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NPL REPORT MAT 5

Characterising Solder Mask Performance

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NOT RESTRICTED

NOVEMBER 2007

Department for **Innovation, Universities** & **Skills**

Characterising Solder Mask Performance

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ABSTRACT

Although the electronics industry currently uses a number of test methods for evaluating solder masks, it has long recognised that they are inadequate, and that other (possibly new) methods are required. In this work a number of parameters of potential use in indicating the degree of cure of solder masks, have been evaluated. Tests using a series of measurement techniques have been undertaken on six different solder masks from three suppliers. Samples of each of the masks prepared under different cure conditions, were measured for thickness, surface roughness, hardness, surface reflectivity, contact angle of sessile drop, surface insulation resistance, capacitance and loss factor, and adhesion. In addition, process evaluations were undertaken for reflow soldering solder-balling and flux spread, as well as wave soldering solder-balling and skips. Underfill voiding measurements were also carried out.

The results indicated that the majority of these measurements did not effectively, or consistently, indicate the degree of cure for the samples tested. Thickness affected many of the test methods to a much greater extent than did the degree of cure.

The best correlation to degree of cure was found using surface insulation resistance testing, where the changes that occurred in SIR variables such as charge flow and SIR range were a good correlation for five of the six masks tested. This test method may have some use in determining degree of cure, but each material would need to be characterised individually and therefore the technique would be considered unsuitable as a test method for an end-user to apply across a range of boards from different suppliers. Additionally no distinct effects of UV cure could be detected with SIR testing or with other testing techniques.

This project has also shown that the representative solder masks studied appear robust in relation to under or over curing. The materials also had very similar properties in terms of process performance. In addition the results indicated that solder masks may well cure to an equilibrium at room temperature faster than expected, which would be advantageous for stability of subsequent processing by assemblers.

ISSN 1754-2979

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Approved on behalf of the Managing Director, NPL,
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CONTENTS

1 INTRODUCTION **1**

2 METHODOLOGY **2**

2.1 TEST SAMPLES 2
2.2 THICKNESS 3
2.3 SURFACE ROUGHNESS 3
2.4 HARDNESS 4
2.5 REFLECTIVITY 4
2.6 CONTACT ANGLE MEASUREMENTS 6
2.7 SURFACE INSULATION RESISTANCE, CAPACITANCE AND LOSS FACTOR MEASUREMENT 7
2.8 ADHESION TEST 8
2.9 SOLDER-BALLING (REFLOW SOLDERING) 9
2.10 FLUX SPREAD MEASUREMENTS 10
2.11 SOLDER-BALLING AND SKIPS (WAVE SOLDERING) 11
2.12 UNDERFILL VOIDING MEASUREMENT 11

3 RESULTS **12**

3.1 THICKNESS MEASUREMENTS 12
3.2 SURFACE ROUGHNESS 14
3.3 HARDNESS 14
3.4 REFLECTIVITY 17
3.5 CONTACT ANGLE MEASUREMENT 23
3.6 SIR MEASUREMENT 24
3.7 CAPACITANCE 28
3.8 LOSS TANGENT 29
3.9 ADHESION TESTING 30
3.10 SOLDER-BALLING (REFLOW SOLDERING) 31
3.11 FLUX SPREAD MEASUREMENTS 32
3.12 SOLDER-BALLING (WAVE SOLDERING) 32
3.13 SOLDER SKIP MEASUREMENTS 33
3.14 UNDERFILL VOIDING MEASUREMENT 34

4 DISCUSSION **36**

5 CONCLUSIONS **40**

6 ACKNOWLEDGEMENTS **41**

7 REFERENCES **41**

1 INTRODUCTION

A solder mask is a coating which covers a proportion of the surface of a printed wiring board and prevents those areas from accepting any solder during reflow or wave solder processing, as shown in Figure 1.

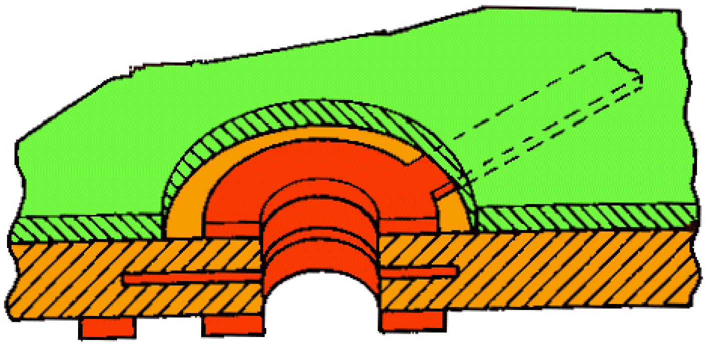

Figure 1: Schematic of PCB structure; solder resist shown in green (Reference 1)

The functions of a solder resist are to:

- Reduce solder bridging and shorts
- Reduce the volume of solder pickup
- Reduce solder pot contamination with copper
- Protect circuitry from handling and the environment
- Provide known dielectric characteristics between conductors and pads
- Provide a barrier against electrochemical dendritic growth
- Provide a dielectric barrier between components mounted over conductor lines

The electronics industry currently uses a number of imprecise, ad-hoc test methods for evaluating solder resists, but the resultant data are known to correlate poorly with performance during assembly. Indeed, the industry has long understood that the test methods contained in national and international specifications are inadequate, and that replacement tests are required.

There are many issues caused in production related to cure of the resist. For example;

- underfills are polymeric encapsulants, which are used to protect components and will be applied over the resist
- outgassing from the solder mask causing voiding during underfill cure
- voids in the underfill can dramatically impact on the reliability performance of the solder joints and on the attachment strength of devices to the resist surface. This is particularly important with modern electronics where impact resistance and drop tests are becoming more stringent
- evolution of gas from resists, and changes in surface tension, can also significantly influence the occurrence, and the adhesion, of stray solder balls during soldering
- absorption by solder masks of solvents and other components from cleaning, which then can be desorbed, can also significantly affect the way solder wets over the mask.

The objectives of this project were:
(i) to evaluate a number of potential test parameters, particularly with respect to issues experienced during assembly operations
(ii) to attempt to benchmark current test methods with new procedures

The main thrust of the project has involved a series of measurements (thickness; hardness; surface roughness; reflectivity - matt/gloss; surface energy – contact angle of sessile drop; SIR – novel use of SIR patterns for resistance/capacitance) on a range of solder mask materials subjected to different curing regimes. The nature and range of the tests were chosen by the industrial partners as having potential for future practical test procedures. Similarly, the curing regimes were designated by industry as appropriate for providing samples with different degrees of cure. In this manner it was hoped to ascertain whether or not any particular parameter(s) could be useful in indicating the degree of cure of the solder mask, and if so, to comment on its wider applicability in a test method.

In addition, some process evaluations have been undertaken. First, the out-gassing of under-cured resist was assessed to qualify the impact on underfill applications. Second, the effect of the degree of cure on solder-balling in both wave soldering and reflow soldering has been assessed. Finally, some flux spread measurements have also been undertaken.

2 METHODOLOGY

2.1 TEST SAMPLES

The project was undertaken in two phases. Phase 1 utilised six different solder masks from three different suppliers, each of whom provided both a gloss and matt solder mask. Each mask was cured using one of three different regimes, 30 min @ 150 °C, 60 min @ 150 °C, and 30 min @ 150 °C + UV. A summary of the phase 1 test samples is given in Table 1.

Table 1 : Summary of phase 1 test samples

Cure @ 150°C mins	Supplier	Resist Finish	Cured Thickness Over Laminate µm
30	1	Matt	5
60	2	Gloss	10
30 + UV	3		25

Phase 2 samples used the same six solder masks. In this phase each mask was cured using 4 different regimes, 30min @ 150^{O}C, 60min @ 150^{O}C, 120min @ 150^{O}C, and 60min @150^{O}C + UV. A summary of the phase 2 test samples is given in Table 2.

Table 2 : Summary of phase 2 test samples

Cure @ 150°C mins	Supplier	Resist Finish	Cured Thickness Over Laminate µm
30	1	Matt	5
60	2	Gloss	10
120	3		25
60 + UV			

2.2 THICKNESS

The thickness of all samples was measured after cure using a laser profiler as shown in Figure 2. The height of the resist over the copper and the height of the bare laminate were both determined from measurements from a matrix of positions across each board, with at least three different boards measured for each mask.

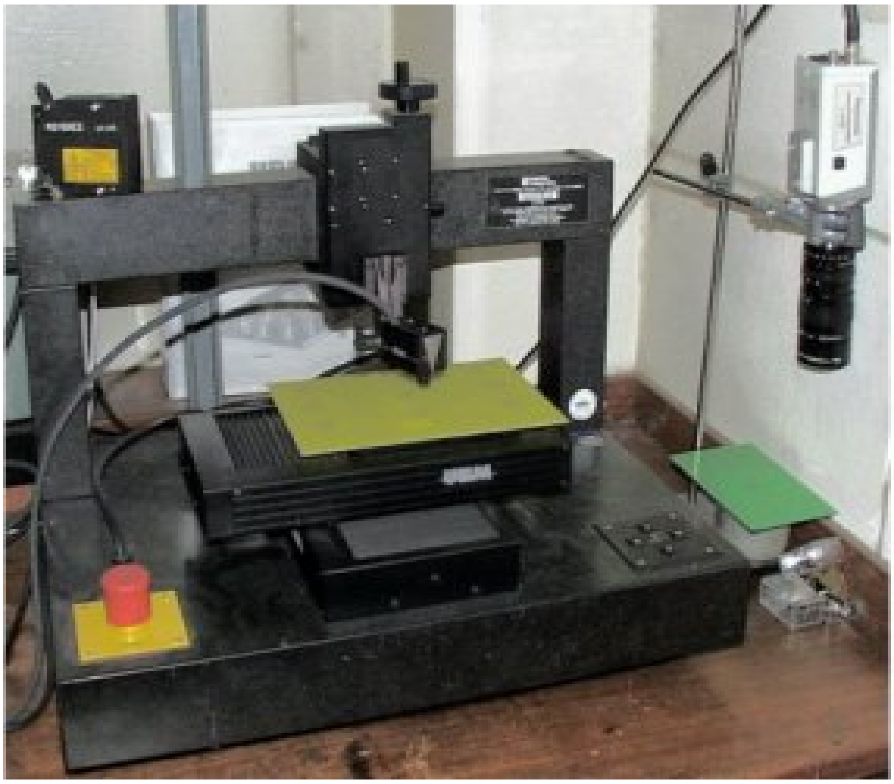

Figure 2: Laser profiler

2.3 SURFACE ROUGHNESS

The surface roughness was also measured using the laser profiler. The roughness of the resist over copper and bare laminate was determined from measurements from a matrix of positions across each board, with at least three different boards measured for each mask.

2.4 HARDNESS

Hardness of the samples was tested as per IPC-TM-650 2.4.27.2 (Reference 2), as called up by SM-840 (Reference 3).

The coated board under test was placed on a solid horizontal surface. Pencils taken from the hardness range 4B-3B-2B-HB-F-H-2H-3H-4H-5H-6H were held firmly against the solder mask at a 45° angle (see Figure 3). The pencil was then pushed away from the operator with uniform downward and forward pressure in a ¼ inch stroke. The lowest pencil hardness not to cut or gouge the solder mask was recorded.

Figure 3 : Pencil hardness test

2.5 REFLECTIVITY

Two methods were used for reflectivity measurements. The first method utilised a hand held gloss meter, similar to that shown in Figure 4.

Figure 4 : Typical handheld Gloss Meter (source: BYK Gardner)

The second method utilised a reference reflectometer at NPL, and this was used to measure reflectance at different angles of incidence and wavelengths of light. A schematic of the equipment is shown in Figure 5 and internal detail of the equipment in Figure 6. Testing was undertaken using a variety of wavelengths with S polarisation, a 60 degree angle of incidence, and a 60 degree detection angle (specular). In trials, a larger angle of incidence was found to give a better signal.

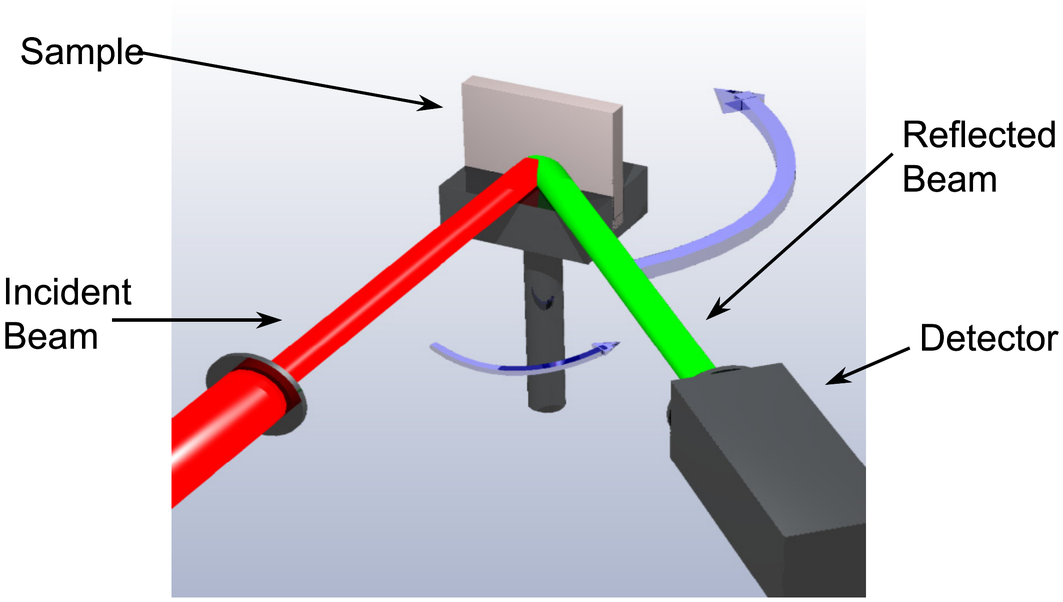

Figure 5 : Schematic of reference reflectometer

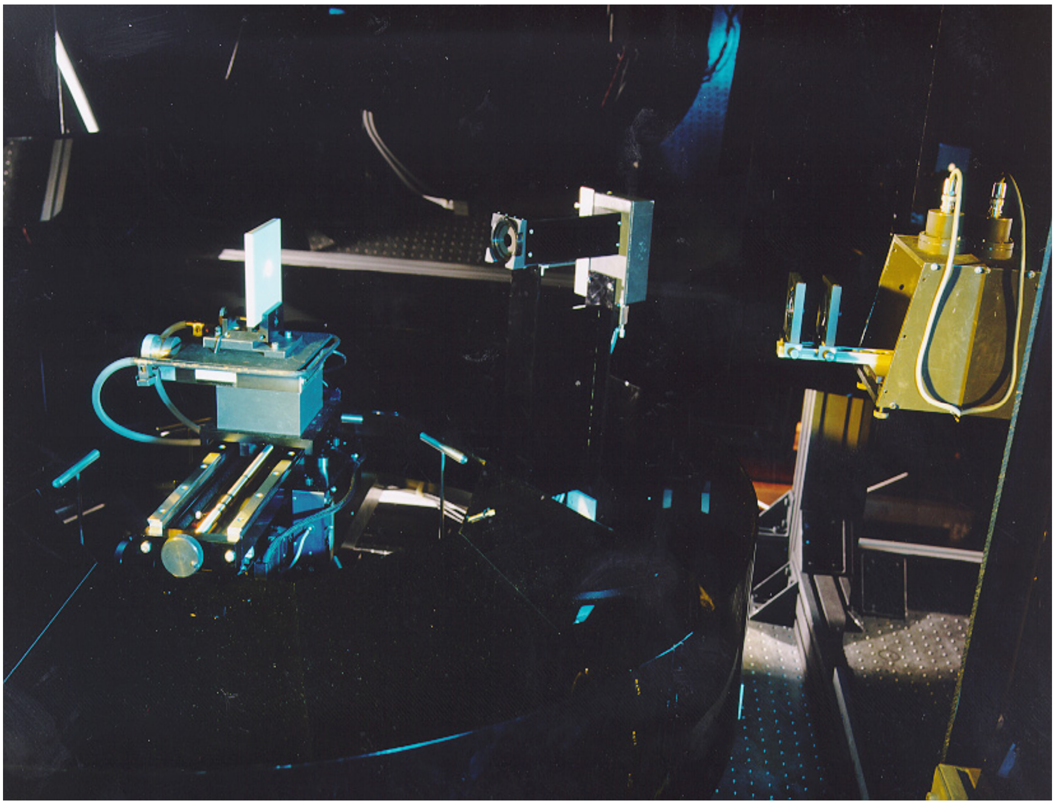

Figure 6 : Internal detail of reference reflectometer

2.6 CONTACT ANGLE MEASUREMENTS

An indication of the surface energy of each mask was made by measuring the contact angle of a sessile drop of IPA on the surface of the mask. A camera system was used to capture and image the drop, and software to calculate the contact angle. A schematic of the equipment is presented in Figure 7. Typical drop images and software equivalents are shown in Figure 8.

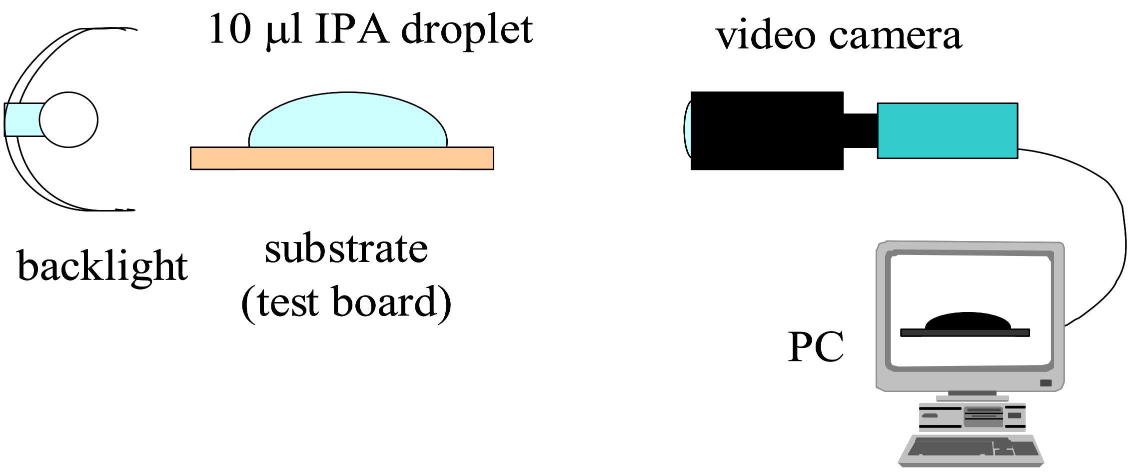

Figure 7 : Schematic of contact angle measurement of sessile drop

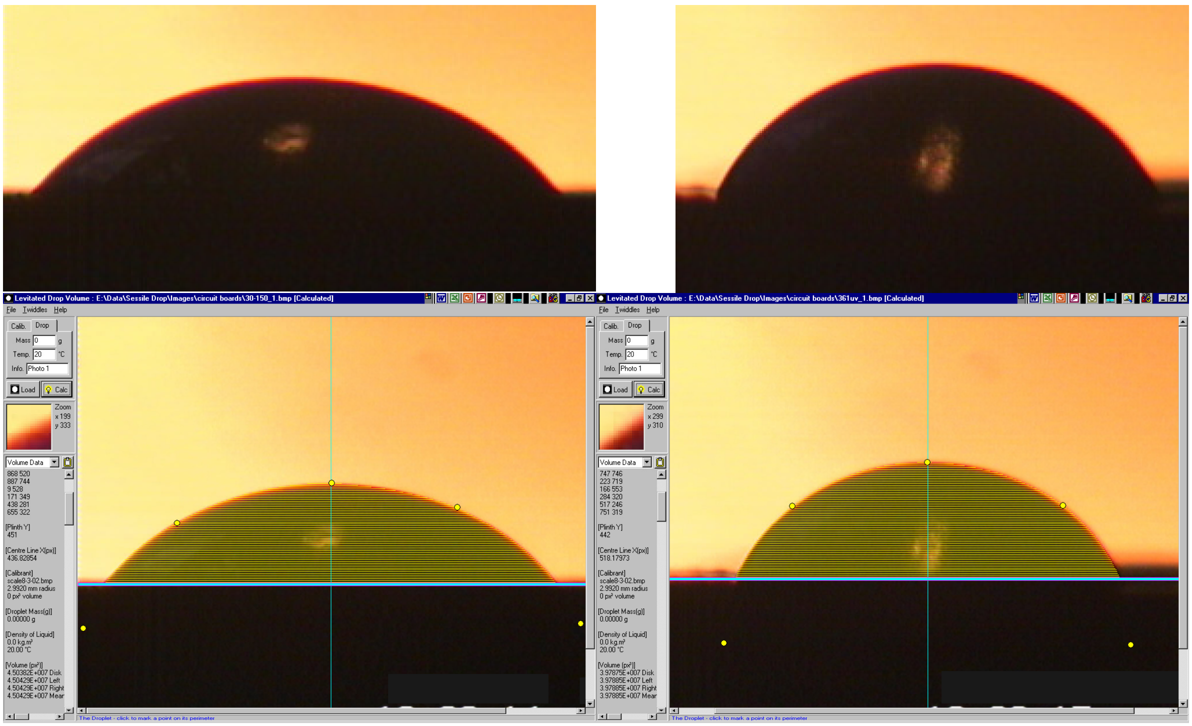

Figure 8 : Images of sessile drops (top) on matt (left) and gloss (right) masks with corresponding contact measurement software images

2.7 SURFACE INSULATION RESISTANCE, CAPACITANCE AND LOSS FACTOR MEASUREMENT

To determine surface insulation resistance (SIR) for the masks, leakage currents across an inter-digitated comb pattern at high temperature and humidity were measured. Tests were conducted at 85%RH, 85^{o}C for 96 hours with a 50V bias. Use of an alternating current with the same comb patterns enabled measurement of capacitance and loss factor for the masks. The comb pattern utilised is shown in Figure 9, whilst Figure 10 provides a schematic for the surface insulation resistance measurements. Both minimum SIR and final SIR measurements were noted for each coating. The change between the minimum value towards the beginning of the test and the final value was investigated as possibly giving an indication of the state of cure of the coatings. The charge flow is defined as the amount of ions swept to the electrodes during initial bias testing, and may also give an indication of cure state.

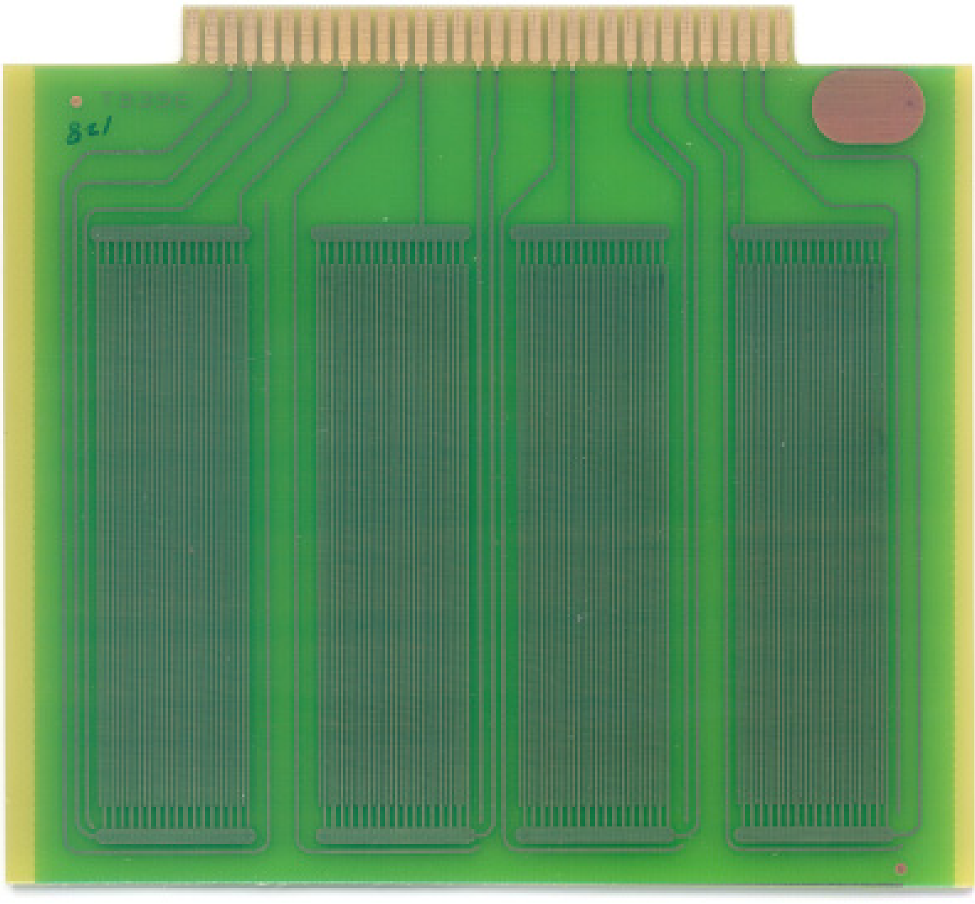

Figure 9 : SIR test board

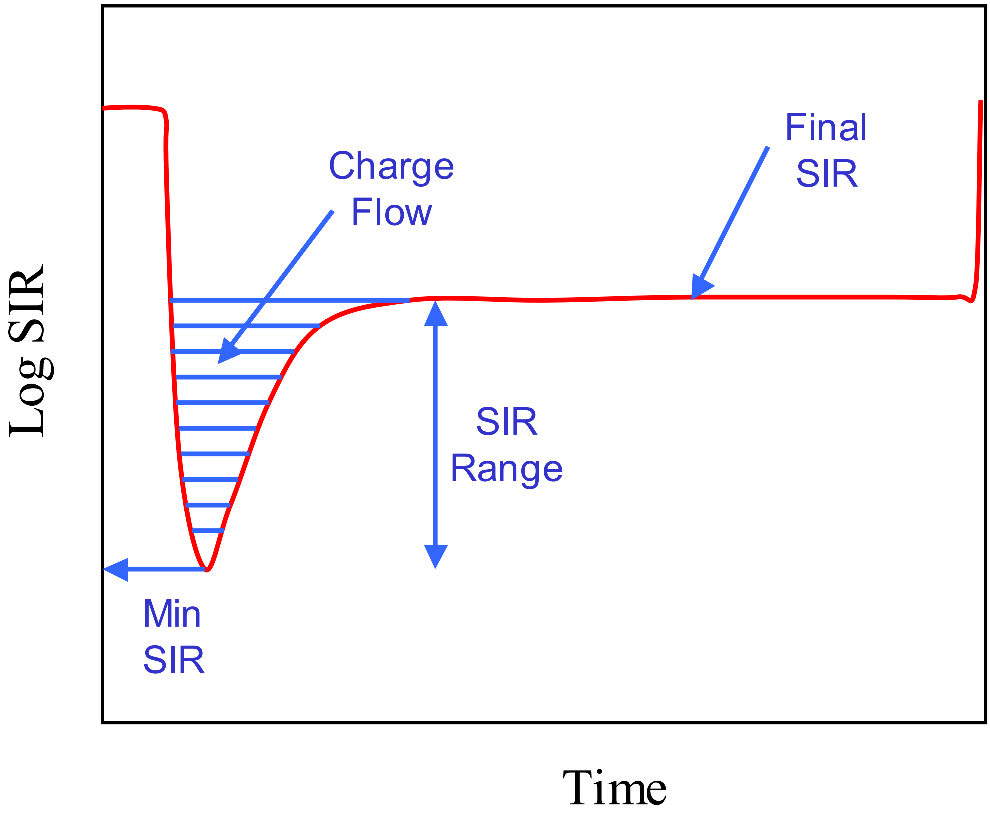

Figure 10 : Schematic of surface insulation resistance output

2.8 ADHESION TEST

The degree of adhesion of the solder mask was measured using a butt adhesion test. Studs were attached to the solder mask using epoxy adhesive, and the pneumatic pressure in an actuator required to break the stud vertically away from the board was measured. A test board with studs attached is shown in Figure 11 and the air pressure and actuator system is demonstrated in Figure 12.

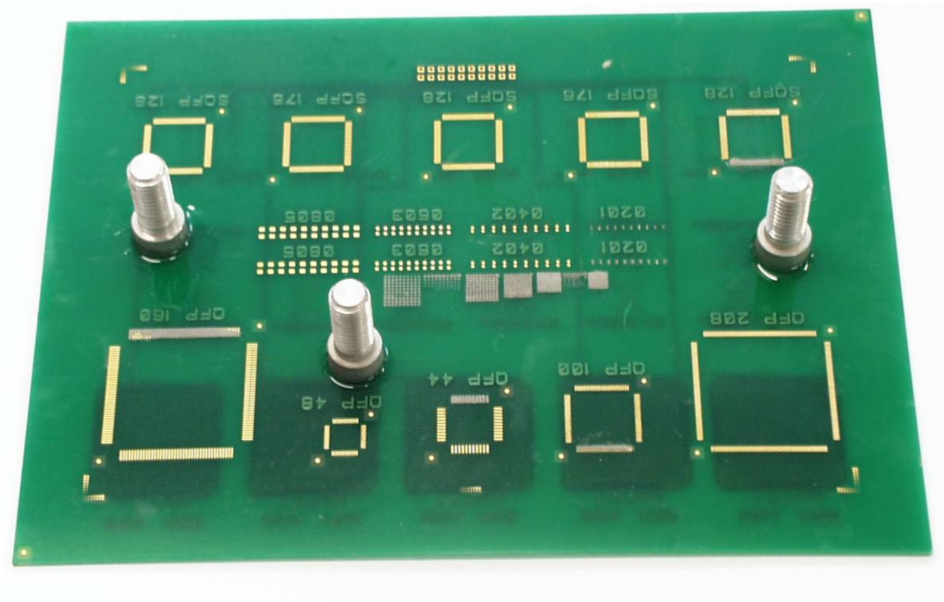

Figure 11 : Example of studs attached to test board prior to adhesion testing

Figure 12 : Butt adhesion test equipment

2.9 SOLDER-BALLING (REFLOW SOLDERING)

The degree of solder balling after reflow soldering experienced by different solder masks was assessed by visual inspection of samples after reflow soldering. A stereo zoom microscope was used to count the average number of balls on one row of square pads per test board. The measurement was based on a minimum solder ball size of 0.004”. To aid inspection, back lighting was used with minimum of top lighting, and a reference film foil was used during all inspections. An example of a reflow solder-balling test board is presented in Figure 13, and trials were conducted on both square and round pads.

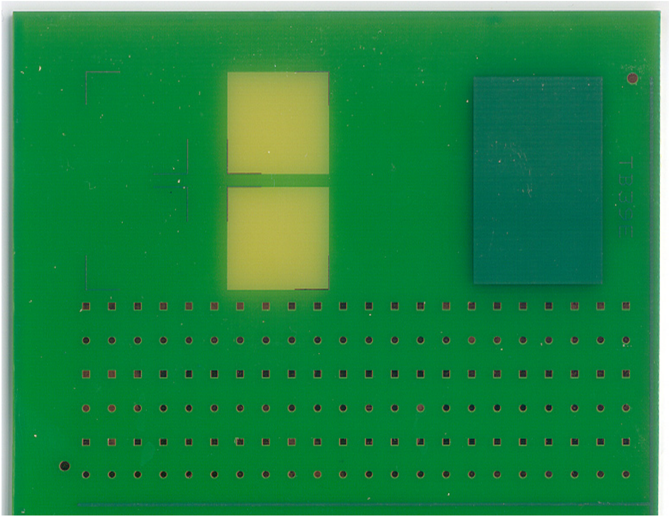

Figure 13 : Example of solder-balling test board

2.10 FLUX SPREAD MEASUREMENTS

Flux spread measurements after reflow soldering were undertaken on round pads using a stereo zoom microscope. An average of five readings from each board were taken. An example of flux spread is shown in **Figure 14**.

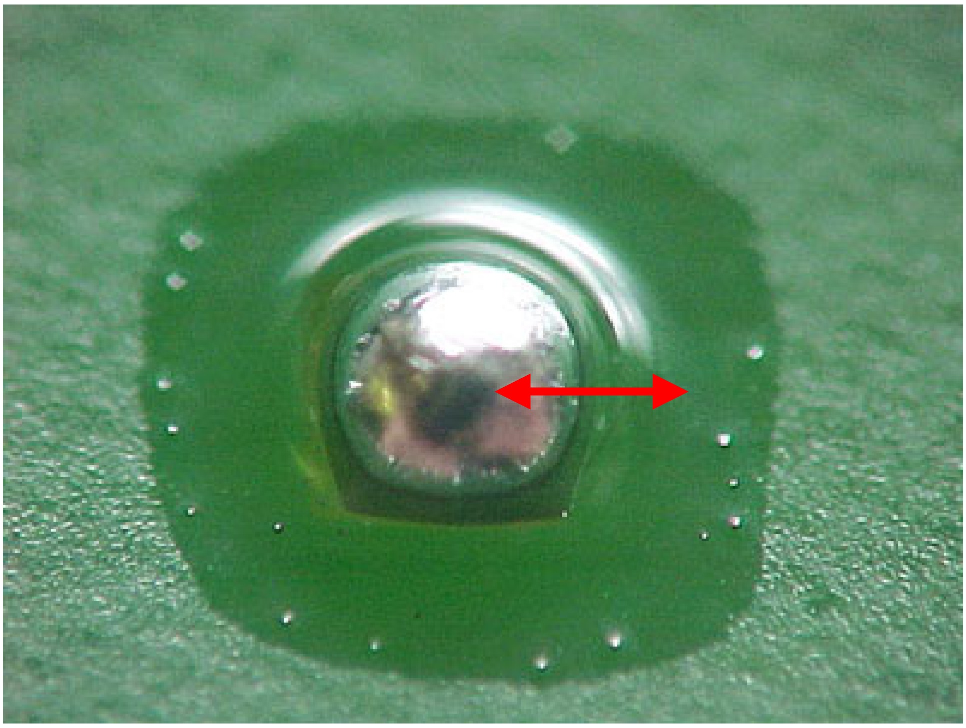

Figure 14 : Example of flux spread after reflow soldering

2.11 SOLDER-BALLING AND SKIPS (WAVE SOLDERING)

The degree of solder-balling experienced by different solder masks was assessed by visual inspection of samples after wave soldering. A stereo zoom microscope was used to count the average number of balls on two patterns of pads at 90 and 45 degrees to the solder wave. The measurement was based on a minimum solder ball size of 0.005". To aid inspection back lighting was used with minimum of top lighting, and a reference film foil was used during inspection. An example of a wave-solder balling test board is demonstrated in Figure 15. The average number of skips per board were also counted. A typical board showing skips is shown in Figure 16.

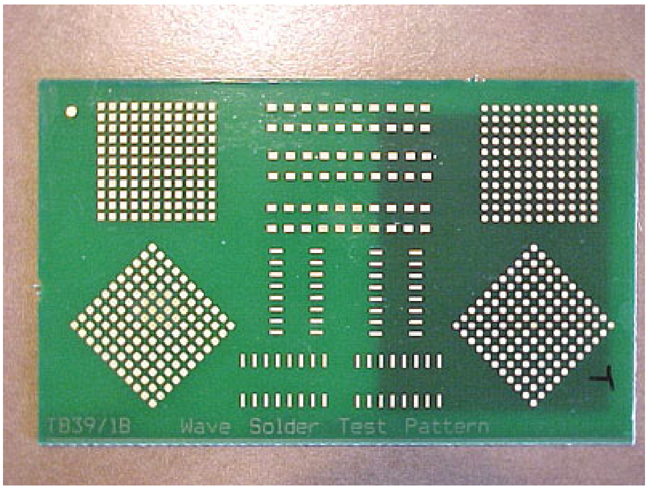

Figure 15 : Wave solder solder-balling test board

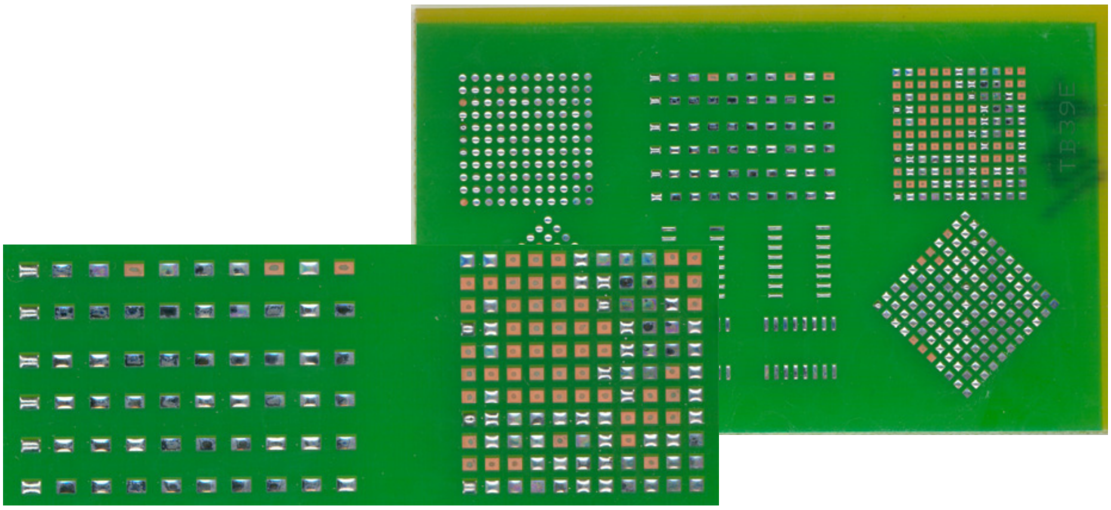

Figure 16 : Example of wave soldered test board showing skips

2.12 UNDERFILL VOIDING MEASUREMENT

No-flow underfill material was dispensed onto each of the sample test boards prior to covering the test sites with a thin glass slide. Test sites were designed to feature solder mask coated and no-coated areas. It was expected that any voiding would be observed from the solder mask coated sites, not from the laminate surface of the board.

A small quantity of glass spheres was placed into the underfill material before the slide was pressed down. These glass spheres were used to give a fixed stand-off height for each slide, in order to provide the opportunity for more consistent assessment of voiding.

The purpose of the underfill material was to allow any outgassing from the solder mask to be observed, a technique that has been used in the past to demonstrate this phenomenon. Small sample boards were tested on a hot plate prior to the full trial, to ensure that the degree of outgassing would not be so excessive as to cause all the glass slides to float off the test sites.

After reflow each of the sample boards was inspected to assess the degree of voiding. Assessment was based on a comparison with series of reference photographs of varying degrees of voiding.

3 RESULTS

3.1 THICKNESS MEASUREMENTS

The thickness measurements on phase 1 samples are summarised in Figure 17 with details of the sample codes given in Table 3. No trends in thickness are apparent in relation to degree of cure, or to the use of UV during cure. The variation in thickness appears to be an artefact of the application method and coating i.e. supplier-related.

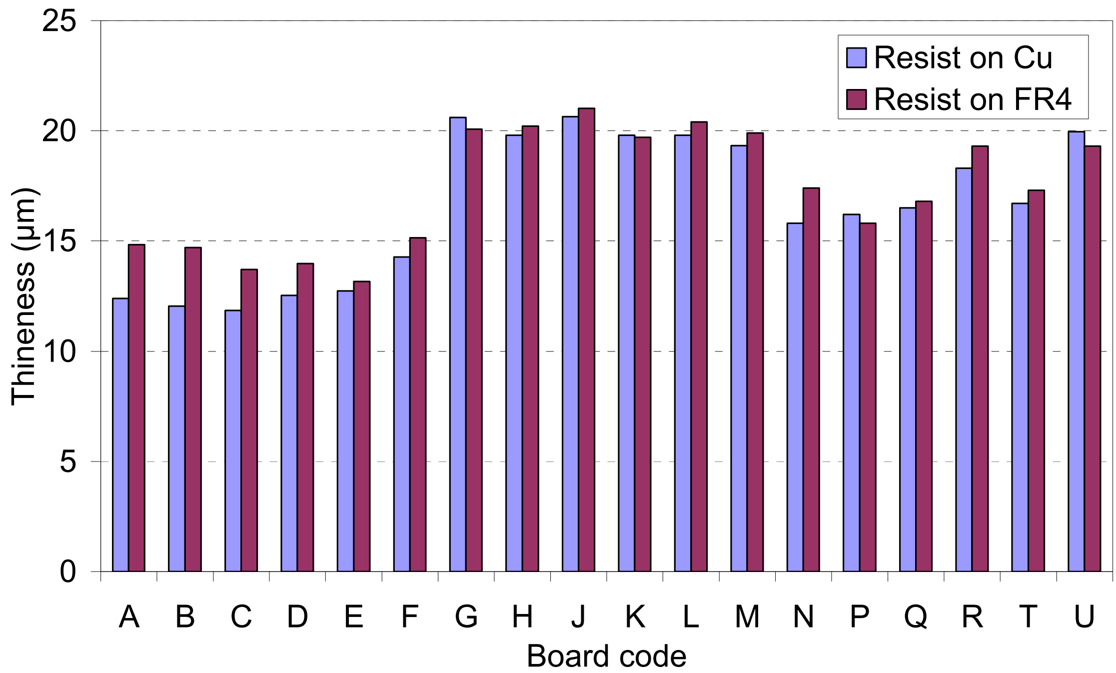

Figure 17 : Solder mask thicknesses on copper and bare laminate for phase 1 Samples

Table 3 : Sample codes for phase 1 samples

Sample Code	Supplier	Finish	Cure
A	1	Matt	30min @ 150°C
B	1	Matt	60min @ 150°C
C	1	Matt	30min @150°C + UV
D	1	Gloss	30min @ 150°C
E	1	Gloss	60min @ 150°C
F	1	Gloss	30min @150°C + UV
G	2	Matt	30min @ 150°C
H	2	Matt	60min @ 150°C
J	2	Matt	30min @150°C + UV
K	2	Gloss	30min @ 150°C
L	2	Gloss	60min @ 150°C
M	2	Gloss	30min @150°C + UV
N	3	Matt	30min @ 150°C
P	3	Matt	60min @ 150°C
Q	3	Matt	30min @150°C + UV
R	3	Gloss	30min @ 150°C
T	3	Gloss	60min @ 150°C
U	3	Gloss	30min @150°C + UV

The thickness measurements for phase 2 samples were undertaken primarily to determine if the coatings were of the thickness requested. The results are shown in Figure 18. It is evident that the coatings were all of the nominated thickness, with the exception of the "10µm coating" from supplier 2 which was much thicker than requested.

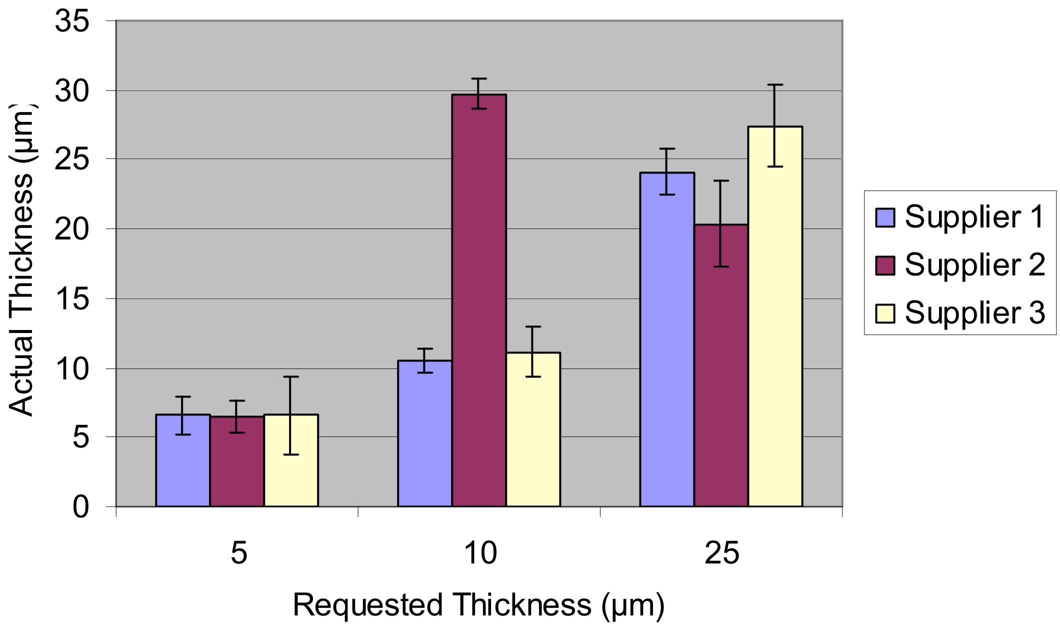

Figure 18 : Phase 2 solder mask thicknesses

3.2 SURFACE ROUGHNESS

The results of the surface roughness measurements on phase 1 samples are summarised in
Figure 19 with details of the sample codes again given in Table 3. It is evident that there is no dependence of surface roughness on the degree of cure, or on the use of UV during the cure. The only variations in roughness appear to be supplier-related i.e. an artefact of the application method and coating. In consequence, no surface roughness measurements were undertaken on phase 2 samples.

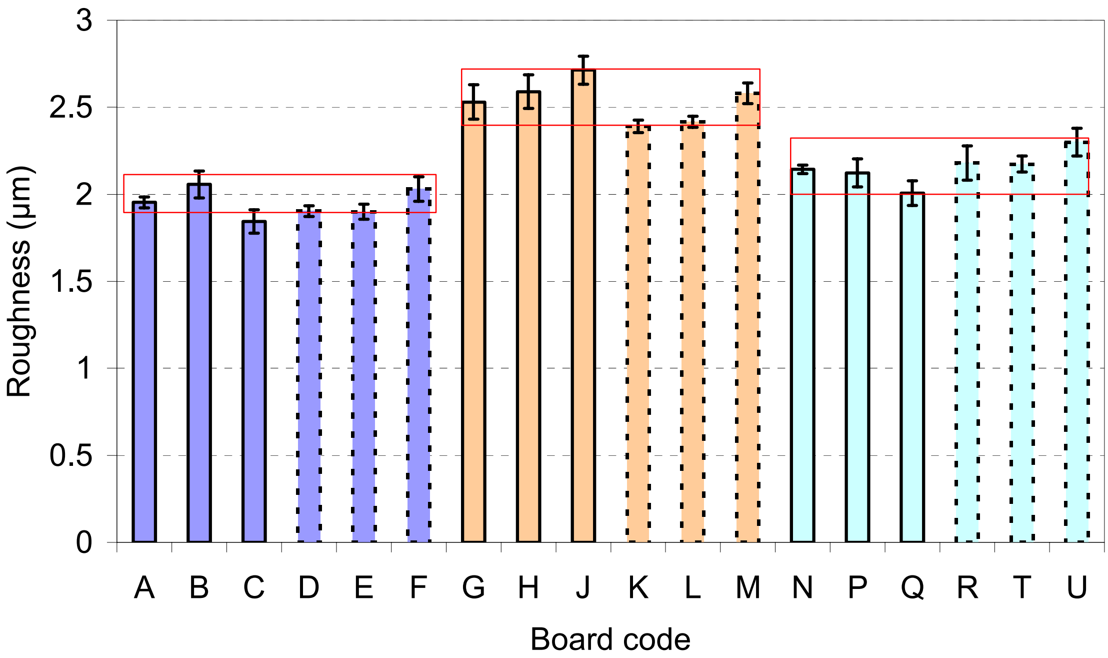

Figure 19 : Surface roughness results for solder masks for phase 1 samples

3.3 HARDNESS

The results of the hardness measurements on phase 1 samples are summarised in Figure 20 with details of the pencil hardness plot values given in
. It is evident that there is little variation of hardness as a function of the degree of cure, or of the use of UV during cure.

Table 4 : Details of plot values for hardness graphs with corresponding pencil hardnesses

Pencil Hardness	4B	3B	2B	HB	F	H	2H	3H	4H	5H	6H
Plot Value (Y-axis)	1	2	3	4	5	6	7	8	9	10	11

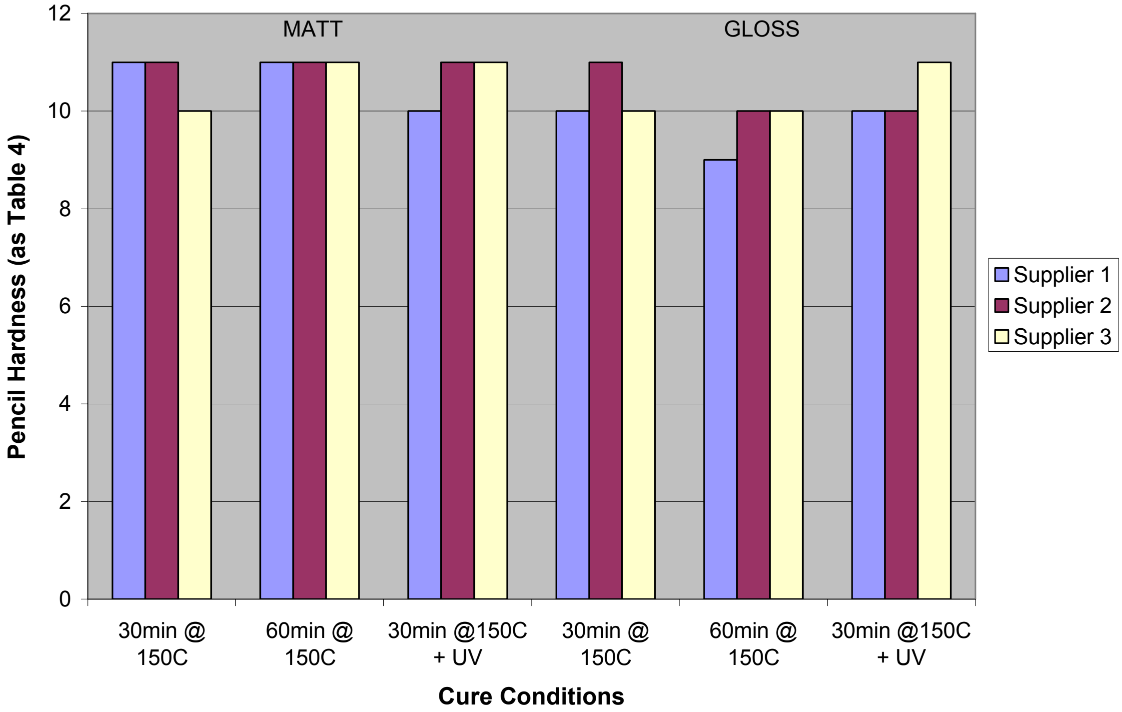

Figure 20 : Hardness results for phase 1 samples

The results of the hardness measurements on phase 2 are summarised in Figure 21 for supplier 1, Figure 22 for supplier 2, and Figure 23 for supplier 3, with details of the pencil hardness plot values given in
. As with phase 1, there was little variation in hardness as a function of the degree of cure, or of the use of UV during cure.

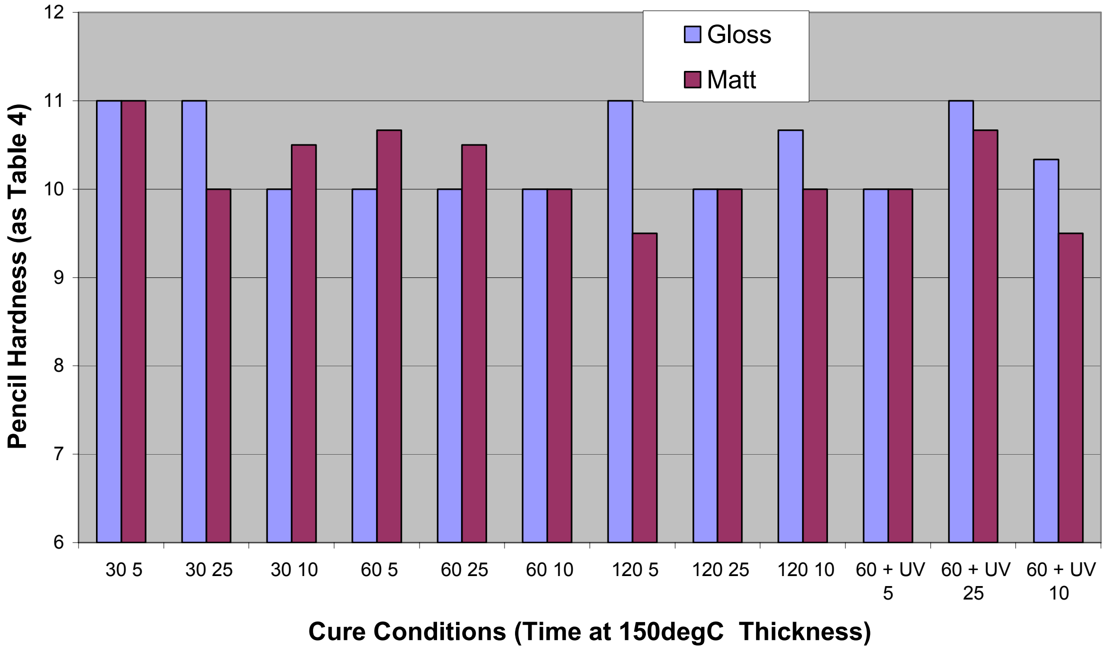

Figure 21: Hardness results for phase 2 samples from Supplier 1

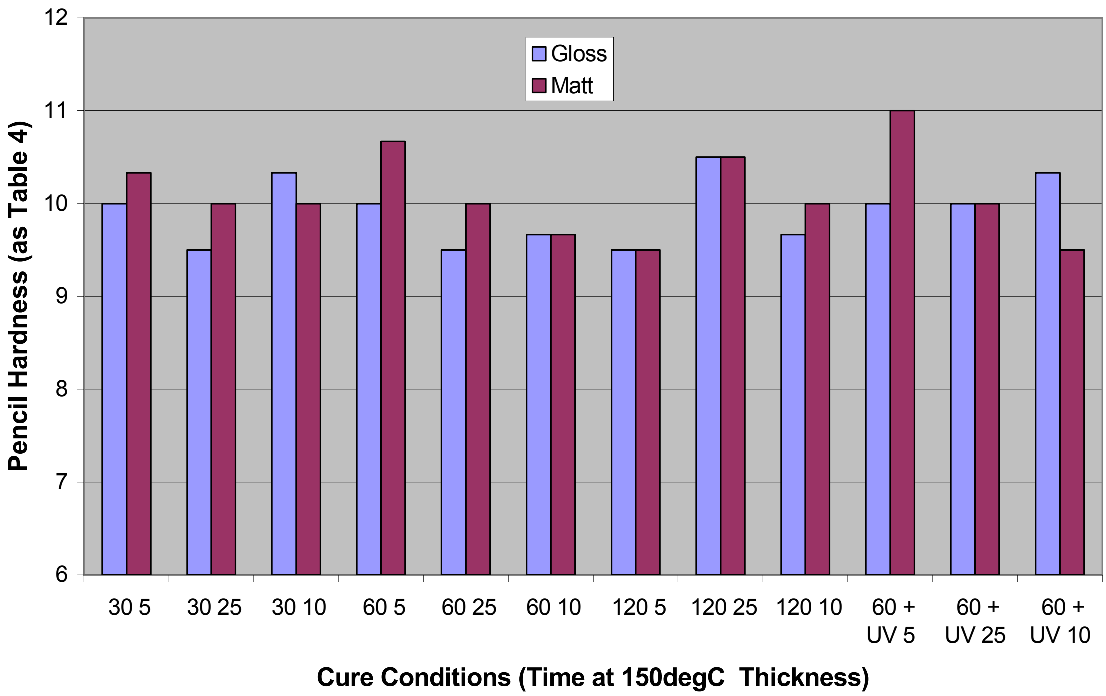

Figure 22: Hardness results for phase 2 samples from Supplier 2

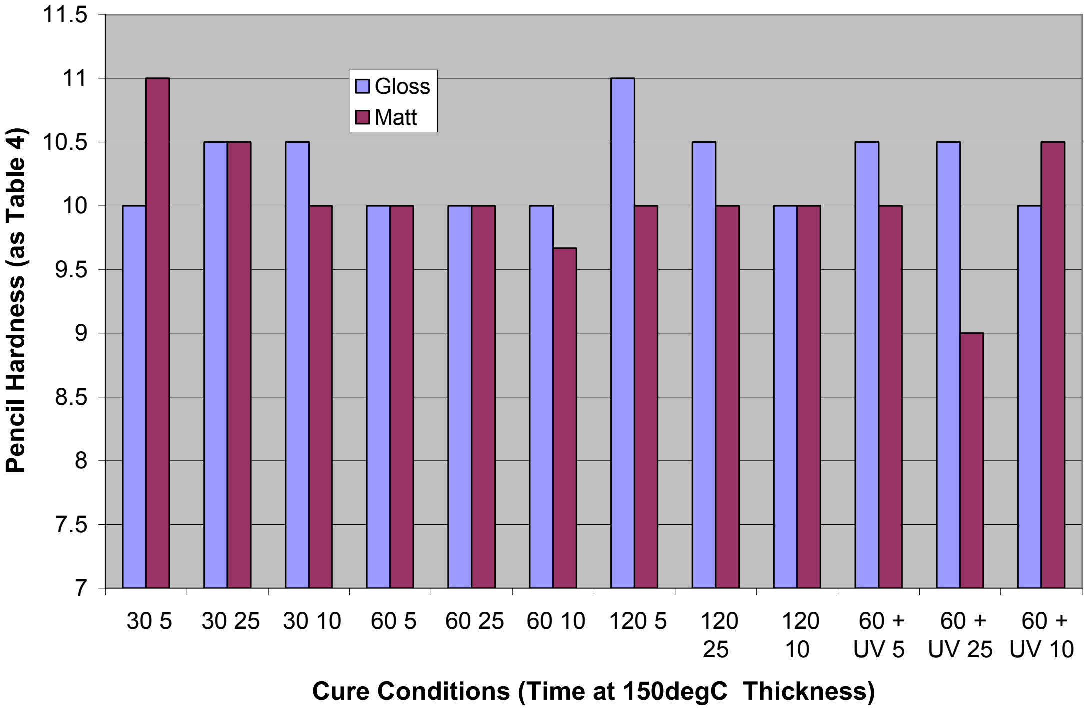

Figure 23 : Hardness results for phase 2 samples from Supplier 3

3.4 REFLECTIVITY

Results for the handheld gloss meter for the phase 1 samples are summarised in Figure 24. These results display a good differentiation between gloss and matt finish types. The gloss coating results approach the high end of meter's capabilities, whilst the matt coating results at the lower end of the instrument's range.

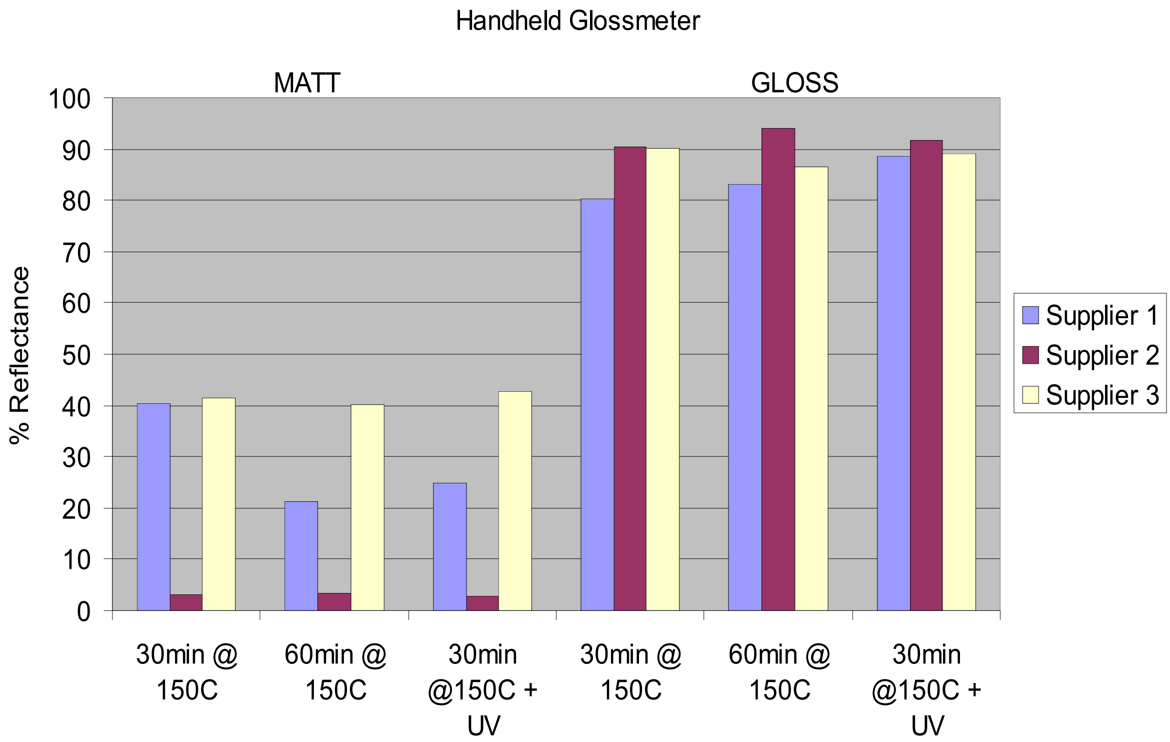

Figure 24 : Phase 1 reflectance results using handheld Glossmeter

Phase 1 samples were also measured using the NPL reference reflectometer. The results for solder masks on copper are shown in Figure 25, with the results for solder masks on laminate in Figure 26. Figure 27 provides a comparison of the results for solder mask on both copper and on laminate (i.e. off copper). These specific wavelength reflectance results provide a better differentiation between the degrees of cure than did the hand held glossmeter results. The technique also provides good differentiation between resist types whilst having a minor dependence on the wavelength used.

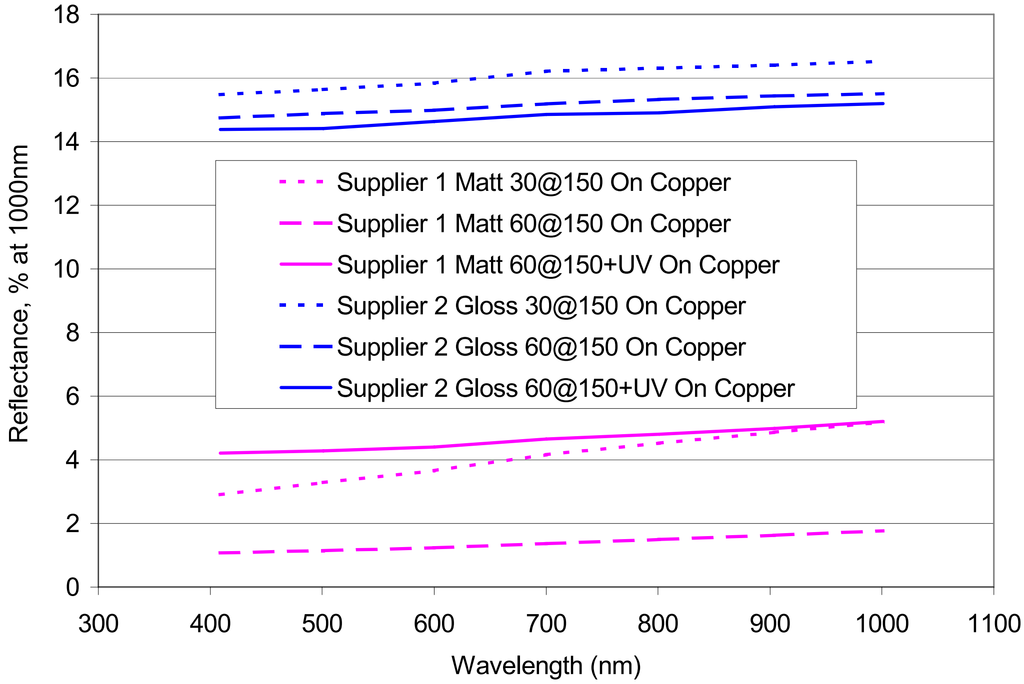

Figure 25 : Phase 1 reference reflectometer results for solder masks on copper

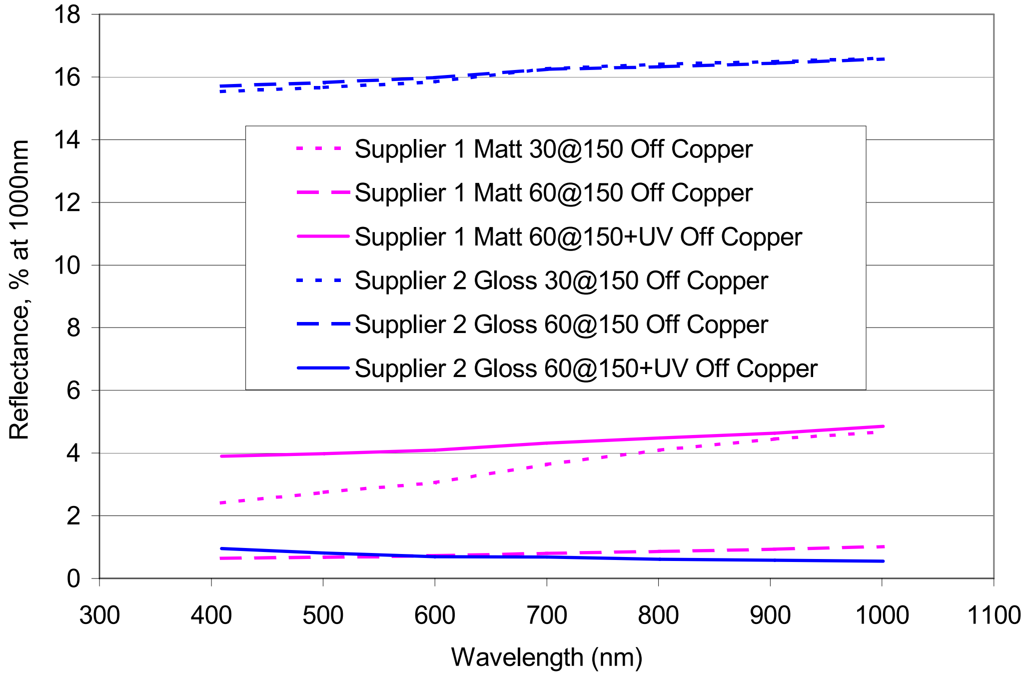

Figure 26 : Phase 1 reference reflectometer results for solder masks on laminate

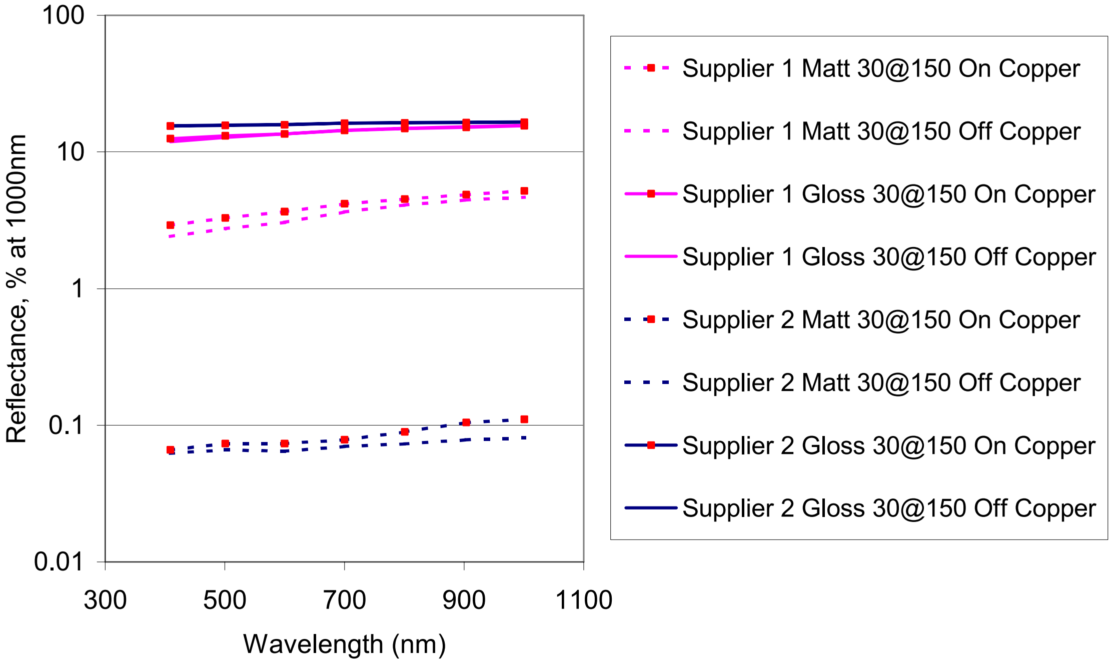

Figure 27 : Comparison of reflectance results for solder mask on copper and on laminate for different mask types for phase 1 samples

The results from the NPL reference reflectometer for the phase 2 samples are summarised in Figure 28, Figure 29 and
Figure 30. The results shown for the samples in Figure 28 were of interest because of a good relation observed with the SIR results given below. However, these results display only small changes in reflectance between different cure regimes for the same solder mask.

Figure 29 presents these same results but normalised for the average reflectance value for each coating. Here some of the results do exhibit a trend of increasing reflectance with increasing cure, but the differences are small and of limited value for the purposes of differentiating between the various degrees of cure..

Figure 30 shows the effect of coating thickness on the reflectance results for the matt finish from supplier 3. These results clearly indicate that the coating thickness (5 µm or 25 µm) and measurement wavelength (409 nm or 1001 nm) are much more significant in affecting the reflectance than is any change due to the degree of cure.

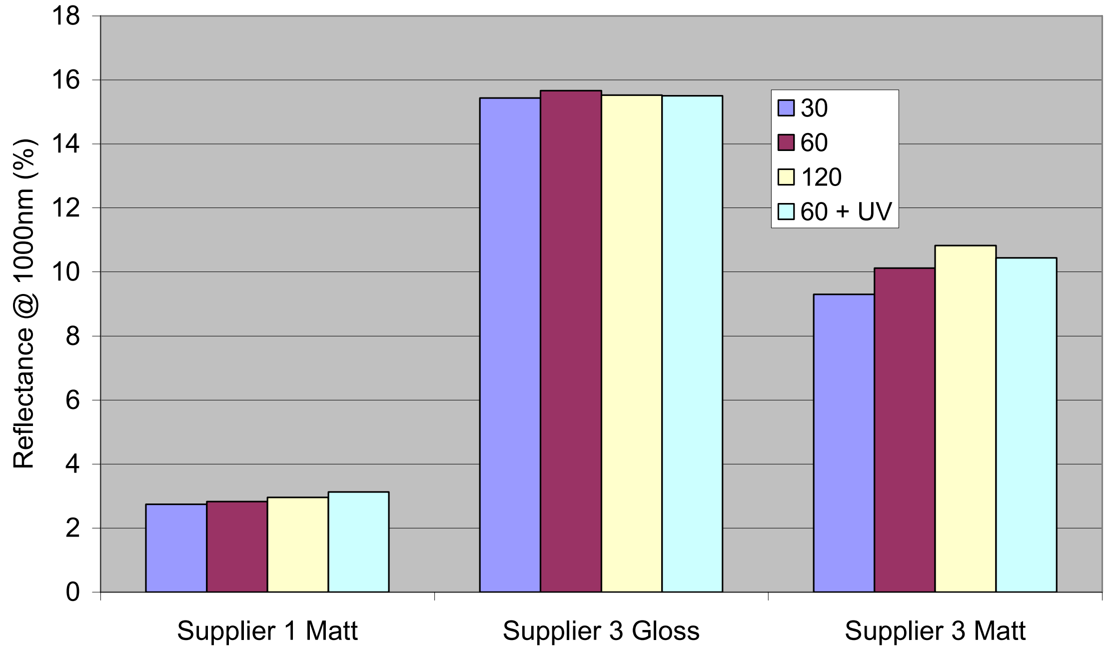

Figure 28 : Reflectivity results showing the effect of cure for phase 2 samples

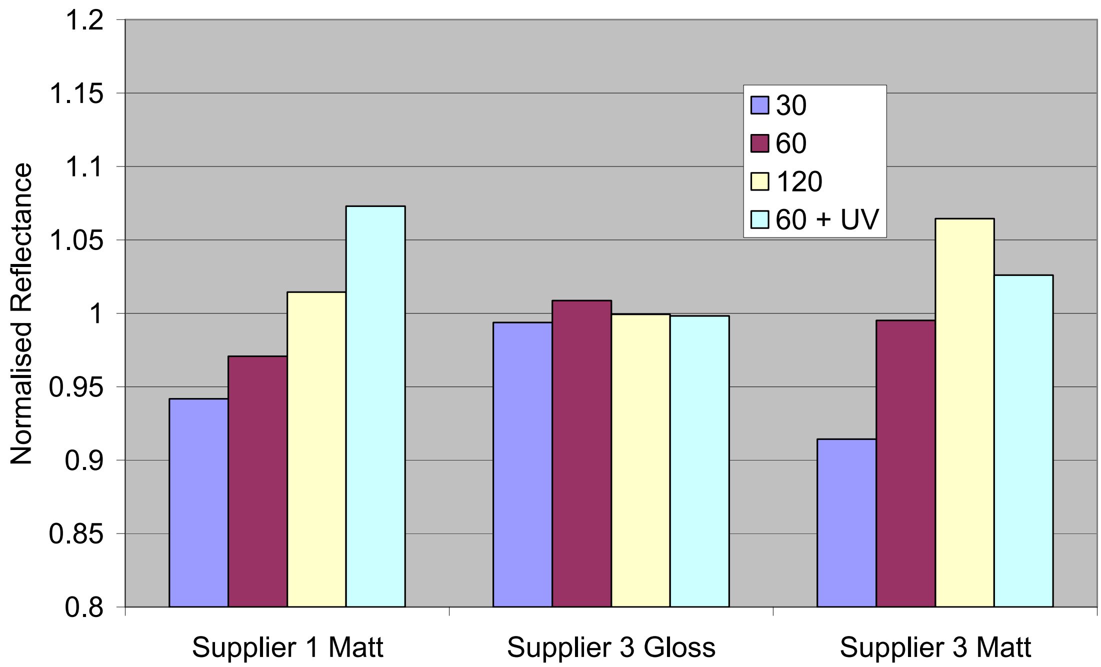

Figure 29 : Normalised reflectivity results showing the effect of cure for phase 2 samples

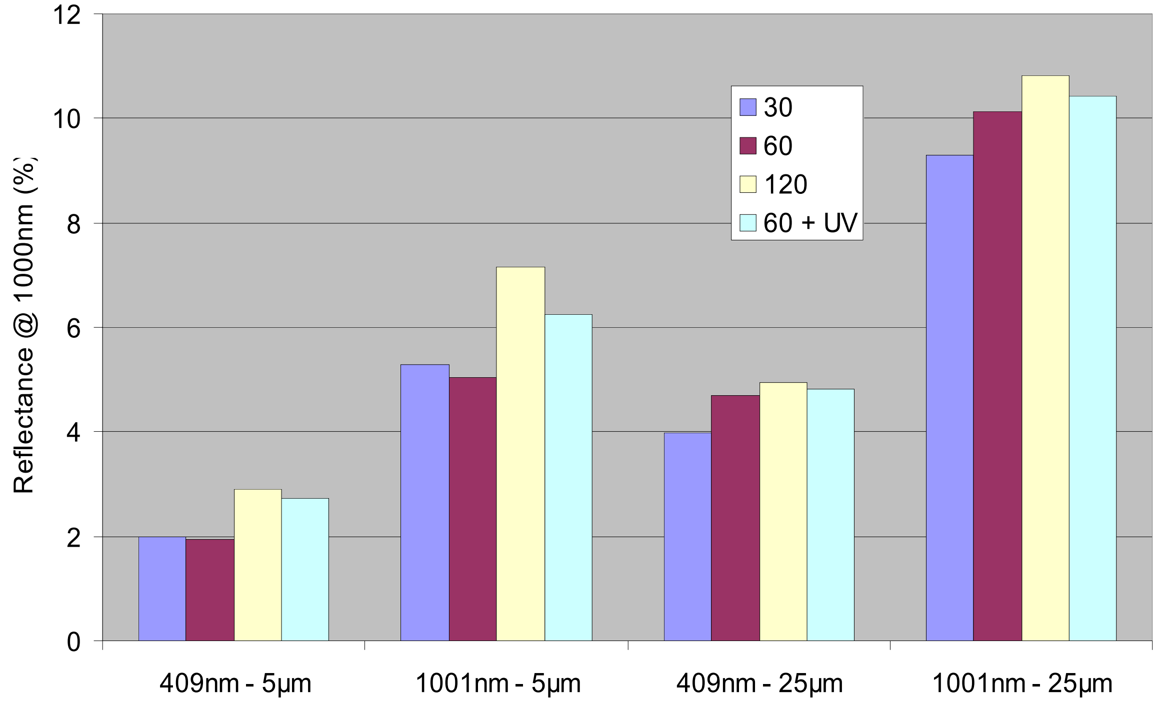

Figure 30 : Reflectivity results showing the effect of coating thickness for phase 2 samples of the matt finish from Supplier 3

3.5 CONTACT ANGLE MEASUREMENT

The results for the contact angle measurements of the phase 1 samples are summarised in Figure 31. These results provide a better differentiation in contact angle between different suppliers rather than between matt and gloss finishes. Increasing cure time (30 to 60 minutes) produced an increase in some cases, but a decrease in others, however the trend was the same for matt or gloss types from same supplier. Moreover, UV exposure tended to increase contact angle.

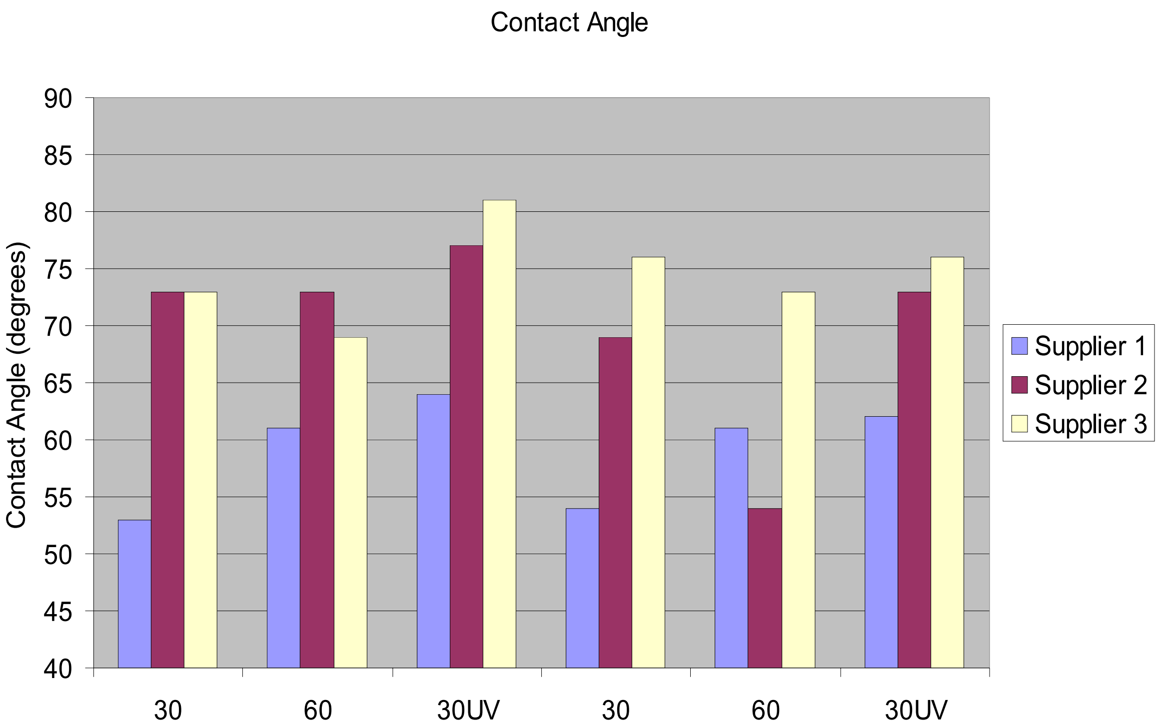

Figure 31 : Contact angle results for phase 1 samples

3.6 SIR MEASUREMENT

The final and minimum SIR measurements for the phase 1 samples are summarised in Figure 32 and Figure 33. It is evident that both the matt and gloss masks from Suppliers 1 and 3, showed an increase in SIR with additional heating, whilst the masks from Supplier 2 did not. There were no clear effects on the SIR associated with the use of UV during cure. Overall, the variation in SIR due to cure conditions was small (<0.6 decades). Compared to uncoated boards, there was only a small change in SIR due to presence of the solder masks (<1 decade).

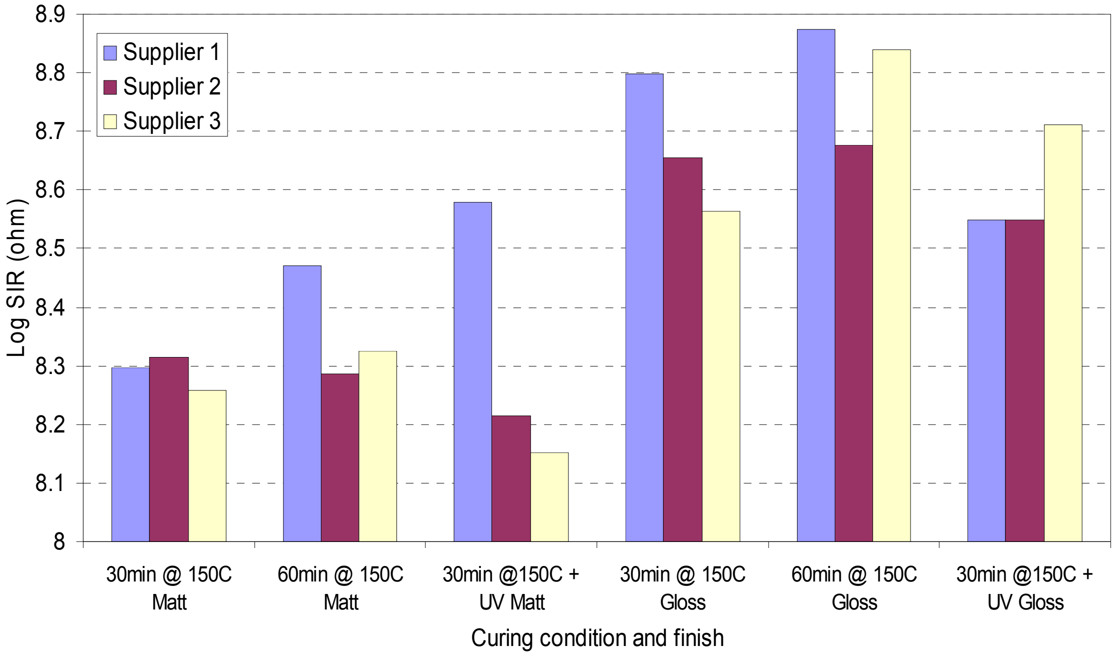

Figure 32 : Final SIR values for phase 1 samples

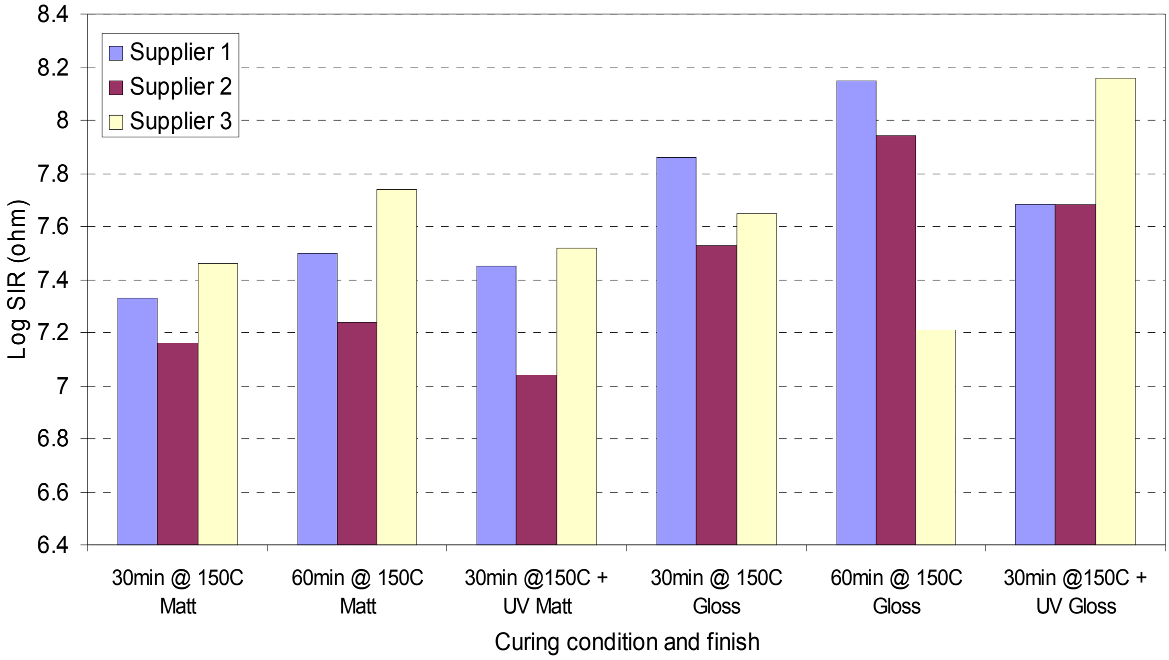

Figure 33 : Minimum SIR values for phase 1 samples

The final and initial SIR results for the phase 2 coatings are summarised in Figure 34 to 37. For the final SIR values for gloss solder masks shown in Figure 34, the thicker solder masks from each supplier gave lowest SIR values. Generally, these results suggest that SIR final value measurements provide little differentiation between different cure states of the masks.

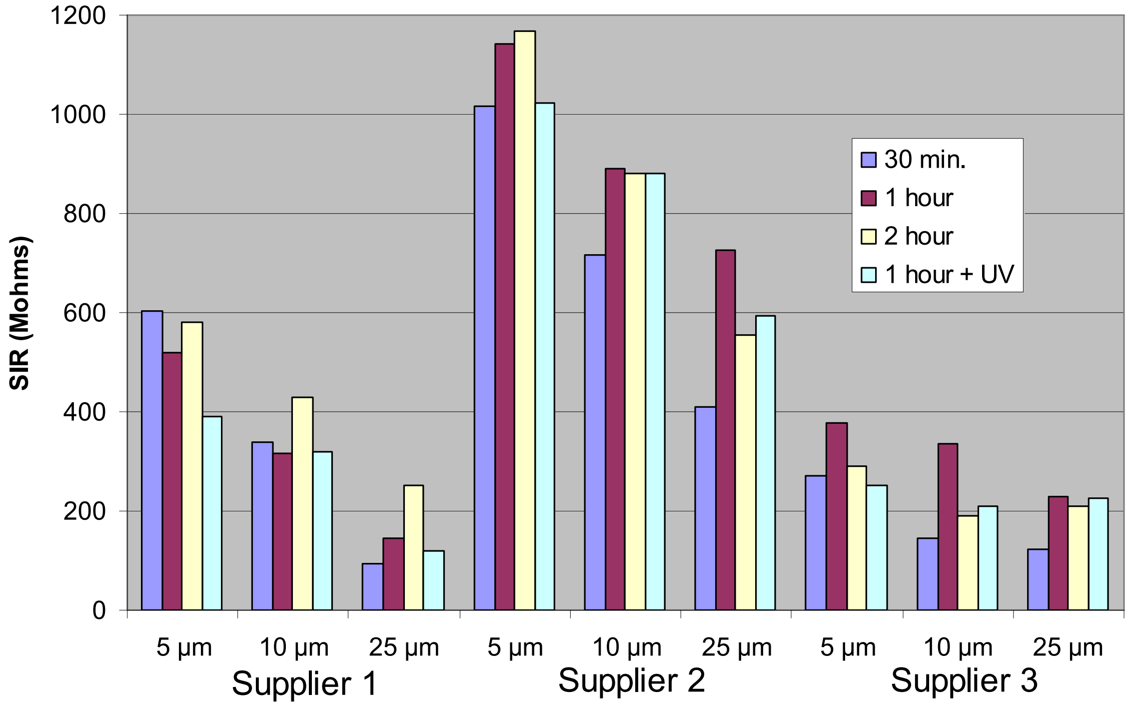

Figure 34 : Final SIR values for phase 2 gloss solder masks

For the final SIR values for matt solder masks shown in Figure 35, the thicker solder masks from each supplier again gave the lowest SIR values. These results suggest that final value SIR measurements provide little differentiation between different cure states of the masks. In addition, the results provide little differentiation between suppliers.

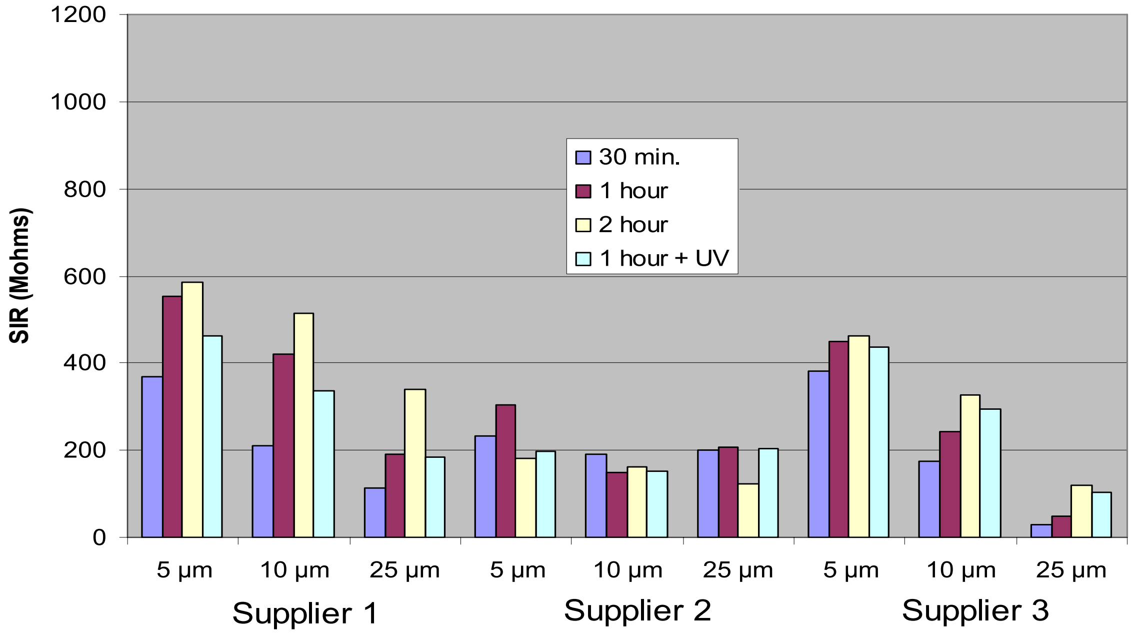

Figure 35 : Final SIR values for phase 2 matt solder masks

For the initial SIR values for gloss solder masks shown in Figure 36, the thicker solder masks did not necessarily give lowest SIR values. Again, these initial SIR results show little differentiation between different cure states of the masks, and little differentiation between suppliers' materials.

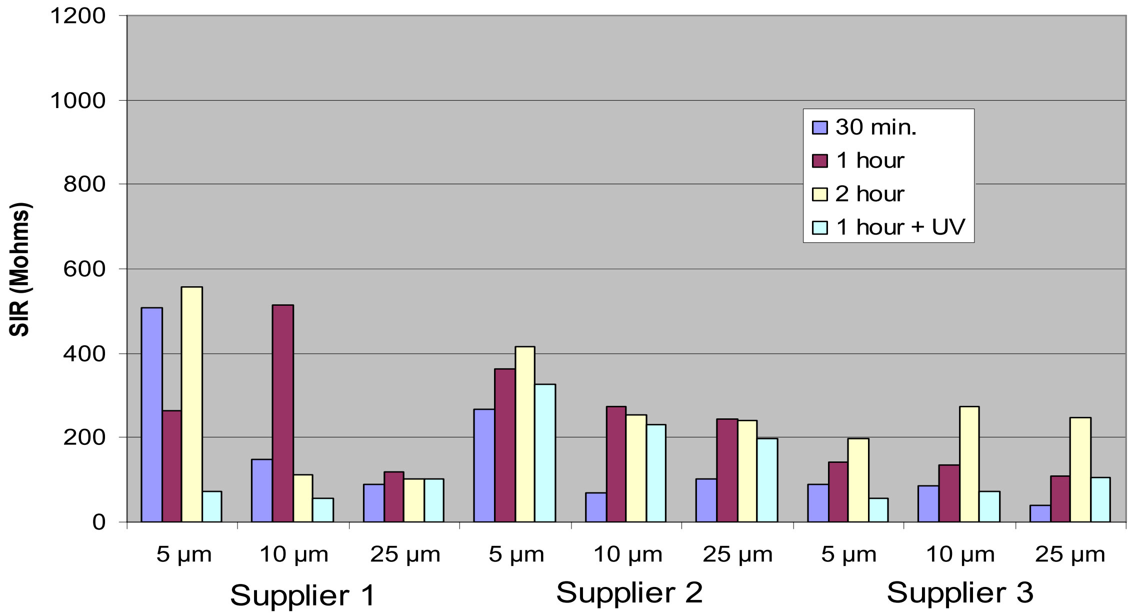

Figure 36 : Initial SIR values for Phase 2 gloss solder masks

For the initial SIR values for matt solder masks shown in Figure 37, the thicker solder masks tended to give the lowest SIR values. Again, these results provide little differentiation between different cure states of the masks, or between different suppliers' materials.

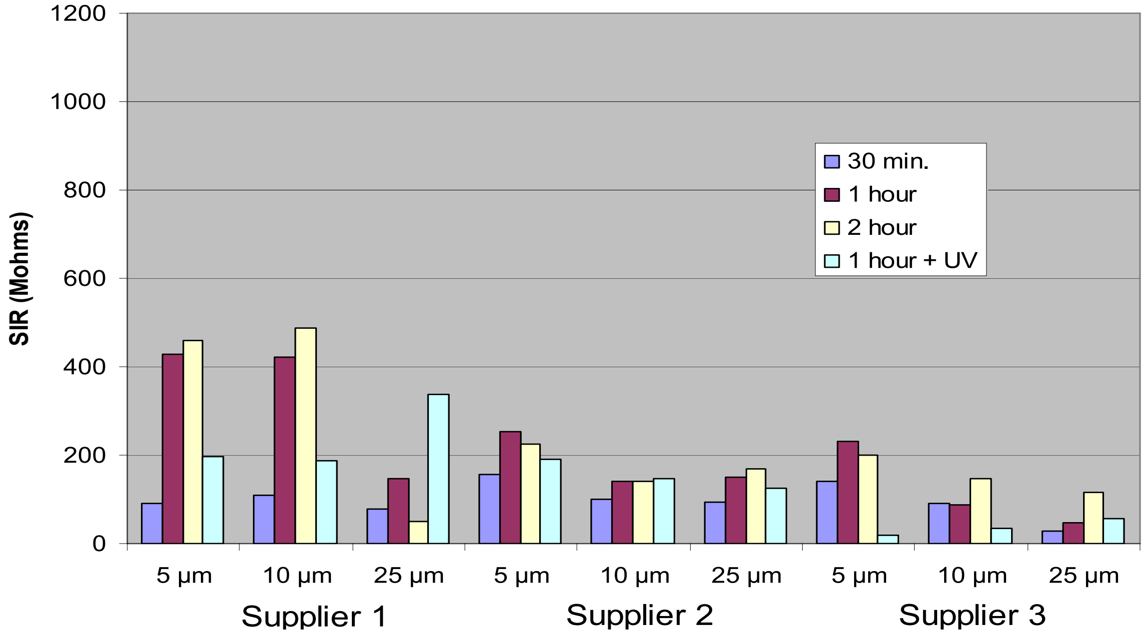

Figure 37 : Initial SIR values for phase 2 matt solder masks

Figure 38 shows an alternative method for reviewing the SIR data. The final SIR values for the matt coatings of each thickness for supplier 3 are plotted against cure condition. A trend of increasing final SIR is evident as the degree of cure increases. This trend is more pronounced for the thicker masks, and can be seen in many of the other coatings, particularly for suppliers 1 and 3 but the trend is not entirely consistent across all coatings.

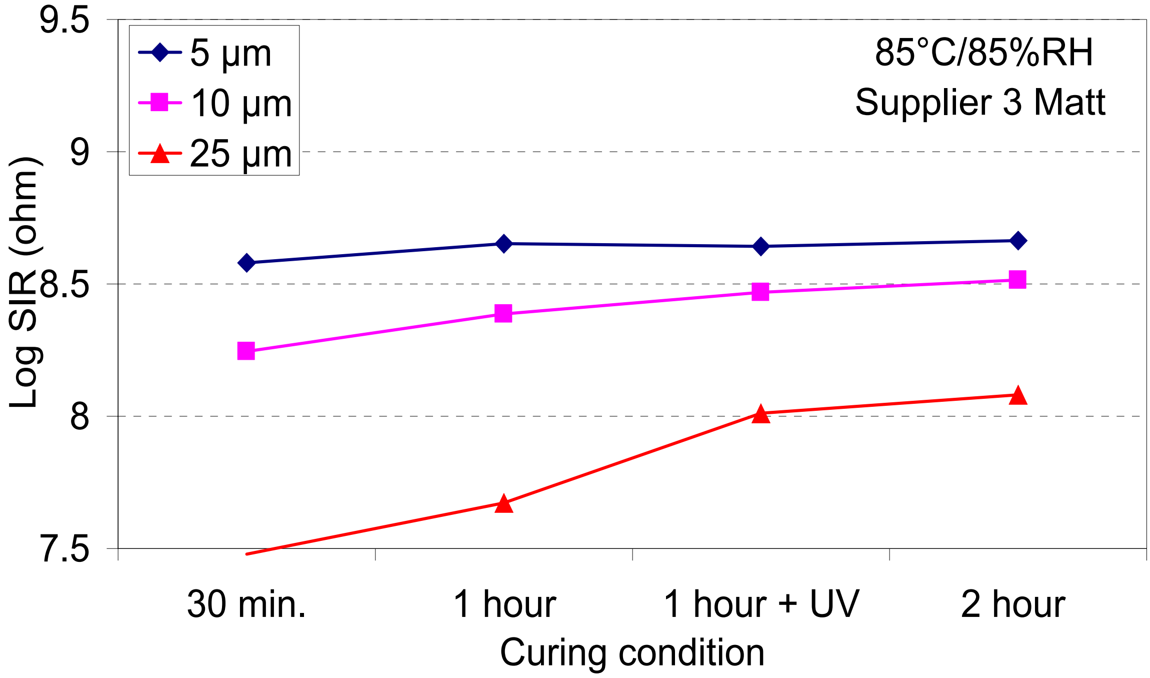

Figure 38 : Final SIR values for Supplier 3 matt solder mask as a function of curing condition

3.7 CAPACITANCE

Figure 39 presents the results of capacitance measurements for the phase 1 coatings. However, it is evident that the capacitance data appear to have no dependence on the degree of cure of the coatings or on their surface finish. This may have been because the measurements were made after SIR testing was completed.

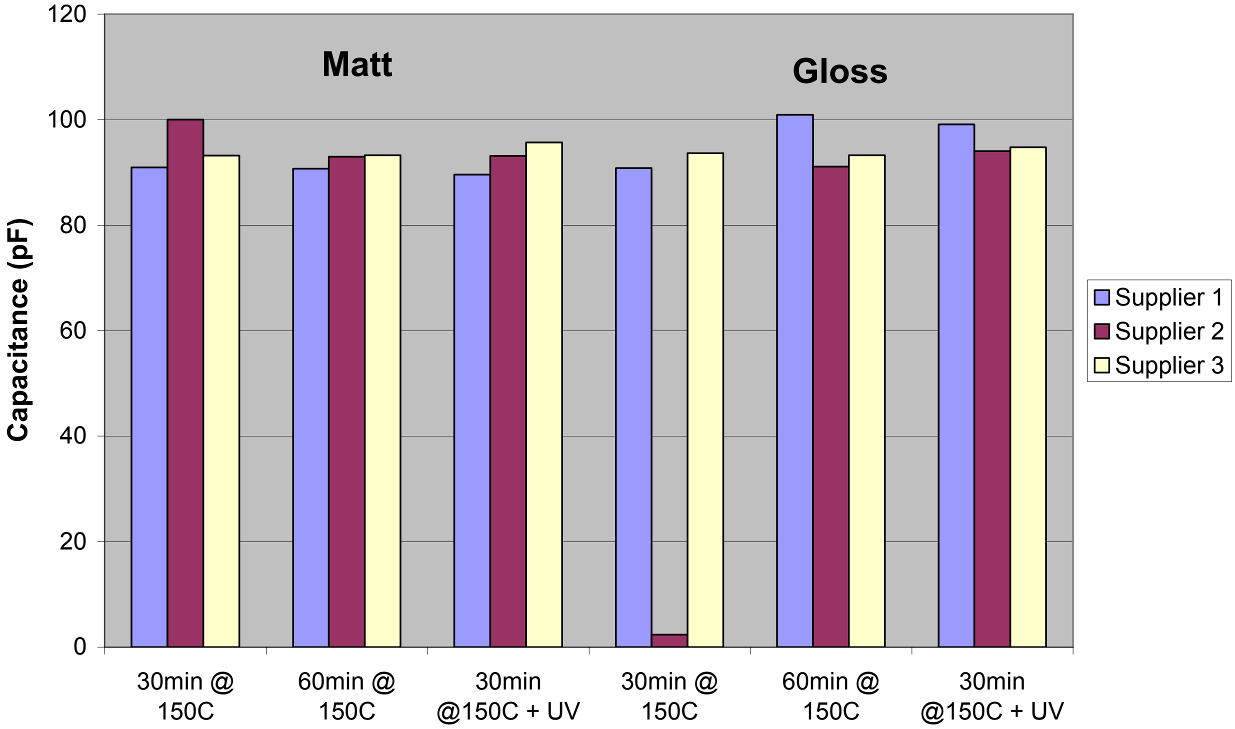

Figure 39 : Capacitance results for phase 1 coatings

3.8 LOSS TANGENT

The results of the loss tangent measurements for the phase 1 coatings are summarised in Figure 40. Again, the values of loss tangent appear to be independent of the degree of cure of the coating and its surface finish. This may have been because the measurements were made after SIR testing was completed.

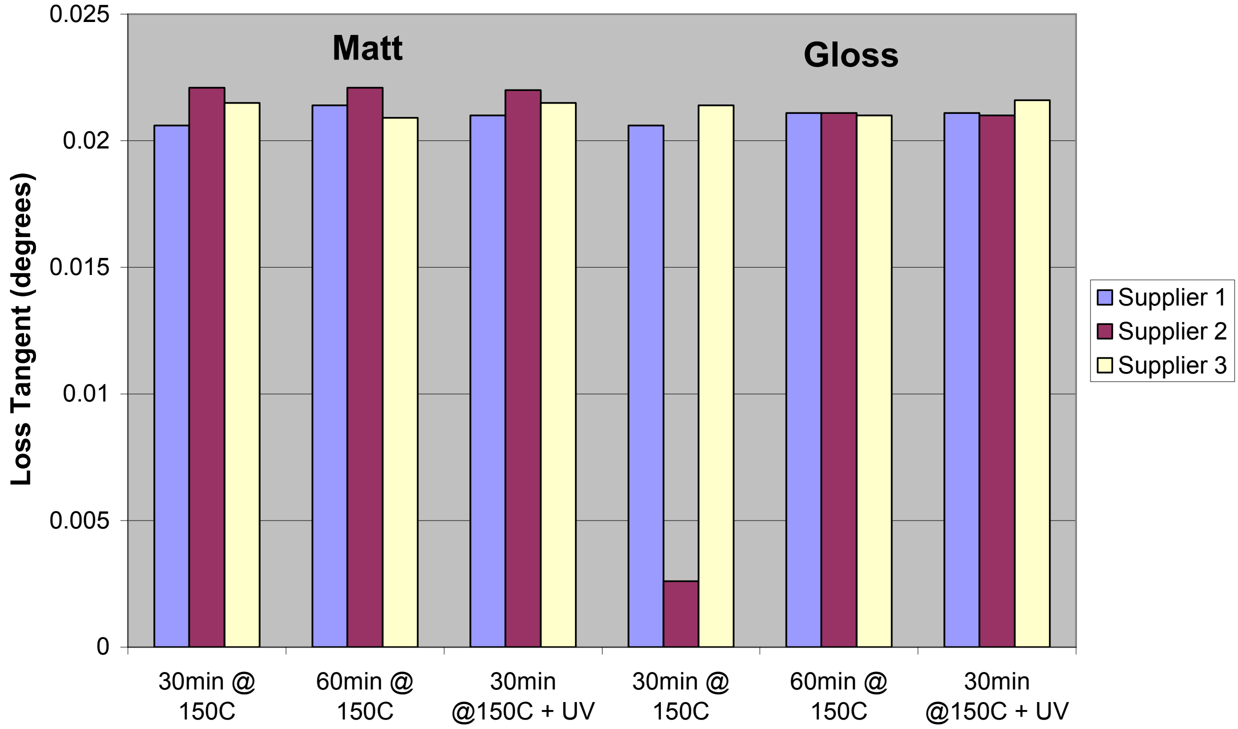

Figure 40 : Loss Tangent results for phase 1 coatings

3.9 ADHESION TESTING

The results of the adhesion measurements for the phase 1 coatings are summarised in Figure 41. Again, there appears to be no dependence of the data on the degree of cure of the coatings or on their surface finish.

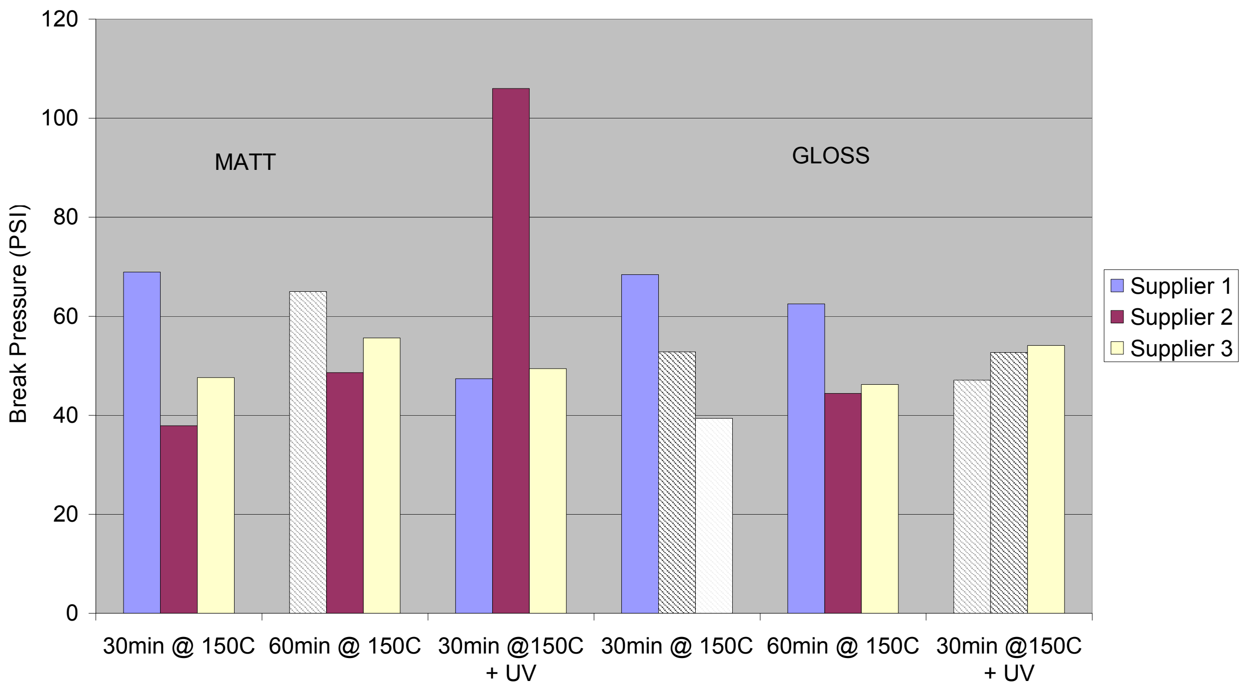

Figure 41 : Adhesion test results for phase 1 coatings

3.10 SOLDER-BALLING (REFLOW SOLDERING)

The results from the solder-balling measurements for reflow soldering of both square and round pads for the phase 2 samples are summarised in Figure 42. It is evident that the pad shape has little effect on the number of solder balls created.

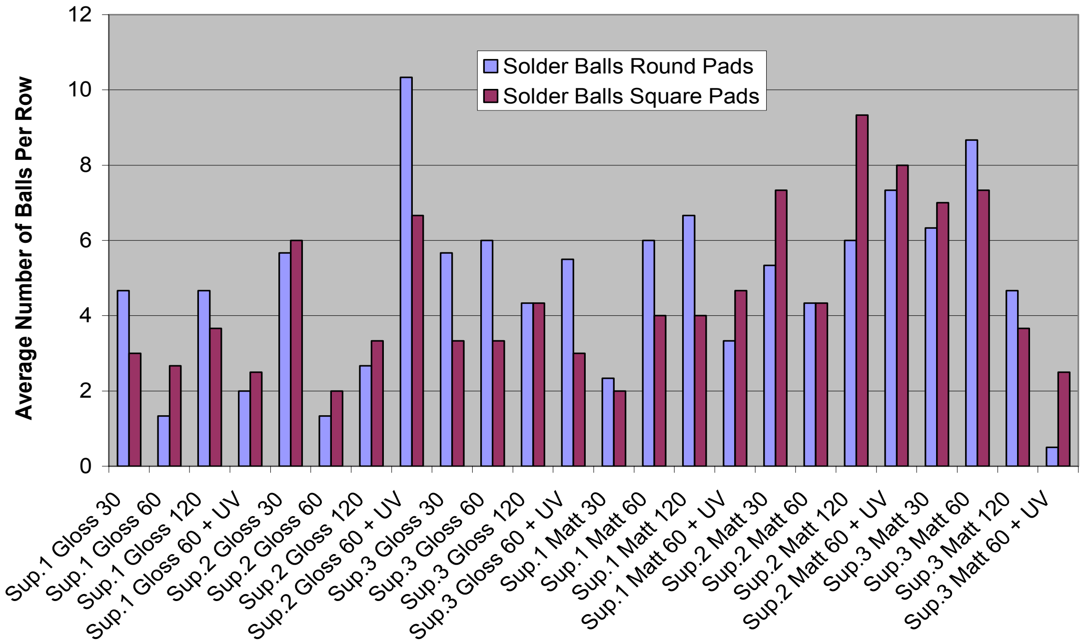

Figure 42 : Average number of solder balls per row of pads as a function of phase 2 coating

The results from the solder-balling measurements for the phase 2 samples (10µm thick) as a function of the degree of cure, are summarised in Figure 43. These results suggest there is no relationship between the number of solder balls created and the degree of cure of the coatings. Nor does there appear to be any correlation between solder balling and the type of coating.

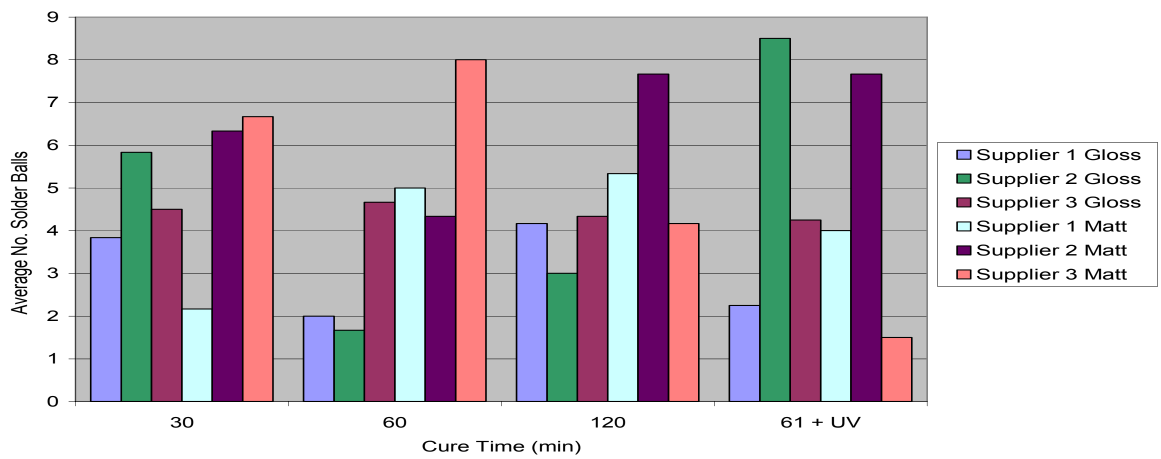

Figure 43 : Average number of solder balls per row of pads as a function of degree of cure

3.11 FLUX SPREAD MEASUREMENTS

The results from the flux spread measurements for the phase 2 samples as a function of the coating type, are summarised in Figure 44. The results suggest that the degree of spread does not appear to be related to the degree of cure or to the material type. The UV cured coatings did tend to gave lower degrees of flux spread. Generally, however, there appears to be no significant links between amount of flux spread and the degree of coating cure or material type.

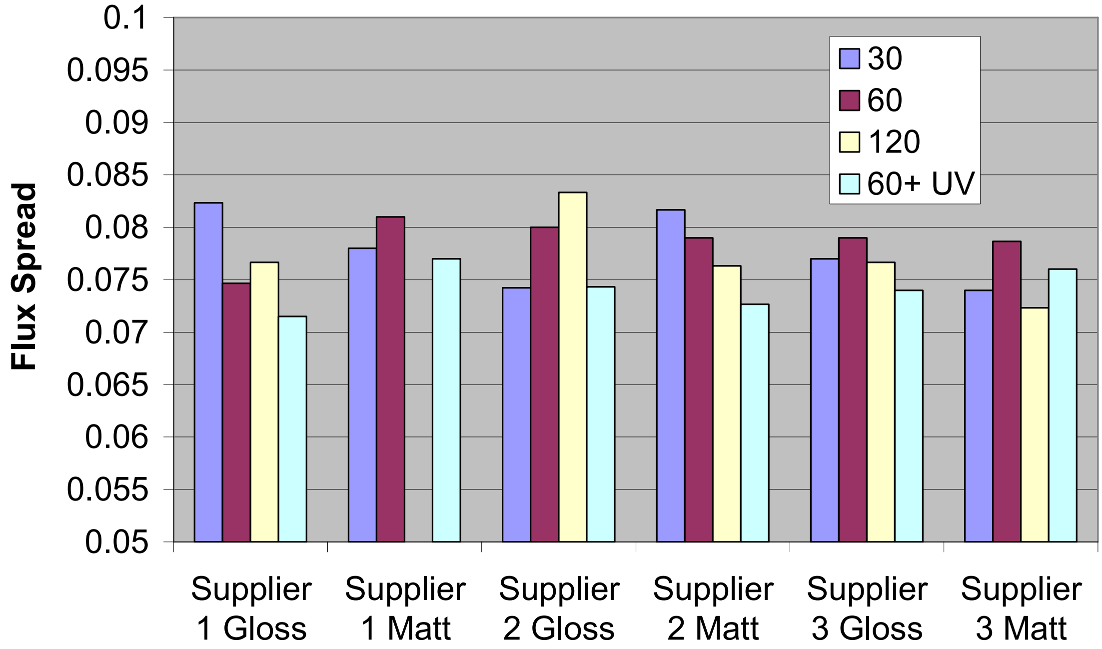

Figure 44 : Flux spread results for phase 2 samples

3.12 SOLDER-BALLING (WAVE SOLDERING)

Figure 45 and Figure 46 present the solder balling results for the wave soldered phase 2 samples for pads at 90 and 45 degrees respectively to the solder wave. For neither set of pads does there appear to be any correlation between the degree of solder balling and the amount of solder mask cure. For pads at 90 degrees to the solder wave, there was some differentiation between suppliers' materials with both suppliers 2 and 3 giving lower solder balling levels than that from supplier 1. For pads at 45 degrees to the solder wave, the material from supplier 2 gave the lowest level of solder-balling.

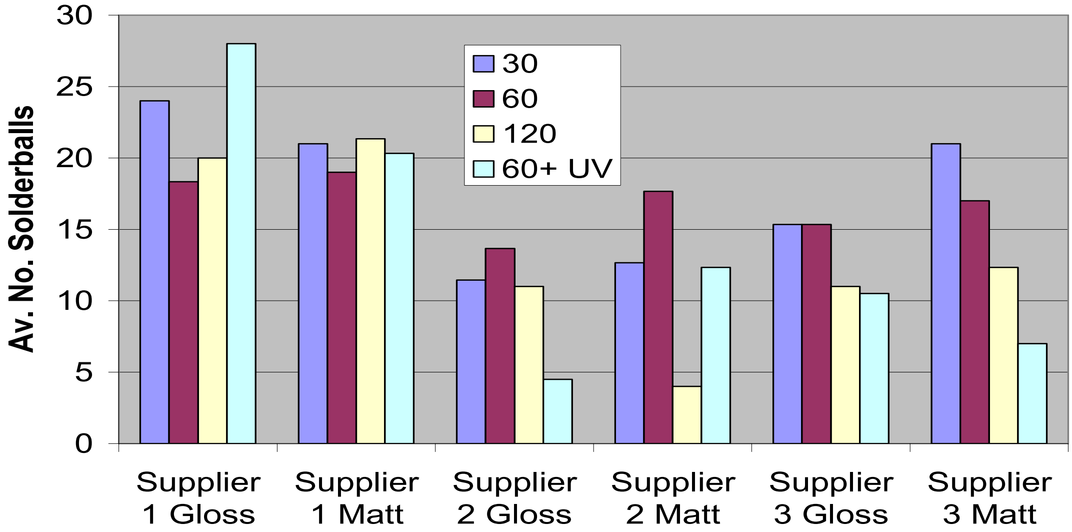

Figure 45 : Solder-balling results for wave soldered phase 2 samples with pads at 90 degrees to the solder wave

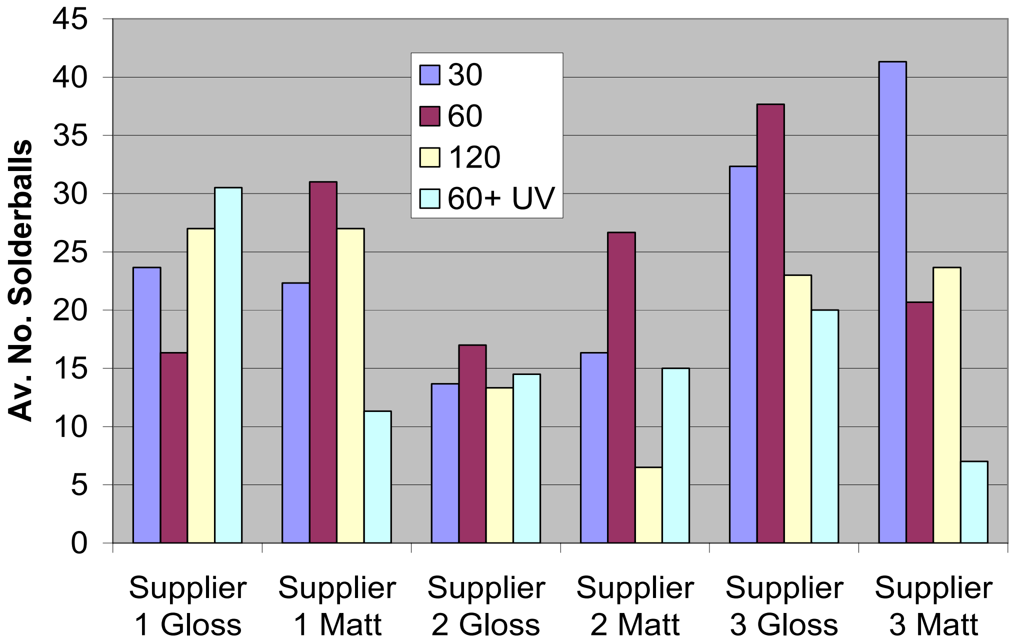

Figure 46 : Solder-balling results for wave soldered phase 2 samples with pads at 45 degrees to the solder wave

3.13 SOLDER SKIP MEASUREMENTS

Figure 47 summarises the wave solder skip results obtained from the phase 2 samples. The results from supplier 2 have been omitted as that coating was considerably thicker than specified (see Section 3.1). For the majority of the solder masks, the round pads produced larger numbers of skips than for the other pad types. However, there appears to be no correlation between the number of solder skips and the degree of cure for the solder masks, nor with the solder mask type.

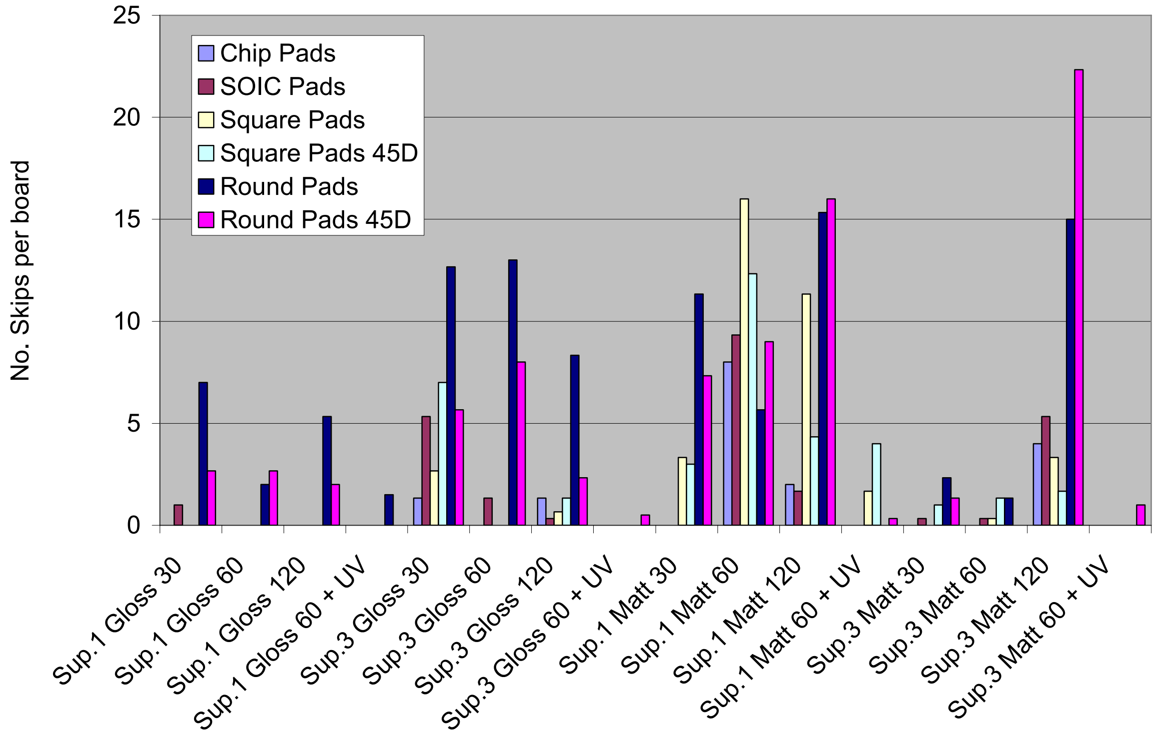

Figure 47 : Wave solder skip results for phase 2 samples

3.14 UNDERFILL VOIDING MEASUREMENT

Figure 48 to 50 summarise the results from the underfill voiding measurements, regarding the effects of solder mask type, the mask thickness, and the degree of cure. For all these parameters, there appeared to be no correlation between the levels of underfill voiding and the variable investigated.

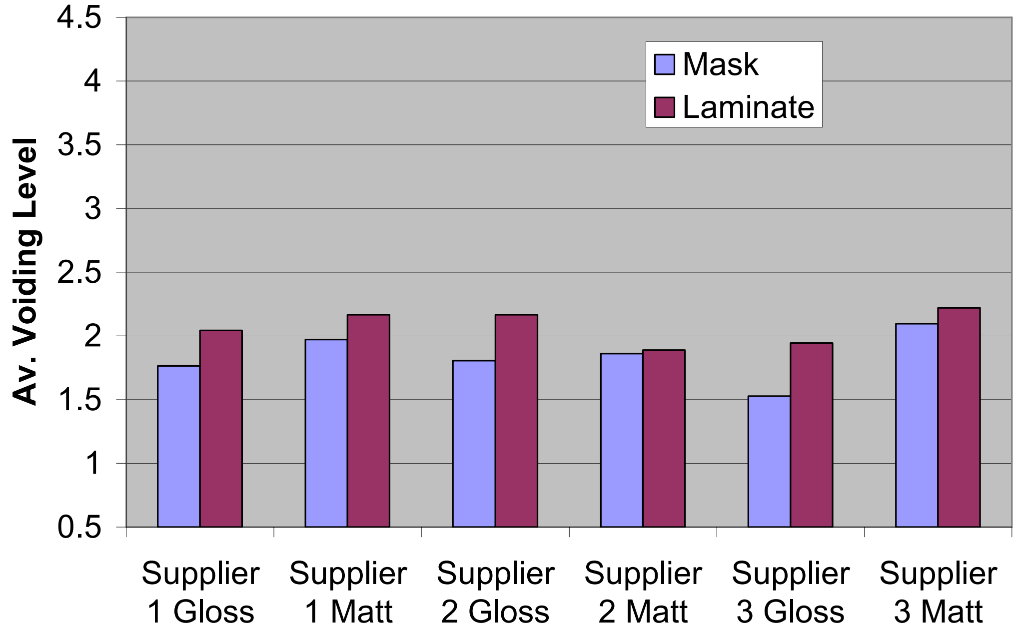

Figure 48 : Effect of mask type on underfill voiding

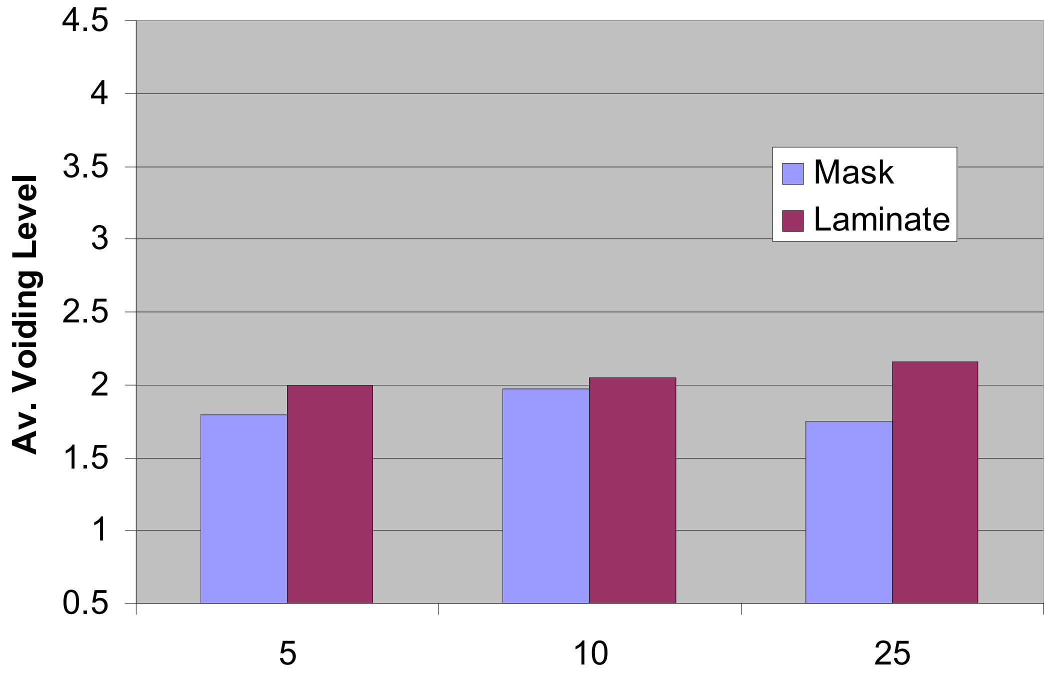

Figure 49 : Effect of coating thickness (average for all masks) on underfill voiding levels

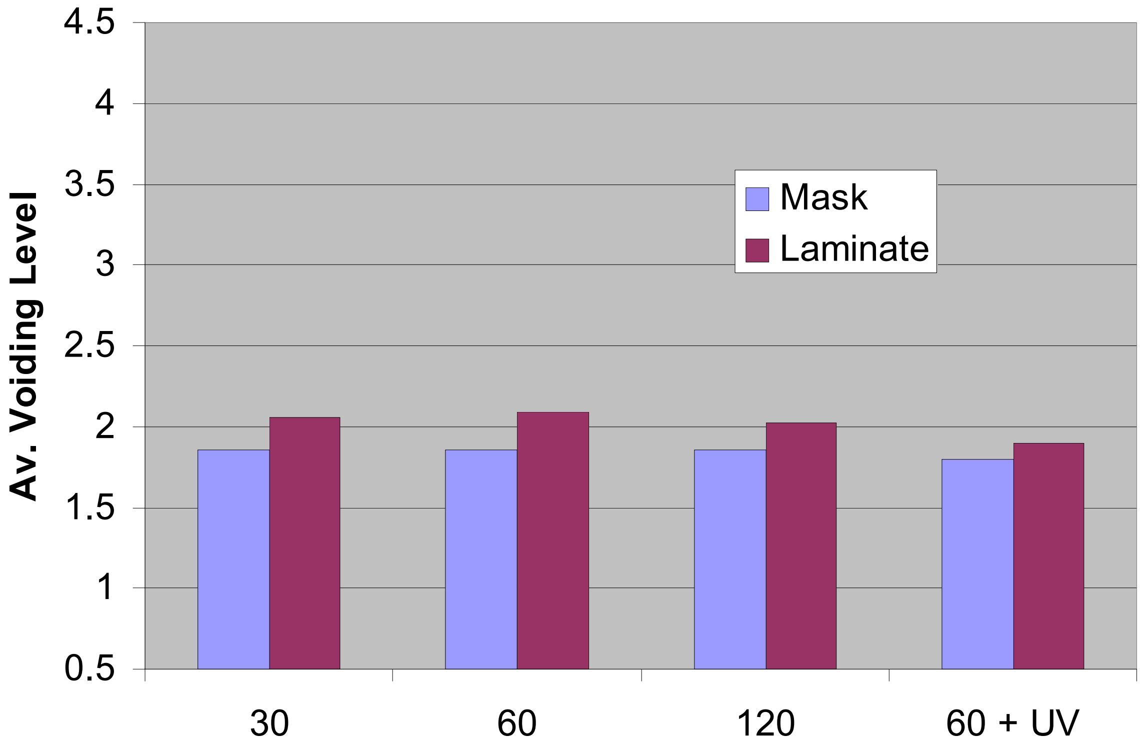

Figure 50 : Effect of degree of curing (average for all masks) on underfill voiding levels

4 DISCUSSION

Some salient points are:

Coating thickness, surface roughness and hardness measurements
None of the measurements of these three parameters were capable of distinguishing between the degrees of cure within solder masks, or between the solder mask types.

Reflectance measurements
As might have been expected, the gloss masks gave much higher reflectance values than their matt-finished counterparts. Additionally, the trends in the SIR measurements were mirrored by the reflectance measurements, but changes in reflectance due to changes in cure were very small. Specific wavelength reflectance measurements provided better differentiation of the degree of cure than the hand held gloss meter. This system gave some differentiation between samples with different degrees of cure as well as solder mask type. There was also good repeatability/consistency across the different wavelengths used during measurement. However, the changes in reflectivity due to curing were dwarfed by changes due to solder mask thickness.

Surface Insulation Resistance
Surface insulation resistance measurements provided a better differentiation between the effects ofsolder mask variables. Final SIR values were strongly dependent on solder mask thickness, but the initial minimum SIR readings were less so. Both final and minimum SIR readings did show some limited dependence on mask cure conditions, but the consistency of this was poor. Longer cure times tended to result in higher SIR values but UV exposure did not improve SIR, in fact it seemed to reduce it slightly.

Generally there was insufficient discrimination between solder mask variables to make surface insulation resistance measurement a useful test method.

Effect of Heating/Degree of Cure on Measurements

Figure 51 presents a graphical summary of the changes in the various measurements taken for all the solder masks as a function of increasing degree of cure. Although there are some significant changes in some measurements (up to 60%), the changes are not consistent across the range of solder masks tested, and therefore there is little confidence in using these test methods to assess curing in a wide range of solder masks.

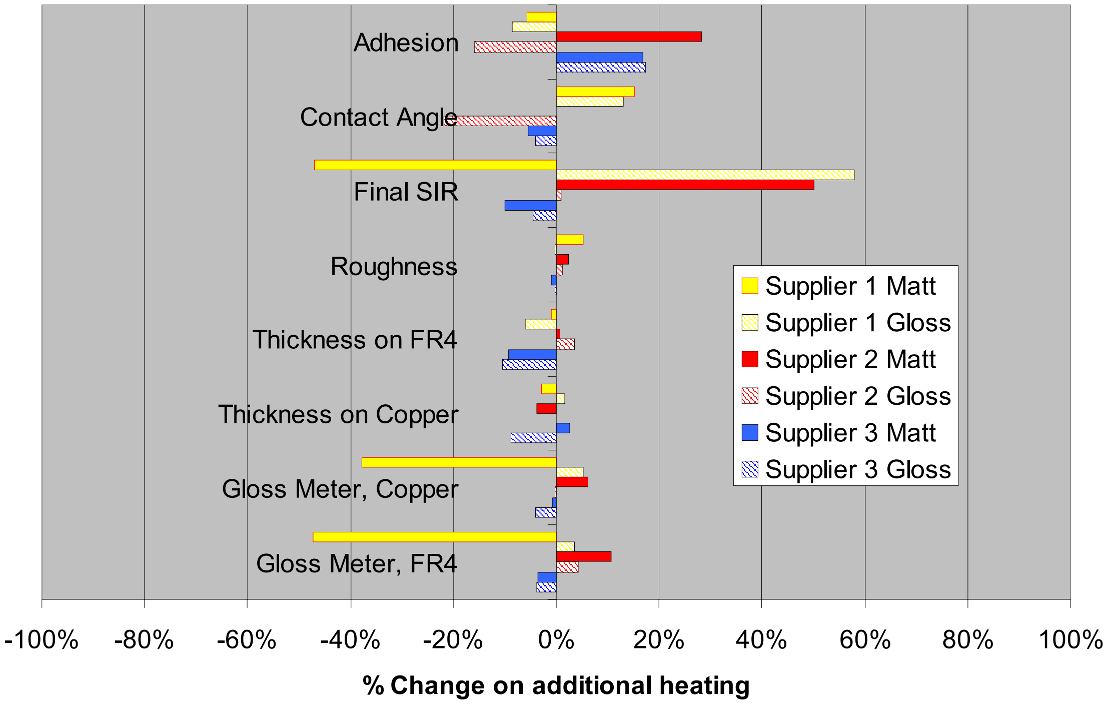

Figure 51 : Percentage change in measured variables as a result of increased cure for all solder masks

Figure 52 provides a graphical summary of the changes that occurred in SIR variables for the range of solder masks tested. In this case, there is an encouraging correlation for five of the solder masks, with only the supplier 3 gloss solder resist appearing inconsistent with this pattern. The changes in minimum SIR due to increased cure are small but the changes in the charge flow (amount of ions swept to the electrodes during initial bias testing) and SIR range (the difference between minimum and final SIR values) are significant (10 to 50%) for the majority of the solder mask coatings.

This test method may have some use in determining the degree of cure, but each material would need to be characterised individually. Hence, the technique would be unsuitable for incorporation into a test method for an end-user to apply across a range of boards from different suppliers.

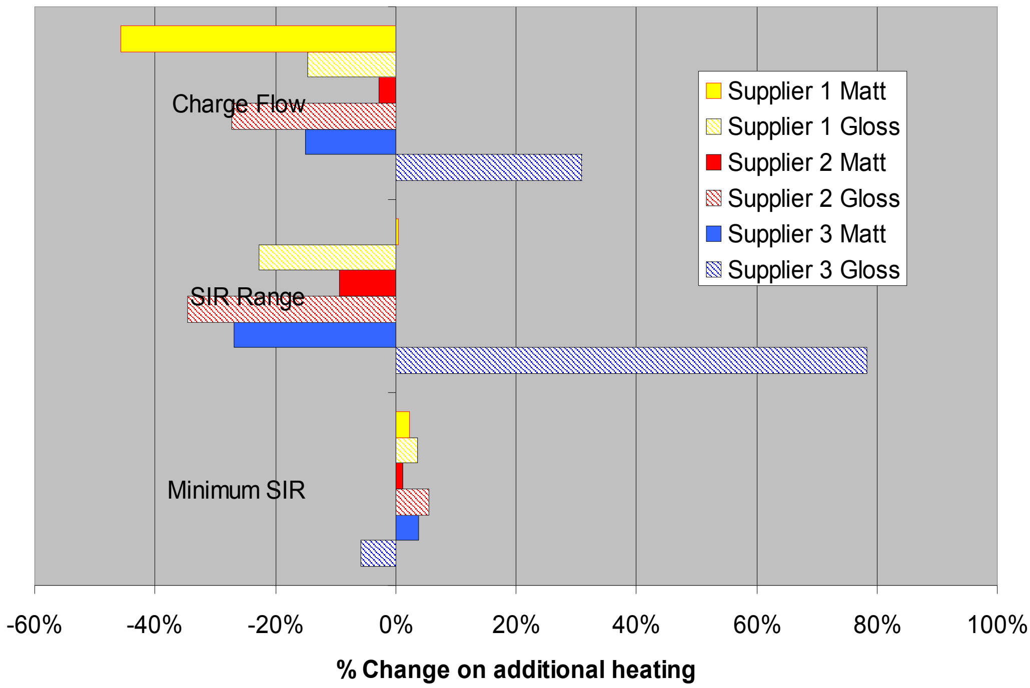

Figure 52 : Percentage change in measured SIR variables as a result of increased cure for all solder masks

Effects of UV Curing

Figure 53 and Figure 54 provide a graphical summary of the results of various measurements taken change for all the solder masks as a result of UV cure, and of increased cure respectively. Although there are some significant changes in some measurements (up to 100%), the changes are not consistent across the range of solder masks tested, and therefore there is poor confidence in using these test methods to assess curing in a wide range of solder masks.

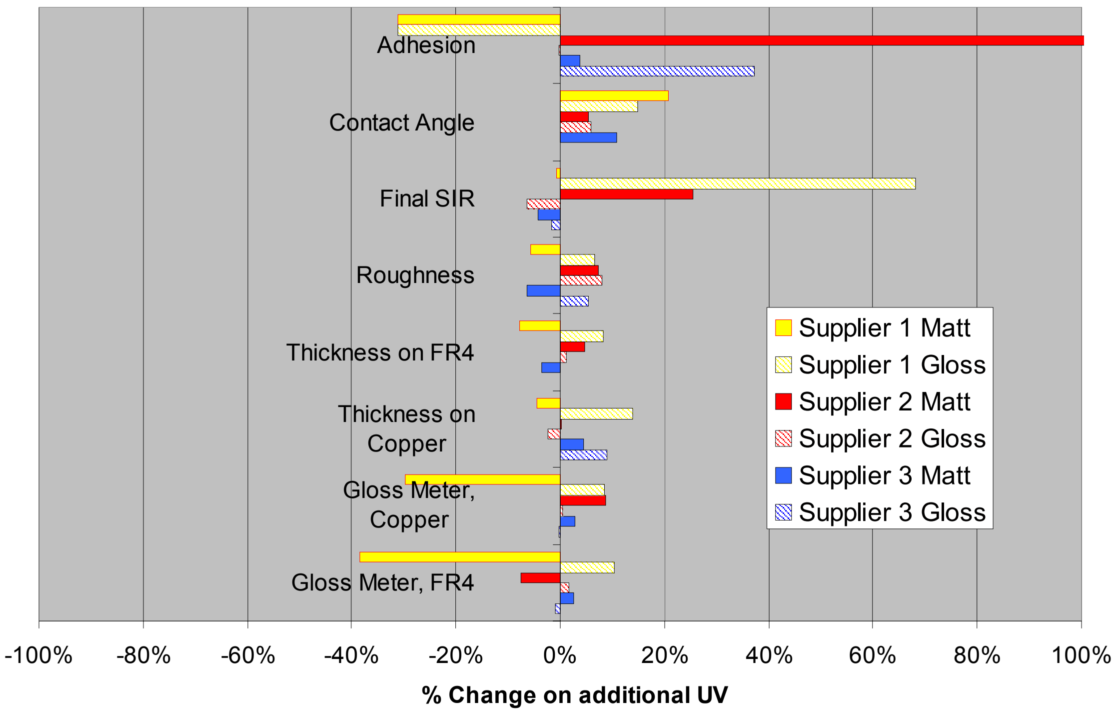

Figure 53 : Percentage change in measured variables as a result of UV cure for all solder masks

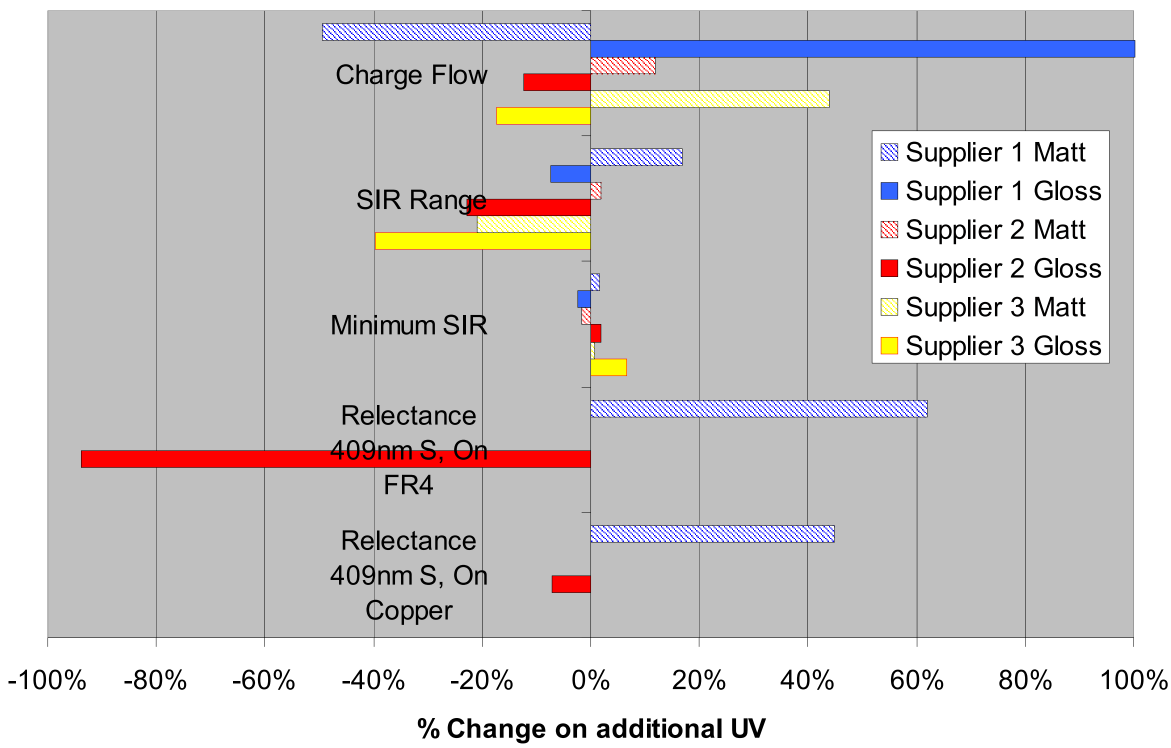

Figure 54 : Percentage change in measured variables as a result of increased cure for all solder masks

5 CONCLUSIONS

In an attempt to evaluate a number of parameters of potential use in indicating the degree of cure of solder masks, tests using a series of measurement techniques have been undertaken on six different solder masks from three suppliers. The curing regimes used to prepare the masks were identified by industry partners as appropriate for producing a range of degrees of cure. Likewise, discussions were held with industry in order to identify the parameters and measurement techniques to be studied. For samples of each of the masks prepared under different cure conditions, the following parameters were measured:

- Thickness
- Surface roughness
- Hardness
- Surface reflectivity
- Contact angle of sessile drop
- Surface insulation resistance, capacitance and loss factor
- Adhesion

In addition, the following process evaluations for the solder masks were undertaken:

- Solder-balling (reflow soldering)
- Flux spread (reflow soldering)
- Solder-balling (wave soldering)
- Skips (solder balling)
- Underfill voiding

The results indicated that the majority of these measurements did not effectively or consistently indicate the degree of cure for the samples tested. Thickness affected many of the test methods to a much greater extent than did the degree of cure.

The best correlation to degree of cure was found using surface insulation resistance testing, where the changes that occurred in SIR variables such as charge flow and SIR range (difference between initial minimum SIR values and final SIR values) were consistent for five of the six masks tested. The changes in minimum SIR due to increased cure are small but the changes in the charge flow (amount of ions swept to the electrodes during initial bias testing) and SIR range (difference between minimum and final SIR values) were significant (10 to 50%) for the majority of the solder mask coatings. This test method may have some use in determining degree of cure, but each material would need to be characterised individually and therefore the technique is considered unsuitable as a test method for an end-user to apply across a range of boards from different suppliers. Additionally no distinct effects of UV cure could be detected with SIR testing or other test techniques.

The results have also shown that the representative solder masks studied appear robust in relation to under or over curing. The materials also had very similar properties in terms of process performance. In addition, the project results indicated that solder masks may well cure to an equilibrium at room temperature faster than expected, which would be advantageous for stability of subsequent processing by assemblers.

6 ACKNOWLEDGEMENTS

The work was carried out as part of a project in the MPP Programme of the UK Department for Innovation, Universities and Skills. We gratefully acknowledge the support and co-operation of the following companies without whose help this project would not have been possible.

Shipley Ronal
Coates Circuit Products
Electra Polymer

7 REFERENCES

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3. SM-840C - Qualification and Performance of Permanent Solder Mask