

# Investigating the Effects of Temperature, Paste Height and Time on the Rolling of Solder Paste

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## Abstract

Based on application, it was found that the rheological properties of the solder paste play an important role in the print performance. Temperature-dependent rheological behaviour of the lead-free solder paste and flux medium used for flip-chip assembly applications were studied. Two commercially available lead-free solder pastes P1 (LF318) and P2 (LF328) prepared from fluxes F1 and F2 were used. The temperatures under investigation were 15°C, 25°C, and 35°C. All the results recorded were put into the Gauge calculator. The snap-off height variable and the condition of the printing equipment were used to determine the print height. Slump test was used to determine the slumping behaviour at room temperature and during reflow. Results show that the properties of solder paste are immensely affected by paste heights, high temperature variations, time and humidity.

**Keywords:** Surface Mount Technology (SMT), Printed Circuit Board (PCB) Assembly, Slump Test, Reflow Soldering, Solder Paste.

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## 1. Introduction

According to Ray, (1997) the current methodological approach of manufacturing conventional electronic assemblies have essentially reached their limits when cost, weight, volume, and reliability are considered. Surface mount technology (SMT) makes it possible to achieve reliability in producing more assemblies at reduced weight, volume and cost. Basically, SMT is used to mount electronic components on the surface of PCBs or substrates. Thus as the trend toward miniaturization and compact product continues, the assembling process of the electronic component or surface mount devices (SMDs) becomes more complex and there is a need for some form of automation (Lau *et al.* 1996). In other words, the automated process of assembling the electronic component or surface mount devices is known as SMT by means of using solder paste as interconnecting material to provide electrical, thermal and mechanical function (Huang *et al.*, 2002, and Nguty *et al.*, 2001).

Greater percentage of the components used on a printed circuit board assembly (PCBA) are based on surface mount technology (SMT) being assembled using solder paste printing (SPP) and then fixed by the reflow soldering (RS) process (Lau and Yeung, 1996). There are three major challenges in the fine pitch stencil printing process. These challenges are the solder paste formulation, the stencil manufacturing process and the optimisation of the process parameters in stencil printing. Stencil printing account for a great percentage of defects in SMT. One of the major courses of these defects is the solder paste behaviour during stencil printing, which is greatly affected by many parameters such as temperature, time, height of paste and viscosity. Apparently, it is necessary to embark on an intensive study on the effects of not only the temperature (Durairaj *et al.*, 2002) but, time and paste height on solder paste with respect to its printing performance.

## 2. Methodology

Two commercially available lead-free solder pastes P1 (LF318) and P2 (LF328) prepared from fluxes F1 and F2 were used as shown in Figure 1. The solder particles for all the paste samples are made of the same tin-silver-copper alloy with a melting point of 217°C. Both P1 and P2 have a percentage metal loading of 88.5%. P1 is a Type 3 solder paste and P2 is Type 4. The flux medium makes up for 11.5% of the solder paste weight. The flux medium contains a stable resin system and slow evaporating solvents with minimal odour. The formulation meets the requirements of the Telcordia (formerly known as Bellcore) GR-78-CORE and ANSI/J-STD-004 for a type ROL0 classification.



**Figure 1:** Lead-free Solder Paste LF318 and LF328

The two lead-free solder pastes LF318 and LF328 used were separated into nine different jars respectively, making it eighteen jars in a whole. Each jar contained one hundred grams of lead-free solder paste. This separation was to allow for the number of experiments that was carried out in the study. For quick and easy identification, LF318 was named P1 and LF328 was named P2. The temperatures under investigation were 15°C, 25°C, and 35°C. As shown in table 1, two solder pastes P1 and P2 were stored at each of these temperatures for 24hours, 48hours, and 72hours respectively, making it nine experiments for each solder paste.

**Table 1:** Storage parameters for P1 and P2 at the thermal chamber.

Solder paste	Temperature (°C)	Storage time (minutes)	Storage time (minutes)	Storage time (minutes)
P1	15(°C)	1440	2880	4320
P2	15(°C)	1440	2880	4320
P1	25(°C)	1440	2880	4320
P2	25(°C)	1440	2880	4320
P1	35(°C)	1440	2880	4320
P2	35(°C)	1440	2880	4320

### 3. Process parameters

The printing parameters used for the experiment are outlined in table 2. Previous work reported by Marks et al (2007) was used as a benchmark.

**Table 2:** Printing parameters

Printing parameters	Values used
Printing/Squeegee speed	20mm/sec
Squeegee loading (or pressure)	8kg
Separation speed	100% (3mm/sec)
Snap-off/Print gap	0.0mm (On-contact printing)

### 4.0 Experimental result

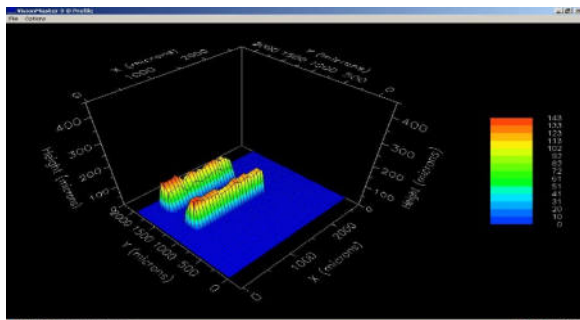
All the results recorded were put into the Gauge calculator. The R&R% got was 19.43%. This is well below 30% which is the acceptable standard. This means that the measurement device is capable of the task.

#### 4.1 Plotting the average

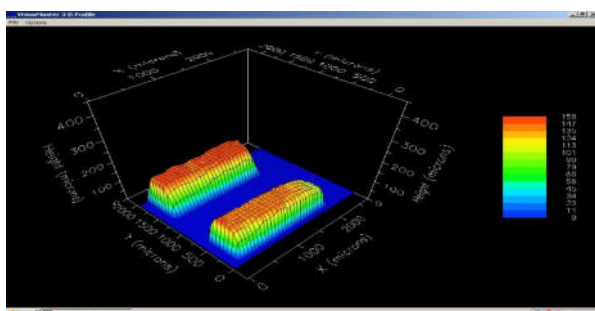
In the formation of solder joints, print thickness determines the volume of solder in the joint. The thickness of the paste print is determined by the thickness of the metal mask of the stencil. Though stencil thickness controls the paste thickness, other variables such as snap-off height and the condition of the printing equipment determine the print height. The reflow solder height is not just a factor of solder paste height only, but also the metal content of the paste. Due to the fact that the print gap for the experiment is 0.0mm, the snap-off height becomes the thickness of the stencil which is 125µm. Therefore at this stage, the average of the average heights got from the regions in the chosen locations on the stencil was computed.

In each of the two locations under investigation, four regions were measured. In each region, two deposits were measured. The averages of the two deposits were taken. Subsequently, the averages of the locations were then

computed based on the four regions. A sample of the 3-D image of the measured heights is shown in Figures 2 and 3. Figure 2 shows the height of P1 while Figure 3 shows that of P2



**Figure 2:** Image of the Solder Paste Deposit for Location 1

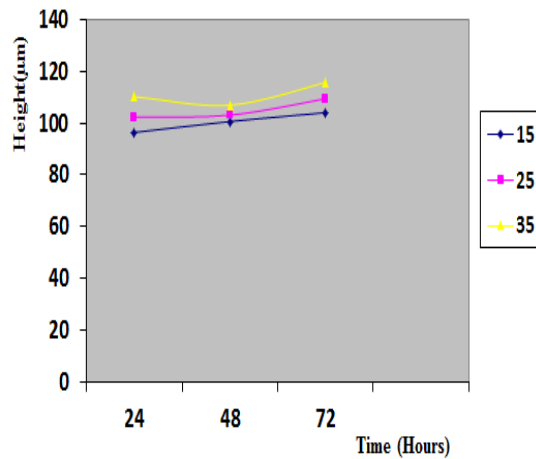


**Figure 3:** Image of the Solder Paste Deposit for Location 2

The blue base indicates the reference point, which is surface of the substrate. The red colour indicates maximum height. The results from the computed averages are shown in Tables 3 and 4, while Figures 4 and 5 show the graphs of the computed average height against the solder paste storage/aging time with respect to the storage temperatures.

**Table 3:** Results for solder paste deposit heights for LF318.

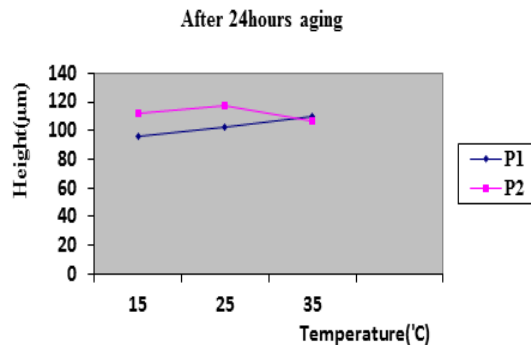
LF318 = P1					
Storage temperature (°C)	Storage time (Hours)	Target height (µm)	Height for Location 1 (µm)	Height for Location 2 (µm)	Average height (µm)
15	24	125	103.36	89.5	96.43
15	48	125	91.63	109.66	100.65
15	72	125	92.24	115.9	104.07
25	24	125	89.15	115.58	102.37
25	48	125	83.48	122.74	103.11
25	72	125	102.08	116.79	109.44
35	24	125	100.25	120.15	110.2
35	48	125	95.26	118.69	106.98
35	72	125	112.02	119.43	115.74



**Figure 4:** Average Height against the Solder Paste Storage/Aging Time With Respect To the Storage Temperatures for LF318.

**Table 4:** Results for solder paste deposit heights for LF328

LF328 = P2					
Storage temperature (°C)	Storage time (Hours)	Target height (µm)	Height for Location 1 (µm)	Height for Location 2 (µm)	Average height (µm)
15	24	125	120.83	103.06	111.95
15	48	125	89.63	109.66	99.93
15	72	125	92.24	108.31	96.76
25	24	125	108.5	126.26	117.38
25	48	125	98.49	102.08	100.29
25	72	125	100.21	115.38	107.80
35	24	125	99.63	114.48	107.06
35	48	125	110.15	133.9	122.03
35	72	125	117.14	129.48	123.31

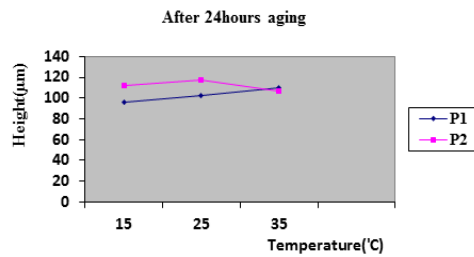


**Figure 5:** Average Height against the Solder Paste Storage/Aging Time With Respect To the Storage Temperatures for LF328

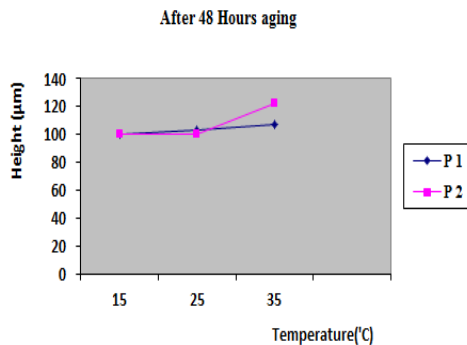
During the printing process for LF318 aged at 15°C for 24 hours, the solder paste just rolled minimally. The temperature of the solder paste during the printing was low, and that had a great effect on the solder paste viscosity. The low temperature made the solder paste viscosity to be too high. The temperature was not conducive for the rheological properties of the solder paste to be at its best. Therefore, the paste could not role, giving rise to skipping and low aperture filling which in effect caused ragged edges. This was one of the contributing factors to the low height seen after the printing. This is evident from the points of the height for 15°C in Figure 2.

It can be observed that as the temperature increased, the height against time also increased. This trend was seen for both P 1 and P 2, except for P 2 stored at 35°C for 24 hours. Normally, it would be expected that increase in temperature would give rise to decrease in height, given that higher temperature would cause the solder paste to

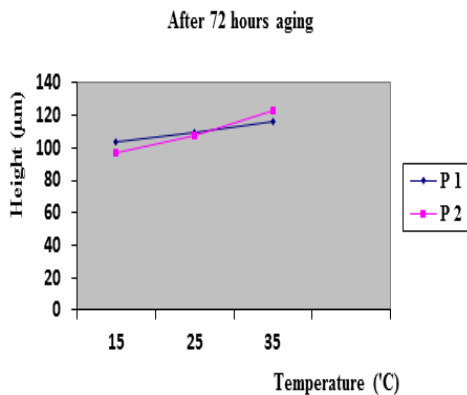
slump. Rather than decrease the height as the temperature increased, the height was increasing. This is because at low temperature, the paste's viscosity increases causing the solder paste flow to slow down or not to flow at all.



**Figure 6 (i):** Comparing solder paste deposit heights of P 1 and P 2 for 24 hours aging.



**Figure 6 (ii):** Comparing solder paste deposit heights of P 1 and P 2 for 48 hours aging



**Figure 6 (iii):** Comparing solder paste deposit heights of P 1 and P 2 for 72 hours aging

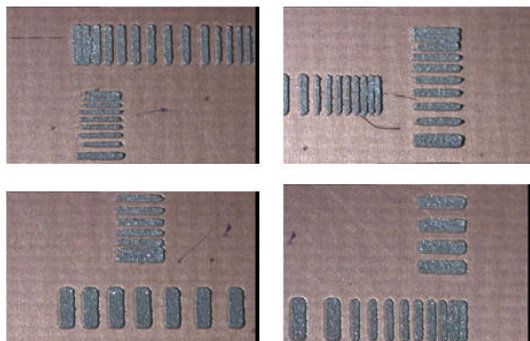
When the solder pastes were compared, it was found as shown in Figures 6 (i), (ii), and (iii) that the height increases as the temperature increases. This trend was seen as earlier discussed, for all the experiments except for P2 aged/conditioned at 35°C for 24 hours. This shows that increase in height with increase in temperature and or storage time is common for both P1 and P2. Judging from common trend of increased height with increased temperature, the behaviour of P2 conditioned at 35°C for 24 hours may be a special cause of variation.

Considering the relationship between paste heights, ability of the solder paste to roll during printing, viscosity, temperature and time, the results got in this experiment was compared with that got by Nguty and Ekere (2000). It was shown that there was an increase of 60% in paste viscosity for samples kept at room temperature apparently, longer time and higher temperature increases viscosity thereby increasing the tendency of the solder paste to roll. However, the temperature must not be excessive.

### 5.0. Slump Test Results

Lee (2002) stated that slump is a phenomenon where the paste viscosity is not high enough to resist the collapsing force exerted by gravity, and consequently results in spreading beyond the area to be deposited. Cold slump was

used to determine the solder paste behaviour. Cold slump refers to the slumping behaviour at room temperature while hot slump refers to slumping during reflow. Figure 7 shows the slump location that was visually observed using a Leica S6D zoom stereomicroscope. From the observations, paste stored at 35°C had the highest level of slumping.



**Figure 7:** Four Edges of the Slump Location for P1

### Conclusion

Considering the slumping behaviour of solder paste, it was believed that the height of the solder paste would decrease as the temperature increased. But this was not obvious, the height rather increased slightly as the temperature increased. This behaviour was as a result of some factors. First, paste was not able to roll at low temperatures such 15°C. Secondly, as the temperature increased, the paste rolled and was able to fill the apertures effectively. Therefore, considering this slumping phenomenon, the paste stored at 25°C for 48 hours produced the best results of good height with minimal slumping. The solder paste can be identified by its properties such as viscosity, normal force, density and surface tension when considered as a homogeneous and kinetically stable mixture. Considering the relationship between paste heights, ability of the solder paste to roll during printing, viscosity, temperature and time, the results achieved was compared and it was shown that there was an increase of 60% in paste viscosity for samples kept at room temperature apparently, longer time and higher temperature increases viscosity thereby increasing the tendency of the solder paste to roll. From the analysis, it is obvious that temperature, height and time have tremendous effects on the rolling of solder paste.

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