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Influence of squeegee impact on stencil printing process: CFD approach

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Abstract. This work has been conducted to predict the real time observation of solder paste Sn96.5Ag3.0Cu0.5 (SAC305) filling process into stencil apertures as well as print quality in stencil printing by using Computational Fluid Dynamics (CFD) approach. A 3-Dimensional stencil printing model was developed and simulated in FLUENT by using different squeegee parameters which are the angle and printing speed. An experimental work was performed to be compared with part of the simulation results in term of print quality for validation purpose. It is found that squeegee angle 60° to 80° has potential to obtain good print quality of solder paste. In addition, print speed range between 35 mm/s to 95 mm/s also can be the good print speed option to achieve good print quality in stencil printing process. Finally, the maximum pressure distribution of solder paste also changes substantially as the squeegee travel further with respect to different values of tested parameters.

1 Introduction

Stencil printing is a process of depositing a viscous fluid which is solder paste onto a bare substrate such as printed circuit board (PCB) through the aperture openings of a stencil. It is originally adapted from the screen-printing process. This process is one of the widely used methods of soldering in Surface Mount Technology (SMT) today as a solution for higher pin count and fine pitch size. This is due to the high requirement of smaller size, lighter weight, and high-performance PCB in electronic packaging. The use of stencil printing for the deposition of conductive interconnects was developed during the late 1960s as companies looked to increase the densities of the products, improve assembly time and drive down production costs. This process was termed in surface mount assembly (SMA) and is currently used today in at least 70% of electronic packaging. The stencil printing is commonly known in SMA as the largest contributor to soldering defect by 60% averagely [1].

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In stencil printing, a thin layer of stainless-steel foil is placed onto a PCB. It has laser cut configuration of apertures that will determine the basic layout of the solder paste deposits on the board. The stencil will be aligned on the top surface of the board and brought in close to or in direct contact with the surface. A squeegee is used to transfer solder paste inside the stencil apertures to deposit a required amount of solder paste on pad of the substrate [2]. For metal blade squeegee, the angle of 60° is the most suitable angle to handle the ultra-fine and larger pitch size because it offers consistency of print and the closest print volume to the designed volume of solder paste. It is also mentioned that the volume of solder paste deposits is proportional to the paste pressure and the highest region of the pressure is at the edge of squeegee [3]. The squeegee provides hydrodynamic pressures in the roll of solder paste that assists the filling of paste inside the apertures by shearing as it moves over the stencil [4]. Once the squeegee is fully swiped the solder paste through the apertures, the stencil is removed out from the board leaving the small volumes of solder paste in the filled apertures on the board as deposits. Fig. 1 below shows the schematic diagram of stencil printing process [10].

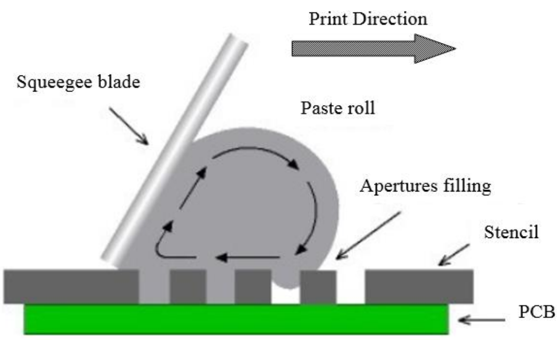

Fig. 1. Schematic diagram of stencil printing process.

One of the remarkable capabilities of stencil printing in SMT packaging is it can place millions of solder paste deposits onto a substrate such as PCB by one print stroke only. In addition, the process can be repeated thousands of times with the same stencil onto the further substrates with good consistency of soldering performance. Thus, it reduces soldering time as well as offers higher process output. More advantages about this process are it does not require large capital investment or highly skilled operators. The combination of the cost advantage with the capability to handle wide range of materials makes it in one of the top list of best option for high volume applications. Furthermore, the compatibility of the method with pre-existing equipment of printing and capability to produce solder bumps within all range of compositional spectrum such as lead-free solders have increased its reputational in SMT packaging [2].

2 Literature Review

Stencil printing is one of the best method for high volume application where the time and process output are concerned. The need of high-performance PCB with smaller size, lighter weight, and higher pin count has contribute to the development of fine pitch and ultra-fine pitch for stencil printing applications [3]. There is various study has been conducted through the years in order to improve the performance of stencil printing in SMT technology

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numerically and experimentally which is the printing quality. Numerical studies have been performed to simulate stencil printing process by using Computational Fluid Dynamics (CFD) methods at macroscopic and microscopic scales by using 2-D model that involves Finite Volume Method (FVM), Lattice-Boltzmann Method (LBM), and Discrete Element Method (EDM). It is found that the volume fraction of solder paste is far lower than normal due to the unrealistic representation of spherical particles by 2-D cylinder that cause artificial blockage of fluid passage at greater volume fraction [12].

Neural network approach model has been proposed to solve the fine pitch printing quality issue of the non-linear behavior stencil printing through the volume prediction of solder paste deposits. The proposed approach is determined to be effective to predict and control the printing quality in surface mount assembly such as paste volume deposited on PCB pad with small prediction errors which is less than 7% [13]. In stencil printing, the stencil experiences pressure exerted by the squeegee on its surface that might affect the behavior of the structure. The deformation behavior of stencil which can affect printing quality has been investigated by using Finite Element Method (FEM) associated with the uneven surface of Printed Wiring Circuit (PWB). Greater surface level differences between the stencil and PWB affect the stencil bending behavior that can lead to excessive solder paste deposits and solder bridges issue [5].

Furthermore, stencil printing process also has been modeled by using Finite Volume Method (FVM) to study the effect of two different characteristics of solder paste on the simulation results. The flow field and pressure distribution of the solder paste along the stencil surface are determined to be compared with non-Newtonian and Newtonian cases. The pressure distribution of the non-Newtonian case is found to be differed from the Newtonian case substantially which means modeling the stencil printing process with Newtonian solder paste properties causes serious mistakes since solder paste is known to be a non-Newtonian fluid [14]. Moreover, the effect of squeegee speed and solder paste density variation on stencil printing process has been studied by using CFD approach through the flow characteristic of solder paste simulation. Based on the study, increment of squeegee speed can cause the shear stress to increase proportional to the increment of solder paste's shear strain [15].

3 Methodology

A stencil printing model is created in 3-Dimensional by using ANSYS Design Modeler that consists of two significant components for the simulation which are aperture bodies and printing body as explained below. In this case, stencil is neglected because the stencil thickness is too thin. However, the thickness of the stencil is counted in the model preparation as the thickness of aperture bodies. Aperture bodies are drawn based on the exact dimension measured by using Alicona Infinite Focus microscope to form a complete stencil printing model as shown in Fig. 2 and Fig. 3. Fig. 4 shows the modeling geometry of the aperture body.

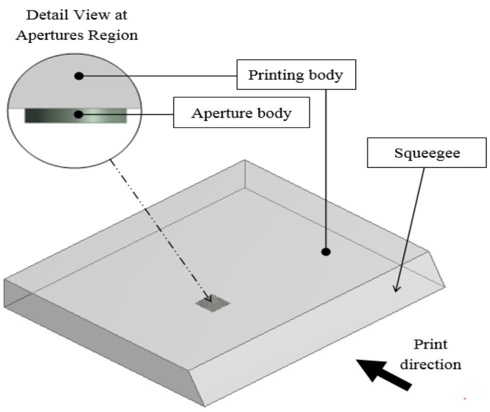

Fig. 2. 3-Dimensional stencil printing model.

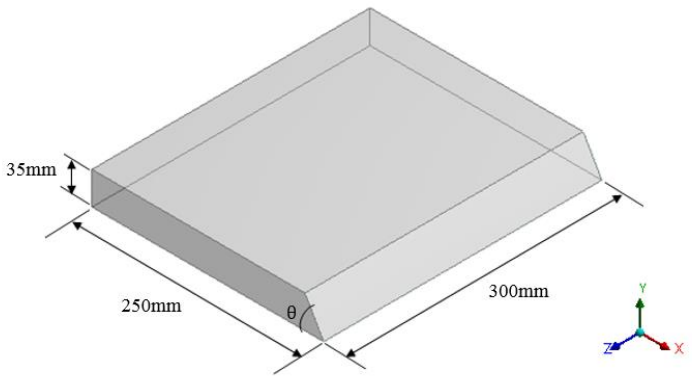

Fig. 3. Printing body dimension of stencil printing model.

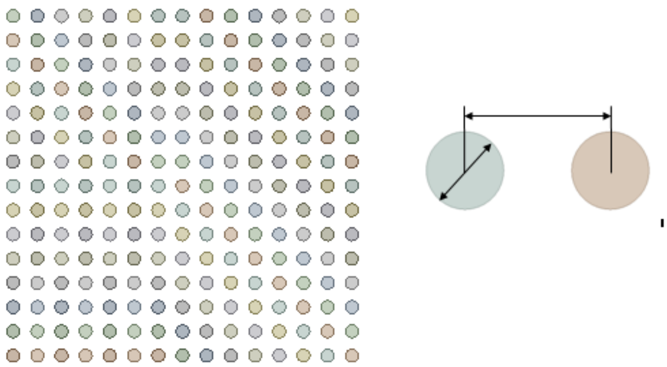

Fig. 4. Design of aperture bodies and dimension.

The thickness of the aperture bodies is the same due to the adoption of stencil thickness that are assumed as constant and perfect (thickness = 0.1 mm). The printing body is made to have a slanted part as the squeegee where the angle is the variable parameter to be tested in the simulation. The angles tested in the simulation are 50°, 60°, 70°, and 80°. The specification of the selected apertures design is 225 I/O; 1.5 mm PITCH. The design has 225 individual aperture bodies by pitch distance 1.5mm to each other. All the fluid bodies are meshed with structured elements consists of hexahedral and wedges for both aperture and printing bodies as shown in Fig. 5. For the printing body, the bottom surface is declared as fluid interface while others are declared as wall. The walls of the printing body are further used in dynamic mesh setting. The interior of the printing body is the zone where solder paste and air are placed together inside it. Furthermore, the top surface of the aperture bodies is declared as fluid interface while others are set as wall. The aperture bodies also have interior zone where fluid from printing body is filled in it. The surface contact of fluid interface between printing and aperture bodies formed fluid connection between the bodies in simulation.

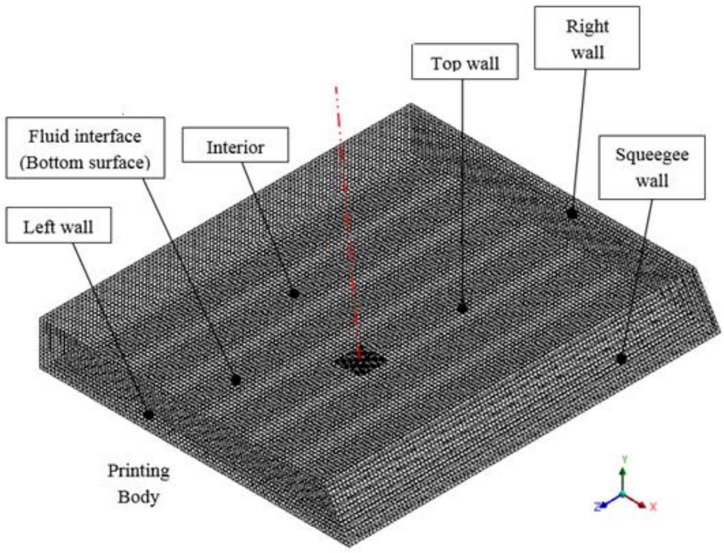

Fig. 5. FLUENT structured meshed model and boundary conditions.

4 Results and Discussions

From Fig. 6, it is shown that the experimental solder deposits coverage area at all comparison locations are greater than simulation at 100% filling stage; squeegee print speed 35mm/s and angle 60°. This indicates the area of paste deposition on the copper plate is bigger than the size of the apertures. In addition, solder deposits coverage area in simulation are similar at all locations which are fully covered the apertures. The highest percentage difference of coverage area is at location 3 by 7.62% while the lowest is at location 1, 2.65% as shown in Fig. 16. This is due to the experimental procedure that has uncontrolled parameters such as printing speed due to manual printing process compared to the simulation. However, the percentage differences for all locations are within 10%. Thus, simulation results generated by FLUENT in the prediction of print quality in stencil printing it is fairly acceptable.

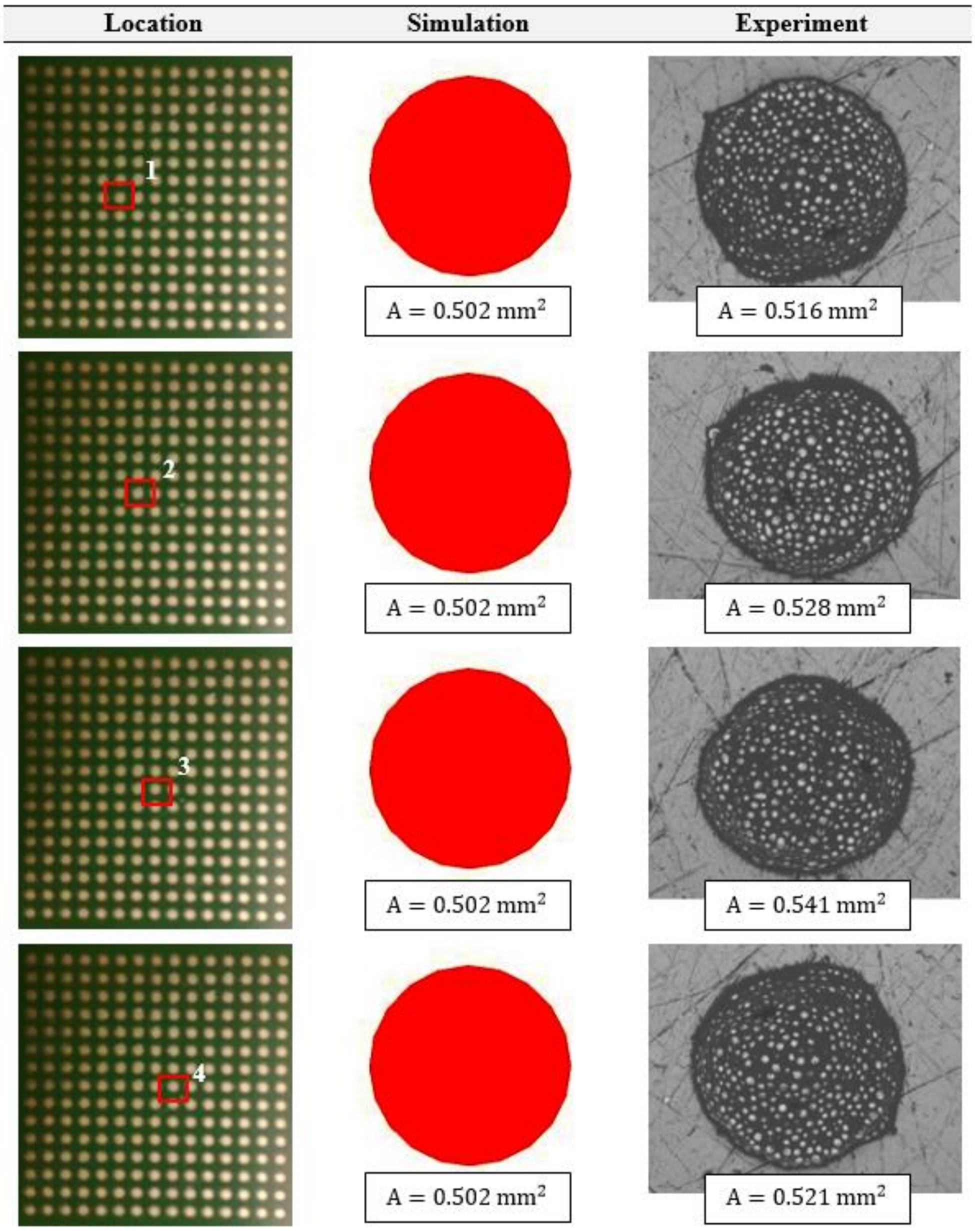

Fig. 6. Observation of solder deposits coverage area, A at different locations.

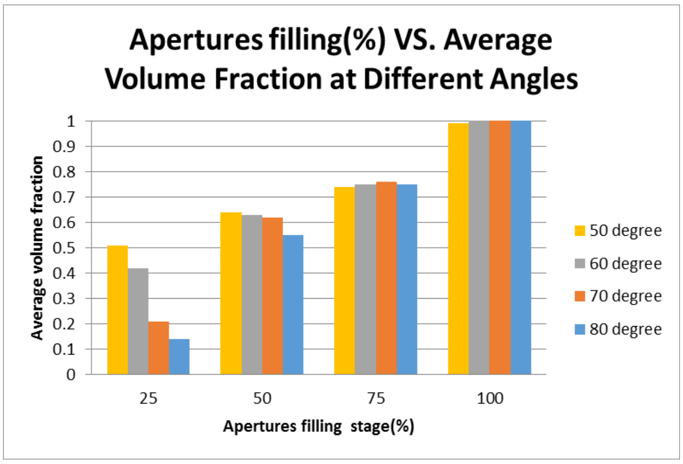

Fig. 7. Average volume fraction (volume-weighted average based) over apertures filling stages at different squeegee angles, θ.

The filling pattern of the solder paste into the aperture is observed by stages with respect to the different angle of squeegee at constant squeegee print speed, 35 mm/s. The average volume fraction(volume-weighted average based) of solder paste inside the aperture through filling stages is shown in Fig. 7. At 25 % filling stage of apertures, the filling pattern between the squeegee angles shows significant differences. 50° squeegee angle has the highest volume fraction while 80° squeegee angle has the lowest average volume fraction. The trend of the filling continues to 50% filling stage but started to have approximately the same average volume fraction at 75%. All squeegee angles achieved average volume fraction at 1 which mean all apertures were fully filled with solder paste at 100% filling stage except for 50° squeegee angle that has a slight drop of average volume fraction due to presence of unfilling aperture holes.

5 Conclusion

The 3-Dimensional stencil printing modeling by using Computational Fluid Dynamics (CFD) approach shows good prediction of stencil printing performance. The approach gives real time observation of printing quality which is difficult to obtain by experimental work during printing process regarding to squeegee print speed and angle. The filling process of solder paste into the apertures shows significant difference filling pattern across the apertures at all filling stages for whole squeegee angles at constant speed 35 mm/s. However, all squeegee angles were successfully filled all the apertures with solder paste except 50° squeegee angle. Thus, operating stencil printing process by using squeegee angle 60° to 80° is possible to achieve good solder paste print quality.

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