Újraömlesztéses forrasztási technológia stencilnyomtatási folyamatának vizsgálata

Kutatási jelentés

1. INTRODUCTION

The most common assembling method to connect electronic components to printed circuit boards (PCB) is reflow soldering technology, where the most advancing heat transfer method is vapour phase soldering. Nevertheless, depositing solder paste by stencil printing onto the soldering pads of the PCB is one of the most crucial steps of this technology; almost 60% of the soldering failures can be traced back to the printing process. The printing process has become even more critical by the spread of ultra-fine-pitch components, like QFNs (Quad-Flat-No-Lead) and μBGAs (Micro Ball Grid Array), as they require smaller and smaller aperture sizes. Investigating this process, even with numerical modelling, is therefore absolutely necessary to reach zero-defect manufacturing. One of the most crucial parameters in numerical modelling to obtain valid results is the material properties. In the modelling of stencil printing, this parameter is the viscosity of solder paste. The pressure along the stencil line in numerical modelling is proportional to the viscosity according to the Riemer's model (1):

$$P = \frac{1}{x}\left(\frac{2\sin^2\theta}{\theta^2 - \sin^2\theta}\right)\eta\left(\vec{r}\right)v \qquad (1)$$

where: P is the hydraulic pressure, η is the apparent viscosity depending on the shear rate in a given cell, $\vec{r}$ is a pointing vector, v is the squeegee speed, θ is the squeegee angle, and x is the distance from the squeegee tip. That is the reason, why correct rheological parameters of solder pastes are required for valid numerical modelling of stencil printing.

Rheological properties of various assembly pastes were already studied before. Durairaj et al. characterised different lead-free solder pastes with viscosity measurements to apply the paste properties into numerical calculations. The viscosity of solder pastes changes during stencil printing, from the initial, first print; and the pastes need some print strokes to stabilise. Consequently, a significant downside of these researches was the fresh sample used for every measurement. It was not possible to obtain adequate information about the time-dependent viscosity change of pastes, which particular information would be necessary for correct numerical modelling of stencil printing. Time-dependent behaviour of solder pastes was studied too, but only the viscosity change over continuous time at constant shear rates was examined, the time-gap between stencil printing cycles was not considered, and thixotropic behaviour of solder pastes was also neglected. Only one research dealt with the thixotropic characteristics of solder pastes using non-fresh samples. In that study, a narrow shear rate sweep (0.01–0.2 1/s) was applied, and there were no rest periods between the measurements, i.e. the time-gap was 0 s. So, we performed a research to investigate the viscosity change of solder pastes during stencil printing; and our aim in this paper is to analyse, how that viscosity change affects the pressure distribution along the stencil line.

2. EXPERIMENTAL PROCEDURE

The geometry of the finite volume model of the stencil printing consists of the stencil, the blade and the solder paste as the domain of the interest. The mechanical properties of the squeegee as well as the printing force can be taken in numerical calculation into account by applying the loaded squeegee angle instead of the unloaded one. The loaded angle was determined as 55° in our previous work. It should be noted that this value is valid for the following conditions: material of the squeegee blade is stainless steel; the blade thickness is 200 µm; the blade height is 15 mm; the unloaded angle is 60°; and the specific printing force is 0.3 N/mm. The boundary conditions for the modelling were as follows: the movement is represented in the frame of reference for an observer travelling with the squeegee; so the printing blade was rigid and fixed, whereas the rigid stencil was moving opposite to the blade with a chosen speed (20 mm/s and 70 mm/s) of the stencil printing process. No-slip condition was set to both of the rigid walls. The paste-air interface had a prescribed shape and free-slip condition was set to it. The model is isothermal since the temperature inside stencil printers is maintained constantly during manufacturing. The optimal mesh type and element size was chosen based on our previous work. The “hybrid mesh” – consisting tetrahedron and polar type elements – with an element size of 70 µm was applied (Fig. 1).

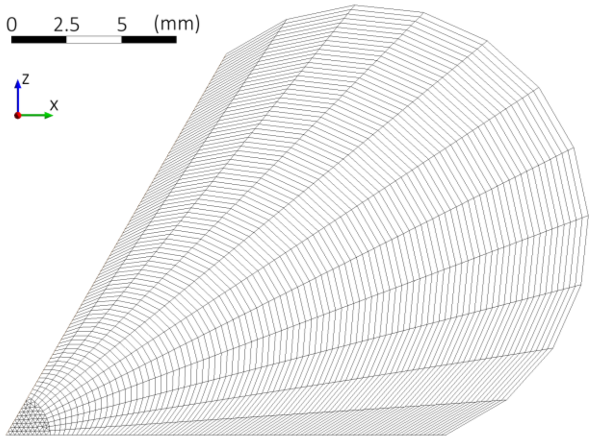

Fig. 1. Hybrid mesh type for FVM calculations.

In our previous research, the viscosity change of a Type 4 SAC305 (Sn96.5Ag3Cu0.5) solder paste during stencil printing was investigated. Basically, the viscosity of solder pastes decreases during stencil printing, but increases in a given extent during the time-gaps between the printing cycles. The degree of viscosity increment between the printing cycles depends on the length of time-gap, thus the overall viscosity decrease also depends on it. In that research, three different time-gap durations were investigated: 15 s, 30 s, 60 s. The results, the viscosity change were quite similar in the cases of time-gaps 15 s and 30 s. Therefore, the time-gap 30 s was omitted and viscosity change for the 15 s (Fig. 2) and the 60 s time-gaps were investigated by the calculations in this research.

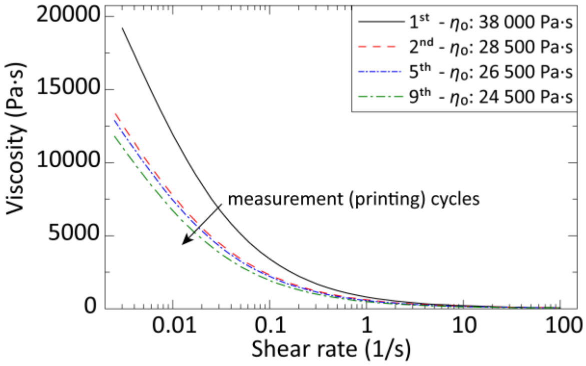

Fig. 2. The viscosity change in the case of time-gap 15 s.

It can be seen in Fig. 2, that the viscosity decrease is significant from the first printing cycle (fresh paste state) to the ninth one. Hence, the viscosity parameters for these two cycles were included in our model. The relative viscosity change as a function of the shear rate in the cases of 15 s and 60 s is illustrated in Fig. 3.

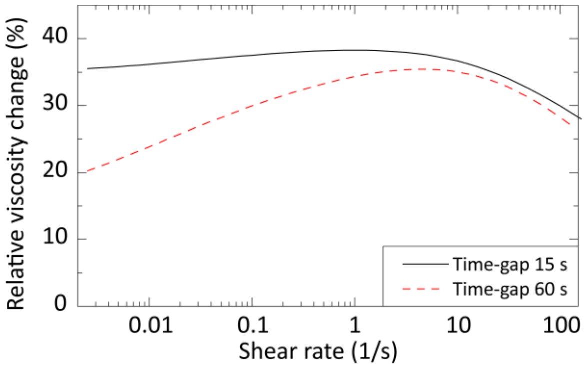

Fig. 3. Relative viscosity change in the cases of time-gap 15 s and 60 s.

It can be observed in Fig. 3, that the relative viscosity change has a global maximum at around shear rates 1–8 1/s; and it is almost the same in the two cases at higher shear rates (~30%). Since the shear rates during stencil printing lie in higher ranges, this suggests that the change in pressure results of numerical modelling will be higher in the case of the faster printing speed (70 mm/s) than in the case of lower printing speed (20 mm/s).

To describe the viscosity properties of a non-Newtonian fluid, the Cross or the Carreau-Yasuda model (2) is fitted to the measurement results generally:

$$\eta_a = \eta_\infty + \frac{\eta_0 - \eta_\infty}{\left(1+\left(\lambda\dot{\gamma}\right)^a\right)^{\frac{1-n}{a}}} \qquad (2)$$

where η_a is the apparent viscosity, η_0 and η_∞ are the viscosity values at zero- and infinite shear rates respectively, $\dot{\gamma}$ is the shear rate, λ is a time constant, a is the dimensionless Yasuda exponent, and n is a power law index. The parameters for the different states of the solder paste are collected in Table 1.

TABLE I. NON-NEWTONIAN VISCOSITY PARAMETERS FOR MODELLING

Parameter	**Different states of the solder paste**		
	Fresh state	***After 9th cycle – time-gap 15 s***	***After 9th cycle – time-gap 60 s***
η_0 [Pa·s]	38 000	24 500	31 500
η_∞ [Pa·s]	33	28	30
λ [s]	445	445	495
a – Yasuda exponent	0.64	0.65	0.67
n – power law index	0.36	0.35	0.33

After including the material properties in the finite volume model, the pressure distribution along the stencil line is calculated, and the difference between the cases is analysed.

3. RESULTS

The numerical calculations were performed by applying printing speeds of 20 mm/s and 70 mm/s. The shear rate for printing speed 20 mm/s is illustrated in Fig. 4.

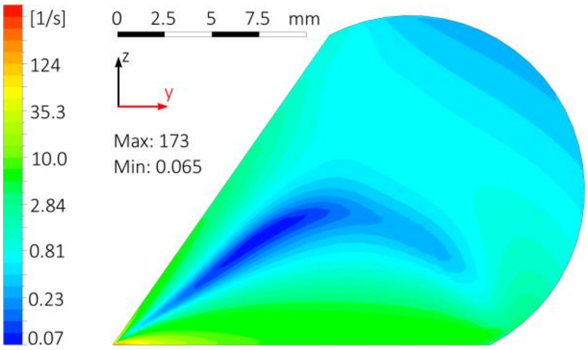

Fig. 4. Shear rate inside the solder paste for printing speed 20 mm/s.

It can be seen, that the shear rate is much higher closer to the squeegee blade tip and decreases exponentially at higher distances from the tip. The maximum and minimum shear rates inside the solder paste are collected in Table 2.

TABLE II. SHEAR RATES INSIDE THE SOLDER PASTE

Shear rate	**Printing speed**	
	20 mm/s	***70 mm/s***
Min. global [1/s]	0.065	0.32
Max. global [1/s]	173	607
Min. by the stencil line [1/s]	3.38	11.2

The calculated pressure for fresh paste and for the printing speeds of 20 mm/s and 70 mm/s are illustrated in Fig. 5 and Fig. 6 respectively.

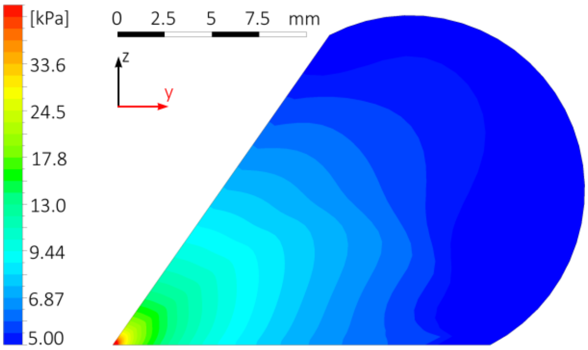

Fig. 5. Pressure – fresh paste state – printing speed 20 mm/s.

The pressure range for the printing speed 70 mm/s is remarkably higher as expected from (1). The pressure profile along the stencil line is illustrated in Fig. 7. By analyzing the pressure profile for the fresh paste state (and by applying non-Newtonian material parameters), it can be stated that the change in pressure between the printing speeds is not linear, i.e. does not follow (1), and it depends on the distance from the squeegee blade. The explanation can be that the shear stress during printing does not depends linearly on the shear strain due to the non-Newtonian fluid properties.

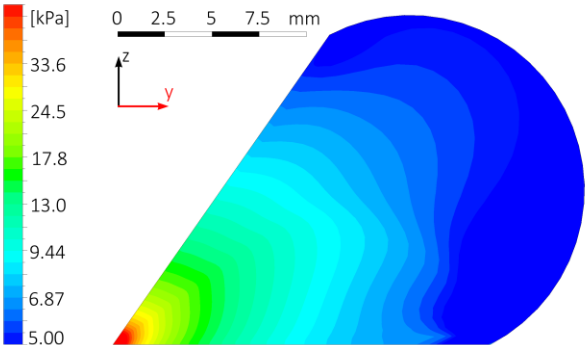

Fig. 6. Pressure – fresh paste state – printing speed 70 mm/s.

Regarding the time-gaps 15 s and 60 s, the pressure profiles are quite similar for a given printing speeds. The reason for the quite similar profiles can be that the shear rate by the stencil line (either for 20 mm/s or for 70 mm/s) lies in the range between n·1 and n·100 1/s. If we analyse Fig. 3, it can be seen that the relative viscosity changes above shear rates n·1 1/s are quite similar for the time-gaps 15 s and 60 s.

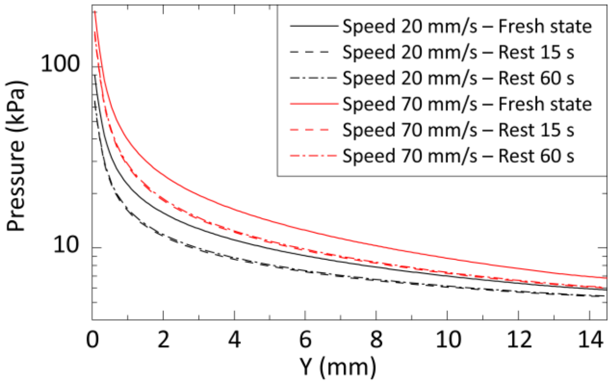

Fig. 7. Calculated pressure profile along the stencil line.

After calculating the pressure profiles, the pressure difference between the different states of the paste was calculated (Fig. 8). This difference equals to the error of calculation, if the viscosity parameters of a fresh paste are used instead of that of a stabilised one (e.g. after the

9th cycle). The change in pressure, i.e. the error of calculation is in the range between 10–30%; and it is higher closer to the squeegee blade where the higher pressure values are arisen. Besides, the average difference is slightly larger for printing speed 70 mm/s.

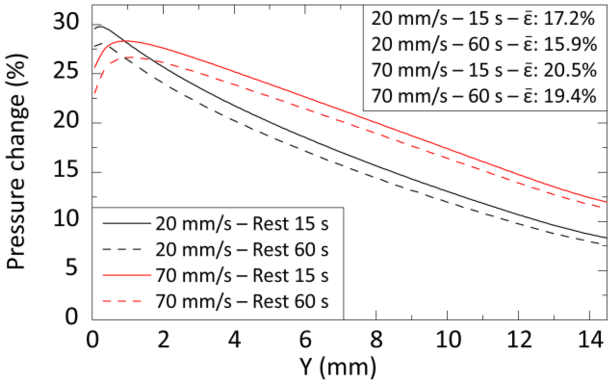

Fig. 8. Pressure difference.

4. CONCLUSIONS

It can be concluded based on the research that a large calculation error can be eliminated, if correct material parameters are used. If using viscosity parameters of a paste in fresh state, the error of Finite Volume results can be as large as 30%. The order of magnitude of the error does not depend significantly on the period of resting, i.e. the time-gaps between the printing cycles. If a numerical method is used for optimising a given stencil printing process, the thixotropic properties of the local paste should be investigated to be able to apply the correct viscosity parameters in the modelling.

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