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**Development of Preheat on
Solderability Testing**

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Development of Preheat on Solderability Testing

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ABSTRACT

As a means of evaluating the solderability of components and PCB pads in electronics assemblies, testing using a wetting balance has become widely established. However, existing solderability testing is carried out on components at ambient temperatures, a process which is not representative of typical surface mount processing, casting some doubts on the relevance of the test results. As part of a DTI-supported programme to further develop solderability testing, NPL has undertaken a study of the effects of pre-heating the components prior to the test immersion, in a way which more closely represents reflow soldering conditions.

This report describes the development of a suitable IR pre-heating system which can be used to heat test samples to controlled temperatures prior to test immersion, allowing testing at temperatures similar to those of reflow soldering. An optimum pre-heat temperature to achieve good solderability appears to be 55 °C below the solder melting point. Higher preheat temperatures can provide misleading wetting data due to flux volatilisation.

Further, the results from an experimental matrix involving two solders (SnPb and SnAgCu), six solder test temperatures, superheats (temperature above the melting point) ranging from 5 to 50 °C, and two fluxes, have been used to identify a set of suitable solderability test parameters. Using the preheating, good wetting can be achieved for SnPb with only 30 °C superheat (i.e. an equivalent reflow temperature of 214°C). In the case of SnAgCu alloy, a 10 °C superheat (i.e. reflow temperature of 237°C) is sufficient to achieve good solderability.

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1 INTRODUCTION

Low defect levels are crucial to any electronics assembly process. However, achieving this is a complex issue, and one potential source of processing defects is the poor solderability of the components. Consequently, a means of measuring the ability of molten solder to wet component terminations (i.e. solderability) is essential, but solderability is a function of many variables, including temperature and flux chemistry. Solderability testing, as described in the IEC 68000 series, has always used a test temperature of 235 °C and a 0.5% activated rosin flux, with SnPb solder. This approach does yield data that can be correlated with process yield [1], but it does use conditions that are unrepresentative of typical surface mount reflow processing. Consequently circuit board assemblers consistently voice concerns over the test procedures and query the relevance of the resulting data. In a DTI-supported programme, NPL has sought to address these issues. In a previous report [2] the use of generic no-clean fluxes, representative of industrial fluxes, was described, and in this work the second issue of test temperature is addressed.

In the solderability test, the component under evaluation is held above the molten solder for a short period of a few seconds, before being immersed to a fixed depth. The component temperature will be just a few degrees above ambient, by virtue of its proximity to the molten solder prior to immersion. The speed of wetting will be dependent on the temperature of the surface being tested. Solderability is therefore critically dependent on the heat transfer into the component and the temperature rise of the termination being tested. This sequence of events is different to that in reflow soldering, in which there are long periods of pre-heating (2 – 3 mins) at elevated temperatures (~150 °C) before a rapid rise to the reflow temperature of ~215 °C. Ideally the solderability test would be conducted at this peak temperature, but lowering the solderability test temperature to 215 °C causes significant delays in the onset of wetting and variability in the results. Hence, if a test temperature of 215 °C is going to be realised, an equivalent of preheating the components is needed for the wetting balance test. In this study the performance of an experimental infrared system to preheat components prior to testing, is evaluated.

Solderability tests provide a measure of the quality of a surface to be wetted by solder, and a common solderability index is the wetting time T, the time required for the force to reach two thirds of its maximum force. In this report this index of wetting time is measured and the data used to assess the wetting properties of different component types, with different finishes, under different preheating temperature.

It is instructive to consider the actual reflow and testing temperature profiles. Testing carried out according to existing methods on cold components, is shown in Figure 1. The molten solder wets the component directly while it is still at room temperature. The component temperature profile is shown in Figure 2, and starts from the mid point B, and follows the profile B-C-D. This rapid increase in temperature is not typical of reflow and wave soldering, where preheating is applied. In Figure 2 another profile starting at A is also shown. This profile, incorporating a pre-heat stage, is more typical of manufacturing and hence has more relevance to users, and is the profile achieved in the solderability work reported here. It follows the profile A-C-D.

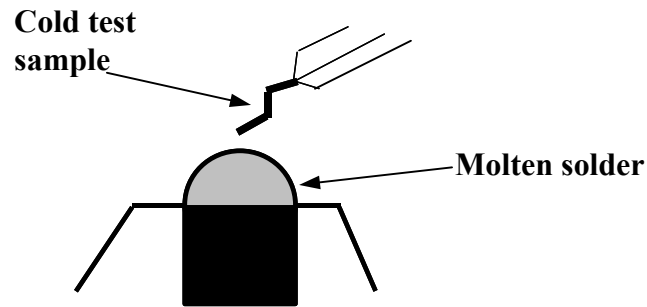


Figure 1: Solderability testing

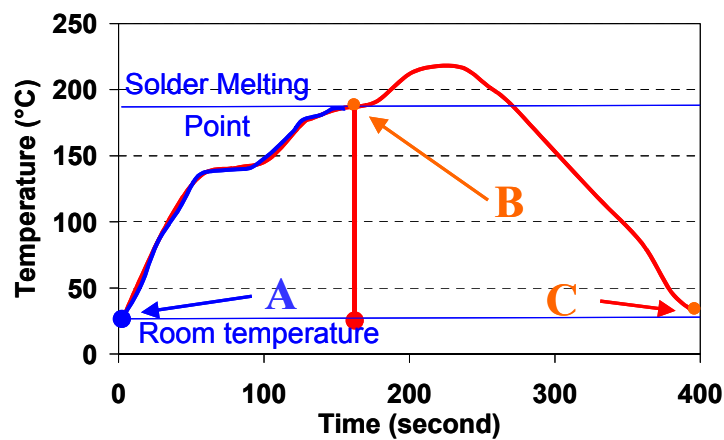


Figure 2: Component temperature profiles during solderability testing and reflow process

2 EXPERIMENTAL

2.1 EXPERIMENTAL MATRIX

* Pre-heat temperatures	Three for each solder alloy Varied between 25 °C and 85 °C below the solder alloy melting temperature.
* Component types	Four – R0603, R1206, SOIC, BGA PCB pads with different finishes
* Solders	Two - SnPb and SnAgCu
* Test temperatures	Four for SnPb (superheat from 20 °C to 50 °C) Six for SnAgCu (superheat from 5 °C to 50 °C)
* Fluxes	Two – (i) Actiec5 (solvent-based with 25% rosin and 0.5% halide according to IEC 60068-2-20) (ii) AOA (iso-propanol based flux with three carboxylic acids (adipic, succinic, glutaric) each added at 1.5% level and rosin (1.5%)[1]

The components were tested in the as-received and aged conditions, and the experimental matrix is summarised in Table 1 ageing was at 155°C for 4 and 8 days for the capacitors and SOICs.

Table 1: Experimental matrix

Component	Finish	Superheat (°C)	Preheat (°C M.P)	Solder alloy	Ageing	Flux
C1206	Sn	20, 30 40, 50	R.T.	SnPb SnAgCu	As-received Aged	Actiec5
PCB pad	AuNi		-25, -55			
SOIC14	Pd		-85			
PLCC20	SnPb	20, 30, 40, 50	RT -55	SnAgCu	As-received	Actiec5 AOA flux
C1206	Sn	5 10	RT -55	SnAgCu	As-received	Actiec5
PCB pad	AuNi					
SOIC14	Pd					
PLCC20	SnPb					

2.2 SOLDERABILITY TESTING

Solderability testing was performed using a Concoat MUST II instrument in the solder globule mode, and the test parameters were set according to the Measurement Good Practice Guide [3]. An exception was made for immersion time, for which was 20 secs was allowed to reach the maximum force due to some low test temperatures. Each flux was used for both globule and components. Three tests were performed on each device.

2.3 IR PREHEATING SYSTEM

An infrared (IR) lamp was developed for preheating the test components, and mounted on the Concoat MUST II instrument. The IR beam was well defined and controlled by a thermocouple, as shown in Figure 3, and the temperature profile was controlled using additional routines running on the MUST instrument. Figure 4 demonstrates that the temperature could be accurately controlled. However, careful consideration was given to the location of the thermocouple which provides the necessary feedback for the control of the IR system. Ideally the thermocouple should be on the component termination to be tested, so that the set temperature will be exactly the preheat temperature for the components. However, in most cases it is not possible to fix the thermocouple directly on the termination, as this would interfere with the wetting. Consequently, the thermocouple was fixed on the supporting clip, close to the test component termination, as shown in Figure 5. There was a slight temperature difference between the thermocouples on the clip and on the component termination as the IR intensity was not uniform due to a small angular dispersion - the mid position along the dotted line experienced the highest temperature. Therefore another thermocouple was fixed on the component termination to measure this temperature difference, as shown in Figure 6. The temperature difference between the two thermocouples for a C1206 component is shown in Figure 7. It is evident that the component temperature follows the clip temperature accurately, but with a stable offset. Subsequently, the temperature on the component was measured and calibrated for each type component and PCB pad.

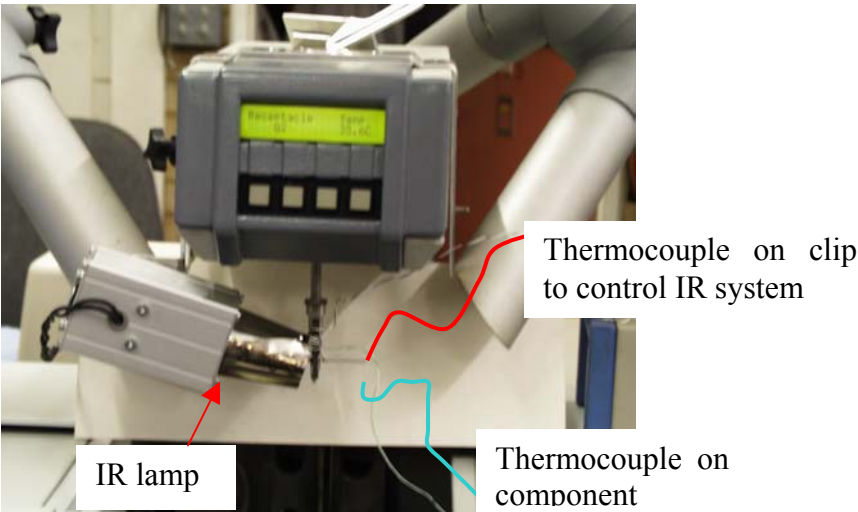


Figure 3: Solderability testing with an IR system

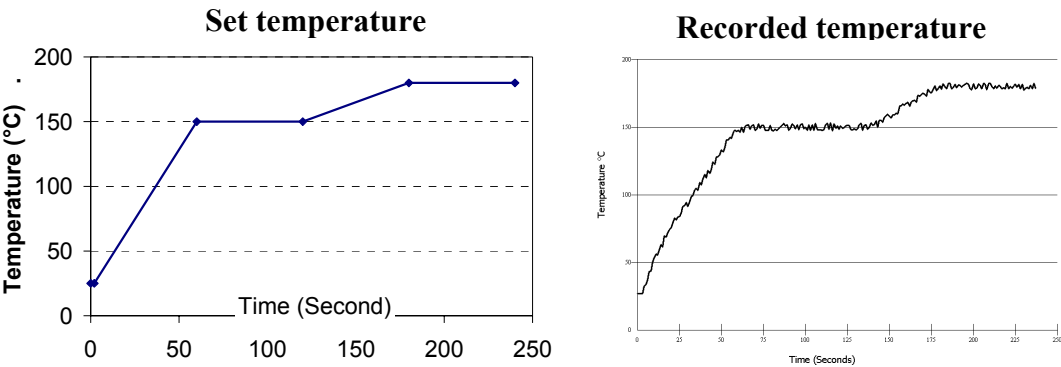


Figure 4: An example of set and recorded temperatures

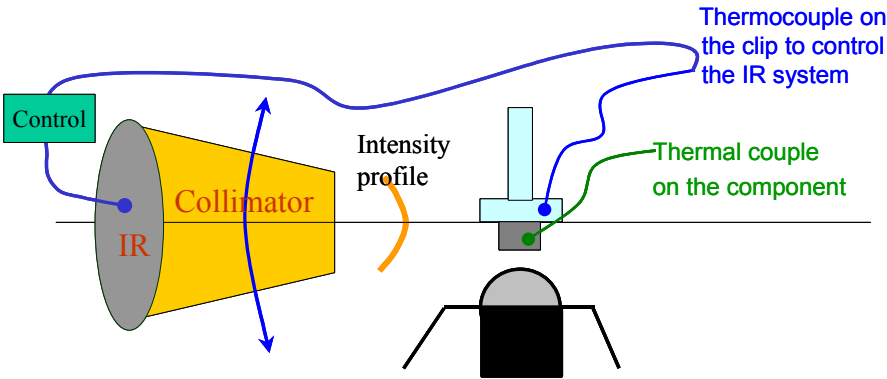


Figure 5: IR intensity profile

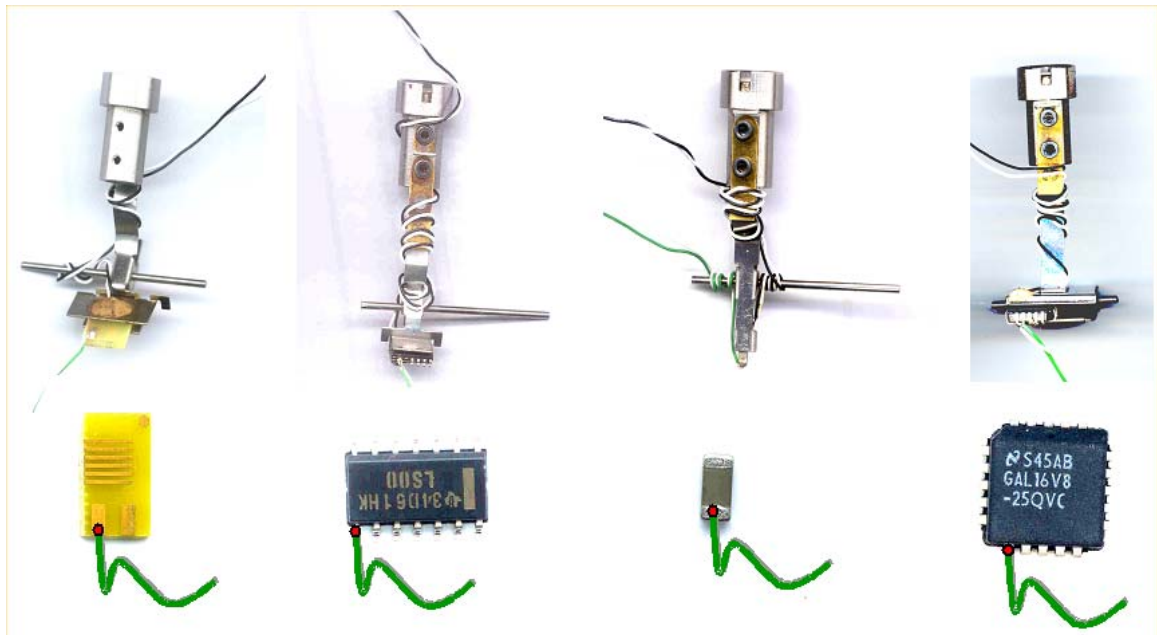


Figure 6: The positions of the thermocouples on clip and component

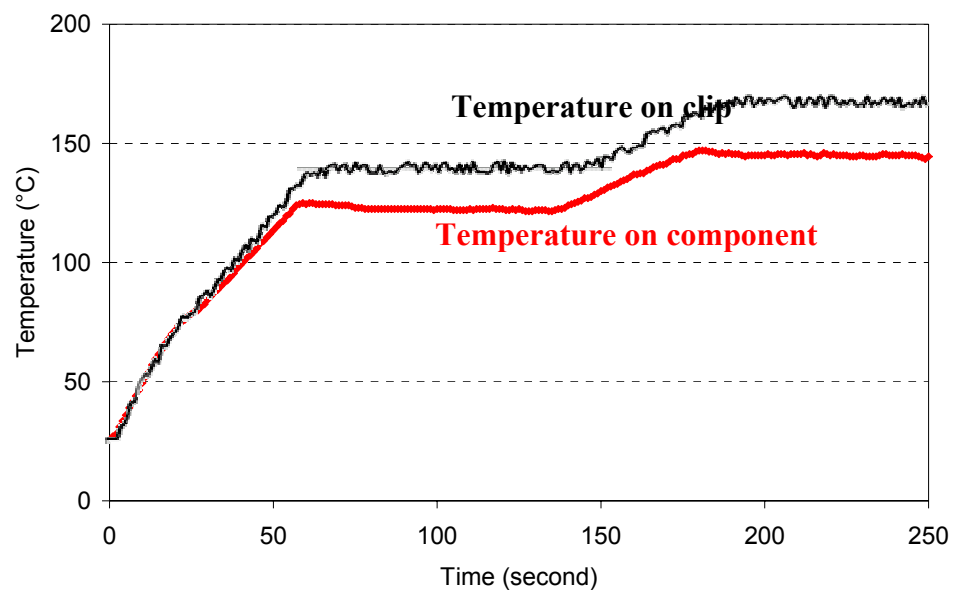


Figure 7: Temperature difference between two thermocouples

2.4 PREHEAT TEMPERATURE PROFILE SETTING

Having established a procedure for setting the preheat temperature on the component the temperature profile for the test component was established. Different preheat temperature profiles for solderability testing were assessed using a C1206 component with SnPb solder alloy at 214 °C, and a preheat temperature of 55 °C below the melting point, i.e. 159 °C. The preheating time ranged from 1 to 5 minutes with different ramp and hold times, as illustrated in Figure 8 - the times for the ramp and hold are given in seconds. The wetting curves with different preheat profiles are shown in Figure 9 - the wetting force at 2 seconds and the time to 2/3 the maximum force are given with standard deviations. There was a significant effect on solderability between the different preheating profiles. With the same preheating temperature the fastest profile gave the best repeatability. However, extended preheat delayed wetting and increased variability of results, and this effect is attributed to flux exhaustion on the component. Therefore *the shortest temperature profile* (30 seconds ramp and 30 seconds dwell) *was used as the preheating time for all subsequent tests.*

The three preheat temperature profiles, measured on the test components for each solder alloy, are shown in Figure 10. The test components were preheated to the preheat temperature over 30 seconds, then after 30 seconds hold at the preheat temperature, the component was dipped into the solder. The equipment was calibrated to achieve the correct preheating temperature for each component type and PCB pad.

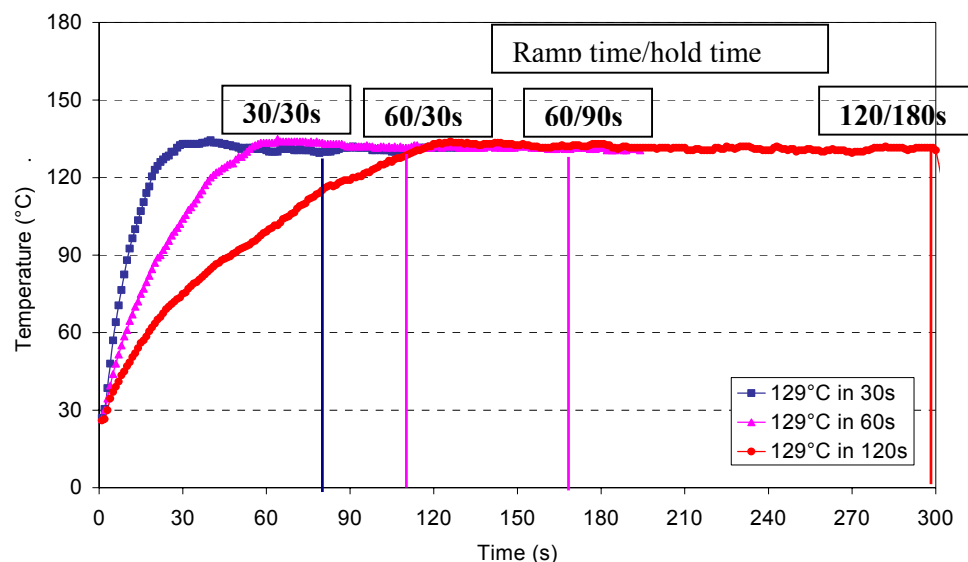


Figure 8: Different temperature profiles for trial

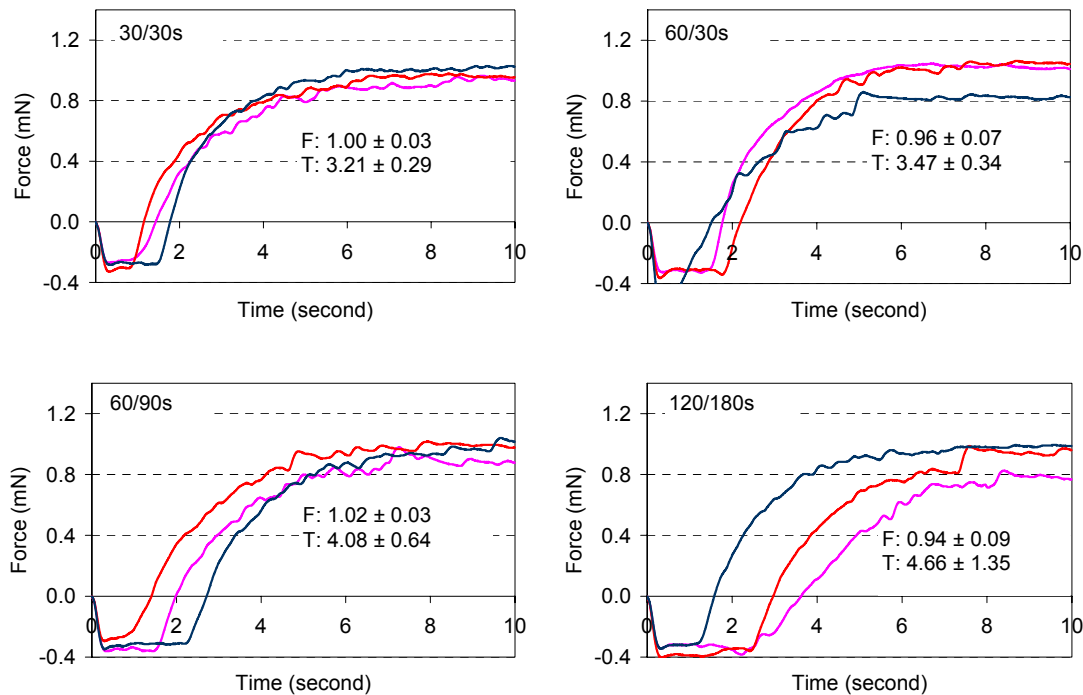


Figure 9: Wetting curves with different preheating profiles for C1206 component with SnPb solder alloy

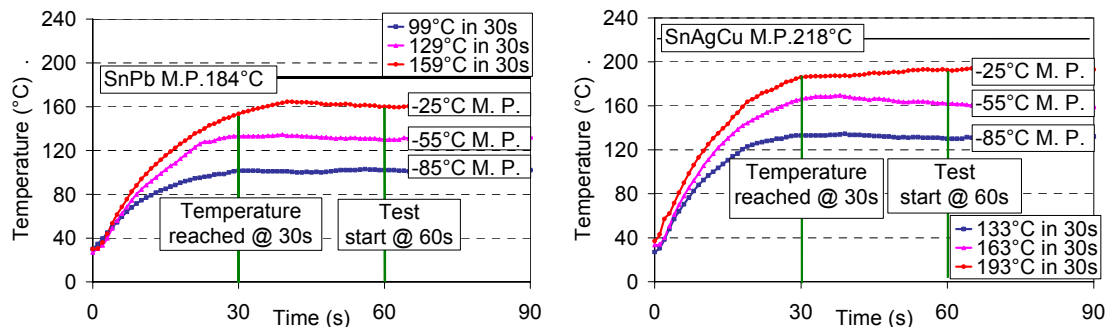


Figure 10: Three preheat temperatures for each solder alloy

3 RESULTS AND DISCUSSION

In Sections 3.1, 3.2 and 3.3 the effects of preheat temperature, solder alloy, and alloy temperature, are discussed. In Section 3.4 the effect of flux is studied.

3.1 PREHEAT TEMPERATURE

The wetting times with preheating temperature for both solder alloys on as-received and aged tin-finished chip capacitors, C1206, are presented in Figure 11 and 12 respectively. The Figures are plotted with increasing preheat and are defined relative to the melting point - the curves are for increasing solder temperature, the temperature above the melting point, or superheat. Similarly, the results for palladium-finished

SOIC14 are presented in Figure 13 and 14, and those for AuNi-finished PCB pads in Figure 15. The capacitors and SOICs were aged at 155 °C for 4 and 8 days respectively.

There are a number of salient points to note from these Figures:

- For the tin-finished chip capacitors there is a clear reduction in wetting time with increasing preheat temperature on as-received components, but on the aged component the trend was not as clear, particularly for the SnPb solder alloy. Similar trends were observed with the SOIC and PCB pads.
- A preheat is required with lower solder temperatures that are typical of peak reflow temperatures. As the preheat temperature is increased there will be a greater tendency for flux volatilisation to occur, and in some of the results an increase in wetting time was observed. At higher preheat temperatures more scatter was observed in the wetting times.
- Considering all the results, in order to achieve quick wetting, repeatable behaviour, a preheat condition of 55 °C below the melting point is optimal for both solder alloys.
- With this preheating good solderability can be achieved with low superheat; only 30 °C of superheat is needed to achieve acceptable solderability for SnPb alloy, and 20 °C for SnAgCu alloy. Therefore the solderability testing temperature can be reduced to 214 °C for SnPb alloy and 237 °C for SnAgCu alloy, which are closer to typical reflow temperatures.

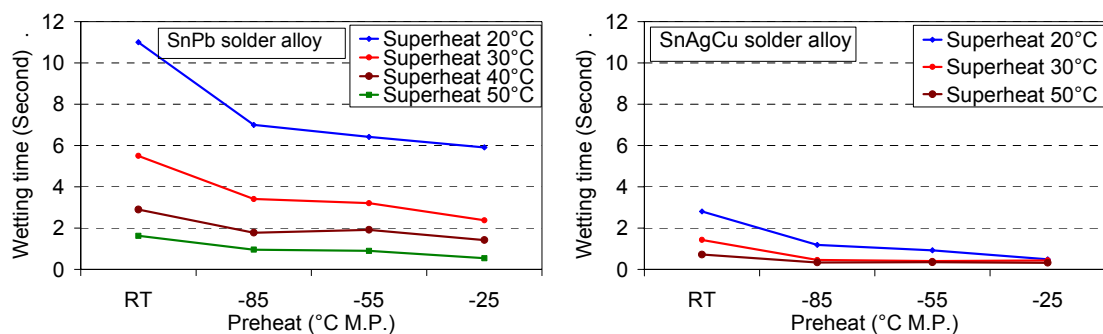


Figure 11: Wetting time with preheat temperature on as-received tin-finished C1206

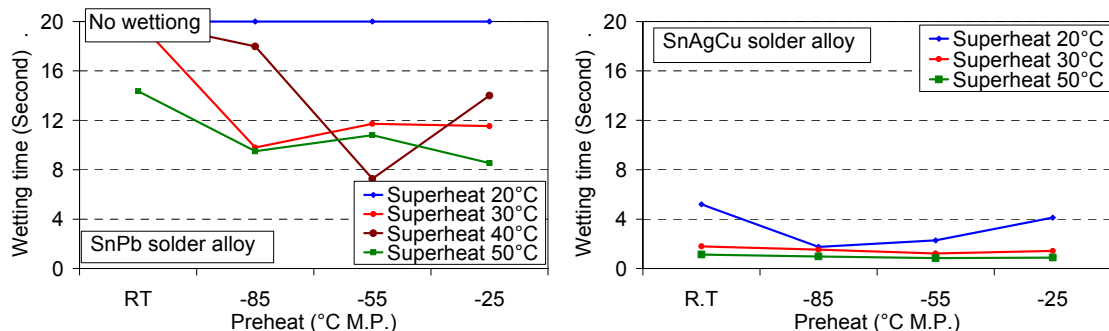


Figure 12: Wetting time with preheat temperature on aged tin-finished C1206

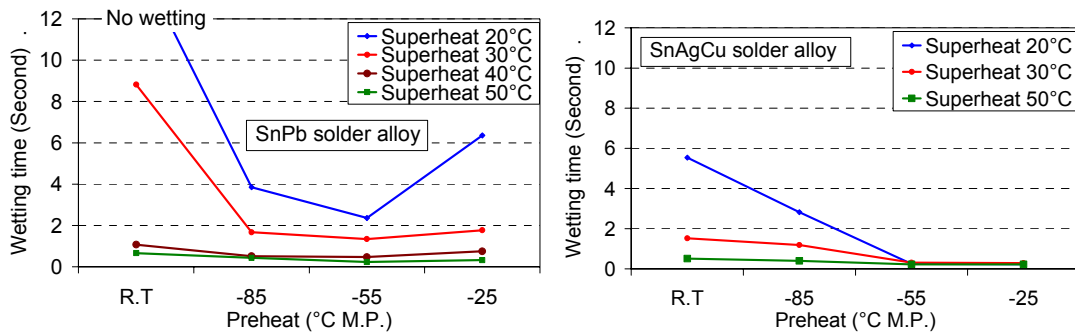


Figure 13: Wetting time with preheat temperature on as-received SOIC14

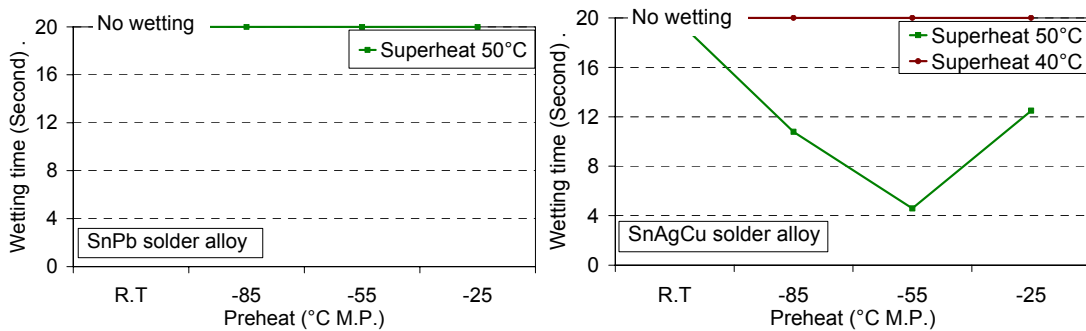


Figure 14: Wetting time with preheat temperature on aged SOIC14

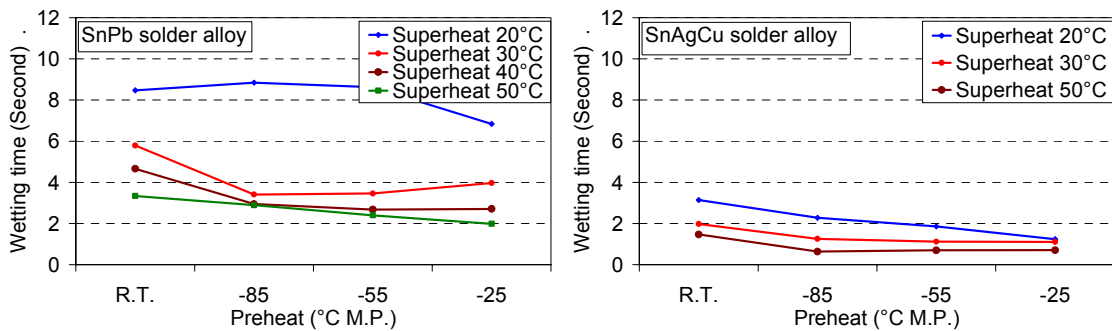


Figure 15: Wetting time with preheat temperature on as-received PCB pad

3.2 SOLDER ALLOY

It is useful to look at the same data from an alloy superheat perspective. Wetting time with superheat temperature on both as-received and aged Sn-finished C1206, the Pd-finished SOIC14, and AuNi-finished PCB pad, are presented in Figures 16, 17 and 18 respectively. The solid lines in the Figures are the results with the SnPb solder alloy, and the dotted results are those for the SnAgCu solder alloy. The results clearly show that with the same superheat and preheat temperature there is a big difference in wetting time between SnPb and SnAgCu alloys. Wetting was much faster for the SnAgCu alloy than for the SnPb alloy at the same superheat and preheat temperatures. Hence, these

results indicate that solderability does not follow a superheat dependency, but is sensitive to the absolute test temperature. Solderability reduces considerably with superheat for the SnPb alloy, but less so with the SnAgCu alloy, particularly with preheating. For SnAgCu solder a 30°C superheat is equivalent to a 50 °C superheat SnPb solder. This suggests that typical peak temperatures, in superheat terms, need not be as high with SnAgCu as with SnPb solder. With SnPb solder the superheat is typically 35 °C but for SnAgCu an equivalent level of solderability can easily be achieved with only 20 °C of superheat.

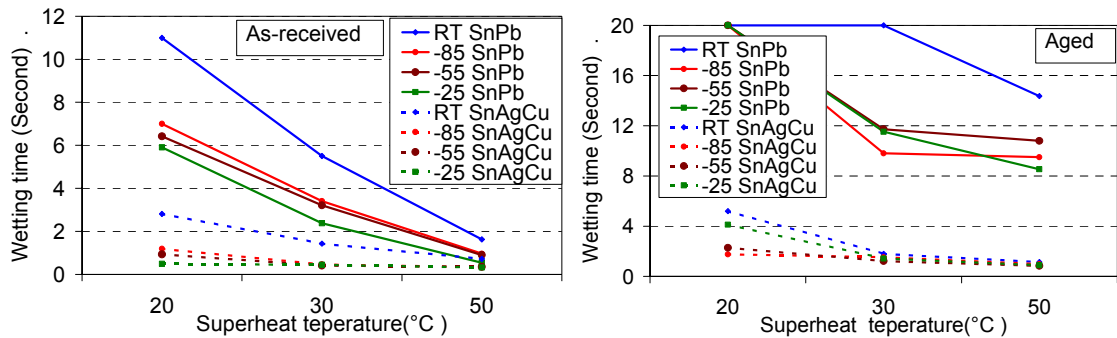


Figure 16: Wetting time with superheat temperature on Sn-finished C1206

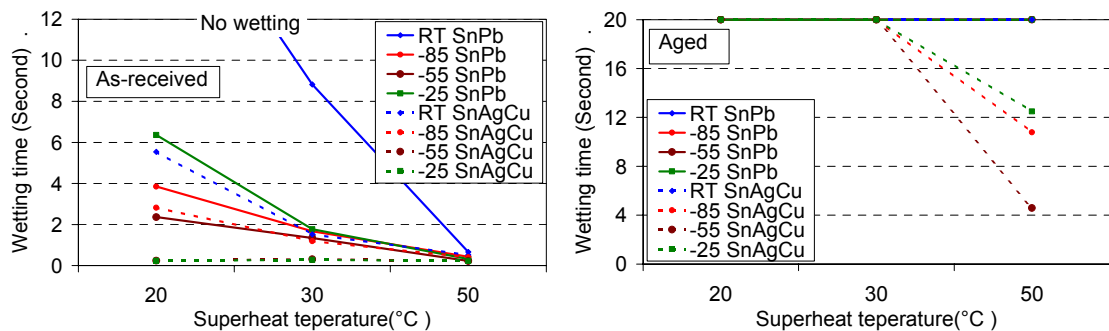


Figure 17: Wetting time with superheat temperature on Pd-finished SOIC14

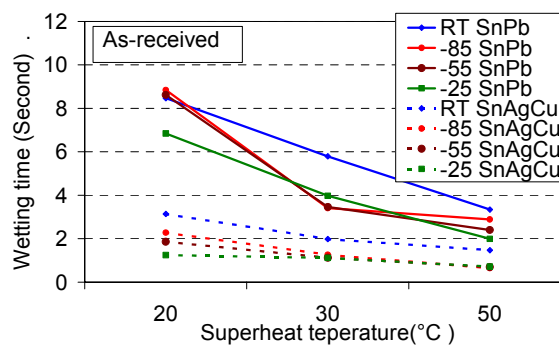


Figure 18: Wetting time with superheat temperature on AnNi-finished PCB pad

3.3 WETTING WITH PREHEATING AT LOW SUPERHEAT FOR LEAD-FREE SOLDER

The above results indicate that with the same superheat SnAgCu alloy gives much faster wetting than does SnPb. Hence further data were recorded at very low superheat, (5 and 10 °C) for the SnAgCu alloy. The wetting results with and without preheating are presented in Figure 19, and show that without preheat at 10 °C superheat the components still wetted (except for the Pd-finished SOIC), although wetting was very slow. With a 5 °C superheat no wetting occurred for any component. However, with preheating the wetting times were all below 5s even at 5 °C superheat. This important result indicates that preheat dramatically improves the wetting at low superheat, and with preheat acceptable wetting can be obtained at 10 °C superheat (and even 5 °C superheat for the SnAgCu alloy). These results imply that, from a solderability viewpoint, the peak reflow temperature, in superheat terms, can be set lower for SnAgCu solder, and the wetting process is more tolerant to process variations.

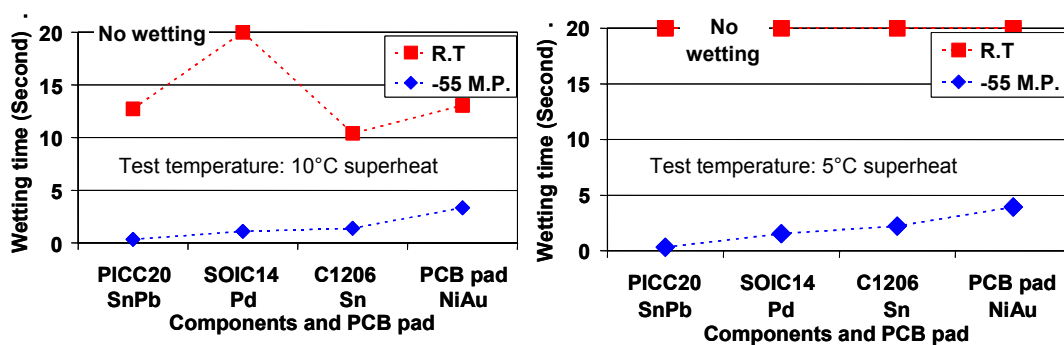


Figure 19: Component wetting times with 5 and 10 °C superheat for SnAgCu alloy, with no preheat and preheat at –55 °C below the melting point

3.4 WETTING WITH PREHEAT FOR AOA FLUX

Using both fluxes, SnPb-finished PLCC components were solderability tested with SnAgCu solder alloy, at different superheat temperatures, and with/without preheat at 55 °C below the SnAgCu melting point (see Figure 20). It is clear that both fluxes generate similar wetting properties, but wetting with AOA was slightly faster than with Actiec5, particularly at low superheat. The wetting time is significantly improved by preheat for both fluxes. Hence *AOA flux can be used with preheat. solderability testing.*

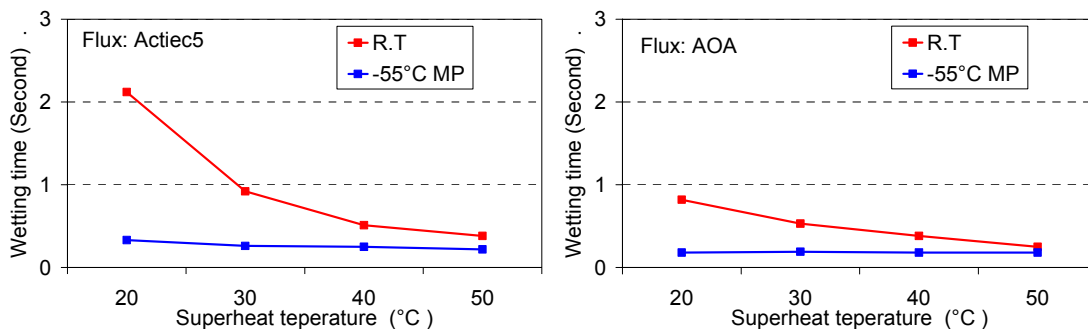


Figure 20: Wetting time with superheat temperature on SnPb-finished PLCC with SnAgCu solder

3.5 SUMMARY

Simply lowering the solder temperature, for SnPb, in the conventional wetting balance test would not be fruitful, leading to poor, or non-wetting of the component. But, with the use of preheat the wetting balance solder temperatures can be modified, and lowered to reflect peak reflow temperatures. In doing this it has been found that the solder temperature becomes less critical and solderability results more repeatable. From the new data solder temperatures of 215 °C and 240 °C, for SnPb and SnAgCu respectively, are recommended, and are close to typical peak reflow temperatures. With SnAgCu, testing at lower temperatures is possible, with good results obtained at 227 °C.

Preheat duration is comparatively short compared to manufacturing processing, but if the preheat is extended in the wetting test, flux volatilisation and a loss of repeatability occur. This reflects the high efficiency of this preheat system to heating an individual component and the low complexity of the solderability test flux vehicle. This study has shown that the preheat duration should be set to 60 seconds, (a 30 second ramp and 30 second hold), with two temperatures, (130°C and 160°C for SnPb, and SnAgCu respectively), corresponding approximately to the 55 °C below the solder melting point.

4 CONCLUSIONS

This work has shown that relevant solderability testing of components can be carried out at temperatures typical of peak reflow temperatures, if the component is preheated. Using preheat temperatures of 55 °C below the solder melting point, the solderability test temperature can be reduced to 215° for SnPb, and 240 °C for SnAgCu, the typical reflow soldering temperatures. For the SnAgCu alloy, the wetting test could be successfully carried out at 227 °C. This work has also shown that a modern generic test flux based on weak carboxylic acids can be used to replace the traditional resin flux, and was demonstrated to work well.

The main encouraging conclusion is that the solderability test method can be modified to include component preheat, and that the following parameters are appropriate for the test method:

- New test method
 - Test temperature:
 - 215 °C for SnPb
 - 240 °C for SnAgCu
 - Component preheat temperature:
 - 130 °C for SnPb
 - 160 °C for SnAgCu
 - Preheat method
 - Infrared lamp
 - Preheat time
 - 30 seconds ramp and 30 seconds dwell

- Flux
 - AOA flux or resin flux

5 ACKNOWLEDGMENTS

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