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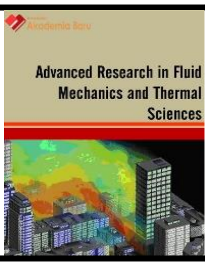

# SAC105 Stencil Printing Process using Cross Viscosity Model

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**ABSTRACT**

The current study shows the used of rheological measurement to get lead-free solder paste SAC105 type 3 viscosity data to be used in numerical measurement. A parallel-plate viscometer is used for the rheological measurement. From the measurement data, numerical simulation investigation is accomplished to study the effect of stencil thickness on SAC105. Cross model is used as the viscosity model for the SAC105. The numerical simulations using ANSYS Fluent with Finite Volume Method (FVM) are carried out at five different stencil thickness. The results show that the volume difference between aperture volume and SAC105 volume are low at 0.0762mm and 0.1016mm (14.6% and 13.9 respectively) and the maximum volume difference is at 0.1778mm (45.4%).

***Keywords:***
SAC105, Rheology, Stencil Printing, SMT, Lead-free Solder Paste

## 1. Introduction

SAC105 is one of the lead-free solder paste that is used in the industry. Mainly used for automotive and mobile industry. The characteristic of the solder that is ductile made SAC105 is suitable for vibration situation and application. SAC105 usually being apply to PCB by Stencil Printing Process. Stencil printing process is where the solder paste is applied to the PCB using a squeegee which has a certain angle. The squeegee then move with a certain speed to swipe the solder paste. The solder paste that being swipe will fill the aperture on the stencil and eventually deposited on the solder pad of the PCB.

Solder paste is a Non-Newtonian, shear-thinning and thixotropic fluid Kravick *et al.,* [1] where the viscosity depends on the shear stress applied on it. Rheological measurement is one of the important thing to be done. The viscosity data is needed for the simulation. Various measurement

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methods have been done by the previous researcher. Zhang *et al.,* [2] used a parallel-plate rheometer for lead-free solder powders (Sn/Ag/Cu) to investigate the dependence of viscosities on the particle size distribution. Parallel plate with the diameter of 25mm and gap of 500micron is chosen. Amalu *et al.,* [3] characterized of three different Pb-free solder pastes for the application of ultra-fine pitch assembly. For this study, shear rate range of 0.001–10 s are used for the viscosity test. Dusek *et al.,* [4] used a cone-plate with a diameter of 24mm and an angle of 1.565. SAC305, SAC405 and Sn62Pb36Ag2.

Min-Jung Son *et al.,* [5] used lead-free solder pastes blended with particles of two different sizes (microparticles and nanoparticles) with the aims to use it for roll-offset (RO) printing for fabrication of solder bumparrays. Rotational rheometer (HAAKE MARS III, Thermo Scientific, Germany) is used to measure the rheological behaviors of Sn–Ag–Cu solder pastes using a cone-and-plate geometry. 1° degree cone angle is used. The diameters and gap width of the cone and plate are 60 mm and 0.052 mm, respectively. Malik *et al.,* [6] study the rheological behaviours of four different lead-free solder paste formulations used for flip-chip assembly applications. The solder paste is formulate based on no-clean flux composition, with different alloy composition, particle size and metal content. The correlation of rheological behaviors with the printing performance also being tested with the series of printing tests. A serrated parallel-plate geometry with a diameter of 20 mm and a gap of 500 mm is chosen.

Simulation works also have been carried out by previous researchers to study Stencil Printing Process. Durairaj *et al.,* [7] used 2-Dimensional Computational Fluid Dynamic (CFD) to compare the flow behavior between lead and lead-free solder paste. Yang *et al.,* [8] helped to solve the fine pitch printing quality issue of the non-linear behaviour stencil printing by proposing a Neural Network approach model. This approach predicts the volume of solder paste deposits. The error of the prediction of volume deposited is less than 7%. This approach shown an effective way by how to predict and control the printing quality in Surface Mount Assembly.

Rusdi *et al.,* [9] used VOF method to simulate SAC387 in stencil printing process. FVM software is used to study the flow characteristic of SAC387 into 5 different size of apertures during stencil printing process. VOF technique is used to track the existence of SAC387 in aperture. A CFD investigation had been done by Thakur *et al.,* [10] for the affecting factors of stencil printing process. The investigation focused on Sn3.5Ag solder paste. CFD approach had been used by Manessis *et al.,* [11] to study the effect of squeegee speed variation and different density solder paste.

Solder paste printing using stencil printing process is commonly used in surface mount technology although it is the main source of the majority of defects in the final assembly [3]. The used of experimental method will cause a lot on cost and time. Alternative method of using numerical simulation is used in this paper. Previous research does not focus on stencil printing for SAC105. This paper focus on the SAC105 printing process at different aperture thickness. Numerical method is a promising tool to help engineers and scientists to evaluate the capability of solder paste in the stencil printing process. Viscosity test helps to give solder paste viscosity data for simulation purpose.

## 2. Methodology

### *2.1 Rheology Test*

SAC105 Type 3 is used in this research. The sample than is tested using Anton Parr Viscometer to gain the viscosity versus shear rate data. From this data we get the cross model parameter for numerical simulation Table 1. The test use Parallel Plate where the solder paste sample is placed between the parallel plates. Top parallel plate rotate while the bottom parallel plate are fixed (Figure

1). The viscosity result is taken at shear rate in the range of 0.0005s$^{-1}$ to 10s$^{-1}$ [6]. The diameter of the top plate is 24.985mm and the gap between two parallel plates is 0.5mm.

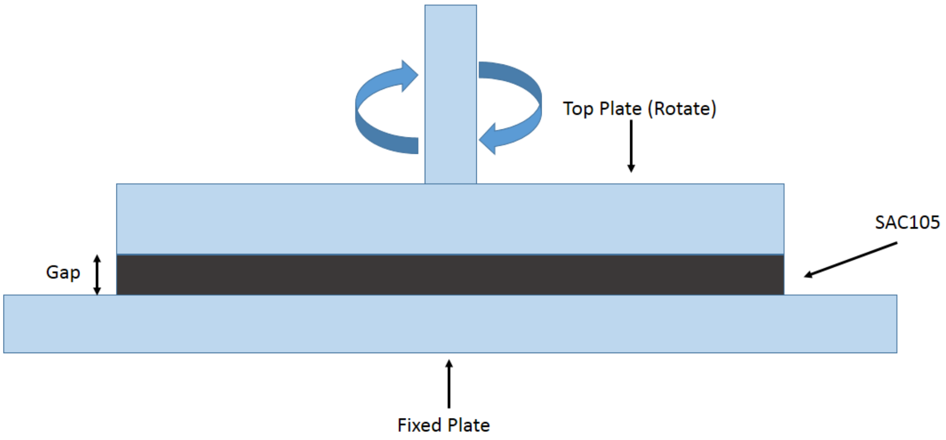

**Fig. 1.** Rheology test schematic diagram

### *2.2 Numerical Simulation*

ANSYS Fluent 17 is used as numerical simulation software. ANSYS FLUENT is a CFD software that use Finite Volume Method to simulate the stencil printing process. This study use Navier–Stokes approach where the process of SAC105 swipe into the stencil aperture can be described by the governing equations of conservations of mass, momentum and energy. The angle of squeegee is fixed at 60° and the squeegee moved at a constant speed of 35mm/s.

### *2.3 Viscosity Model - Cross Model*

Cross model is a most appropriate model to describe the rheological behaviour in stencil printing process. The description of the SAC105 is assumed as Generalized Newtonian Fluid by using the Cross model with Arrhenius temperature dependence.

$$\eta(T,\dot{\gamma}) = \frac{\eta_0(T)}{1+\left(\frac{\eta_0\dot{\gamma}}{\tau^*}\right)^{1-n}} \tag{1}$$

with

$$\eta_0(T) = B\exp\left(\frac{T_b}{T}\right) \tag{2}$$

*B* is an exponential-fitted constant, $T_b$ is a temperature-fitted constant, *n* is the power law index, $\eta_0$ is the zero shear viscosity and $\tau^*$ is the parameter that describes the transition region between the zero shear rate and power law region of the viscosity curve.

### *2.4 Volume of Fluid (VOF) and Boundary Conditions*

The numerical simulation is a multiphase simulation where SAC105 and air are defined as two distinct phases. VOF tracked the filling of the SAC105 over time. The function of VOF technique is for free surface locating and tracking [12], [13].The VOF scheme is to locate and evolve the distribution of the liquid phase by assigning for each cell in the computational grid a scalar ($f$) which specifies the fraction of the cell's volume occupied by liquid [14][15]. Thus, when the cell contains only SAC105, $f$ will equal to 1 ($f = 1$), in cells which are void of SAC105 (or air) the $f$ will equal to zero ($f = 0$) and when the value is between 0 and 1 ($0 < f < 1$) it is “interface” cells or referred as the SAC105 front. The following transport equation governed the equation of melt front over time:

$$\frac{dF}{dt} = \frac{\partial F}{\partial t} + \nabla \cdot (uf) = 0 \tag{3}$$

Figure 2 depicts the boundary conditions defined on the 3D model.

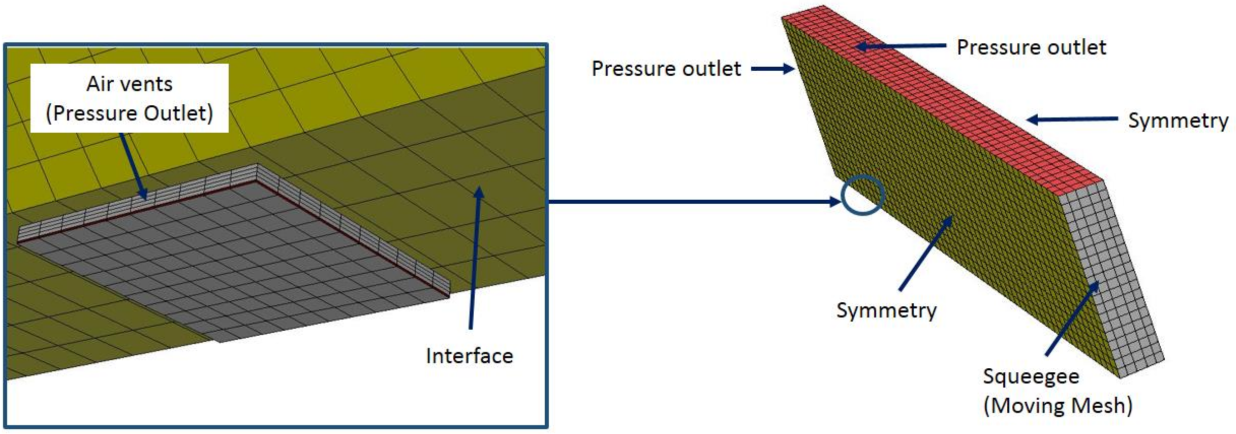

**Fig. 2.** Numerical simulation boundary conditions and meshing

## 3. Results

### *3.1 Rheological Measurement*

From the experimental measurement (Figure 3), SAC105 shows Non-Newtonian characteristics of fluid. It also shows that shear thinning properties because of the viscosity decrease when the fluid is experienced the shear force [1]. The rheology data from the rheological measurement is used by the numerical simulation. The Cross model value of SAC105 is inserted to the numerical simulation material properties (Table 1).

**Table 1**
The values of Cross model parameter for SAC105

| Solder Paste | $\eta_o$[Pa s] | t* [Pa] | n [-] | l [s] | $r^2$ [-] |
|---|---|---|---|---|---|
| SAC105 | 1.65E+04 | 1.01E+04 | 7.35E-01 | 1.64E+00 | 0.984 |

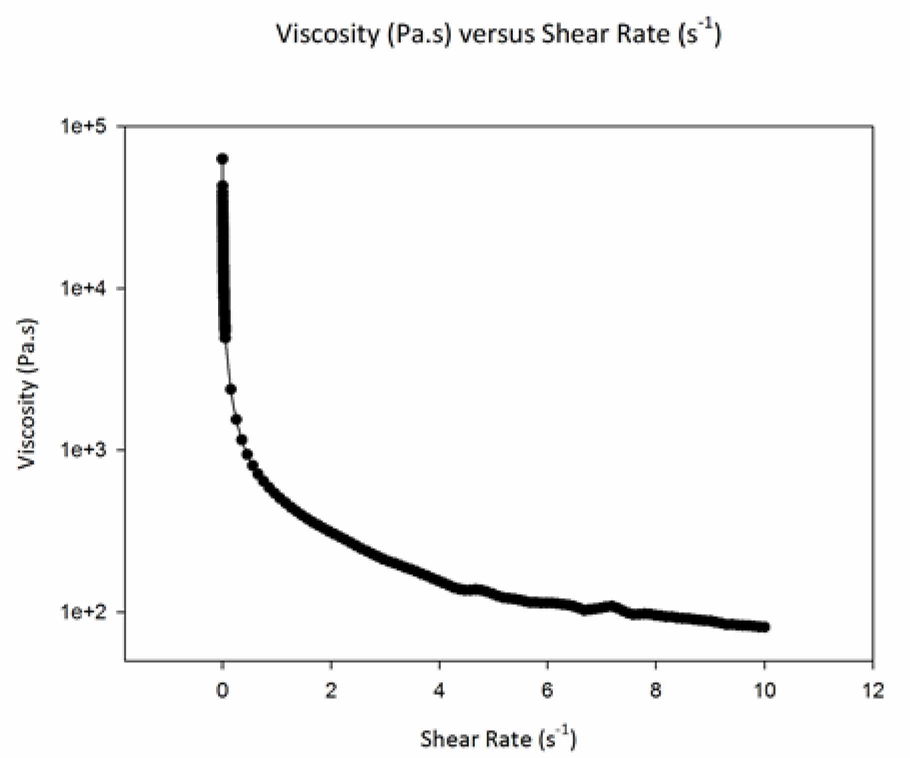

**Fig. 3.** Experimental measurement of Viscosity versus Shear Rate for SAC105

### *3.2 The Effect of Stencil Thickness*

In this study, five different stencil thickness is studied. The opening of the aperture is remained constant at 2.54mm × 2.54mm. The test configuration for this simulation is in Table 2. To fill 100% the solder paste volume must be same as aperture volume (solder paste fully occupied aperture).

**Table 2**
The values stencil thickness and aperture volume

| Stencil Thickness (mm) | Aperture Volume (mm$^3$) |
|---|---|
| 0.0762 | 0.4197 |
| 0.1016 | 0.5642 |
| 0.1270 | 0.6678 |
| 0.1524 | 0.7138 |
| 0.1778 | 0.6266 |

Figure 4 shows the volume of solder paste at different stencil thickness with the aperture volume. The aperture volume is the targeted volume that solder paste must achieve to get 0% of volume difference (fully occupied). The results show that when we increase the thickness, the solder paste volume is increasingly diverging from the aperture volume.

From Figure 5, the volume difference is slightly different between stencil thickness of 0.0762mm and 0.1016mm (14.6% and 1.39% respectively). When the thickness pass the 0.1016mm mark, the volume difference percentage increasing rapidly. This can be shown from the minimum volume difference percentage is 13.9% (at 0.1016mm) and the maximum volume difference percentage is 45.4% (at 0.1778mm). By increasing the thickness of the stencil, the volume of the aperture also increases. The current stencil printing parameter setting is not suitable for a much higher volume of aperture than 0.5642mm$^3$. Higher aperture volume need more time and force to make sure the flow ability of the solder paste is higher to fill the aperture at the given time.

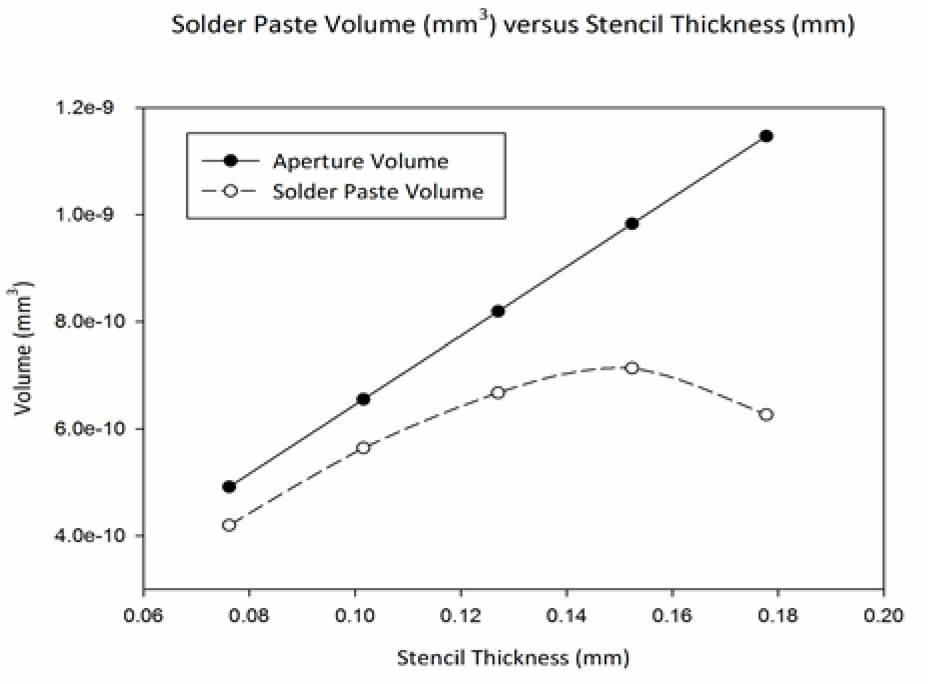

**Fig. 4.** Solder paste volume in aperture compared to aperture volume

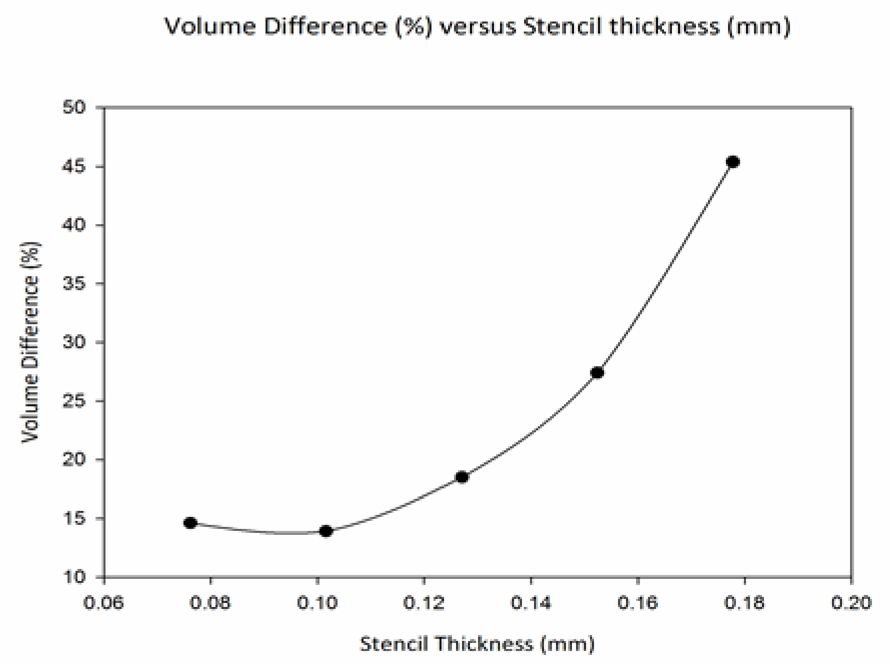

**Fig. 5.** Volume difference (%) at different stencil thickness

## 4. Conclusions

Experimental and numerical simulation works have been presented in this study. The experimental data of rheological measurement shows that SAC105 must be treated as Non-Newtonian fluid. The experimental data than being used in terms of Cross Model Parameter in numerical simulation study. Numerical simulation focus on the effect of stencil thickness for SAC105 Type 3. The result shows that the volume difference percentage is low at 0.0762mm and 0.1016mm (14.6% and 13.9 respectively) and the maximum volume difference is at 0.1778mm (45.4%).

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