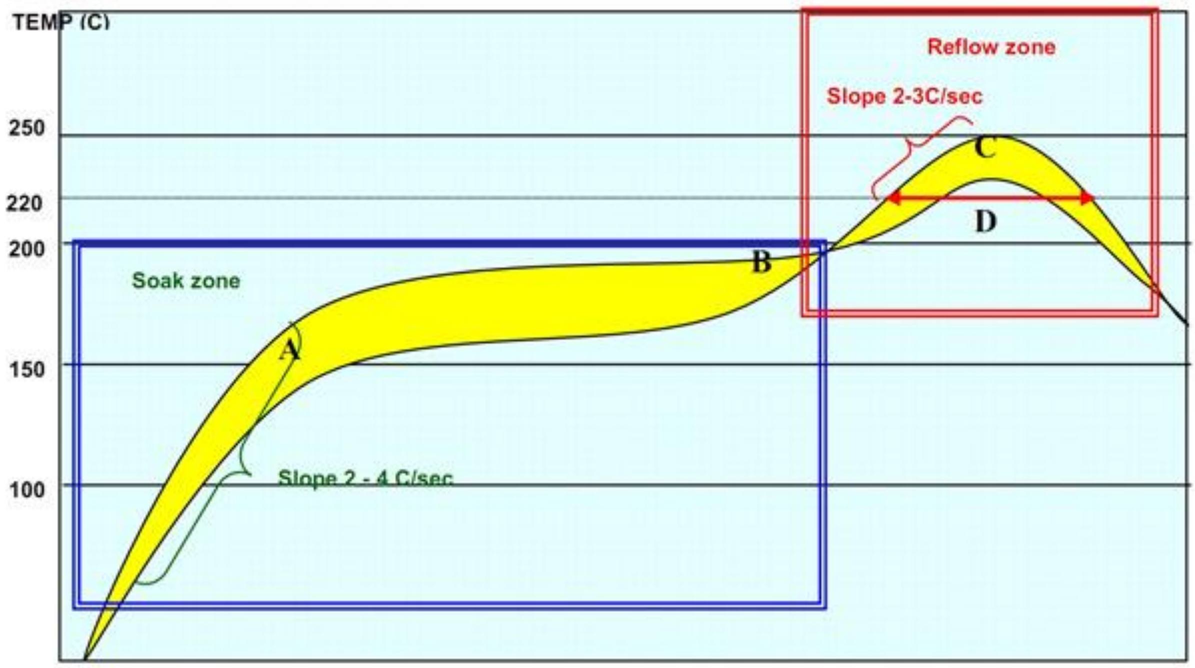

Fig. 1. Solder profile (Soak zone 60-120 s, Reflow zone 30-60 s)
(full colour version available online)

At the reflows and the wetting angle measurements (which were examined at the point "C") we used this temperature ranges.

All investigated substrates consist of the same base epoxy PCB material with two copper layers, on the upside and on the bottom side. The copper layer thickness is approximately 35 μm and the immersion tin final finish is directly deposited on the copper. The layer thickness of immersion tin amounts to approximately 1 μm. Fig. 2 shows a cross section of the typical PCB configuration.

The reflow samples was prepared in the vaccum chamber of the wetting angle measuring equipment. The PCB substrates were heated up without soldering paste, that means one reflow. The last reflow is enacted with soldering paste, and contain the wetting angle measurement.

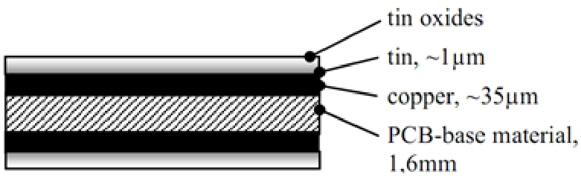

Fig. 2. Cross section of a typical PCB configuration with immersion tin final finish [19]

Wetting experiments were performed in sessile drop equipment following the method described in Ref [16]. The substrate and the soldering alloy were positioned into the middle of the furnace at ambient conditions.

At inert atmosphere the pressure was then reduced to 0.1 Pa at room temperature in the chamber. The vacuum was replaced by a 10^5 Pa 99.999 % Ar gas. This procedure was repeated 3 times.

Subsequently, the temperature was raised to soldering temperature (~523K) using a heating rate of 4 K/s. Since only a small portion of the gas chamber was heated, the pressure around the droplet remained at about 10^5 Pa during the run of measurements.

The contact angle was directly measuring the profile of the drop, fixing and processing the data, using self-made evaluation software (Fig. 3.). Though the resolution of this software is below 1 degree, the total uncertainty of the measured values is higher: ± 3°.

After the measurment process at 523 K, the furnace was switched off and cooled slowly to the ambient temperature (the whole cooling time was around 25 minutes). Subsequently the furnace was opened and the solidified sample was removed.

3. Results and discussions

Two samples after the measurement process are shown in Fig. 4. The molten solder created a lenticular shape in the top of the PCB chips and the flux spread the solder. The main reason of the different spreading in Fig. 4. was the oxidization of the immersion tin layer on the PCB chip. Sample A (in Fig. 4.) was made under air atmosphere and flux covers smaller surface of the PCB than sample B (in Fig. 4.), which was measured under Argon atmosphere. The flux couldn't spread the whole PCB surface

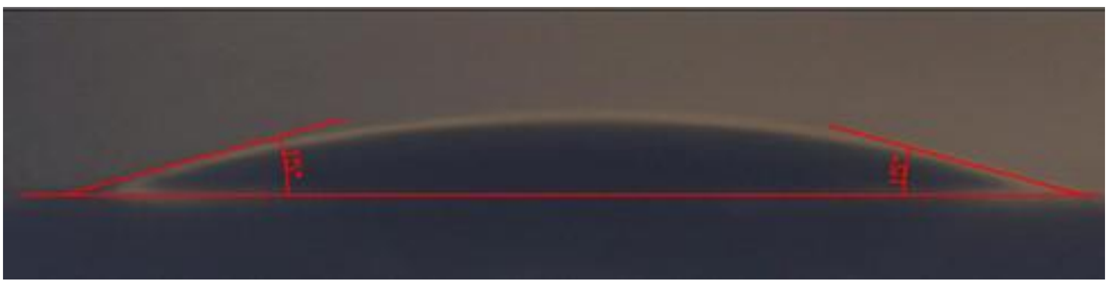

Fig. 3. The drop profile at three reflow under Ar with the measured contact angles
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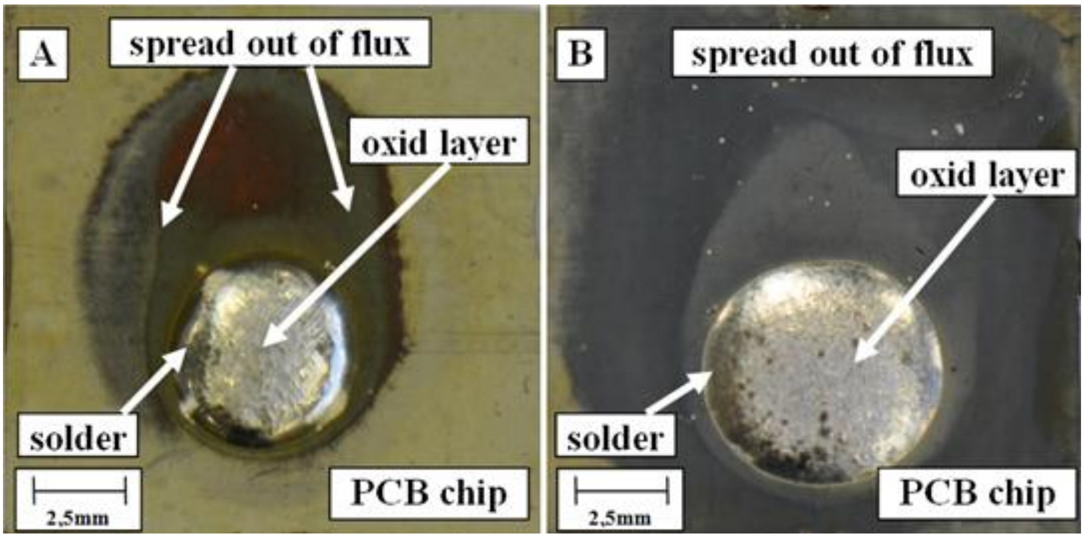

Fig. 4. Solder spread test with lead free solder alloy on PCB
(full colour version available online)

because too much tin oxide formed under air atmosphere. Another oxide layer centralized on the top of the solder, which was formed by the oxygen content of the solder paste. This oxide layer was formed under both atmospheres so the measuring conditions had no effect for the formation.

3.1. Pore formations in the solder

Porosity is a frequently problem when using solder pastes and reflow soldering. There are a certain number of publications that explained the influencing factors on pore formation [17, 18].

Porosity forms easily, because the examined solder paste normally contains 11.5 volume percentages of volatile components (e.g. flux). Flux vapour will be produced during reflow soldering due to thermal decomposition. Some gases may be entrapped between the flat surface of the printed circuit board (PCB) and the solder, and cause pore formation during solidification. The Fig. 5. shows the cross section of the solidified solder and pores. The surfaces of pores are smooth and usually bright, indicating that the porosities were formed mainly by entrapped gases [18].

3.2. Wetting angle measurements

The Fig. 6. shows the measured wetting angles of the solder pastes on PCB chips as a function of reflows by different measuring atmospheres. The effect of different atmosphere is easily definable. The measured wetting angles when using Argon atmosphere is about 12˚. This value is in the well solderable range. On the contrary the wetting angles under air atmosphere are around 24˚. This value is double

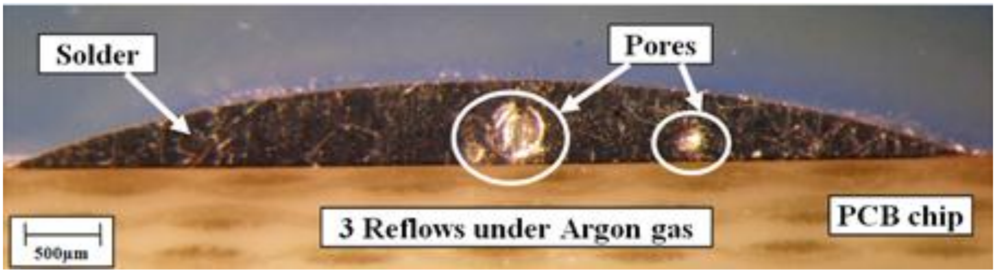

Fig. 5. Pores in the cross section of solder
(full colour version available online)

of the former results. It means that the solderability deteriorate when the solder was measured under air. The effect of increasing number of reflows increases the wetting angle values by both measuring atmospheres. The wetting angles increased from 12° to 16° when Argon atmosphere was used and increased from 24° to 28° when measured in air atmosphere. The increment of the wetting angle approximately 4° between the samples with 1 reflow and 4 reflows. The explanation of the difference between the wetting angle values is the different oxygen concentration. Well known, that the presence of oxygen deteriorates the wettability. That is why the values under air are higher than under Argon. These differences indicate an increasing thickness of the tin oxide layer.

3.3. Cross section study

To investigate the Cu/solder joints a microscopic cross-sectional study was necessary. A microscopic image of the sample is shown in Fig. 7. During heating up, the molten solder reacted with the immersion tin and the Cu layer and formed different types of intermetallic compounds at the Cu-solder interfaces. The formation of intermetallic compounds between the molten solder and substrate is the case of reactive wetting. It is well known that the occurrence of the intermetallic compounds (IMCs) between solders and substrate metals is an indication of good metallurgical bonding. A thin, continuous and uniform IMC layer is an essential requirement for good bonding [20]. However, due to their inherent brittle nature and the tendency to generate structural defects, too thick IMC layer at the solder/conductor metal interface may degrade the reliability of the solder joints. For example, a small duration of peak temperature results in an incomplete wetting and cold joint formation. On the other hand, too high peak temperature or prolonged peak temperature duration may result in the formation of a brittle joint [20]. The investigated cross sections of the samples showed that the solder paste evenly melted and wetted good the whole PCB surface. There was a continuous and uniform transitional layer between the Cu and the solder indicating that the created bonding was good.

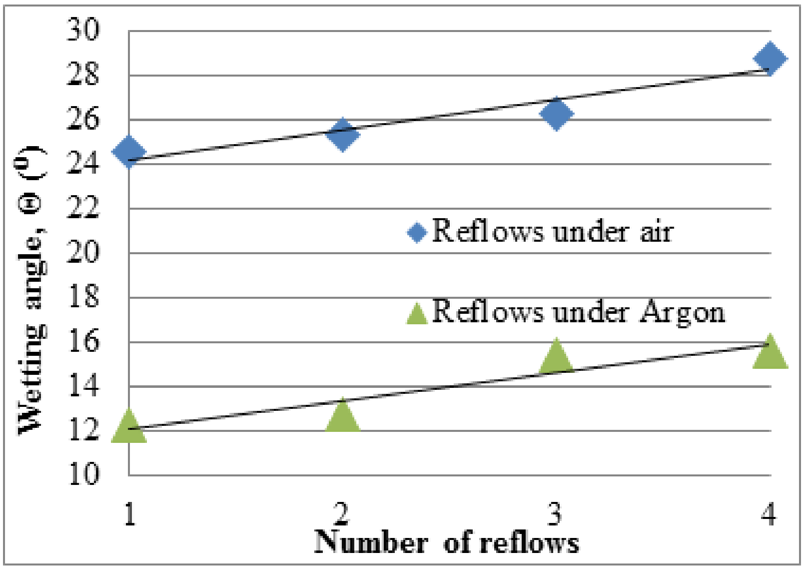

Fig. 6. Wetting angle measurements of Sn 96.5 Ag 3 Cu 0.5 alloy on PBC substrates at 523 K

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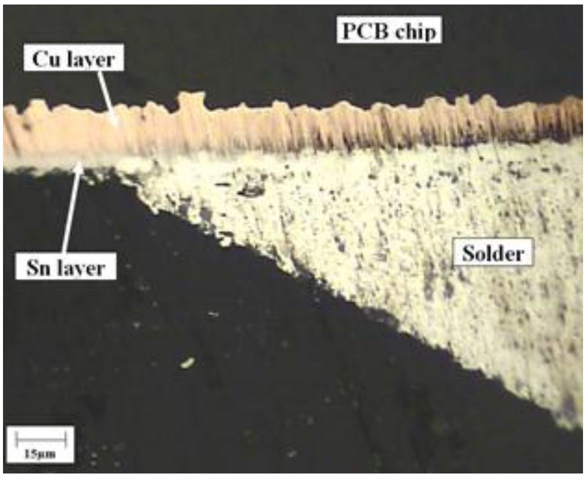

Fig. 7. The investigated solder interface
(full colour version available online)

3.4. Topography measurements

The PCB chips were scanned with an atomic force microscope to determine the surface topography after the reflows. It was expected that the wetting parameters would deteriorate when the number of reflows increasing. The increasing number of reflows increases the surface oxidation on the PCB chip surface and causes the growth of the tin oxide layer. Previous measurements are shown that at inert atmosphere the surface oxidation is less than at standard atmosphere [16]. The surface roughness measurements can refer the level of surface oxidation. The Fig. 8. shows three different topographic measurements of heat treated samples under standard atmosphere. The periodic change of surface roughness minimums and maximums show that the surface oxidation increased with the increasing reflow numbers. The difference between the extreme values decreased and it is indicating that the newly formed oxide layer fill the valleys and makes the surface smoother. The Fig. 9. shows three different topographic measurements of heat treated samples under Argon atmosphere. The sample which had one reflow under Argon atmosphere has smaller surface roughness extreme values than the sample which had one reflow under standard atmosphere. This result corresponds with the expected result which based on scientific literature [16]. The topography of the samples which had one and two reflows under Argon atmosphere have the same changes like the samples which had one and two reflows under standard atmosphere. The surface roughness extreme values of the sample which had 3 reflows under Argon atmosphere show that the surface became rougher than the samples which had one or two reflows under Argon atmosphere and not smoother. A little amount

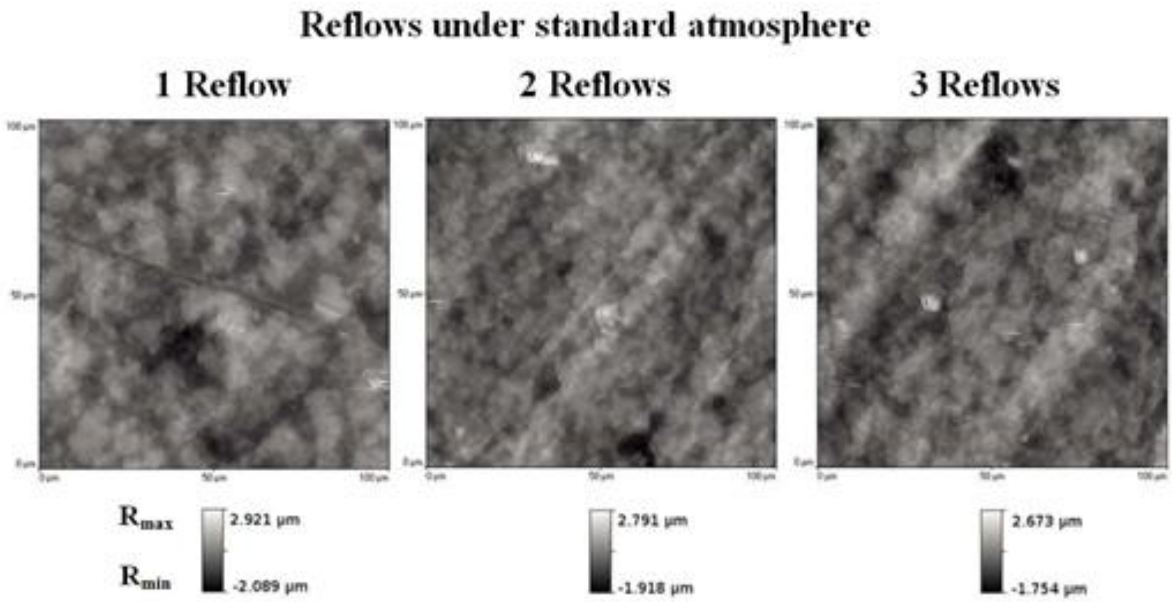

Fig. 8. Topographic pictures of heat treated samples under standard atmosphere with 1-2-3 reflows

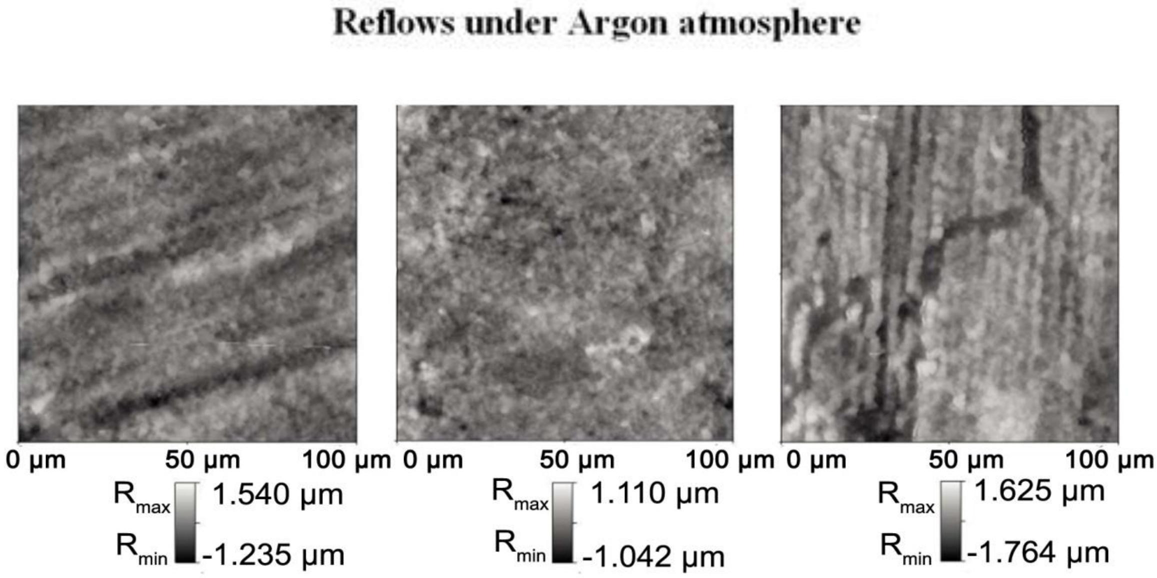

Fig. 9. Topographic pictures of heat treated samples under Argon atmosphere with 1-2-3 reflows

of air got into the chamber during the third reflow, that is the reason for the topography values are higher of the sample which had 3 reflows under Argon atmosphere.

4. Conclusions

The reflow and atmosphere dependence of the wetting angle are measured on PBC substrate for Sn 96.5 Ag 3 Cu 0.5 melts.

- It was found, that the reflow dependence of the wetting angle is remarkable by increasing the reflow numbers the wetting angle increasing approximately 4˚ both atmosphere.
- The soldering atmosphere has a huge impact on Pb free soldering, at inert gas atmosphere the wetting conditions provide an approximately 12˚ wetting angle better than at standard atmosphere.
- At inert gas atmosphere the flux of the Senju M705-GRN360-KV Lead-free Solder Paste working better and spreading out more than at standard atmosphere
- Some gases may be entrapped between the flat surface of the PCB substrate and Senju M705-GRN360-KV Lead-free Solder Paste, and may cause pore formation during solidification.
- The PCB topography measurements clearly shows that the standard atmosphere and the number of reflows increase the surface oxidation, which affect the wetting conditions too.

Acknowledgements

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