

# RHEOLOGY AND WETTING CHARACTERIZATIONS OF FLUX AND SOLDER PASTE FOR BGA PACKAGES

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## ABSTRACT

Package failures related to solder joint reliability need to be addressed at the first level, second level, and package to socket interconnects. As the ball size, pitch, and ball to ball spacing are reduced, it poses a challenge to material and process development. Flux materials are typically used in the solder process to remove the oxides on the pad and solder surfaces. A clean surface results in a stronger solder joint. Due to the flux chemistry and formulation differences, the rheological behavior of the fluxes can vary. There are two types of commonly used flux materials in terms of their rheology properties: Newtonian and non-Newtonian fluids, depending on the formulation chemistry. Fluxes with non-Newtonian fluid behavior have complex rheological properties. Flux viscosity has always been an important material property for manufacturability. It is critical to have a good understanding of the rheology properties of the flux and paste and its correlation with process and package parameters. This can help in optimizing the process conditions and reducing manufacturing related defects. The rheological properties and wettability of fluxes and pastes were studied. The rheological properties of flux and pastes were measured across a wide range of shear rates with various rheometers to correlate the rheological properties with process conditions. Wetting angles of the flux were measured for flux spread studies. The process of solder joint formation relies heavily on wetting parameters such as solder wetting force and wetting time in the presence of flux and/or solder paste materials. The correlation between wetting parameters, package assembly yield, and reliability data can provide a guideline for flux and solder paste material selection and process optimization.

The solder wetting balance test is one of the most common methods for solder wetting evaluation. This method can be used for flux, solder, and surface finish evaluations. The method with a molten solder pot, however, cannot be used for solder paste evaluation since the paste is a mixture of solder and flux.

In this paper, we will discuss a solder paste wetting method. A high resolution solder wetting balance was used for the solder paste wettability analysis. Solder wetting analysis for solder balls and solder paste with different pre-test conditions provide useful information for material selection and reflow process optimization studies. The effects of solder surface oxidation and paste aging on the solder-paste wetting interactions were investigated.

Wetting balance tests were performed for the characterization of paste and solder ball wetting behaviors. In addition, the understanding of the effect of solder ball reflow in relation to paste wetting was also analyzed in this work. In general, wetting test results showed that paste aging and improper paste used in SMT resulted in significant reduction in the wetting force. For the case of a multiple-reflowed solder ball, a decreasing trend in the wetting force was observed. The high resolution solder wetting balance was proven to be a useful technique in supporting the development of SMT paste materials.

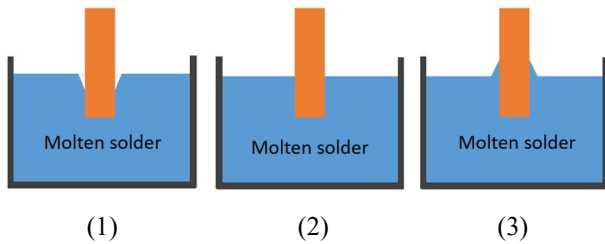
Key words: flux, solder paste, rheology, solder wetting, materials process

## INTRODUCTION

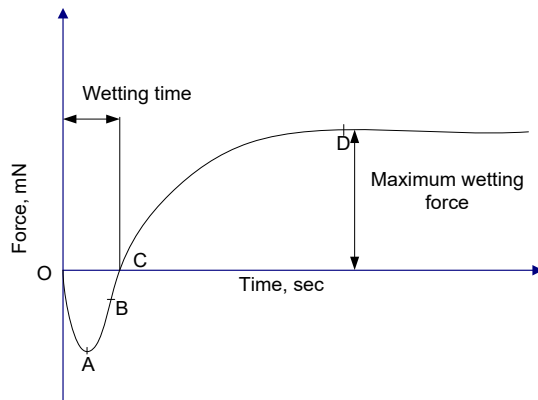
During the BGA solder ball attachment manufacturing process, flux or solder paste is applied to the metal pads of the substrate. The substrate with the solder ball attached is reflowed in a reflow oven to form the solder joint. The surface mount technology process interconnects the BGA substrate to the motherboard with printed paste. Flow properties of flux and paste are important for material manufacturing, shipment, storage, and processing. Most flux and all the pastes used in BGA package are typically non-Newtonian fluids with complex rheology properties [1,2]. The viscosity will depend on shear rate, deformation, and thermal history. It is critical to properly characterize the rheology behavior of the material related to its process conditions. Due to the wide process conditions, different rheology test methods need to be used. In this paper, we will discuss several rheology test methods used for flux and paste characterizations. The correlation between the rheology properties and material performance in the process will be discussed.

In the solder wetting balance test for flux, a metal coupon is first coated with flux and dipped into a molten solder pot with a controlled immersion speed and immersion depth. The wetting force as a function of time is measured for a fixed dwell time, while the coupon is inserted in the molten solder pot. The three major steps in the solder wetting test are shown in Figure 1: (1) The coupon is inserted in the molten solder bath and the solder is displaced by the coupon. (2) The solder melt is leveled as its meniscus rises alongside of the coupon. (3) The solder meniscus reaches

the maximum height. A typical solder wetting curve is shown in Figure 2.



**Figure 1.** Schematic of the previous generation solder wetting balance test.



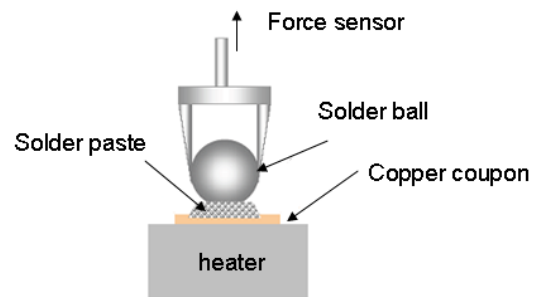
**Figure 2.** Schematic of a typical wetting force and time curve from a standard isothermal solder wetting balance test.

At point O, the specimen starts to contact the solder surface. At point A, the solder melt surface is depressed by the specimen giving rise to an upward force on the specimen. The specimen reaches the maximum negative force. It is evident that wetting has commenced and the solder meniscus starts to rise up the test specimen. At point B, the solder meniscus vanishes and the only force exerted on the specimen is buoyancy. At point C, the force on the specimen turns positive. This is the zero force crossover time, which signifies the solder wetting time. At point D, the wetting force reaches a maximum value.

Key parameters from the solder wetting balance test are the wetting force in millinewtons (mN) and the wetting time in seconds. Appropriate test methods have been established for the selection of solder, flux, and surface finish materials. However, this standard solder wetting balance test has some limitations. Since it requires more than one kilogram of solder to fill the solder bath, it takes more than an hour to heat up to the test temperature. It can only run the test at isothermal temperatures and typical SMT process solder ball reflow conditions could not be simulated.

A different type of solder wetting balance, which is capable of conducting test under SMT reflow process conditions, is

used for solder ball wetting study on solder pastes. The solder paste wetting differences for packages with lands of various surface finishes can also be studied. A schematic of solder ball and solder paste wetting test is shown in Figure 3. The solder paste is typically printed on a copper coupon. A sample holder is used to pick up the solder ball and is loaded onto a balance system, which is connected to a sensitive force sensor. The heating stage is pre-heated to about 230°C or programmed to any reflow temperature profiles. The copper coupon with solder ball is loaded on the heating stage quickly and it is critical for the paste to align with the solder ball. During the test, the stage rises up with a predefined speed until it reaches a pre-defined immersion depth. The wetting force vs. wetting time curve is recorded in the test. With small paste volume, the paste can reach the test temperature very quickly.



**Figure 3.** Schematic of solder ball and solder paste wetting test.

In this paper, four case studies of solder wetting tests were demonstrated with a resolution wetting force of 0.01mN in accuracy. This allows to determine dynamic wetting characteristics of various solders consisting of alternate alloys on different land surface finishes, and paste/flux formulations. The effectiveness of different solder pastes for head and pillow defects is compared. For a large package, the effect of oxidation on the solder ball in controlling the non-wet open defects are described. The solder wetting studies relating the effect of solder ball reflow and bake are discussed.

## RHEOLOGY CHARACTERIZATIONS

### Shear Viscosity Test for Flux and Paste

Flux and paste are non-Newtonian fluids and their viscosity is shear rate and time dependent. Fluxes are often kneaded at a constant speed before the flux print process. After the kneading process, the viscosity of flux is reduced, making the flux print more consistent. Figure 4 shows effect of kneading on the flux viscosity reduction. The viscosity was measured with a spiral pump type viscometer at 25°C.

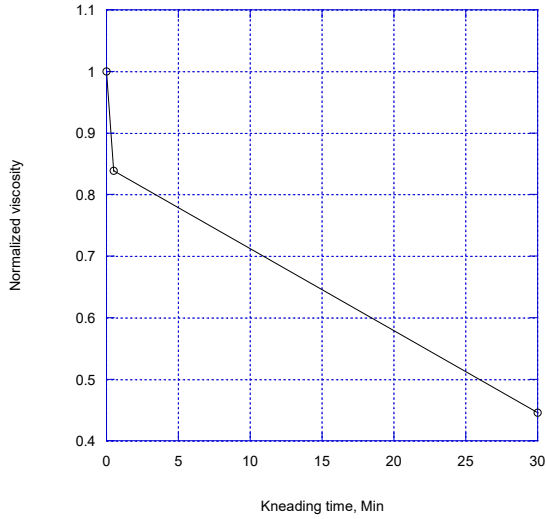


Figure 4. Kneading time effect on flux viscosity.

Shear rate sweep viscosity for two ball attach fluxes is shown in Figure 5. The viscosity was measured with 25mm parallel plates and 0.5mm gap. As the shear decreases, the viscosity difference increases. The contact angle of these two fluxes on solder resist and CuOSP are shown in Figure 6. The contact angle of flux A is much lower than flux B. Flux A has over spread and bridging issues due to its low viscosity and low contact angle.

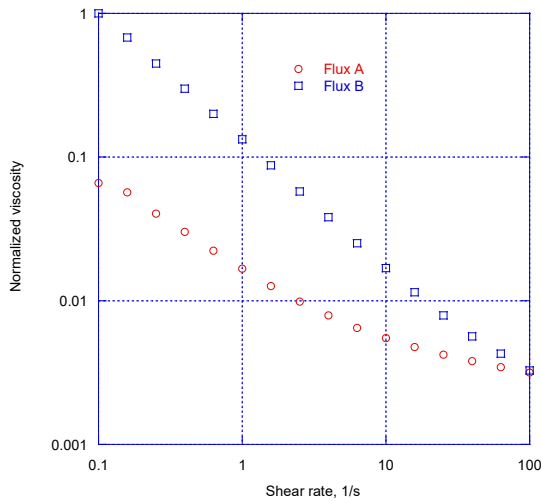


Figure 5. Flux shear rate sweep viscosity.

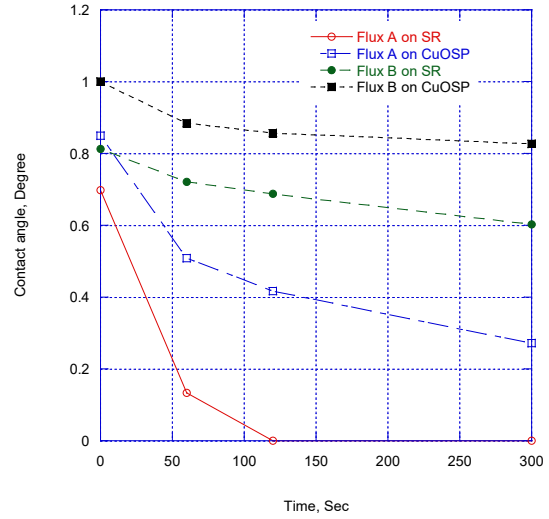


Figure 6. Flux contact angle at 60°C.

Pot life viscosity data for a solder paste is shown in Figure 7. The sample was aged at 25 and 40°C for up to 48 hrs. The viscosity was tested at both 25 and 40°C at 10 RPM. The viscosity for the 40°C aged sample has a significant increase.

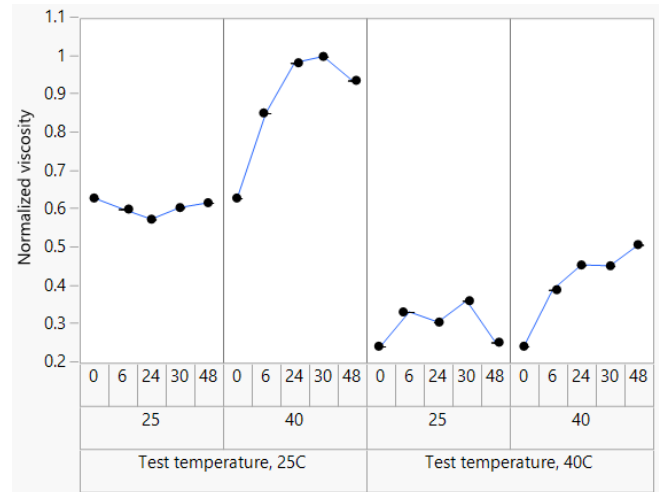
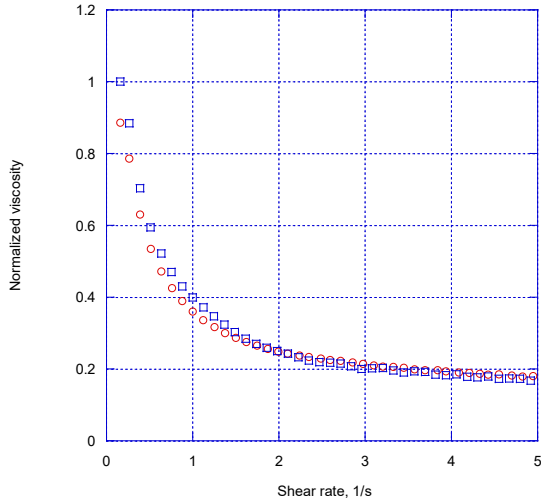
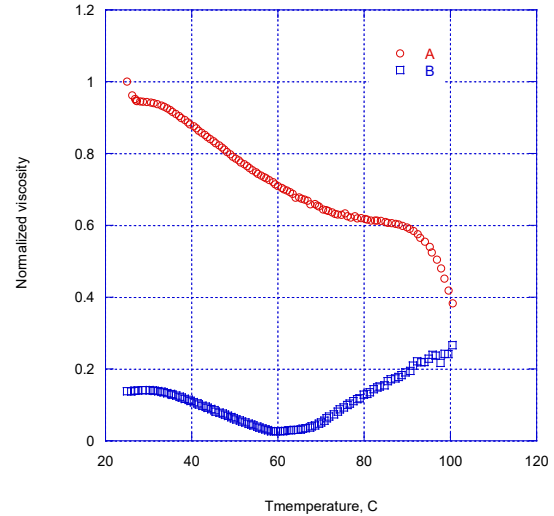


Figure 7. Solder paste pot life viscosity.

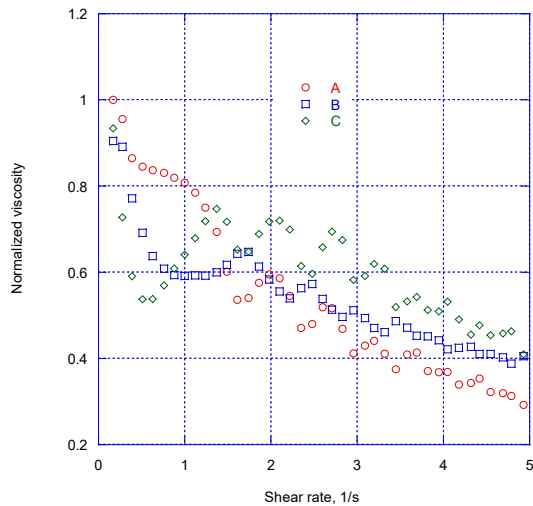
Shear rate sweep viscosity for solder paste is shown in Figure 8. Due to the high metal loading, the paste would spin off the plate at a high shear rate. So the shear rate sweep test was only up to 5 1/s shear rate. Shear rate sweep viscosity for the solder paste with performance issues is shown in Figure 9. The viscosity data is very noisy compared with the paste viscosity shown in Figure 8. This paste may have phase separation, imperfect mixing, or sedimentation issues.



**Figure 8.** Solder paste shear rate sweep viscosity.



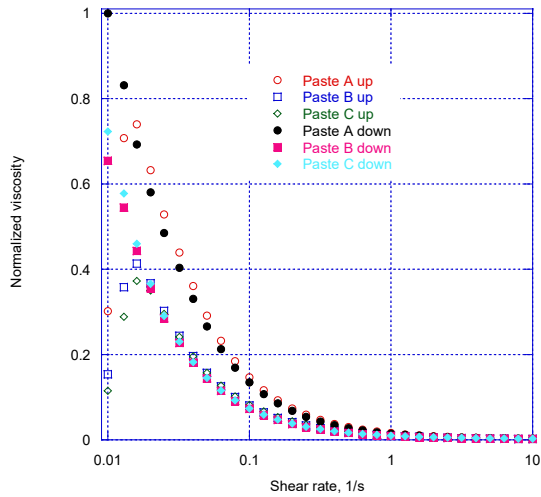
**Figure 10.** Dynamic temperature ramp viscosity for solder paste.



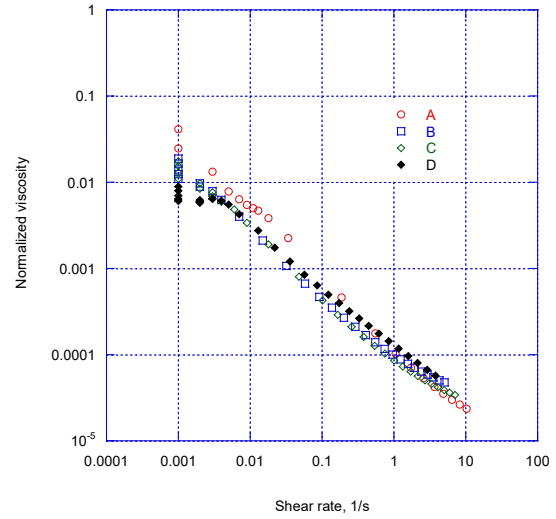
**Figure 9.** Shear rate sweep viscosity for paste with poor performance.

Dynamic temperature ramp viscosity for two solder pastes are shown in Figure 10. The viscosity was measured at 500 Pa stress, 1Hz frequency, and 3.5C/min ramping rate. Paste A shows the viscosity decrease with temperature. Paste B shows the viscosity increase with temperature. The viscosity increase with temperature for paste B may be due to solvent evapoartion, more solder sphere interaction, and less lubrication. The temperature ramping rate is limited for a rheometer and it is hard to match the ramping rate of a reflow profile for flux and paste reflow process. It is difficult to measure viscosity change during reflow.

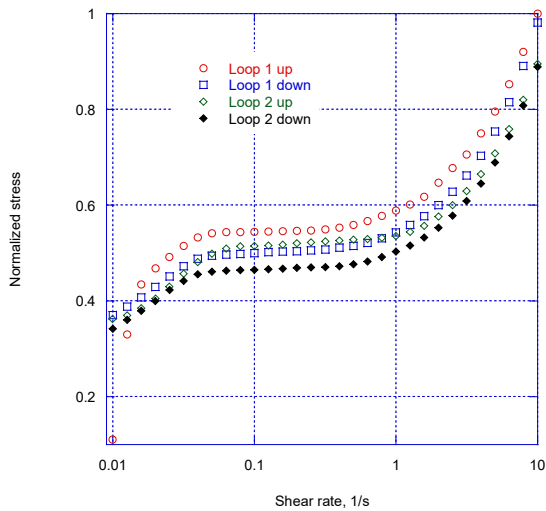
A shear rate loop test was conducted for three solder pastes. The shear rate was ramped up from 0.01 to 10 1/s. All the three pastes had a maximum viscosity at 0.016 1/s as shown in Figure 11 in the shear rate up ramp. The viscosity for all the pastes monotonically increased with a decrease in shear rate in the shear rate down ramp. This could be due to solder spheres *locked* in the upward ramp, and only the flux component was moved at low shear rate, which resulted in low viscosity at low shear rate. The high viscosity at low shear rate in the down ramp may be due to more solder sphere and flux interactions. The viscosity for paste A is much higher than paste B and C at low shear rates. This high viscosity at low shear rates could cause stringing during squeegee release and paste coning after screen print. Figure 12 shows the stress vs shear rate curve for the shear rate loop test. The stress was measured for paste A in two up and down shear rate loops from 0.01 to 10 1/s. The stress decreased with shearing at the same shear rate and formed a hysteresis loop. This decrease could be from a structure breakdown.



**Figure 11.** Viscosity hysteresis for solder paste.

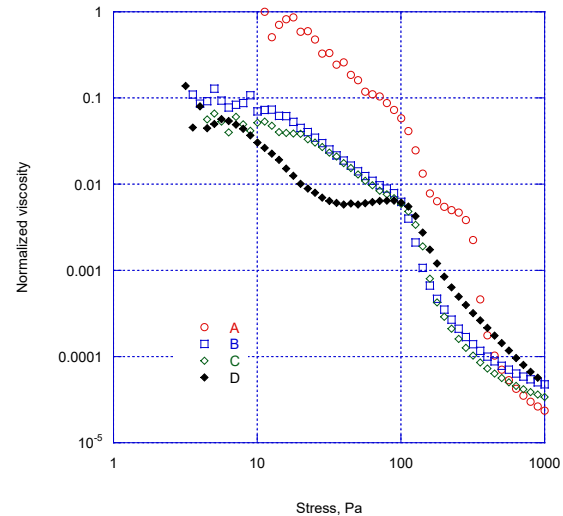


**Figure 13.** Viscosity vs. shear rate in a stress sweep test for solder paste.



**Figure 12.** Stress vs. shear rate in viscosity hysteresis test for solder paste.

The viscosity vs shear rate curves are shown in Figure 13 for 4 solder pastes. The viscosity was measured in a stress sweep test from 0.8 to 1000 Pa stress. Paste D had slumping issues. The viscosity of paste D at 0.001 1/s shear rate is lower than other pastes. The viscosity vs shear stress curves are shown in Figure 14. The viscosity of paste D is much lower than other pastes at shear stress below 100 Pa and its yield stress is also much lower than other pastes.



**Figure 14.** Viscosity vs. shear stress in a stress sweep test for solder paste.

### High Shear Rate Viscosity Test

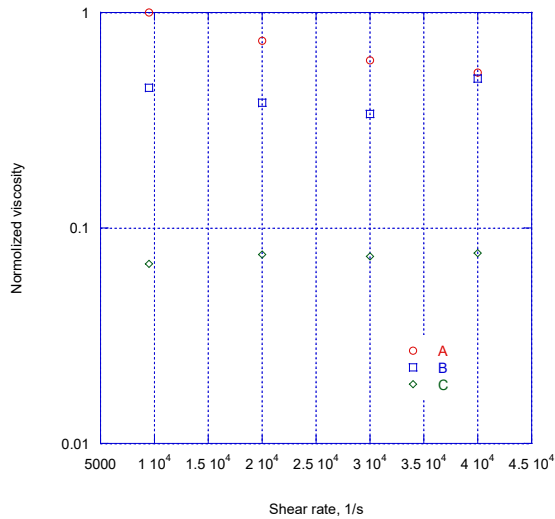
The flux and paste have very wide rheological properties and are used in various assembly processes. Due to wide viscosity ranges of the flux and paste materials, no single rheometer can cover all the materials. Low viscosity material needs to use a low viscosity fixture with a large surface area in contact with sample liquid such as concentric cylinder to test. For high metal loading pastes, the paste can be spun off from the plate and results in artificially low viscosity at a high shear rate with parallel plate fixture. As

shown in Figure 15, the paste was spun off the edge of the plate fixture after a shear rate sweep test up to 1000 1/s shear rate.



**Figure 15.** Solder paste sample after a high shear viscosity test in between parallel plates.

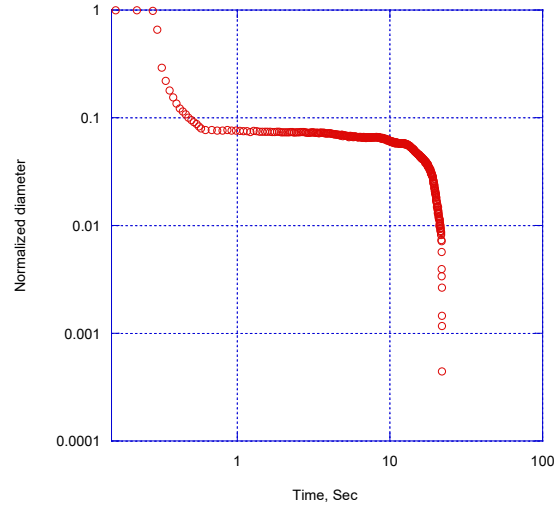
Figure 15 shows the open gap on the edge after a high shear test. The problem can be resolved with a capillary rheometer test [3]. The flux and paste could be subject to high shear rate processes and the capillary rheometer can be used for a high shear rate test [3]. Figure 16 shows viscosity for three fluxes obtained in a capillary rheometer test at 70°C with 0.5 mm diameter and 4 mm long capillary die.



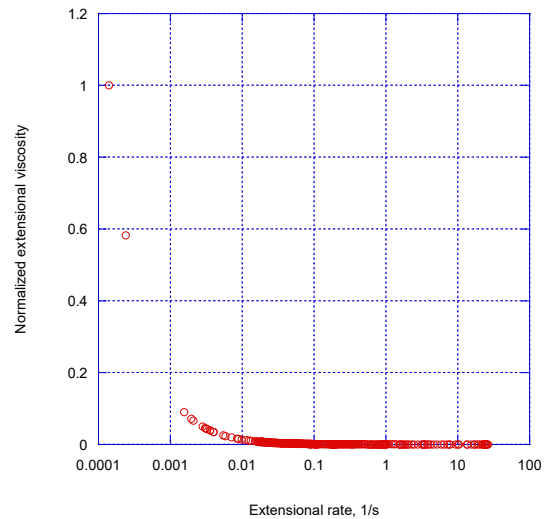
**Figure 16.** Flux viscosity at high shear rate from capillary rheometer test.

### Extensional Viscosity Test

Flux and paste materials could undergo extensional deformation or both shear and extensional deformations in processes such as screen printing. A capillary break up extension rheometer is used for extensional viscosity measurement [4]. The material is sandwiched between two 6 mm diameter plates and the top plate is pulled away at a predefined speed. The diameter at the neck is measured with a laser micrometer with time until the material breaks. The diameter at the neck as a function of time for a solder paste is shown in Figure 17. The initial and final gaps are 1 and 18.8mm, respectively. The pulling speed is 30mm/s. The extensional viscosity vs extensional rate curve is shown in Figure 18.



**Figure 17.** Diameter at the neck for a solder paste using an extensional rheometer.



**Figure 18.** Extensional viscosity measured with an extensional rheometer.

The break time obtained from the extensional viscosity for several solder pastes are shown in Table 1. At 10 mm/s pulling speed, pastes A, C, and E have long break times and these pastes had stringing issues. At 1mm/s pulling speed, the break time was dramatically reduced for most pastes. The pastes had less stringing issue at 1mm/s rate.

**Table 1.** Break times for solder paste from an extensional viscosity test.

Paste sample	10mm/s speed	1mm/s speed
A	1.00	0.24

B	0.45	0.24
C	1.00	0.18
D	0.12	0.19
E	1.00	0.21
F	0.83	0.25
G	0.62	0.24
H	0.67	0.41
I	1.00	0.43

## SOLDER WETTING BALANCE TEST METHOD

### Solder Wetting Test for Flux

In the flux solder wetting balance test, a test coupon is first coated with flux. Then the coupon is dipped into a pot with molten solder with a controlled immersion speed and immersion depth. The wetting force as a function of time is measured in a fixed dwell time, while the coupon is inserted in the molten solder pot. Key results from the solder wetting balance test are wetting force and wetting time [5]. The solder wetting force and time for fluxes with different wettability are shown in Table 2. For the flux with good wettability characteristics, the wetting force was larger and wetting time was shorter than other fluxes.

**Table 2.** The solder wetting force and time for fluxes.

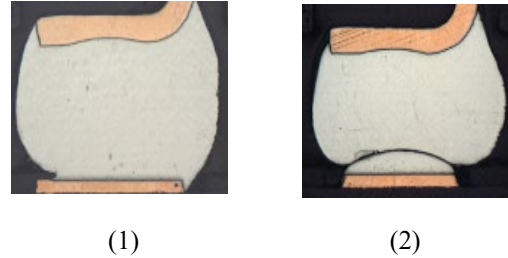
Sample	Normalized wetting force	Normalized wetting time
A	0.84	0.30
B	0.48	1.00
C	1.00	0.11
D	0.95	0.12
E	0.98	0.12

The paste solder wetting test is more challenging than the flux wetting test. Because the paste has a flux component the isothermal test is not suitable for the solder paste wetting test. The solder wetting balance for paste needs to have the capability to run a reflow profile and test the wetting in reflow condition. Due to its small sample size and low wetting force, it is difficult to get repeatable results. However, the paste and solder ball aging can be studied with the paste wetting test. The test conditions are close to the real process.

### Head and Pillow Defect

Head and Pillow (HnP) surface mount defects, as shown in Figure 19, are observed during the development of lead-free solder SMT process. The HnP solder defects can occur at the edges and at the corners of the package (or socket) being attached due to reflow-induced dynamic warpage. When HnP occurs, only the solder balls at the center of the package form good solder joints with the board side lands. During the reflow, the solder balls that are located at the edges of the package are not in contact with the paste as the reflow temperature approaches the peak temperature. This results in poor bonding between the solder balls and the

solder paste, and directly decreases the removal rate of surface oxides from the solder balls due to insufficient fluxing reaction. The solder balls at the edges of the package can only have contact with the paste after the collapse of the center balls during the formation of solder joints at the peak reflow temperature. The remaining surface oxide of the solder balls due to this delay inevitably results in HnP defects. Other factors such as reflow process conditions and package/socket design can also modulate the HnP defect rate. Here, we will focus on the material aspect of the problem, especially the paste and solder ball effects on the HnP defect.



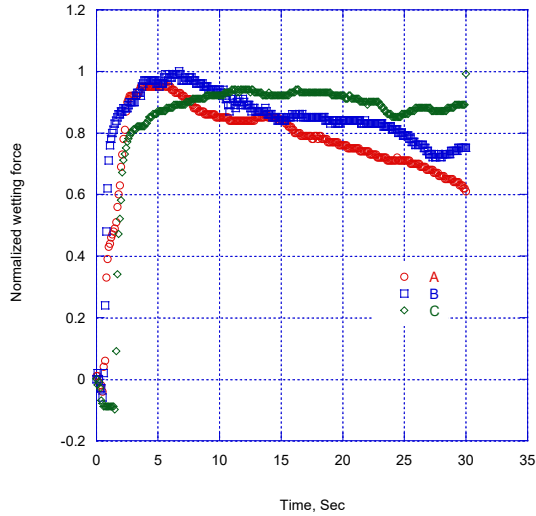
**Figure 19.** Good (1) and (2) HnP solder joints.

HnP solder joints were observed on Socket with solder paste material 'C'. Three solder pastes, 'A', 'B', and 'C', were used for the solder ball on solder paste wetting tests. The test conditions are shown in Table 3. The pastes were printed on a Cu plate and pre-heated for 0, 5, 10, and 30 sec at 232°C prior to the wetting test to simulate the delay in contact between the edge ball and the paste.

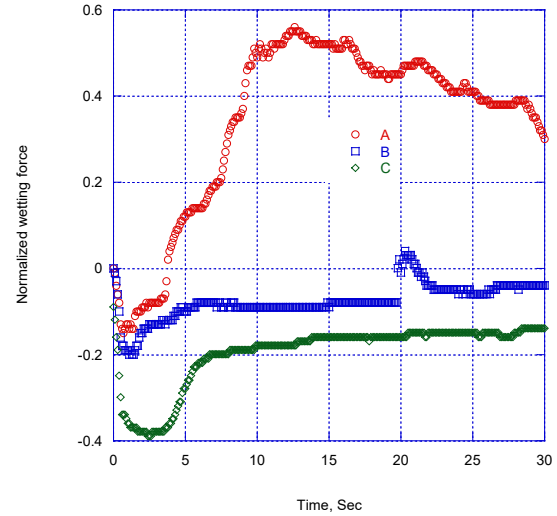
**Table 3.** Test conditions for solder ball and paste wetting test

Temperature, °C	232
Stencil diameter, mm	0.66
Stencil thickness, mm	0.127
Immersion Speed, mm/s	0.1
Immersion Depth, mm	0.05
Immersion time, Sec	30

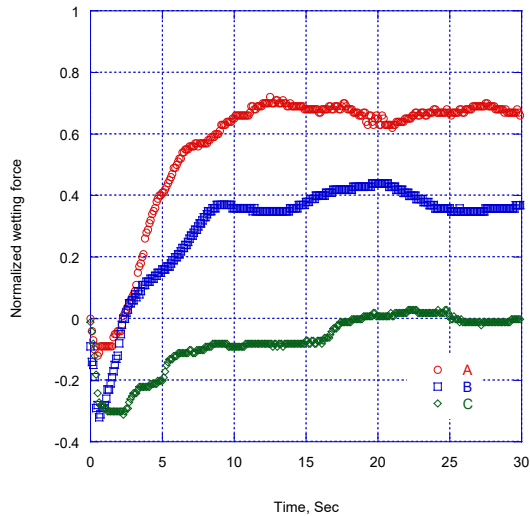
Without pre-heating, all three pastes showed short wetting time and equivalent high wetting force, as shown in Figure 20. For the samples with 5 sec and 30 sec pre-heat time, as shown in Figures 21 and 22, paste C exhibited a steep decline in the wetting force with much longer wetting time required as compared to the pastes A and B. This indicates poor wetting characteristic of paste C on the solder ball after the paste pre-heat.



**Figure 20.** Wetting force time curves with no preheating time.



**Figure 22.** Wetting force time curves for 30 second preheating time.



**Figure 21.** Wetting force time curves for 5 second preheating time.

The summary of the wetting balance test results is listed in Table 4. Significant differences in the wetting characteristics of three types of solder paste were observed in response to paste aging time. Paste C showed an order of magnitude drop in the wetting force for just 5 sec of preheat time. With lower wetting forces, the solder joint formation gets hindered as a result of poor flux activity for the removal of surface level oxides and contaminants. The increase in the wetting time in the case of paste material C also leads to lower activity. In this study, wetting force is the dominant parameter in addressing the reaction activity of the flux component in the paste. Material A exhibited significantly less changes in the wetting force compared to the paste materials B and C with preheat or aging time. SMT studies with these materials trended in a similar way, with higher HnP solder joint defect formation with C, lesser extent with B, and no sign of HnP for A.

**Table 4.** Summary data for solder ball and solder paste wetting study.

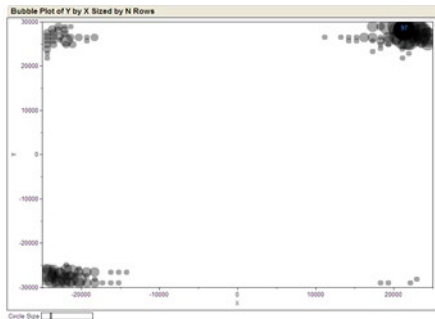
Material	Preheat time at 232°C, Sec	Normalized wetting force	Normalized wetting time
A	0	0.95	0.05
B	0	1.00	0.05
C	0	0.92	0.07
A	5	0.96	0.07
B	5	0.75	0.50
C	5	0.07	0.92
A	30	0.61	1.00
B	30	0.06	0.52
C	30	N/A	N/A



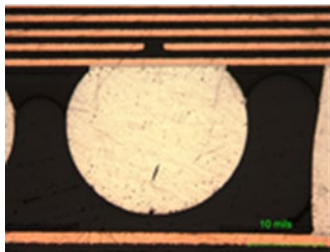
### Non Wet Open Defect

Another defect in the SMT process of package on board is Non Wet Open (NWO). Failure analysis of the NWO indicated a strong location commonality at the package corners, as shown in Figure 23. It was clear that the failure was related to the package warpage that resulted in non contact solder joints with the lands during the reflow. Optical cross-section image of a NWO as shown in Figure 24 reveals that even though paste is printed on board land pads prior to the SMT reflow, almost the entire paste is lifted onto the solder balls after the SMT reflow, without any formation of inter-metallic compound (IMC) layer on the pad surface.

The key hypothesis of the NWO issue was that the solder paste was lifted by the corner balls due to dynamic warpage of the large package, in addition to preferential adhesion of the paste to the solder balls over the land pads. For this NWO failure, it was found that one of the key factors was the good adhesion of the paste to the corner solder balls that led to paste lifting at elevated temperature and left-over flux residue on the solder balls. In this case, it was pondered whether baking or oxidation of solder ball surfaces would reduce the extent of preferential adhesion of the paste to the solder ball to avoid NWO formation. In order to study the effect of pre-baked solder balls on the wetting characteristics of the paste, the solder balls from two suppliers were subjected to two bake conditions (175°C /24hrs. and 200°C /1hr.) in air.



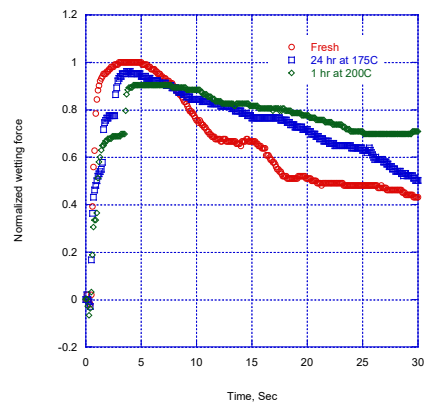
**Figure 23.** Mapping of NWOs in multiple packages, showing a strong location commonality at package corner.



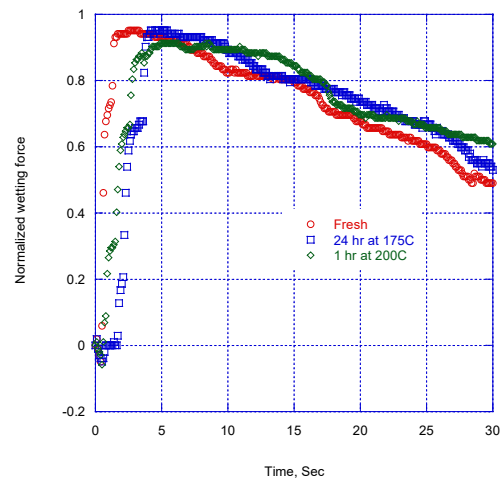
**Figure 24.** Cross section optical image of typical NWO joint on the corner balls resulting from paste lifting.

The wetting characteristics and oxide thickness of the solder balls from both supplier A and supplier B were compared at

both incoming and post-baked conditions. Figures 25, 26, and Table 5 indicate that the wetting force was slightly decreased, but the wetting time increased relatively for the post baked solder balls with a ~2X oxide thickness increase for supplier A and a ~5X oxide thickness increase for B. In the case of 175°C/24hr baked condition, the wetting time for supplier A was significantly less in comparison to that of supplier B. This suggests the adhesion characteristics of the paste on the solder balls could be optimized through the bake. However, a significant drop in the wetting time of the solder balls from supplier B that baked at 200°C/1hr was observed and might be attributed to the roughening of the solder ball surfaces.



**Figure 25.** Effect of bake on wetting for solder ball A.



**Figure 26.** Effect of bake on wetting for solder ball B.

**Table 5.** Summary data for effect of solder baking on solder ball and solder paste wetting

Solder ball	Solder ball bake condition	Normalized wetting force	Normalized wetting time
A	Fresh	1.00	0.26

A	24 hr at 175°C	0.96	0.32
A	1 hr at 200°C	0.91	0.63
B	Fresh	0.96	0.19
B	24 hr at 175°C	0.95	1.00
B	1 hr at 200°C	0.96	0.49

To validate the above wetting test results, a set of SMT experiments was performed with the post-baked solder balls. It was found that the oxidation of post-baked solder balls resulted in a significant improvement in NWO performance. For example, with a sample size of 50 units, the additional bake of solder balls from the supplier B at 200°C for 1hr, and at 175°C for 24hrs showed a NWO-free SMT process. This indicates that the adhesion of the paste to the solder balls could be tailored by oxidation of solder balls through pre-baked process. The indication was further reinforced with the finding on the control leg where the units that were built without pre-baked condition consistently gave rise to 10% of NWO failure rate. It was also observed that the wetting force obtained in this study did not show any significant difference in response to subtle differences in surface oxide thickness of a few nanometers. Reliability testing of packages with second level solder balls require several reflows in air to check for any abnormal failures in regard to the moisture exposure. A typical reflow process has a peak temperature between 230 and 240°C and remaining above liquidus temperature for about 45 seconds. The wetting characteristics of solder balls post reflow is of general interest in understanding solder joint formation at SMT.

The wetting characteristic of the solder balls from supplier B were tested with the solder paste after 1X and 2X reflows. Pre-heating of the solder paste was maintained at 232°C for 5 seconds. Figure 27 and Table 6 show a slight reduction in wetting force of ~6% after 2X reflow as compared with the fresh solder ball. While it was expected to observe a decreasing trend in the wetting force with additional reflows, there was no obvious trend observed in the wetting time. A slight increase in wetting time was seen on 1X reflow, but no difference was shown between 2X reflow and the fresh solder ball. In general, one expects higher extent of solder surface oxidation of the solder ball at liquidus temperature in air. However, the kinetics of Sn based solder ball oxidation is very slow [6] and the solder ball surface oxides likely got replaced with molten Sn during reflow. This explains the minimal effects on wetting time observed on the paste with the reflowed solder balls. Also included in this study was the effect of 20 sec paste pre-heat time at 232°C for 2X reflowed solder balls. In this case, a significant increase (50%) in wetting time was noted with ~10% reduction in wetting force. This was believed to be due to evaporation of low boiling temperature flux components in the paste which results in increased viscosity and hence leading to reduction in efficiency of oxide removal.

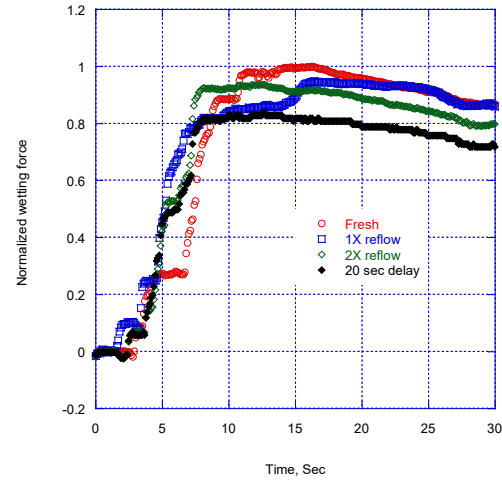


Figure 27. Effect of reflow on solder ball wetting.

Table 6. Summary data for effect of solder ball reflow on solder ball and solder paste wetting.

Sample	Preheat time, Sec	Normalized wetting force	Normalized wetting time
Fresh ball	5	1.00	0.65
1X reflow	5	0.98	0.89
2X reflow	5	0.94	0.65
20 sec delay time	20	0.89	1.00

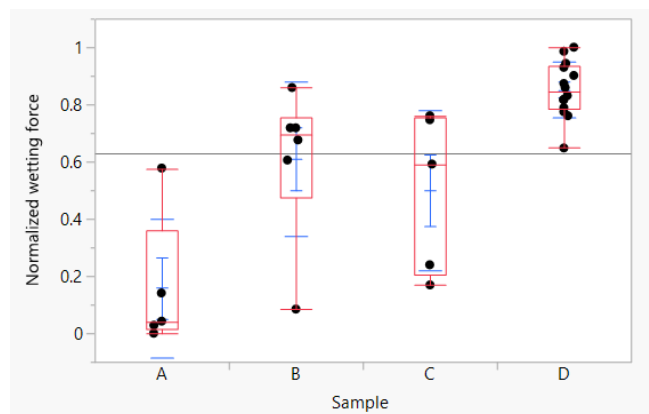
Reflow parameters, package warpage, solder ball, and solder paste formulations can all contribute to NWO defects. The NWO defect rate varied between solder pastes. In order to investigate the effect of solder wetting properties of solder pastes on the NWO defects, four solder pastes from three different suppliers were chosen for the copper wire on solder paste wetting test. Both fresh and baked solder pastes were used for the solder wetting balance test. The test parameters in Table 7 were used for the test.

Wetting force of fresh pastes in the copper wire on solder paste wetting test is shown in Figure 28. Solder paste A has the lowest wetting force. The wetting force of pastes baked at 200°C for 1 min in the copper wire on solder paste wetting test is shown in Figure 29. The paste was baked on a hot plate for 1 minute after it was printed on a copper plate. The wetting force for solder paste A dropped almost to zero. Paste A was eliminated from further tests. The wetting force of pastes baked at 200°C for 5 min in the copper wire on solder paste wetting test is shown in Figure 30. The wetting force for paste B was dropped to zero and it was eliminated from further tests. The wetting force of pastes baked at 200°C for 10 min in the copper wire and

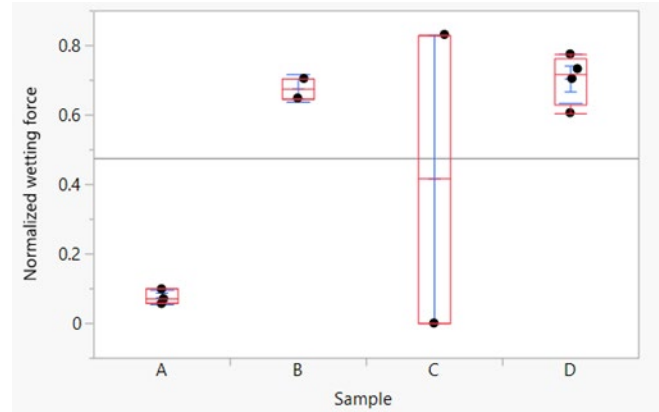
solder paste wetting test is shown in Figure 31. The result shows that solder paste D has the highest wetting force after baking. The wetting time of fresh pastes in the copper wire on solder paste wetting test is shown in Figure 32. Paste A has the longest wetting time among the four solder pastes. The wetting time of pastes baked at 200°C for 1 min in the copper wire on solder paste wetting test is shown in Figure 33. Although paste A has a short wetting time, this is not a good indicator for good wetting. A good wetting paste needs to have both high wetting force and short wetting time. The wetting time of pastes baked at 200°C for 5 min in the copper wire on solder paste wetting test is shown in Figure 34. Paste D had the shortest wetting time. The wetting time of pastes baked at 200°C for 10 min in the copper wire on solder paste wetting test is shown in Figure 35. Overall, Paste D had the best wetting properties from this study, which correlates with its yield in the SMT process. Paste D had the least NWO defects.

**Table 7.** Test Condition for copper wire on Solder paste Test.

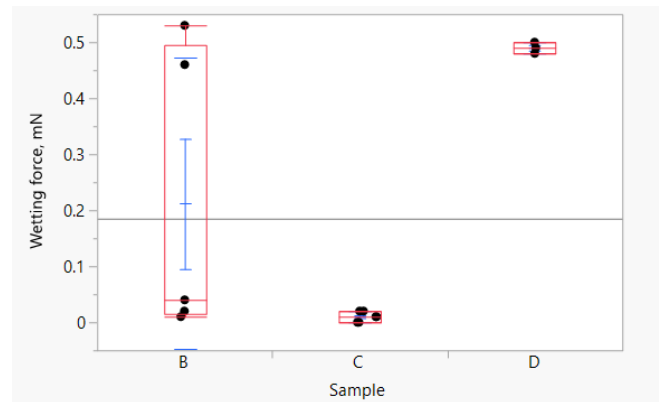
Test Speed, mm/s	0.2
Immersion Depth, um	10
Immersion Time, Sec	10
Peak Temperature, °C	235
Cu wire diameter, um	510
Stencil aperture:, mm	3.2
Stencil thickness, um	200



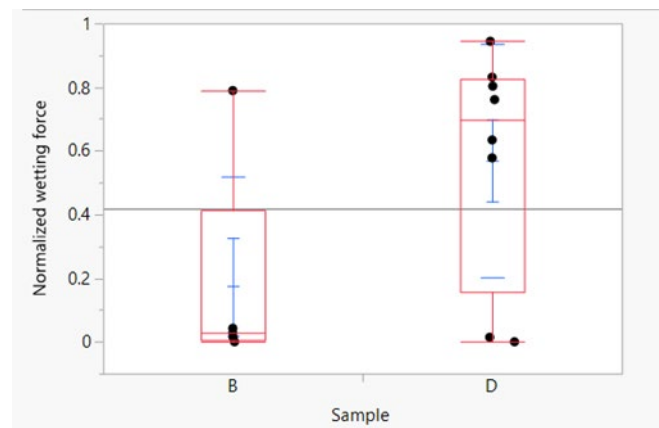
**Figure 28.** The wetting force of fresh pastes in copper wire on solder paste wetting test.



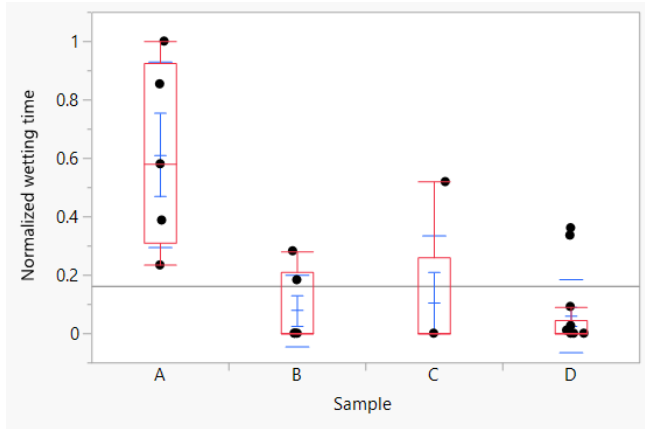
**Figure 29.** The wetting force of pastes baked at 200°C for 1 min in the copper wire on solder paste wetting test.



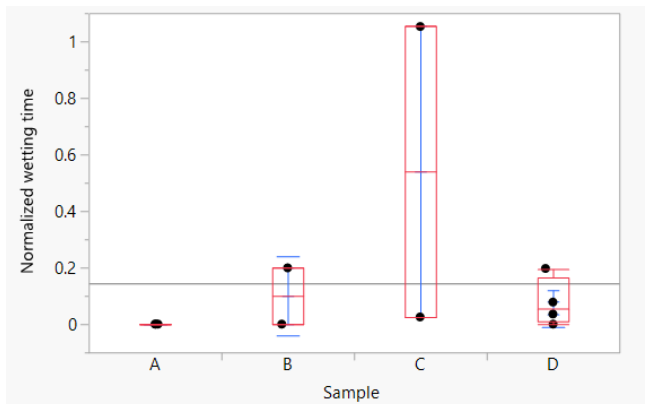
**Figure 30.** The wetting force of pastes baked at 200°C for 5 min in the copper wire on solder paste wetting test.



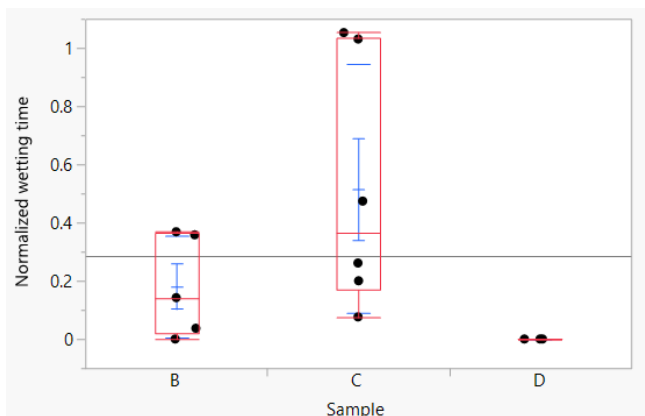
**Figure 31.** The wetting force of pastes baked at 200°C for 10 min in the copper wire on solder paste wetting test.



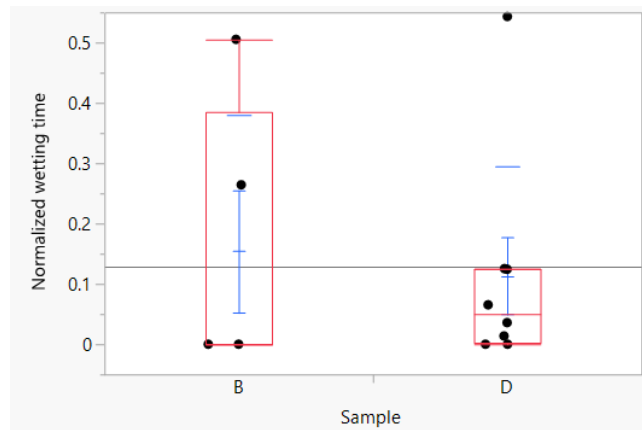
**Figure 32.** The wetting time of fresh pastes in the copper wire on solder paste wetting test.



**Figure 33.** The wetting time of pastes baked at 200°C for 1 min in the copper wire on solder paste wetting test.



**Figure 34.** The wetting time of pastes baked at 200°C for 5 min in the copper wire on solder paste wetting test.



**Figure 35.** The wetting time of pastes baked at 200°C for 10 min in the copper wire on solder paste wetting test.

## CONCLUSIONS

The rheology properties of flux and paste are quite complicated due to their non-Newtonian fluid behavior. The effect of time and deformation histories on the viscosity of flux and paste were studied. The low shear rate viscosity and yield have related to some process issues. The low shear viscosity has a workable window. Too high will cause stringing and too low will cause over spread and bridging. Stringing will cause to ball fall off from deposited paste. High shear rate viscosity for fluxes were measured with a capillary rheometer. Extensional viscosity and break time for paste were measured with an extensional rheometer. The required material properties can be very different from process to process. New process drives new material development and thus new characterization techniques need to be developed to face new challenges.

Wetting balance tests have been successfully performed for the characterization of paste and solder ball wetting behaviors for the resolution of HnP defects and NWO defects. In addition, the understanding of the effect of solder ball reflow in relation to paste wetting were also acquired in this work.

In general, wetting test results showed that paste aging and improper paste used in SMT resulted in significant reduction in the wetting force. However, in the case of NWO defects, the oxidation of the solder ball surface showed a measurable increased in wetting time with negligible effect in the wetting force. For the case of multiple-reflowed solder ball, a decreasing trend in the wetting force was observed.

The effect of solder paste aging on the solderability was studied. Solder pastes showed different levels of wetting in the Cu wire on paste test, which correlated with the NWO defects of the pastes. Aging has more impact on solder paste wetting properties than solder ball.

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