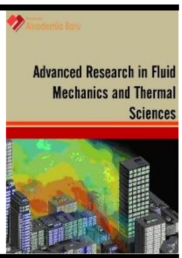
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Effect of Temperature on Solder Paste During Surface Mount Technology Printing

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ARTICLE INFO

Article history:
Received 25 April 2020
Received in revised form 5 August 2020
Accepted 10 August 2020
Available online 25 September 2020

Keywords:
Solder paste; SAC305 solder paste; surface mount technology printing; scanning electron microscope; e-waste

ABSTRACT

There are lots of companies manufacturing electronic components that have commonly used the Surface Mount Technology printing process. However, the temperature of solder paste printing on the Printed Circuit Board can influence the presence of defects in Surface Mount Technology. In this paper, the experiment called Surface Mount Technology printing is built and tested to characterize the temperature of solder pastes in order to prevent the electronic waste and rejection rate of the malfunctioning electronics due to poor soldering. The microstructures of solder paste on printed circuit board and copper substrate are inspected under Scanning Electron Microscopy. It is focused on two parameters that affect the performance of a printed circuit board, which includes the filling areas of solder paste and the distance between ball grid arrays. From the experiment and analysis results, the filling area decreases as the temperature increases during the Surface Mount Technology printing process. In short, when the temperature of SAC305 increases, the viscosity and filling areas decreases. In fact, SAC305 gave the second rank of smallest area (18.86%) and distance (43.43%) after SAC307. The average area and distance are fair enough for the solder to hold the component placement, unlike SAC307 which likely causes tombstone.

1. Introduction

Modern technology produces electronic circuits by using a method called Surface Mount Technology (SMT) in which the surface of printed circuit boards is mounted directly with components. The reflow soldering is a method used to connect components on the circuit boards. The quality of solder paste printing on the Printed Circuit Board (PCB) greatly affects the reliability and conductivity

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https://doi.org/10.37934/arfmts.75.3.99107

of SMT. The key elements of SMT consist of types of solder paste to be mounted on the printed circuit board. The lead-free solder is preferred compared to leaded solder due to the Europian Union legislation boycotting the usage of Pb solder [1]. This is because lead elements can cause serious poisoning, thus it is very unsafe for consumers. However, this rheology has likely to account for majority defects in the surface mount assembly such as bridging effect on the PCB that may cause short circuits after the installation of the components.

Secondly, the pressure and angle of the squeegee to sweep are necessary to have the best equality on thick film solder [2]. Stencil printing needed as its function to separate the solder paste and the printed circuit board to establish electrical conductivity [3]. Moreover, the addition of Ag influence the reactions during soldering between SAC solder paste and Cu substrates when the liquid solder is discharged after a long exposure time [4]. They concluded that the addition of Ag decrease the interfacial energy on liquid-Sn solder but increase the wettability of solder. The disorientation angle of the concentrated area decreases with the increasing Ag content but increases with increasing solder temperature. The higher the Ag content, the thicker the intermetallic compound layer.

Otherwise, the solder paste temperature is believed to influence the SMT printing. A very high temperature of solder paste will develop paste slump and solder bead formation whereas a very low temperature of solder paste may cause the solder paste too thick to produce a good print definition. Clog stencil apertures is likely to occur and result in open joints. Generally, as the temperature increases, the shear strength and elastic modulus decrease [5]. Based on the experiment results, the chemical reaction and diffusivity are increased as the temperature increases [6]. The poor soldering process causes defects on the PCB. The presence of defects in PCB such as solder bump, bridging effect, tombstoning and poor wetting are the common failures in Surface Mount Technology. Those PCBs with defects are most often rejected and are more likely to turn into electronic waste (e-waste). E-waste consists of a multitude of components, some containing toxic substances which, if not handled properly, can have an adverse effect on human health and the environment [7-9]. A cooling system is introduced to control the SMT temperature [10]. Therefore, the temperature of the solder pastes needs to be characterized.

Back then, many researchers have shown interest in the effect of temperature on solder pastes. The sensitivity of solder pastes viscosity towards various temperatures has been investigated in [11]. Numerous laboratory experiments and simulations of the behavior of solder paste at different range of temperatures such as thermal cycling test on the assembled of SAC PBGA by using SAC [12], the properties of mechanical strength of several solder pastes over certain temperature [5] and the effect of joint size on the growth of IMC thickness during isothermal aging at temperatures [13]. The dwell times and temperature extremes give a great influence on the lead-free solders [14]. An ideal temperature is a crucial setting to have a better solder performance of the PCB in terms of shapes, area and time [15]. This paper presents the effect of the temperature of SAC305 solder paste during the SMT printing process. The temperature of the surrounding may affect the appearance and efficiency of paste deposition thus the SAC305 solder paste will be set as the benchmark of reference for SMT printing experiment.

In section 2, the experimental procedures to investigate the effect of temperature during the SMT printing process are presented. Then, the data collections of different solder pastes that have been analyzed and recorded through SEM are discussed in section 3. Furthermore, the result of SMT printing is analyzed by measuring the filling area. Lastly, section 4 outlines the conclusions.

2. Methodology

The temperature variation experiment is conducted during SMT printing. This study focused on the effect of viscosity of solder paste along with the filling areas at high temperatures. The procedure is quite crucial because the solder needs to handle with care. Scanning Electron Microscope (SEM) is used to identify any irregularities of microstructure on the printed circuit board after stencil printing. The result of SMT printing is analyzed by measuring the filling area. ImageJ software is used to calculate the results. Figure 1 shows the flow process of SMT printing.

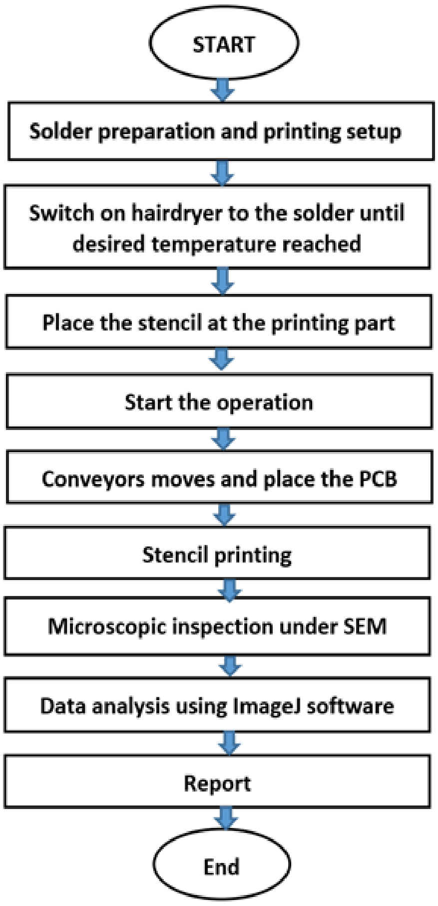

Fig. 1. Flow chart of the SMT printing

2.1 SMT Printing Process

The PCB must be in the same size and pattern as the stencil for the printing to be successful. Figure 2 shows the type of PCB for the printing experiment and the area of inspection under the microscope.

SAC305 solder paste is used as a constant variable for this experiment. This type of solder paste is a homogenous and stable suspension of solder alloy particles. It is stored in the refrigerator and must be taken out 1-2 hours before running an experiment. The solder paste must be gently stirred around 1 minute to ensure the mixture is even and lighter. Then, apply uniform thickness of solder paste on stencil by using a stick as shown in Figure 3.

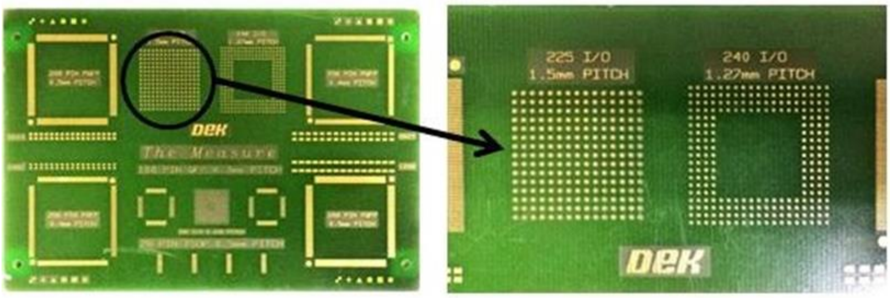

Fig. 2. PCB used for printing and the area of inspection

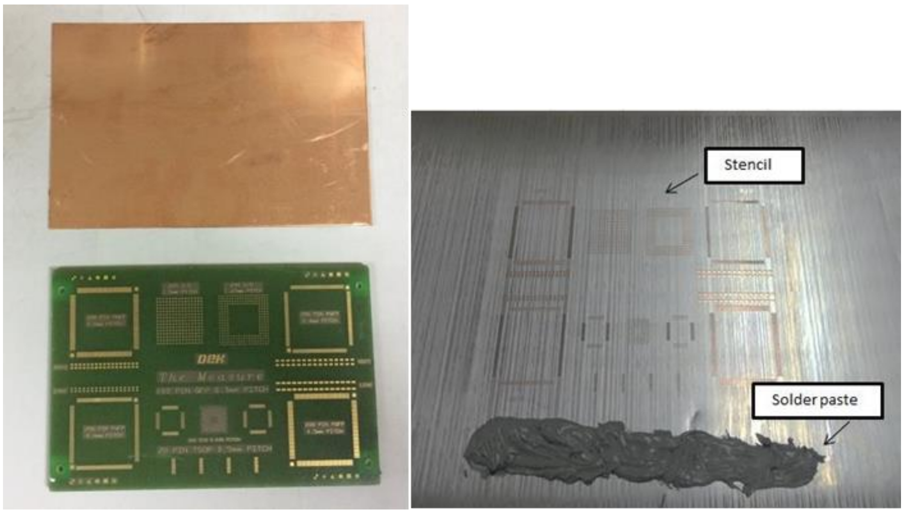

Fig. 3. Copperplate with the same size as PCB for reflow and position of solder paste on the stencil

The experiment is conducted using the printing model DEK265 as shown in Figure 4 at SMT laboratory. Firstly, the moderate amount of solder paste is carefully spread onto the stencil and placed on the conveyor. The parameters as listed in Table 1 are set in the computer and the machine starts to operate.

Fig. 4. Printing Model DEK 265

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 75, Issue 3 (2020) 99-107

Table 1
Printing parameters

Printing machine	DEK 265
Squeegee type and angle of attack	Metal, 60 degree 
Stencil thickness and material	150µm and stainless steel
Squeegee speed	60 mm/s
Separation speed	1 mm/s
Squeegee loading (pressure)	7 kg

The printing only takes around 30 seconds and the PCB is taken out. Then, the PCB is sent to the microscopic lab for further inspection under SEM. After completing the experiment, the PCB is cleaned with dry cloth and acetone. As a precautionary step, wearing gloves is necessary while handling with acetone and solder paste. For temperature variation, a hairdryer releasing heat is injected towards the solder paste until the desired temperature obtained measured by thermocouple as shown in Figure 5. The temperature ranges are 27°C to 50°C.

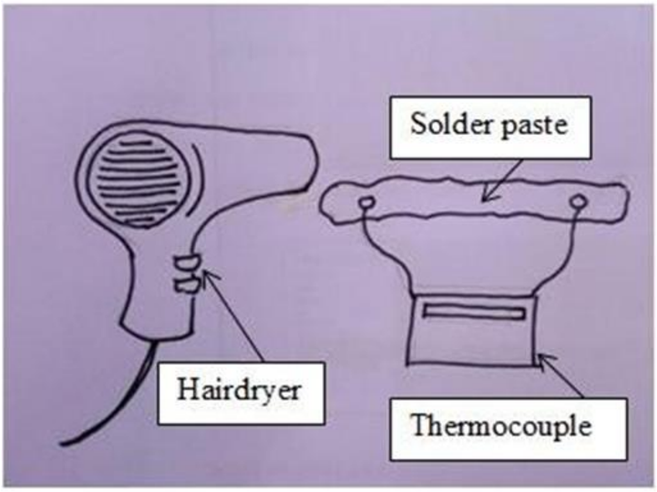

Fig. 5. Process of releasing heat to the solder paste

Scanning Electron Microscope (SEM) is used to identify any irregularities of microstructure on the printed circuit board after stencil printing. It can focus on the topography and composition of the soldering. The filling areas of solder pastes and the distance between ball grid arrays (BGA) are calculated by using ImageJ software. ImageJ is an open platform image processing program designed for scientific multidimensional images.

3. Results

SMT printing experiment is conducted using SAC305. This is because SAC305 is widely used for packaging electronic components. Figure 6 shows the SEM images at various temperatures after printing.

Based on the SEM images as shown in Figure 6, the solder paste fills the BGA perfectly at a temperature of 23°C, 33°C and 43°C. As the temperature increased to 53°C, the filling areas started to reduce and becoming lesser when it reached 73°C as described in Table 2. This defect is called poor wetting of solder paste. The poor wetting of solder is shown as Figure 7 where the solder is not completely filling the BGA.

Temperature (°C) | SEM images after SMT printing *Procedure for calculating the filling areas*

A B C

23
33
43
53
63
73

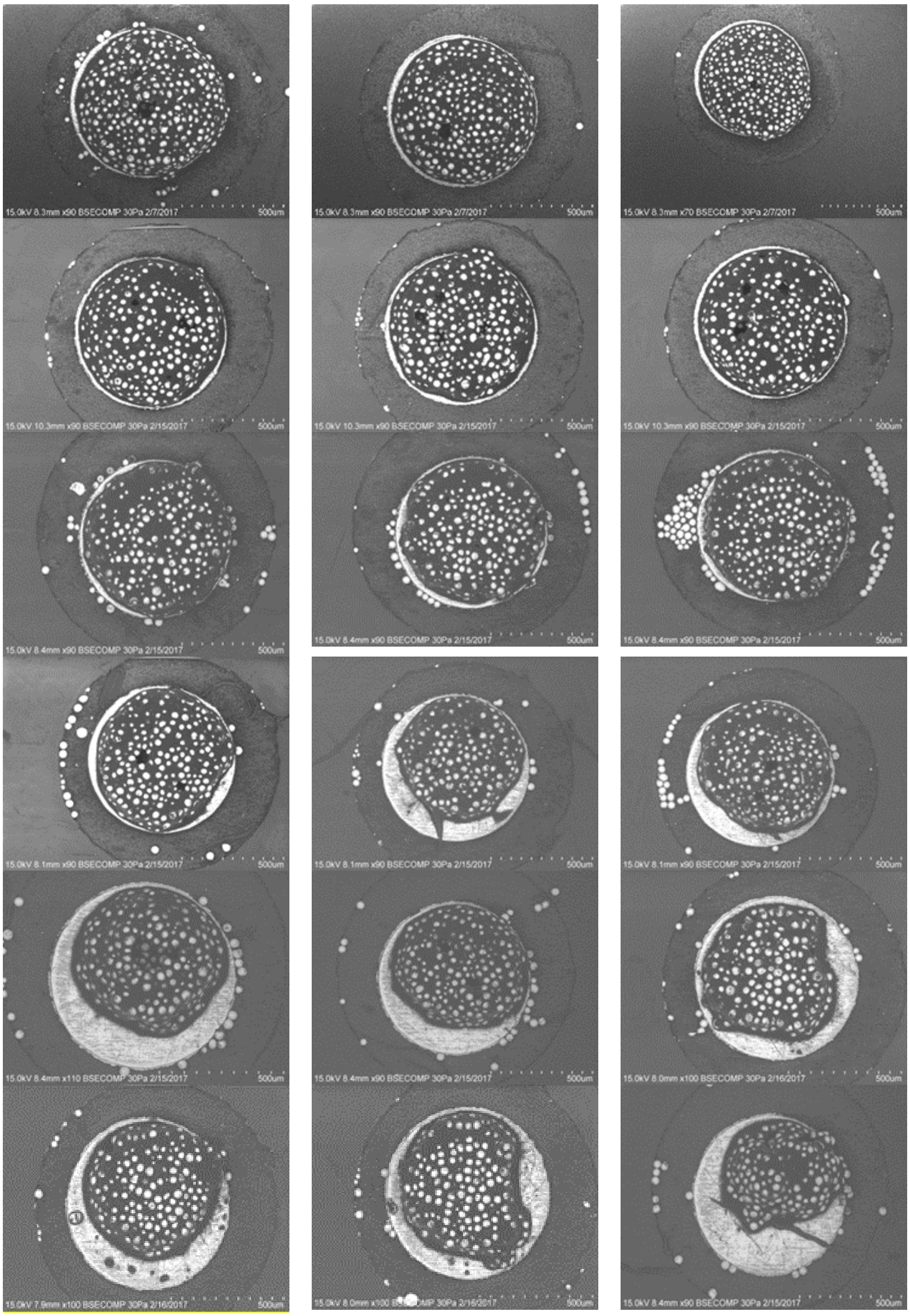

Fig. 6. SEM images at various temperatures after printing. (A=filling up apertures with solder paste, B=contact point of solder paste and substrate, C= the end of the printing process)

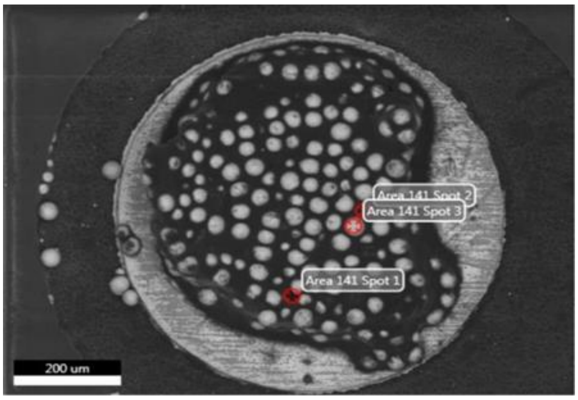

Fig. 7. Poor wetting of the solder

Table 2
Area calculated at a temperature of 53°C, 63°C and 73°C

Temperature	Area calculated (mm)	Average area	Percentage difference (%)	Temperature	Area calculated (mm)
53	0.4427	0.3687	0.4087	53	0.4427
63	0.342	0.3857	0.3757	63	0.342
73	0.3537	0.3837	0.2867	73	0.3537

When the temperature of the solder increases, the viscosity decreases. Typical solder paste has the viscosity range from 10 to 1000 Pa.s. The viscosity is introduced by [16] Isaac Newton with its basic law of viscosimetry. It describes the flow behavior of an ideal liquid. From this experiment results, the first three temperatures which are 23°C, 33°C and 43°C had done a good job of maintaining the viscosity of the solder and performed good wetting until the end whereas the next three temperatures are failed to do so. Other than that, the solder is oxidized at high temperature is also the main cause of poor wetting. Temperature is an important parameter to wetting and spreading of liquid solder. Higher temperatures promote greater atomic activity thus increase reaction rates exponentially and the fluidity of the liquid solder. The formation of the intermetallic compound of certain alloy compositions is also determined by temperature. The higher the temperature, the higher the percentage of oxygen.

Table 3 shows the EDX analysis found oxygen element in solder at 73°C in a different spot. This EDX analysis proved that there are oxygen element existed in the solder at temperature 73°C. Oxidation is the result of oxygen and moisture reacting with the solder alloys during printing [17,18]. To prevent this matter from happening, SMT printing should be done under room temperature (27°C). Through this experiment, to maintain the quality of the printing process, the maximum temperature of the solder paste is 43°C. In a real working environment of factories which is always exposed to high temperature because of the releasing heat from other machinery, SMT printing can still be running and have the good outcomes but the temperature should be no more than 43°C. The increase of temperature is damaging the thixotropic agent in the solder medium thus it failed to maintain a good slump until the end of the printing process [19].

Table 3
EDX analysis found oxygen element in solder at 73°C

Spot (Refer to Figure 7)	1	2	3
Oxygen (weight %)	8.46	7.48	1.36

4. Conclusions

In this study, the experiment is conducted to investigate the effect of temperature of SAC305 solder paste during the SMT printing process. The temperature variation is 23°C to 73°C. This study focused on the effect of viscosity of solder paste along with the filling areas at high temperatures. The PCB is inspected under SEM and the filling areas of the BGA are calculated for each temperature. Based on the experiment results, when the temperature of SAC305 increases, the viscosity and filling areas decreases. As a conclusion, the most favorable and optimize temperature for SAC305 during the SMT printing process is 23°C to 33°C because the solder performed good wetting and fits perfectly in the BGA.

Acknowledgment
The authors would like to extend their appreciation to University Sains Malaysia (Research University Grant No. 1001/PMEKANIK/8014072 and Bridging Grant No. 304.PMEKANIK.6316103) for providing financial and technical support for this research.

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