

USING RHEOLOGY MEASUREMENT AS A POTENTIALLY PREDICTIVE TOOL FOR SOLDER PASTE TRANSFER EFFICIENCY AND PRINT VOLUME CONSISTENCY

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ABSTRACT

Industry standards such as J-STD-005 and JIS Z 3284-1994 call for the use of viscosity measurement(s) as a quality assurance test method for solder paste. Almost all solder paste produced and sold use a viscosity range at a single shear rate as part of the pass fail criteria for shipment and customer acceptance respectively.

As had been reported many times, an estimated 80% of the defects associated with the surface mount technology process involve defects created during the printing process. Viscosity at a single shear rate could predict a fatal flaw in the printability of a solder paste sample. However, false positive single shear rate viscosity readings are not unknown.

Intuitively, solder paste is subjected to several shear rates during the printing process. A squeegee forcing paste into an aperture may be the highest, and most critical strain rate applied to solder paste during the process. Separation of the stencil from the printed circuit card may be the second most important. Paste interaction with the squeegee is also a critical step for a high yield process. Very low shear force behavior may be an indicator of the potential for slumping.

Using a cone and plate fixture on a variable speed rheometer, this study will examine the correlation between rheology and print volume and print volume repeatability of the pastes. The goal is to determine if a specific set of viscosity vs. shear strain rate curves can predict the defect rate of a solder paste, and possibly create a more accurate prediction of the solder pastes value in use to users. The expectation is that this work will lead to a rich sequence of further valuable studies.

INTRODUCTION

Being able to predict the transfer efficiency and print volume reproducibility of solder paste are valuable data points for any circuit assembly process. Knowing how many good boards that can be expected from a jar of solder paste is critical for a contract manufacturer working on paper thin margins. Tier 1 automotive suppliers who in most cases, cannot re-work defective assemblies, pay dearly for defects. Defective assemblies must be discarded, and production lines are stopped until the root cause of the defect is determined and corrected.

Commercially available solder pastes use an upper and lower limit for viscosity. Generally, this viscosity is measured at one shear rate, typically the shear associated with a spiral viscometer rotating at 10 revolutions per minute (RPM). If the powder contained in solder paste is dissolved by the acid activator in the solder paste flux, the viscosity of the solder paste will quickly increase. If the viscosity increases more than 20 to 30% above the upper limit of the specification, poor printing results will be highly likely. The solder paste will not roll evenly over the stencil and apertures in the stencil will remain unfilled, causing skips in the paste printing pattern.

The purpose of the study was to determine if there is a correlation between print yields and rheology. The ultimate goal would be to use rheological measurements to better predict the print volume and print volume repeatability of any sample of solder paste.

Another benefit of this test method is the reduction in wasted solder paste. Using a spiral viscometer requires an entire 500 gram jar of paste. Because of the lengthy exposure to relatively high shear, this 500 gram sample is no longer suitable for use in an assembly process. Only a very few grams of solder paste are used in the cone and plate rheology measurement.

This study was limited to one no-clean paste flux, SAC 305 lead free powder and three particle size distributions. It should be noted that water soluble solder paste also can increase in viscosity and become unprintable due to the same mechanism. In fact, water soluble pastes may tend to do this more quickly when exposed to elevated temperatures. They also can increase in viscosity in the presence of very low humidity. Evaluating water soluble paste behavior is beyond the scope of this study.

EXPERIMENTAL CONDITIONS

Three solder pastes were manufactured for the experiment using commercial scale equipment. There have been multiple examples of lab size solder paste batches showing differing rheological properties versus commercial scale batches. In this experiment the same batch of flux was used to make all three pastes.

Note that using a given lot of paste flux, varying the particle size distribution at a fixed metal loading will lead to different viscosity results. A Type 3 powder at 89% metal loading will have a lower viscosity than a Type 4 powder at the same metal loading. These differences in viscosity are more pronounced at lower shear rates. Figure 1 shows one lot of flux with two PSDs of SAC 305 powder at one metal loading.

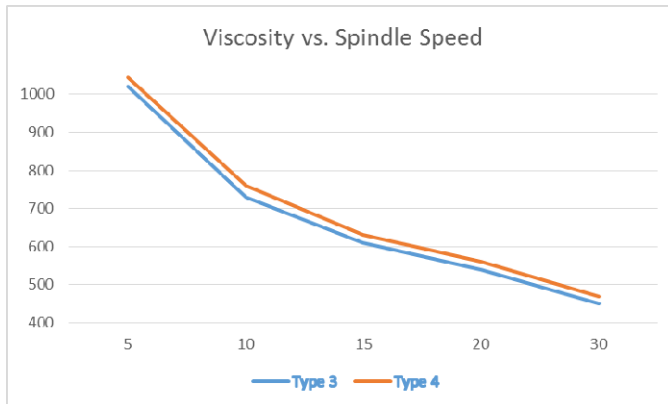


Figure 1: Viscosity (Y axis) vs. Viscometer Rotational Velocity (RPM X Axis)

The three pastes were also subjected to a standard print volume and print volume repeatability evaluation. A standard test vehicle was used. (Figure 2), using an uncoated .004 in. (100 μ) thick, laser cut stainless steel stencil. Print volumes were measured using a Koh Young Aspire solder paste inspection (SPI) device. These measurements were then exported to Minitab statistical analysis software program and process capability was reported.

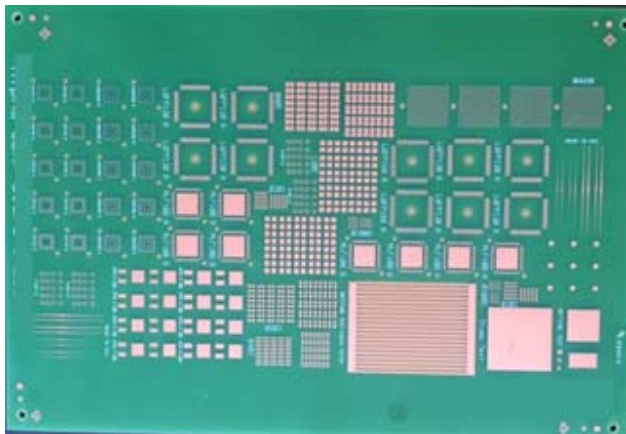


Figure 2: Print Volume Test Vehicle

RHEOLOGY MEASUREMENT

Cone and Plate Rheometer

A Malvern Kinexus rheometer fitted with a cone and plate probe was used to measure rheology. The device among many other things, is capable of creating a continuum of shear rates, while measuring the viscosity of the solder paste at each shear rate. Figure 3 is a photo of the device.

Figure 4 is a close up of the cone and plate mechanism. Because of the heat that is developed from the friction of the solder paste trapped between the cone and plate, a cooling unit is connected to the base plate. A water bath maintained at 25°C is adjacent to the device, and a continuous stream of 25°C water flows under the bottom plate, maintaining an isothermal condition for the viscosity measurement.

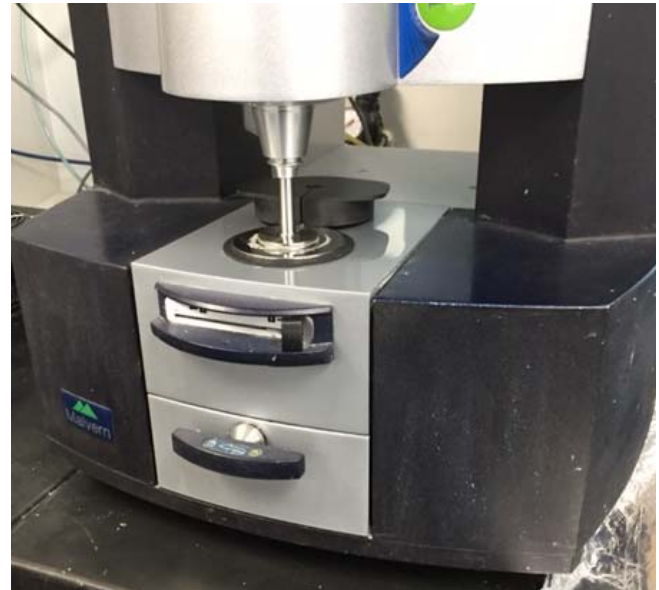


Figure 3: Cone and Plate Rheometer



Figure 4: Close up of the Cone and Plate Mechanism

Shear viscosity was measured while shear rate was continuously logarithmically ramped from 0.1 to 100 s⁻¹ for a total measurement time of 2 minutes. 10 measurements were made per decade of shear viscosity.

RESULTS AND DISCUSSION

Table 1 details the metal loading and initial viscosities of the three pastes at room temperature (25°C). As mentioned above, the metal loading needs to be decreased as powder size distribution decreases in order to obtain the same 10 RPM Malvern measured viscosity.

Table 1: Metal Loading and Viscosity of 3 Pastes Used

	Type 3	Type 4	Type 5
Metal Loading	88.73	88.32	88.22
10RPM Viscosity	1373	1373	1388

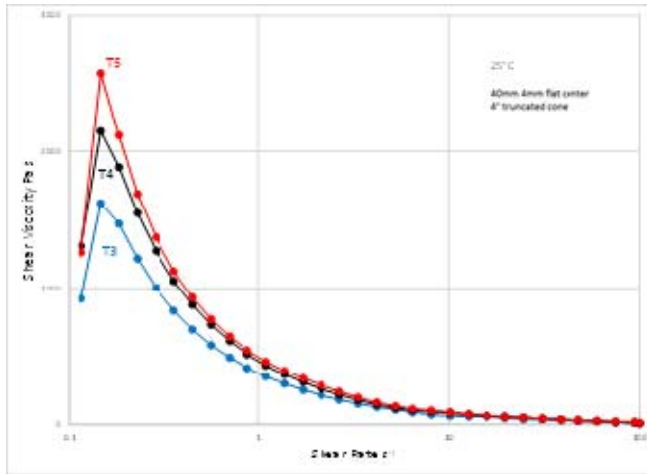


Figure 5: Viscosity vs. Shear Rate for 3 Pastes

It is interesting to note that the divergence in viscosities tends to be greater at lower shear rates. Conversely, the viscosities converged at the higher shear rates.

The print volume reproducibility (CpK) of the pastes made with Type 3, 4 and 5 powders when the area ratio was 0.79 was 2.89 ± 0.14 (see Figure 6). This converts to an expected defect rate of less than 0.6 parts per trillion.

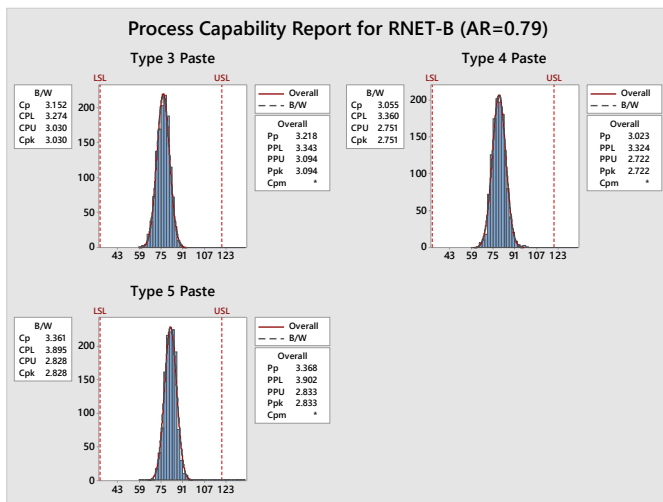


Figure 6: Histogram of Deposits @ AR=0.79

The print volume reproducibility (CpK) of the pastes made with Type 3, 4 and 5 powders when the area ratio of 0.79 was 2.89 ± 0.14 (see Figure 6). This converts to an expected defect rate of less than 0.6 parts per trillion.

The performance of the 3 pastes diverged at a 0.54 aspect ratio. (See Figure 7). In other words a 210μ (.008") square aperture in a 100μ (.004") thick stencil. The paste made

with Type 3 powder showed a CpK of 1.23. This translates in an estimated defect rate of greater than 100 per million opportunities. The paste using Type 4 powder showed a CpK of 1.82, translating to an expected defect rate of approximately 50 per billion opportunities.

Finally, the paste that used the type 5 powder showed a CpK of 3.48, translating to an infinitesimally small expected defect rate of 1 in 2.56×10^{17} opportunities.

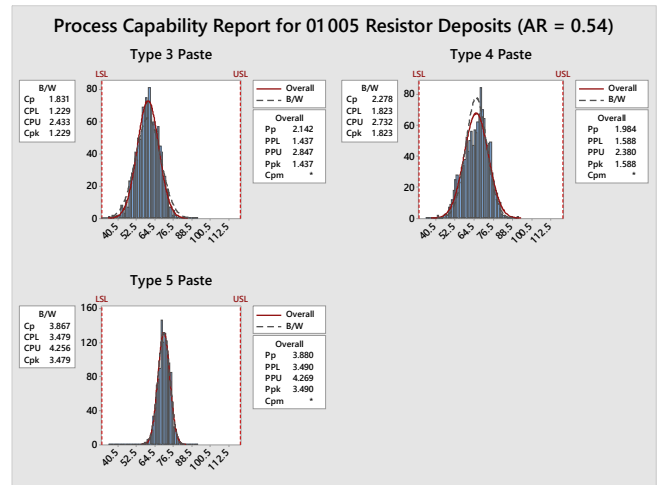


Figure 7: Histogram of Print Deposits @ AR=0.54

The results are three rheology profiles that are different at low and medium shear rates, and three different print performance levels at an area ratio of 0.54. The question is whether or not there is a cause and effect between these two observations. See Figure 5.

A second type of rheology test that may be more relevant to the print process is the shear stress sweep. In this measurement, the shear stress is cycled from low to high and back to low. Intuitively, this is similar to a set of squeegee blades pushing a bead of paste back and forth. Figure 8 shows the results of the three test pastes. Again, there is a consistent pattern between the Type 3, 4 and 5 pastes. This is another indication that a rheological footprint may be a predictor of print quality.

There is a distinct hysteresis between the high to low stress sweep and the low to high sweep. At high stress, the solder paste behaves mostly like a viscous liquid and shows shear thinning, but as the stress decreases and viscosity increases, a discontinuity occurs at about 100, 75 and 65 Pa for types 3, 4 and 5 powder respectively. The discontinuity viscosity is lower for the type 5 powder than the types 3 and 4. After the discontinuity, the viscosity decreases somewhat with decreasing shear stress.

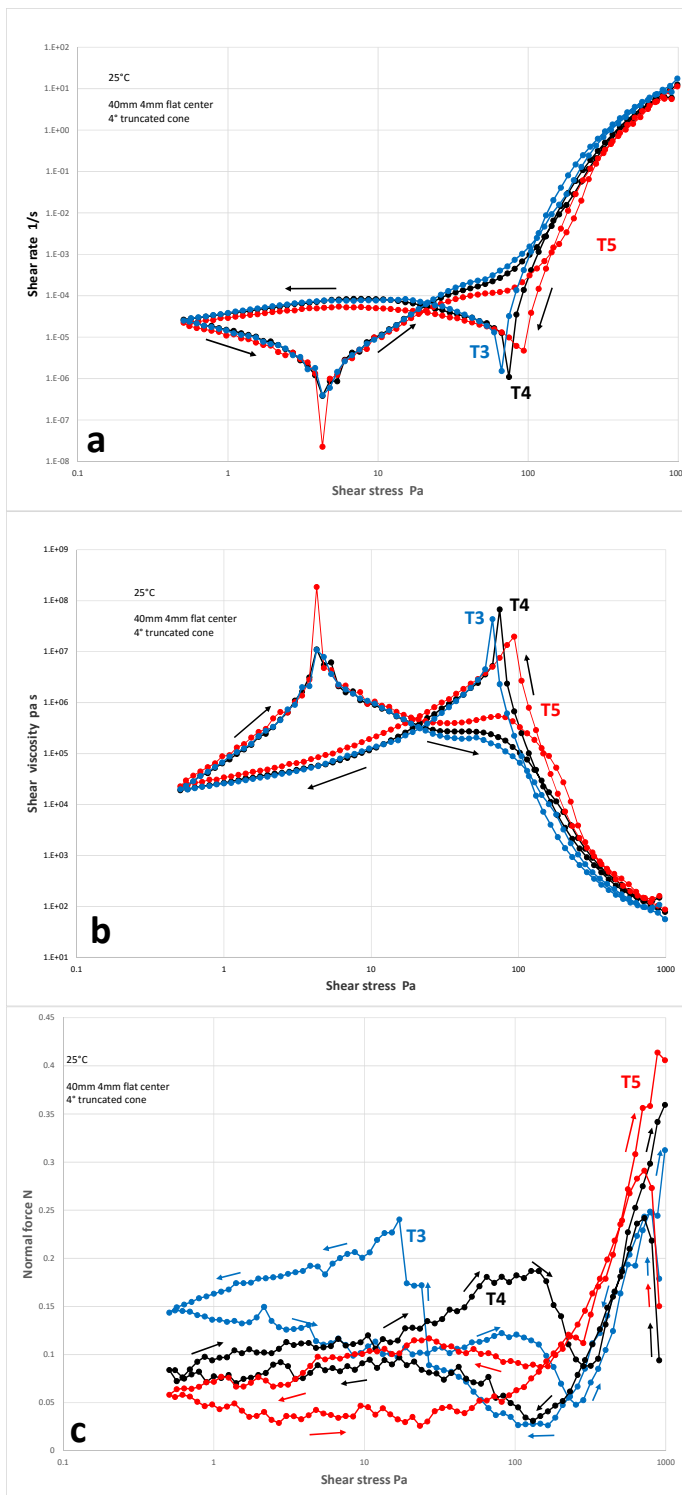


Figure 8: Shear stress sweep; a. shear rate vs. shear stress, b. shear viscosity vs. shear stress, c. normal force vs. shear stress

During the low stress to high stress sweep, the viscosity increases with shear stress until another discontinuity occurs at about 4 Pa for all three pastes, after which the viscosity decreases slowly showing a quasi-solid behavior until the stress is about 100 Pa when shear thinning starts.

Figure 8c shows the normal force measured during the shear sweep measurements. The normal force is perpendicular to the direction of the shear stress. The data is rather noisy, but distinct differences between the pastes made with the three types of powder are observed. All of the pastes show high normal force at high shear rates, which decrease with decreasing stress. However, the type 3 paste increases with decreasing stress below 100 Pa until a discontinuity is reached at about 20 Pa. In addition, there is a strong hysteresis observed in the reverse sweep. The normal force remains almost constant with stress, until about 100 Pa, when it decreases slightly with stress until a minimum occurs at about 250 Pa and the normal force increases with stress. The paste made with type 5 powder shows similar increases of normal force between 100 and 1000 Pa, but almost constant normal force at stresses less than 50 Pa, the decreasing stress having high normal force than the increasing stress. The normal force behavior for the type 4 paste is between that of the type 3 and type 5 pastes.

Oscillation sweeps can also be used to look at the properties of solder pastes. During these measurements, the truncated cone rotates clockwise and counterclockwise sinusoidally. By making oscillatory measurements, the solid-like (elastic, in phase with displacement) and liquid-like (viscous, out of phase with displacement) behavior of materials can be separated. Figure 9 shows frequency sweep measurement data. Here a step-wise sweep of frequencies between 10 and 0.1 Hz was made at a constant complex shear stress of about 10 Pa. Figure 9a shows complex modulus vs. frequency, and in Figure 9b, the complex modulus is divided into its in phase (elastic, solid-like) and out of phase (viscous, liquid-like) components. For all three pastes, the elastic modulus reaches a steady value at about 10 Hz, but the viscous modulus continues to increase with frequency. Likewise, Figure 9c shows viscosity decreasing with frequency. The T5 paste has the highest viscosity at low frequency and T3 the lowest viscosity, with T4 being somewhere in between.

CONCLUSIONS

The three types of rheology measurements studied here all show trends that mirror the print volume and volume reproducibility for the three pastes used in this study. A low area ratio, 0.54 amplified the correlation of the rheology measurements to the print deposit reproducibility.

The paste sample size required for rheological testing is an order of magnitude lower than what is required for spiral viscosity testing. Both suppliers and users could see a significant reduction in wasted material if rheology would become the standard for solder paste inspection.

Obviously, more testing, including a round robin test by the IPC-JSTD-005 would be required before this type of test method could be elevated to an industry standard.

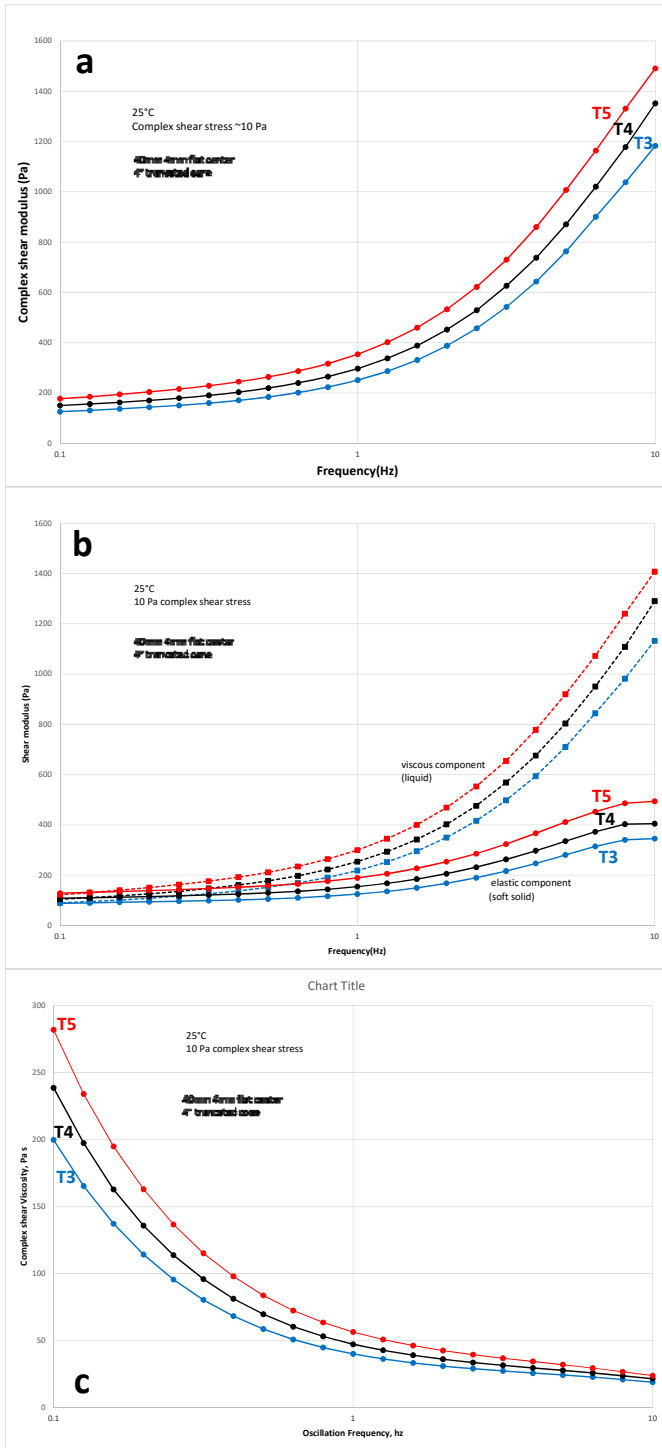


Figure 9: Oscillation frequency sweep; a. complex modulus vs. frequency, b. elastic and viscous modulus vs. frequency, c. complex viscosity vs. frequency.

ACKNOWLEDGEMENTS

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