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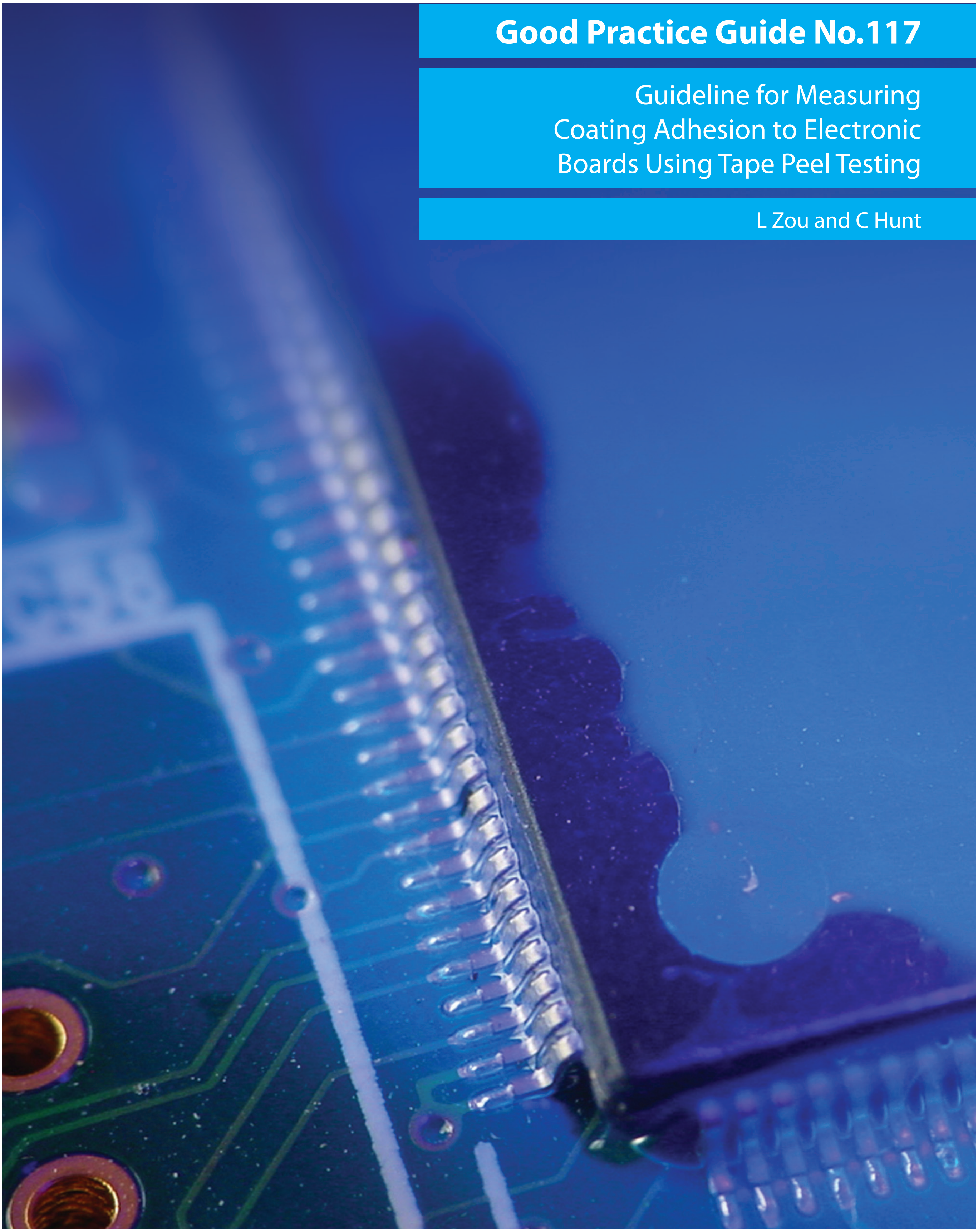
Good Practice Guide No.117

Guideline for Measuring Coating Adhesion to Electronic Boards Using Tape Peel Testing

L Zou and C Hunt



National Measurement System

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Guideline for Measuring Coating Adhesion to Electronic Boards Using Tape Peel Testing

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Abstract

A new test method (tape peel method) to evaluate conformal coating adhesion on electronic assemblies has been developed. The approach directly measures the peel force needed to remove a conformal coating. This is the only quantitative method to assess conformal coating adhesion force. This document describes equipment, material, parameter and the procedure to assess conformal coating adhesion.

Coatings have low cohesive strength and so a reinforcement tape is used. The application of the coating and tape to the substrate, and the procedure for peeling are described.

The method is validated using different type coatings and substrate materials, which include FR4 Printed Circuit Board (PCB) without resist, bare PCB copper, contaminated PCBs, resists, assemblies and components. The results are detailed in appendix F. These results demonstrate that tape peel test is a sensitive method for measuring coating adhesion on different materials found on PCB assemblies. This technique allows coatings adhesion to be compared on different surfaces that include contaminated surfaces, component bodies and resists.

This guide contains six appendices that cover experimental work that supports the given procedures. Appendix A covers the selection of the supporting cloth; Appendix B describes a post application of the supporting cloth with second application of the coating; Appendix C investigates how the technique can be used to assess coating cure; Appendix D covers the effect of peel speed; the Appendix E studies the effect of tape width; and Appendix F validate the method with different coating types and substrate materials.

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Contents

1 Introduction

Electronics are now being used in a wide range of applications and under increasingly severe conditions, and the challenge is to achieve higher levels of reliability in these hostile environments, particularly in safety critical applications. Conformal coatings have been applied to electronic circuits to achieve a high degree of protection, even in environments that would normally be considered hostile for electronic equipment[1,2].

Coatings are typically semi-permeable membranes and can prevent contaminants from harsh operating environment reaching the circuit, however will not be completely impermeable to the wide range of contaminants. Previous work has demonstrated that permeation of contaminants is dependent on coating material (molecular chemistry), coating coverage, contaminant and concentration of contaminant[3,4]. However to achieve optimum protection performance of conformal coating, good adhesion to the electronic circuit is essential[5,6]. There is an increasing requirement to assess coating adhesion. There is no direct measurement method to assess coating adhesion force due to low cohesion force of coatings. An indirect method to evaluate coating adhesion exists, the "*cross hatch method*"[7]. With this method the operator can influence the test outcome. Another commercial method uses dyne pens to assess substrate surface energy. This method is based on a visual inspection of pen mark to give a number, and is open to user interpretation, and hence there are accuracy issues.

A new test method (tape peel) has been developed here to measure coating peel force directly. Conformal coatings are normally less than 100 µm thick, and the adhesion force is higher than its cohesion strength, particularly for such thin coatings. These thin coatings cannot be directly peeled from substrate. A solution to this problem is to support the coating with a tape that reinforces the coating, but does not change the bond between the coating and the substrate. Using this impregnated tape with a free portion than can be gripped, the coating can be peeled and the adhesion force measured. It is critical that the reinforcement tape does not interfere with curing of the coating. The development of the test procedure and parameters are covered in the appendices.

2 Overview tape peel testing for coating adhesion measurement

2.1 Tape peel testing

A tape is placed on the substrate and a liquid coating applied with a syringe, as shown in Figure 1, leaving a coating free portion. Following curing of the coating the impregnated tape is peeled from the substrate at 90°, monitoring the force during the peel, as shown in Figure 2. If the bonding between coating and tape is higher than that between coating and substrate, then the coating adhesion to the substrate, is directly measured. However, for a strong bond between coating and substrate, the failure may occur between tape and coating. Although the peel force between coating and substrate cannot be measured in this situation, this scenario is indicative of acceptable adhesion of the coating to substrate. Since the selected tape has high adhesion to coatings, as detailed in Appendix A, there should not be any coating adhesion concern.

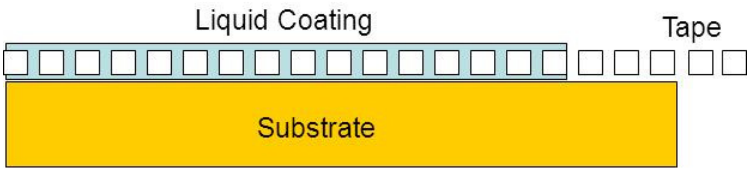

Figure 1: Tape peel test sample

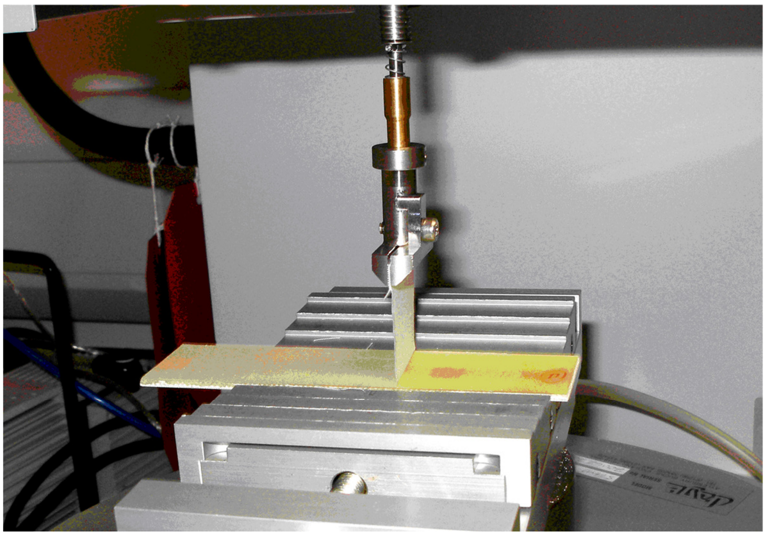

Figure 2: Tape peel testing

2.2 Tape peel testing on cured coating (Post coating application of tape method)

The method described so far has the tape applied simultaneously with the coating. Here we explore the possibility adhering the tape by applying a second layer of the original coating. We refer to this as the so-called post coating method. If successful, this would obviate the need to always embed the tape in the initial coating, allowing any coating to be tested at any point in assembly without the need for any previous preparation. Therefore for an already cured coating, apply the same liquid coating with a tape as shown in Figure 3. After the liquid coating has been cured, peel the tape from the substrate and monitor the peel force during the peel in exactly the same manner as before. There is a limitation to this method, in that a good bond is needed to form between the two coating layers. Some coatings, such as acrylics, the top of the original layer will soften with the application of the second, and hence a strong bond will be formed. Therefore, tape peel will work for a restricted set of coatings only. An investigation for the post coating method is given in Appendix B.

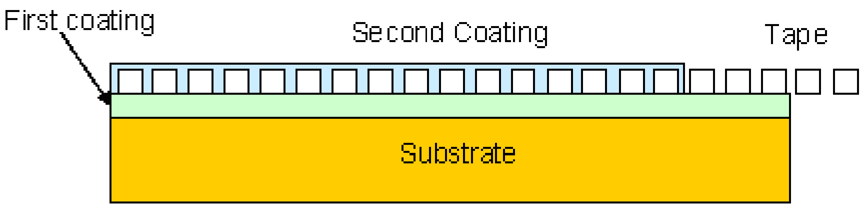

Figure 3: Tape peel test sample on cured coating

3 Materials and equipment

3.1 Materials

1. Cloth: a specific cloth material, 65% polyester + 35% cotton with at least 15% open area, as shown in Figure 4, the thickness of the cloth should be approximately 120 µm. This material type has been proven to demonstrate high adhesion forces when peeling coatings. Details are given in Appendix A.

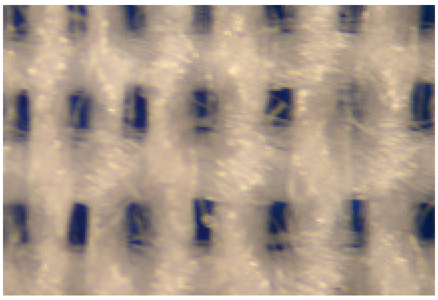

Figure 4: 65% polyester + 35% cotton cloth

2. Disposable plastic pipette with volume marks.
3. 250 ml glass beaker.
4. General purpose grade acetone.

3.2 Equipment

Equipment that is capable of performing 90° peel with controlled speed, between 0.5 and 2mm/s, force measurement range 0 to 100N with 0.1N sensitivity.

3.3 Peel tape preparation

1. Accurately cut a peel tape from the cloth, suggested widths of the tape are 25mm or 10mm. The wider the tape the more accurate the results. The length of the tape should be 10mm longer then the substrate, as shown in Figure 5. This allows for one end of the tape to be easily gripped, and clamped in a test

machine. The total length should be long enough to allow for 20mm of peel force measurements

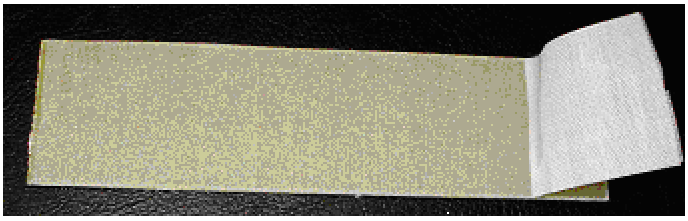

Figure 5: Test sample

2. Using tweezers to hold one end of the tape, and place the tape into a beaker with 200 ml acetone and rinse for 30 seconds. Then remove and dry on a clean paper towel.

3.4 Test sample preparation

1. Using a pipette apply a sufficient volume of conformal coating to cover the substrate uniformly. Spread the coating as necessary, but leave approximately 10mm substrate without the coating, as shown in Figure 5. A 500 µm wet thickness of coating is recommended.
2. Place the peel tape firmly onto the substrate to get good wetting of the tape and good contact between tape and substrate, and make sure that there is no bubbles trapped underneath the tape.

3.5 Coating cure condition

Before the tape peel test is performed, coating should be cured according to coating supplier's recommendation. However, for some coatings solvent evaporation at high temperature may cause bubbles and reduce the adhesion force. This occurrence is probably because the peel tape acts as an additional barrier hindering solvent evaporation. Room temperature curing will avoid this problem. If higher temperature curing is required an initial room temperature cure for a few hours, and then followed by the high temperature cure is recommended. Furthermore, using coating supplier's cure condition, the maximum adhesion force is not always reached. Some studies on effect of coating cure condition on adhesion force are detailed in Appendix C.

3.6 Tape peel testing

1 Place the fully cured test sample on peel test machine, attach the free end of the tape to the machine, then start to 90° peel.
2 Make sure that the peel edge is normal to the tape, as shown in Figure 7.

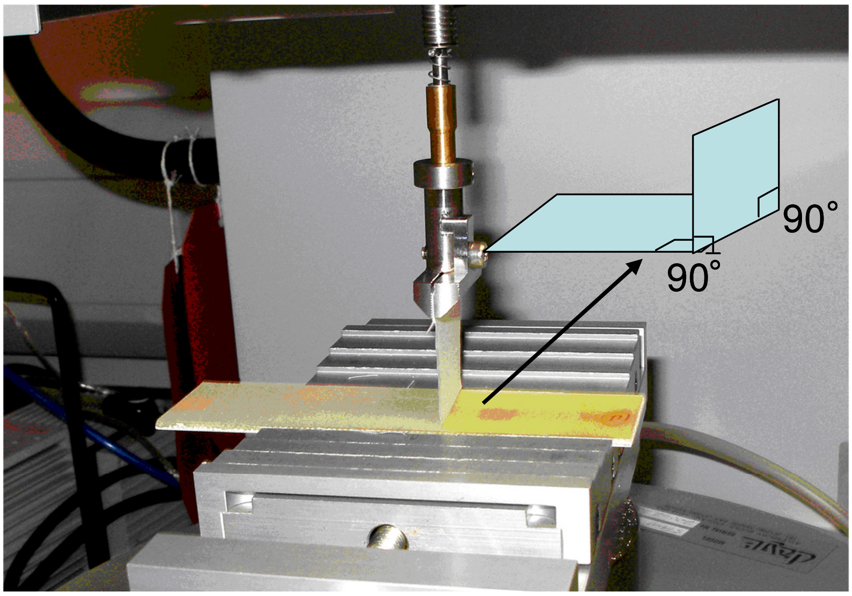

Figure 7: 90° tape peel testing

3.7 Peel parameters

1. The vertical pull and the horizontal movement of the table should be equal to maintain the 90° pull angle.
2. A peel speed of 1mm/s is recommended. Peel speeds in the range 0.5-2.0mm/s was found not affect peel force, the details are given in Appendix D. Peel speeds out this range should be checked.

3.8 Test results

1. The test results should be represented with the graph of distance (mm) and peel force PF_{n*}, as shown in Figure 8. (* n is the tape width in mm)
2. The results also can be represented with the average peel force (N) on whole peel length. If the result presented in this way, the peel force for the first 5mm distance should not be included. The tape width should be indicated in the results, as the peel force is a function of the tape width, the details can be found in Appendix E.

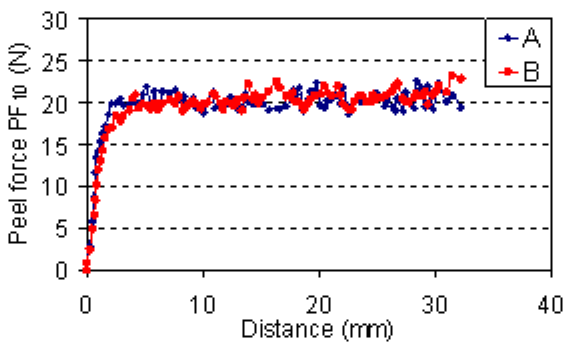

Figure 8: An example of peel force with distance for two samples

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6 "Overcoming adhesion issues" Dow Corning Conformal Coating Bulletin, form number 11-1119-01, https://www.dowcorning.com/content/publishedlit/11-1119_Adhesion_bulletin.pdf?DCWS=Electronics&DCWSS=Conformal%20Coatings

7 IPC-TM-650 Test Methods Manual 2.4.2B "Adhesion, Solder Mask (Non-Melting Metals)"

Appendix A: Supporting material selection

A1 Selection of the embedded tape materials

The most important part in tape peel testing is to select a suitable embedded tape that will support the coating during the peel from the substrate. The tape should have high adhesion to the coating, but must not affect the coating curing process. Meshes or clothes are possible materials, as they both have enough open area to allow solvent evaporation from the coating, and not affect coating curing process. It is advantageous that the threads or filaments have a high surface area for adhesion to the coating.

Seven cloth five mesh tapes, as shown in Figure A.1 and A.2, were investigated using tape peel testing to select the best performance. These materials are commercially available.

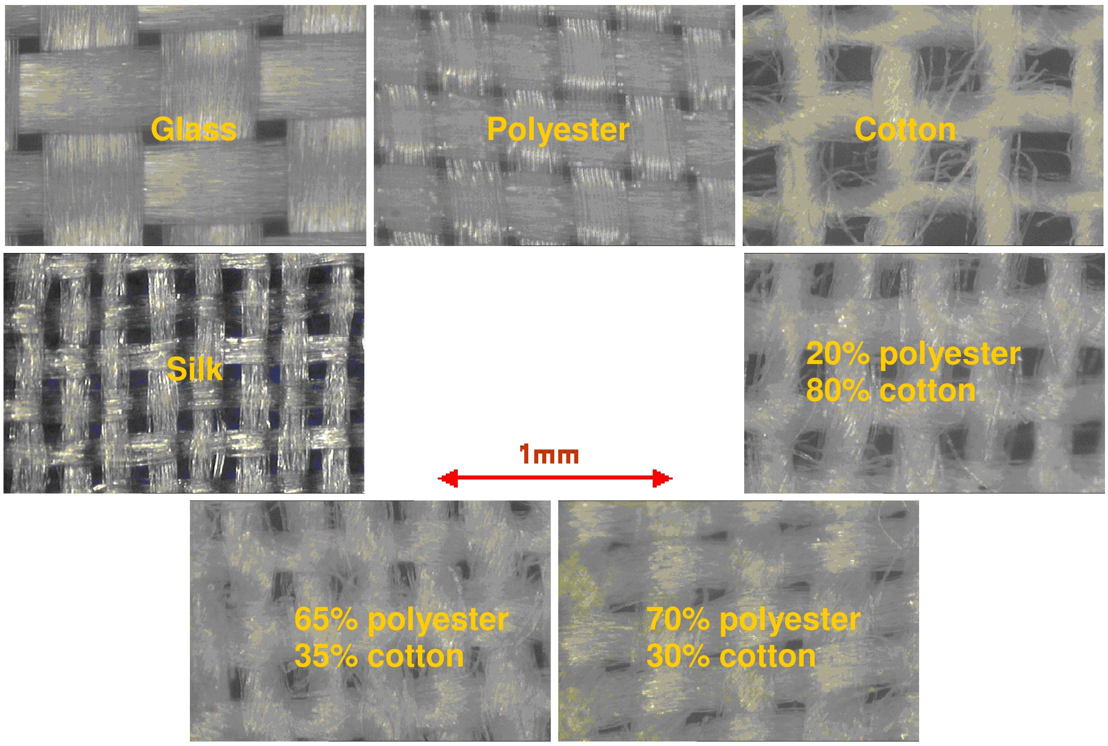


Figure A1: Seven cloth materials

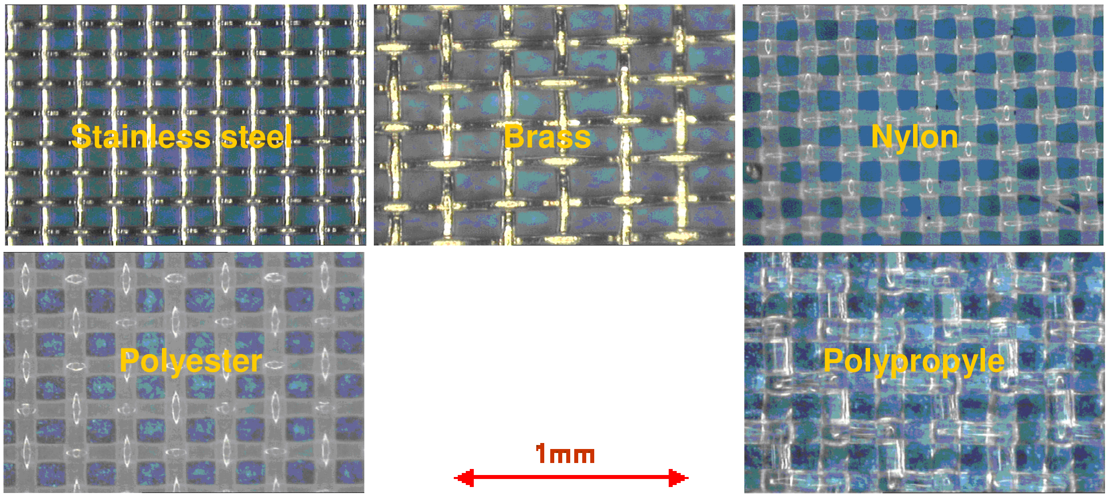


Figure A2: Five mesh materials

A2 Peel testing

A2.1 Test sample

25mm wide tape was cut from different mesh and cloth materials in order to prepare the test sample, FR4 PCB substrate and an acrylic coating (acrylic A) were used for all samples.

A2.2 Peel test condition

Peel testing was performed on a Dage4000 machine with 90° peel capability. The peel speed was 1mm/s and the peel distance was 35mm, which is the maximum distance the machine can peel. Peel force and peel distance were recorded during the peel. Two test samples for each material were tested.

A3 Results and discussions

The test samples were visual inspected and clearly showed that they all failed at the interface between coating and the embedded tape. An example for 65% polyester + 35% cotton cloth material after the test is shown in Figure A4, revealing the coating left on the substrate after test. This indicates that for strong bonding between a clean PCB and coating exceeds the adhesive strength of the embedded tape to the coating. Therefore the assessment of the different tapes indicates the relative adhesive strength of the various tapes and not that of the acrylic to the PCB.
The peel force with distance for different mesh and cloth materials are presented in Figure A5 and A6 respectively. The average peel forces from 5mm to 35mm peel distance from two samples for each material are compared in Figure A7 and A8.

Results in Figures A5 - A8 clearly show that the repeatability of two tests for all test materials is reasonably good. Tape adhesion varies with different tape materials, and appears to be sensitive to the tape structure. A comparison of the mesh and cloth materials shows that in general the cloth materials gave higher adhesion force. This probably can be attributed to the single filament mesh not having the same surface area as the cloths. Overall the 65% polyester plus 35% cotton cloth material has the highest adhesion force to the coating.

A4 Peel tape selection

According to the results in A3, 65% polyester + 35% cotton cloth material with 15% open area is the best choice used for supporting material for tape peel testing.

A5 Validation of the peel tape

On a clean PCB the failure always happened at the tape/coating interface instead coating/substrate interface. Here we proposed to contaminate the PCB to reduce the adhesion between coating/substrate to show coating/substrate interface failures.

A5.1 Test sample

A surfactant used in a general purpose liquid cleaner was chosen to contaminate the PCB. The surfactant was dissolved in de-ionised water with three different concentrations, as listed in Table A1. 1.0 ml solution was dispensed on 2.5 x 10mm PCB sample, and then the sample was dried at 100°C for 5 minutes. An acrylic coating (Acrylic A) was used for all samples.

A5.2 Peel testing

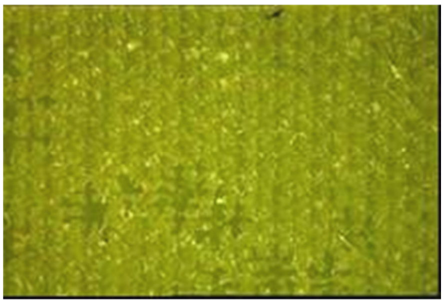
Peel testing was performed on a Dage4000 machine with 90° peel, and the peel speed was 1mm/s. The peel distance was 35mm, Peel force and peel distance were recorded during the peel. Two test samples for each contamination level were tested.

A5.3 Results and discussion

The peel force with peel distance with different contamination levels are presented in Figure A9. The average peel forces from 5mm to 35mm distance from two samples for each contamination level are compared in Figure A10. The substrate and peel tape were inspected under a microscope after testing, the pictures are shown in Figure A11. The results clearly demonstrate that peel force decreased with increasing substrate contamination, the failure mode changed from tape/coating interface to coating/substrate interface. When contamination on the substrate increased to 3% surfactant the peel force dramatically dropped to 12 N from 37 N for the clean PCB, and the failure occurred at coating/substrate interface. For medium contamination boards with 0.5% and 1% surfactant loadings, there was a mixed failure mode between the tape/coating and coating/substrate interfaces. The failure at the coating/substrate interface increased with contamination, as shown in Figure A11.

A5.4 Conclusions

A cloth tape has been shown to work well with this peel test. With a clean PCB substrate the failure is typically at the tape/coating interface, but as the PCB surface is contaminated with surfactant the adhesion failure moves to the coating/substrate interface. Hence the coating peel force can be measured, and this will be explored further in Appendix F.



Substrate PCB

Peeling material

Figure A4: Substrate and peeling material surface after test for 65% polyester + 35% cotton cloth material

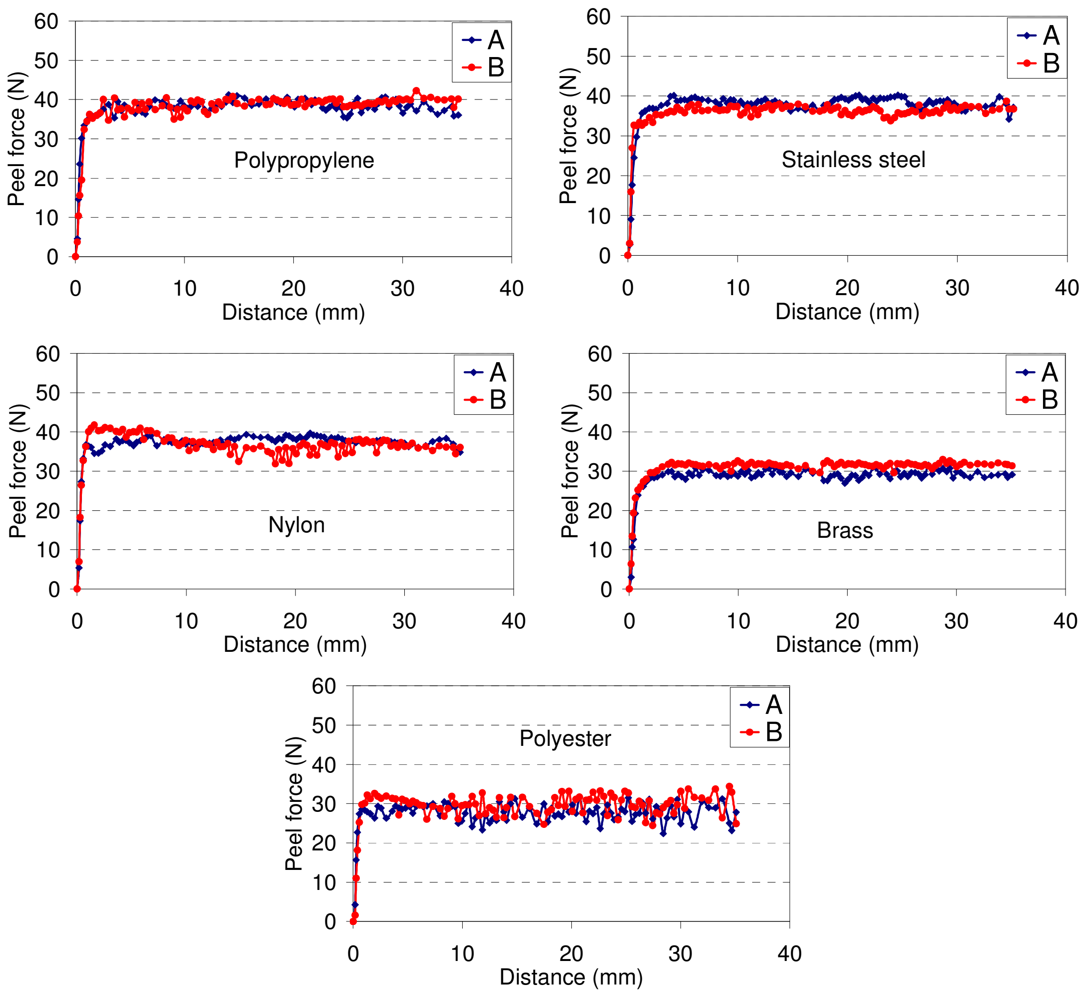


Figure A5: Peel force with peel distance for different mesh materials

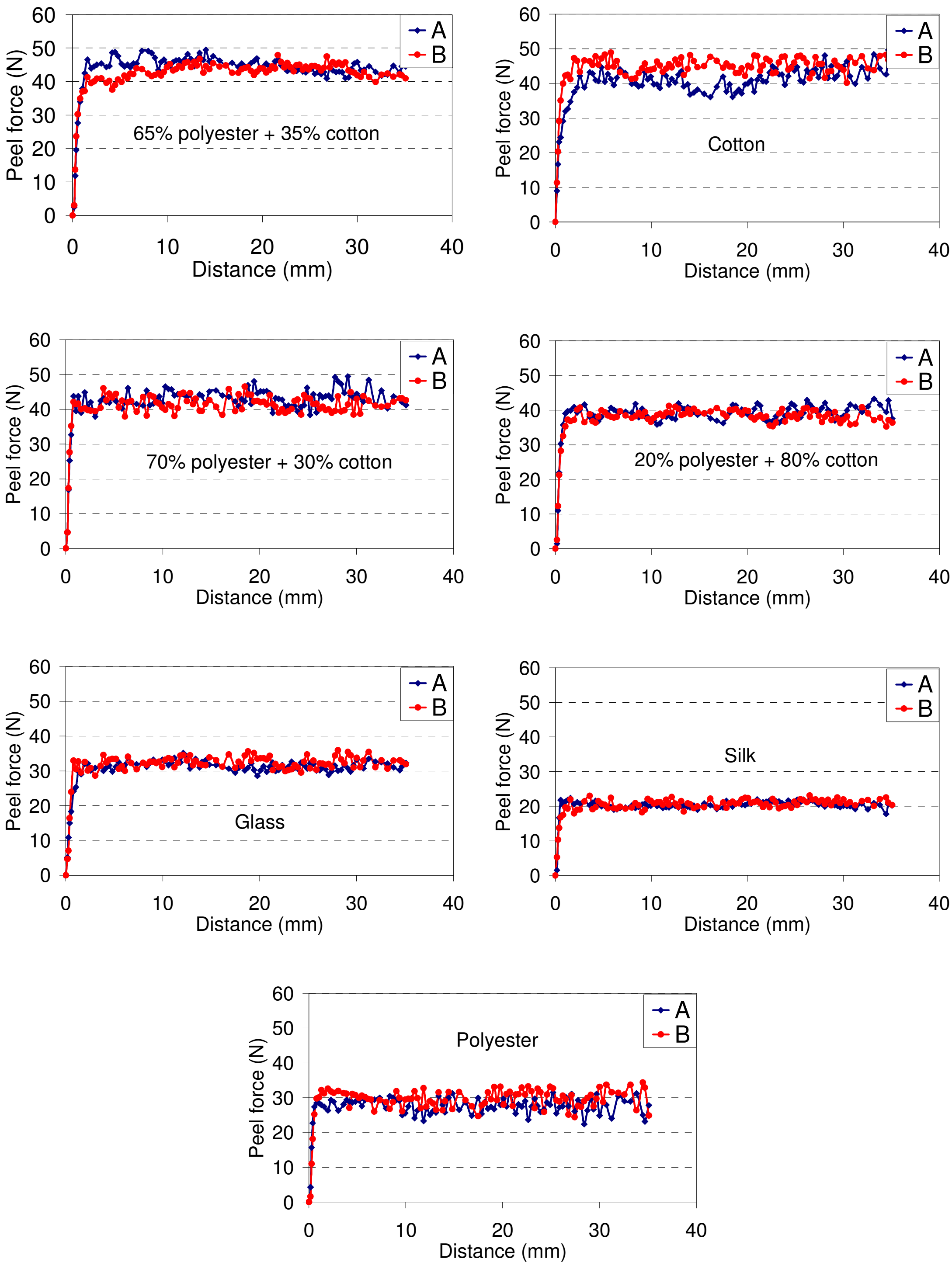


Figure A6: Peel force with peel distance for different cloth materials

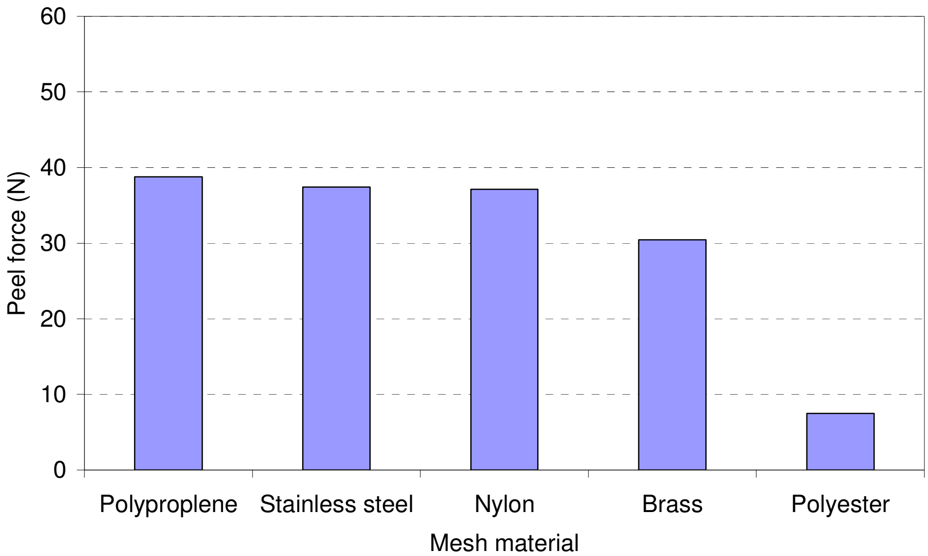


Figure A7: Average force for different mesh materials

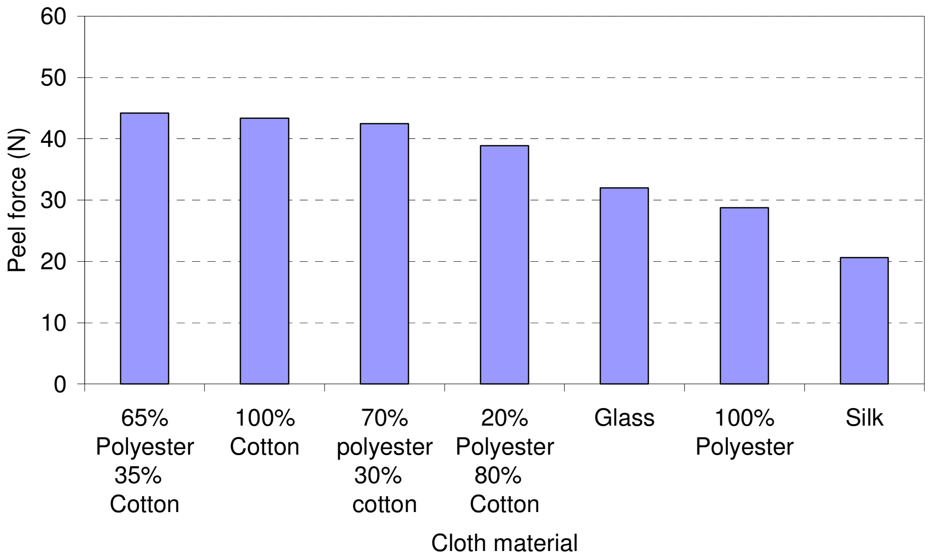


Figure A8: Average force for different cloth materials

Table A1: Contamination levels for PCB

Coating	Contamination (% in DI water)
Acrylic A	None
	0.5%
	1.0%
	3.0%

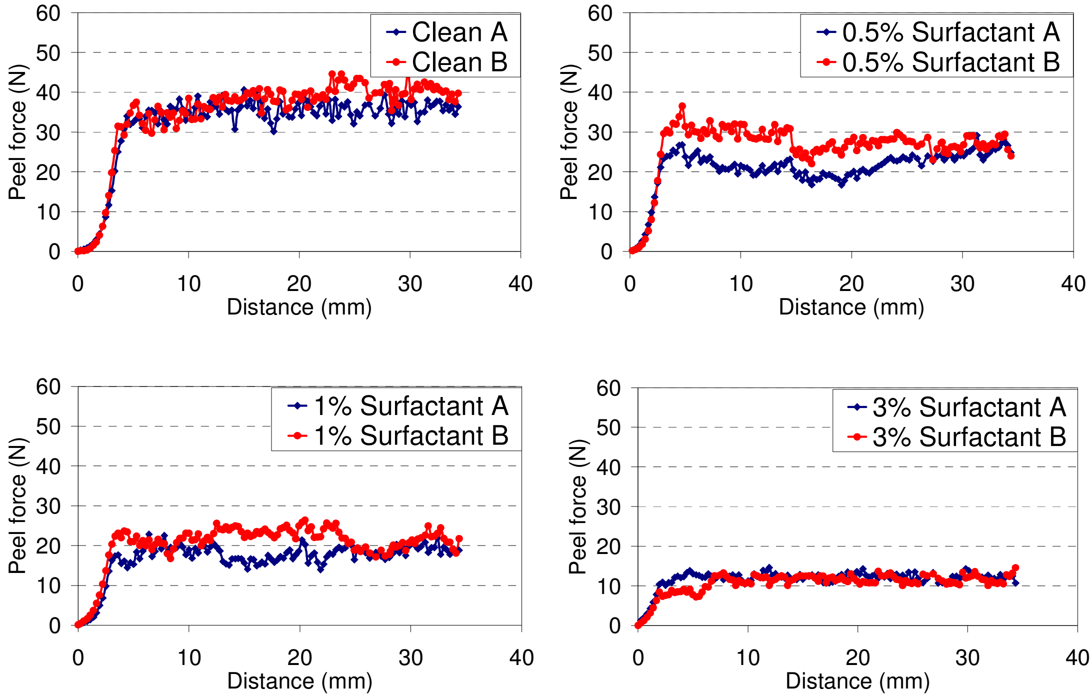


Figure A9: Peel force with peel distance from different contamination samples

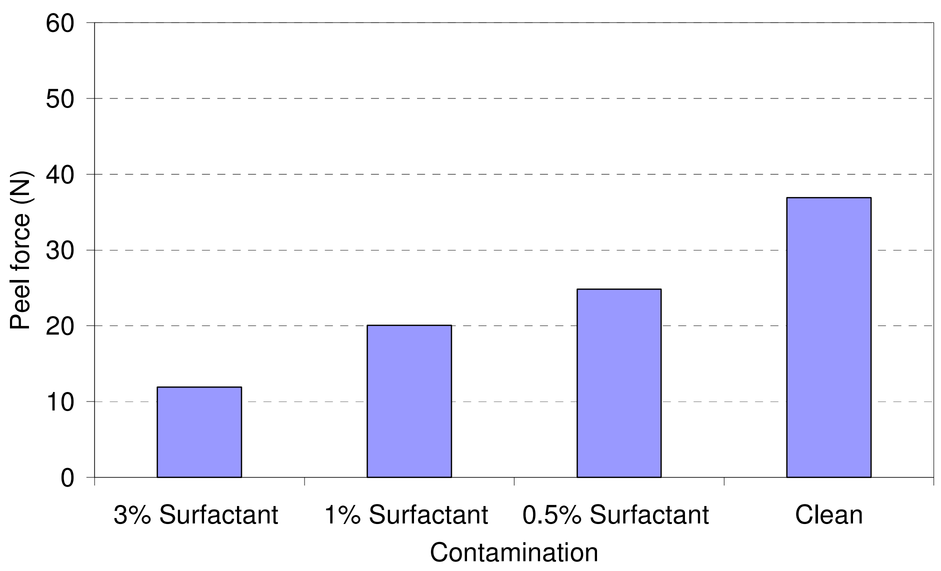


Figure A10: Average force for different contamination samples

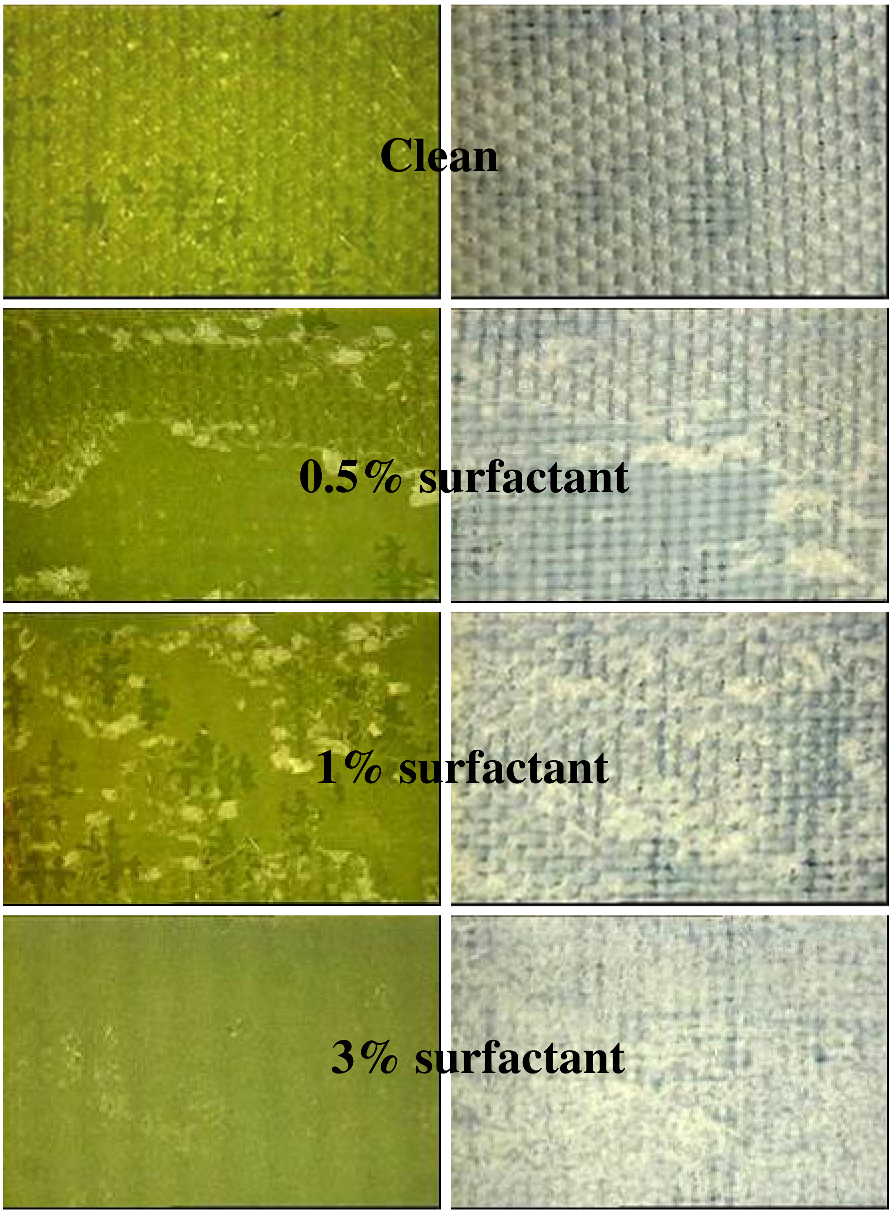


Figure A11: Substrate and peel tape after testing for different contamination samples

Appendix B: Post coating application of tape

The purpose of this work is to assess the opportunity to evaluate coating adhesion for existing coated board using tape peel testing.

B1 Test sample and test condition

The post coating application of a tape method is to evaluate coating adhesion of cured coating to using tape peel testing. In the laboratory the first liquid coating was applied on the substrate, after first coating had been cured, then the same liquid coating was applied with the tape. Tape peel test was performed after second coating had been cured. In Figure B1 a schematic of the sample configuration is shown. Two curing options for the first coating were evaluated, one was fully cured, and the second was for the coating being cured for 60 minutes. This latter condition would be typical of a board from a process line. A 25mm wide tape test sample was used. There were two substrate materials conditions, a bare FR4 PCB and a curtain coated solder resist A finished board. The FR4 PCB was used to represent strong bonding formed between coating and substrate, and resist A board was used to represent an example of weak bonding formed between coating and substrate. Again a 65% polyester + 35% cotton tape was used for the test. Three type coatings were tested. The experiment details are listed in Table B1.

Peel testing was performed on Dage4000 machine with 90° peel, and peel distance of 35mm. Two test samples for each coating and substrate were tested.

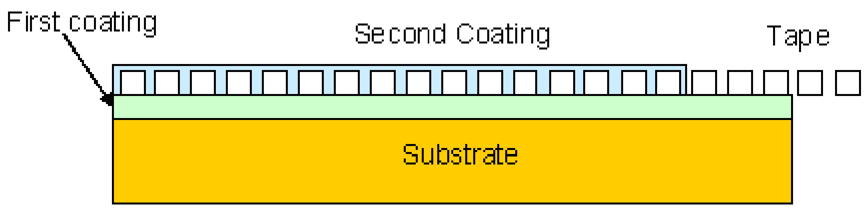


Figure B1: Double coating method

Table B1: Experiment details

Coating	Substrate	Application
Acrylic B Polyurethane Silicone	FR4 PCB Resist A	Second coating applied after first coating
		Fully cured
		60 minutes

B2 Results and discussions

The peel force with distance results using post coating method for acrylic coating are plotted in Figure B2. The location of the interfacial failure is also annotated in the figures. Ideally, for a successful test, the failure should be between the coating and the substrate. Similarly the results for polyurethane and silicone coatings are given in Figures B3 and B4. The results clearly show that the suitability of post coating method depends on the coating type and the magnitude of the peel force. For the acrylic and silicone coatings, the failure was either at the substrate or the tape was pulled out of the coating. This is consistent with the second coating forming a strong bond with the original coating, and hence the appearance of a single coating. For the polyurethane coating it was observed that this strong bond was not formed, with failures between the two coating layers. This was the case even if the first coating was only cured for one hour in ambient condition. If the adhesion force between coating and substrate is greater than that between two coating layers, the peel force measured from peel test was the force between two layers, as was the case for PCB substrate with polyurethane coating. However if the adhesion force between coating and substrate is less than that between two coating layers, the failure occurred at the coating /substrate interface, and the force measured is the peel force of coating to substrate, as seen for resist A substrate with polyurethane coating, then post coating method can be applied. Therefore using the post coating method, the tested samples need to be inspected to ascertain where the failure occurred, and to make sure the measured peel force is that for coating adhesion to the substrate.

B3 Conclusions

Application of post coating method is limited. Peel force measured from the test is not always the coating adhesion force to substrate, sometimes this can be the force between two coating layers, or even the cohesion force within a layer, which is being measured, depends on coating type and adhesion force of coating to substrate. This makes thing more complex, and care is needed in interpretation of the peel force measurements.

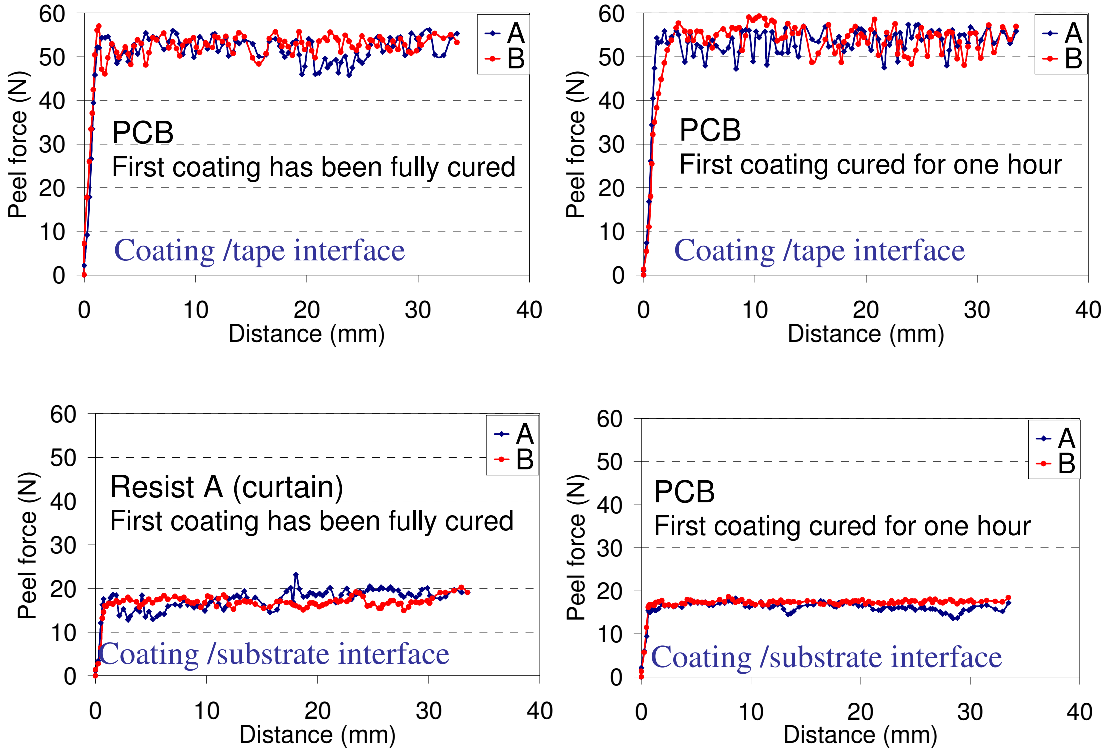


Figure B2: Peel force with peel distance with post coating method for acrylic coating

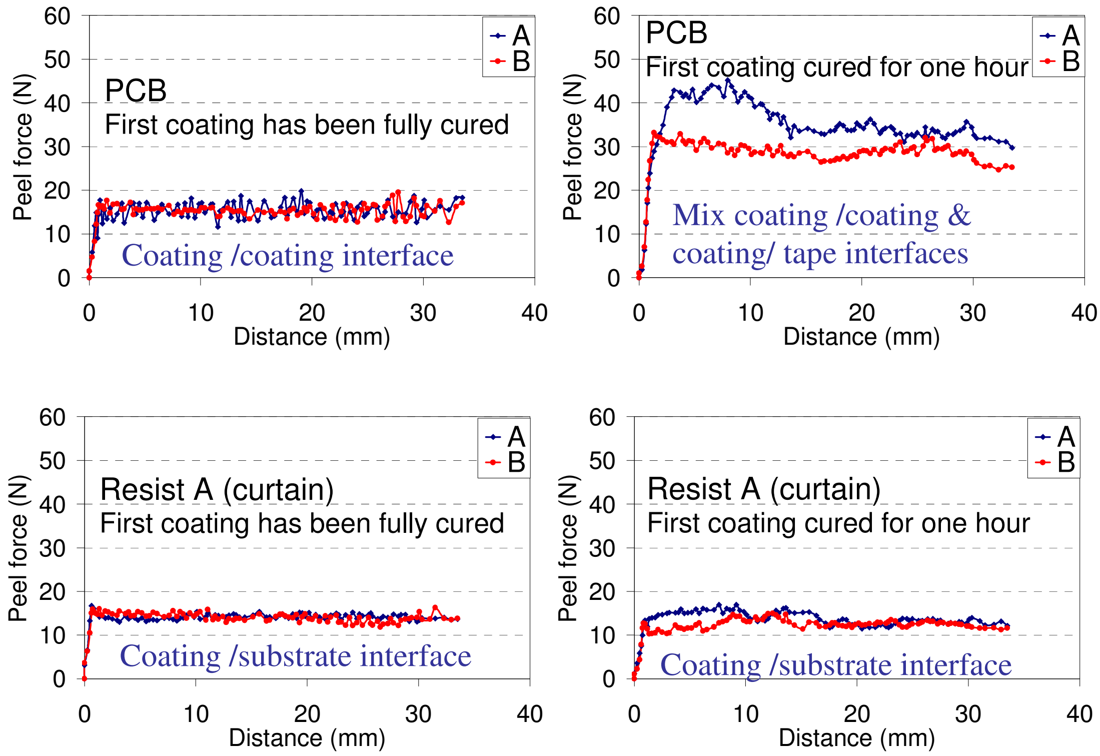


Figure B3: Peel force with peel distance with double coating method for polyurethane coating

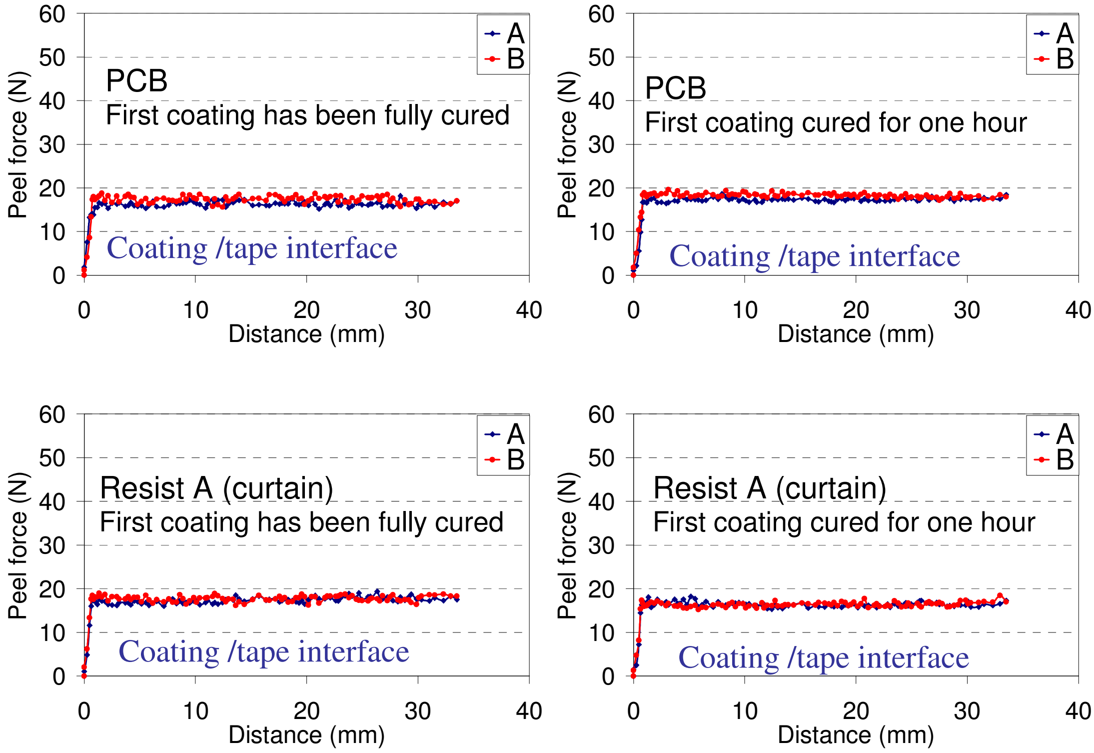


Figure B4: Peel force with peel distance with double coating method for silicone coating

Appendix C: Conformal coating cure conditions

In order to achieve good adhesion force between coatings and substrates, coatings need to be fully cured. Coating cure conditions are normally recommended by coating suppliers. However, the maximum adhesion force is not always reached from these cure conditions. In this work, peel force was measured for different cure times and temperatures for three coating types: acrylic, polyurethane and silicone to demonstrate the importance of coating cure condition.

C1 Test sample and test condition

The same 25mm wide test sample with FR4 PCB substrate and 65% polyester + 35% cotton cloth was used for the test. The types of coating cure temperatures and times investigated are listed in Table C1.

Table C1: Cure temperature and time for three coatings

Acrylic A		Polyurethane		Silicone	
Ambient (hours)	72°C (minutes)	Ambient (hours)	80°C (minutes)	Ambient (hours)	Ambient (hour) + 80°C (minute)
1	20	16	30	24	24 hour + 20 minute
2	40	40	60	48	48 hour + 20 minute
4	70	66	90	72	72 hour + 20 minute
8	120	96	120		
24		144			
48		216			
96					

Peel testing was performed on a Dage4000 machine with 90° peel, and peel distance was 35mm. Two test samples for each coating and each cure condition were tested. For the high temperature cures, peel testing was conducted 60 minutes after removal from the oven.

C2 Results and discussion

The peel forces with distance from different cure conditions for the three coatings are plotted in Figures C1-C6. The average peel forces from 5mm to 35mm distance from two test samples for each cure condition and coating are compared in Figure C7, and clearly show that adhesion force increased significantly with cure time for all coatings, and that for high temperature cure this occurs more rapidly. For the acrylic coating the maximum force was reached in 48 hours in ambient conditions. However, for the high temperature (72°C) cure, some bubbles appeared underneath the peel tape, as seen in Figure C8, and reduced the adhesion force. This is probably because the acrylic cured by solvent evaporation, and at this temperature the peel tape may have hindered solvent evaporation by not allowing the solvent to escape fast enough thus causing the bubbles underneath the tape. Therefore when using this test with coatings that cure with solvent evaporation, a high temperature cure is not recommended. However, a high temperature cure can be used, if there is an initial room temperature cure for a few hours, which is then followed by the high temperature cure. For the polyurethane coating the maximum peel force was achieved in 90 minutes at 80°C, but took 146 hours in ambient condition. For the silicone coating full cure at ambient was achieved in 72 hours, for the heated condition at was found optimal to use 48 hours at ambient followed by 20 minutes at 80°C.

C3 Conclusions

The peel force of a coating strongly depends on the coating cure stage, with the maximum force achieved when the coating is fully cured. For a production board the cure process will continue for an extended period. However, for tape peel testing the measured force is very sensitive to the cure state, and hence in most cases the coating should be in its fully cured state before the testing. Apart from this cure time and temperature investigation, the cure conditions in Table C2 were used for all test samples.

Table C2: Cure condition for three type coatings

Acrylic	Polyurethane	Silicone
24 hours in ambient + 30 minutes @ 80°C	24 hours in ambient + 60 minutes @ 80°C	24 hours in ambient + 20 minutes @ 80°C

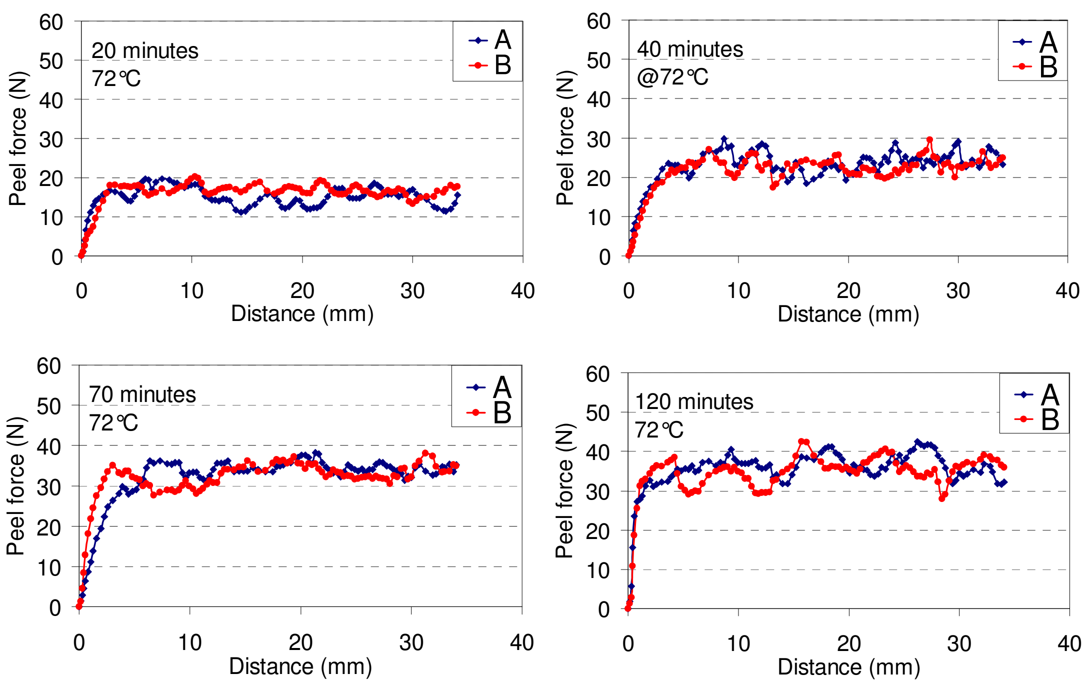


Figure C1: Peel force with peel distance for acrylic coating cured at 72°C

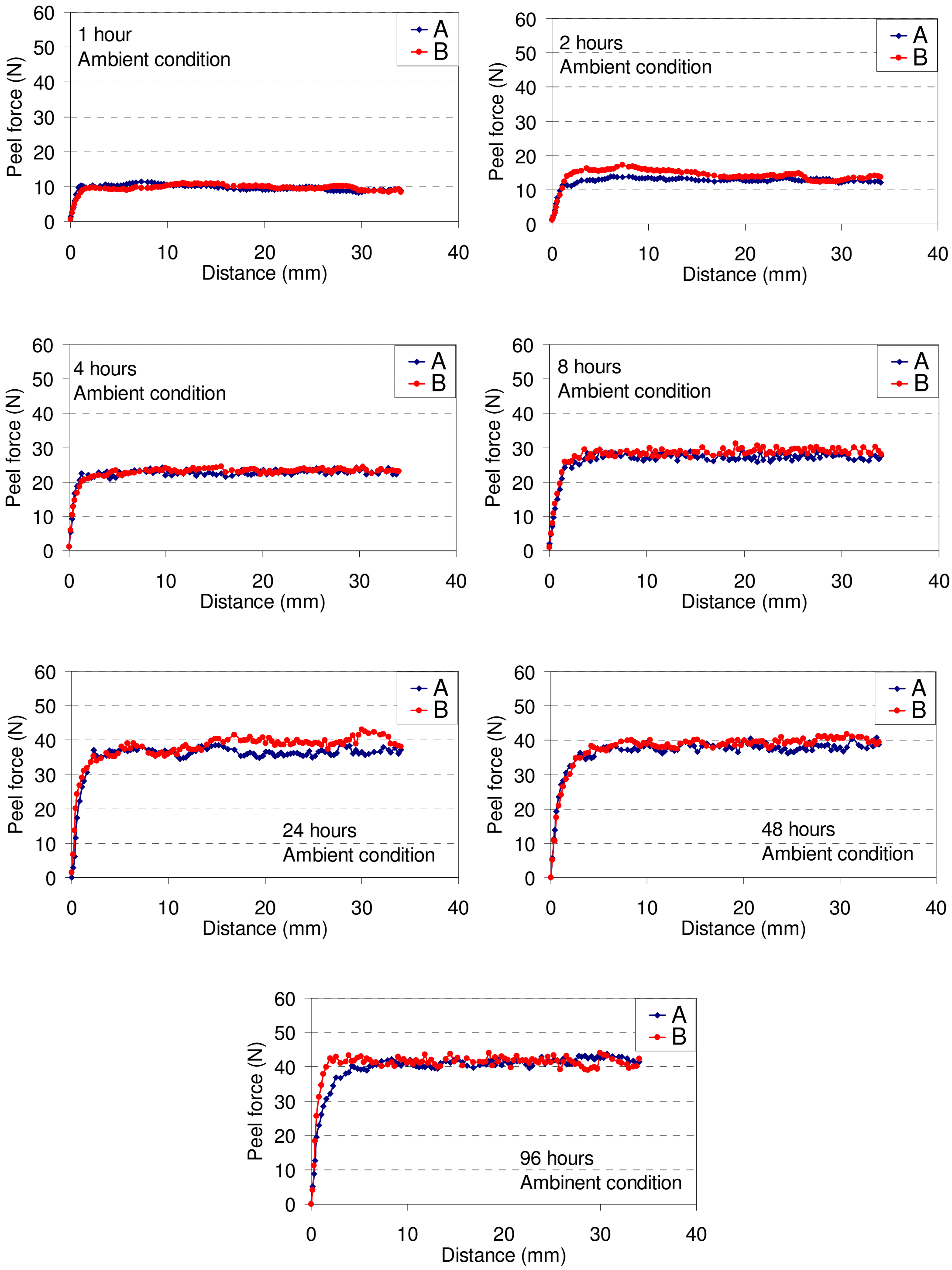


Figure C2: Peel force with peel distance for acrylic coating cured in ambient condition

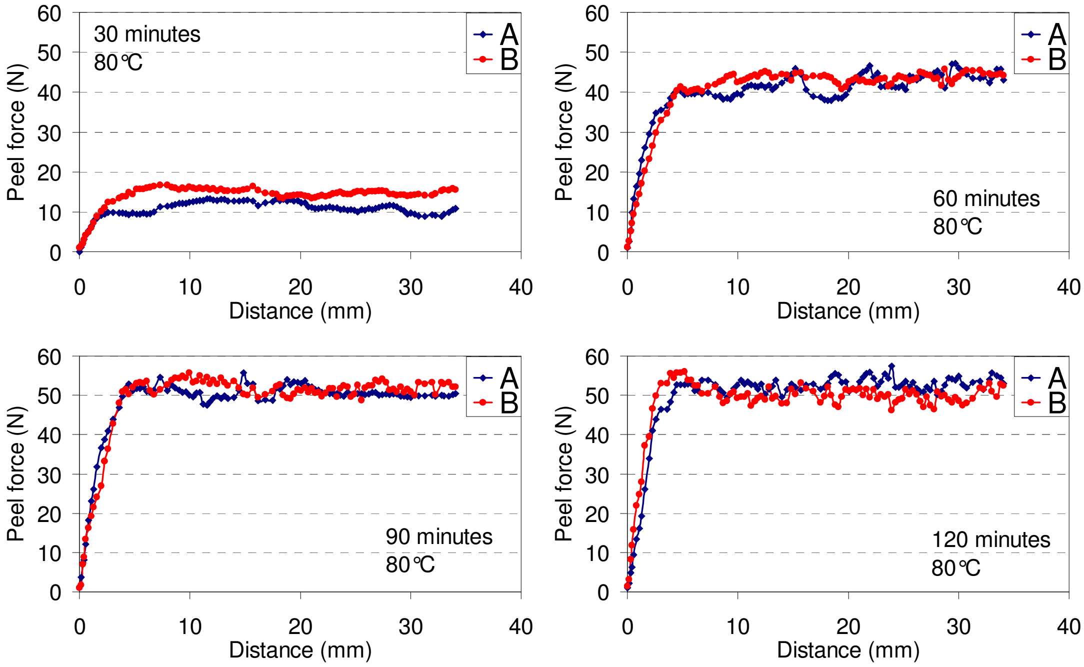


Figure C3: Peel force with peel distance for polyurethane coating cured at 80°C

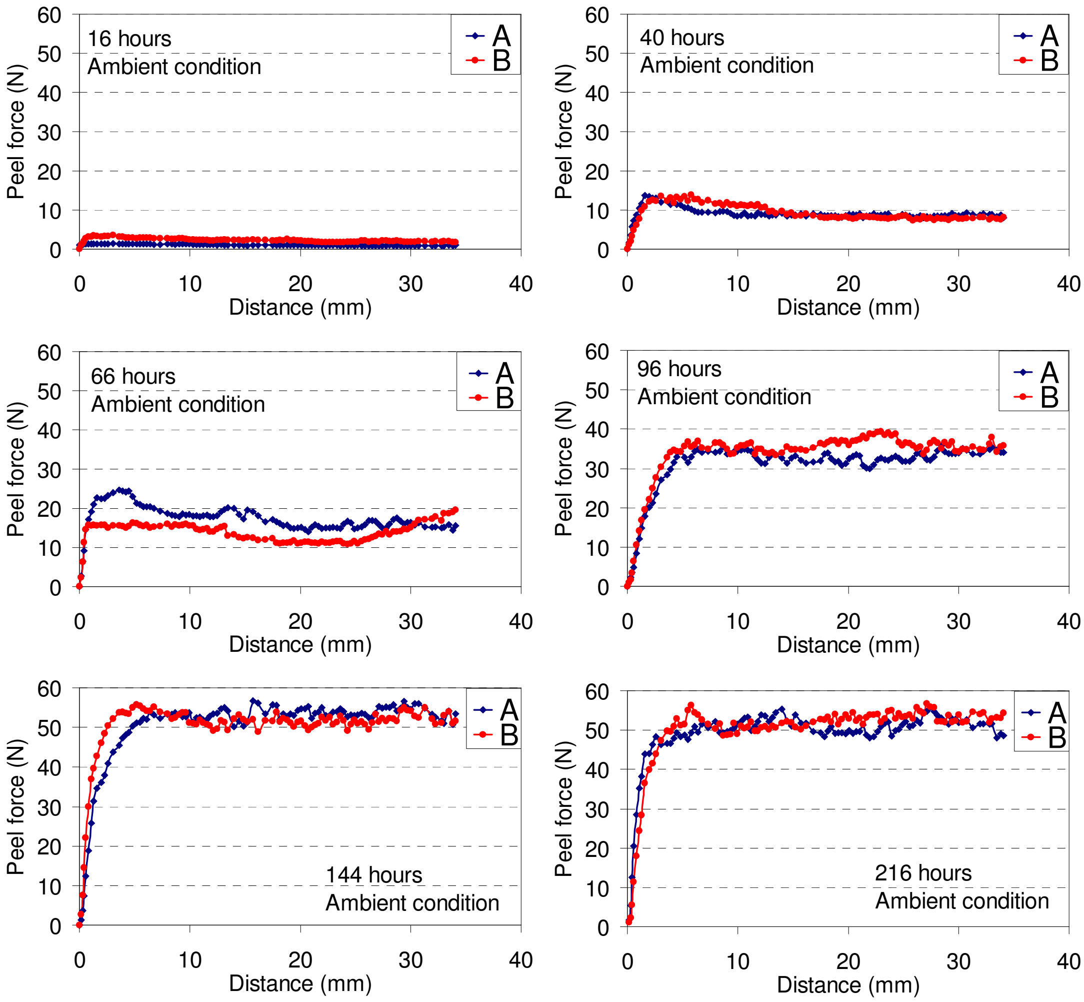


Figure C4: Peel force with peel distance for polyurethane coating cured in ambient condition

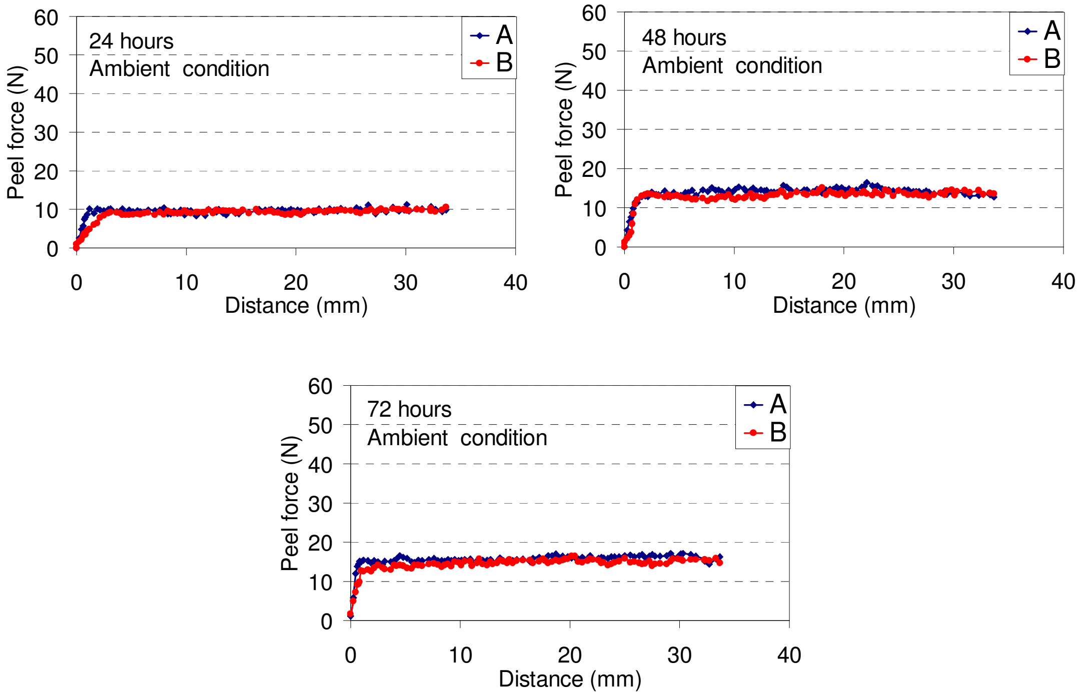


Figure C5: Peel force with peel distance for silicone coating cured in ambient condition

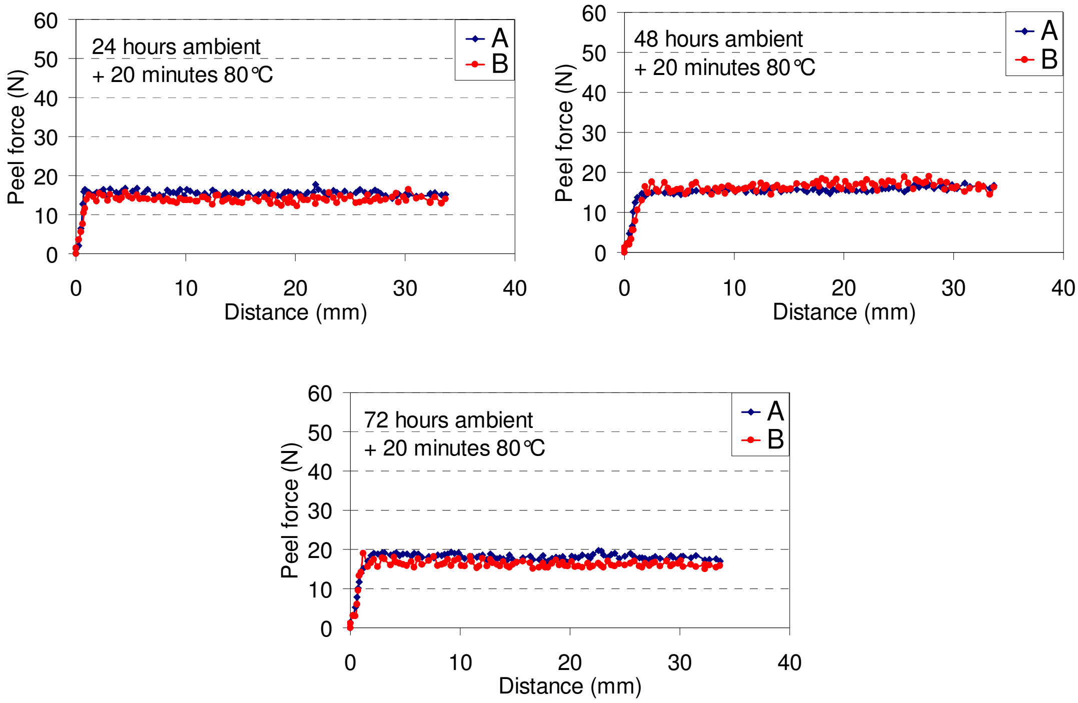


Figure C6: Peel force with peel distance for silicone coating cured in ambient condition and followed by high temperature cure

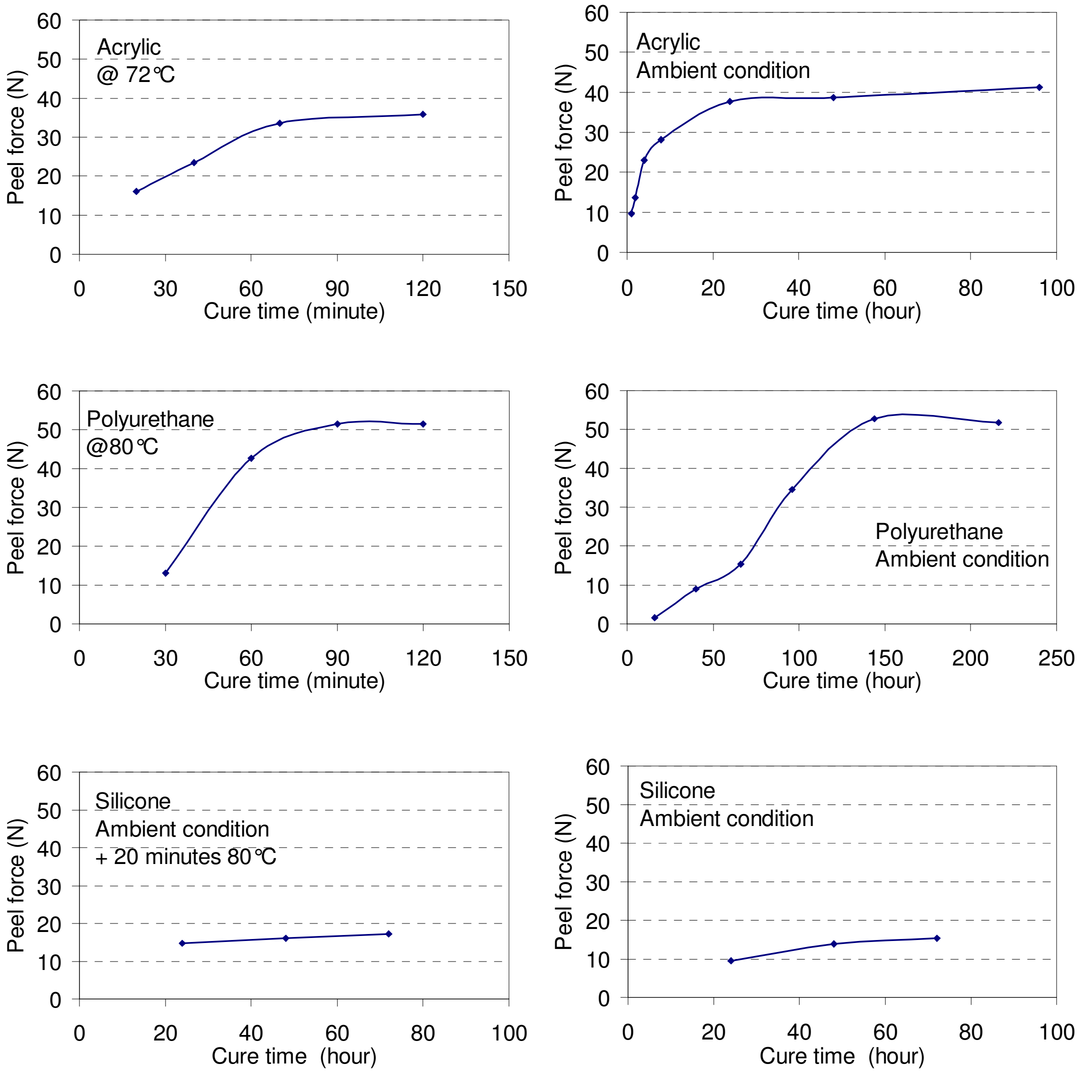


Figure C7: Average peel force from different cure conditions for three type coatings

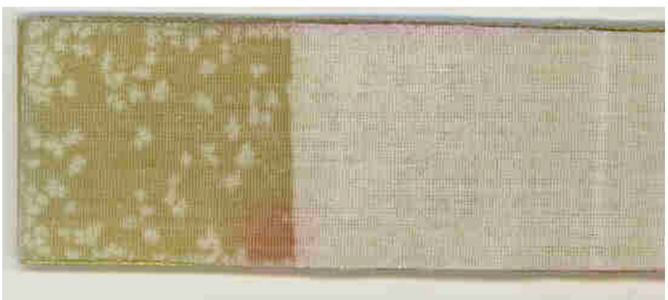


Figure C8: Bubbles created at high temperature cure (72°C) for acrylic coating

Appendix D: Effect of peel speed on adhesion force

Peel speed maybe an important parameter for this tape peel test. The effect of peel speed on coating adhesion force was investigated, and hence defined the appropriate speed for representative results in addition to establishing the acceptance in speed variation between different machines and operators.

D1 Test sample and test condition

The same 25mm wide test sample with FR4 PCB substrate and 65% polyester + 35% cotton cloth was used for the test. Three type coatings and three peel speeds were investigated, and are listed in Table D1.

Peel testing was performed on a Dage4000 machine with 90° peel, and a peel distance of 35mm. Two test samples for each material were tested.

Table D1: Test coatings and peel speeds

Coating	Peel speed (mm/second)
Acrylic B Polyurethane Silicone	0.5
	1
	2

D2 Results and discussions

The peel force behaviour with distance at different peel speed for three coatings are plotted in Figure D1-D3 respectively. The average peel forces from 5mm to 35mm distance from two samples for each speed and coating were compared in Figure D4, and clearly show that there is no significant difference on adhesion force from different speed tested for all coatings.

D3 Conclusions

Coating adhesion force is not affected by peel speed in the tested range 0.5 to 2mm/s, so any peel speed can be selected in this range. However if a speed outside the range is used, it will need to be checked first.

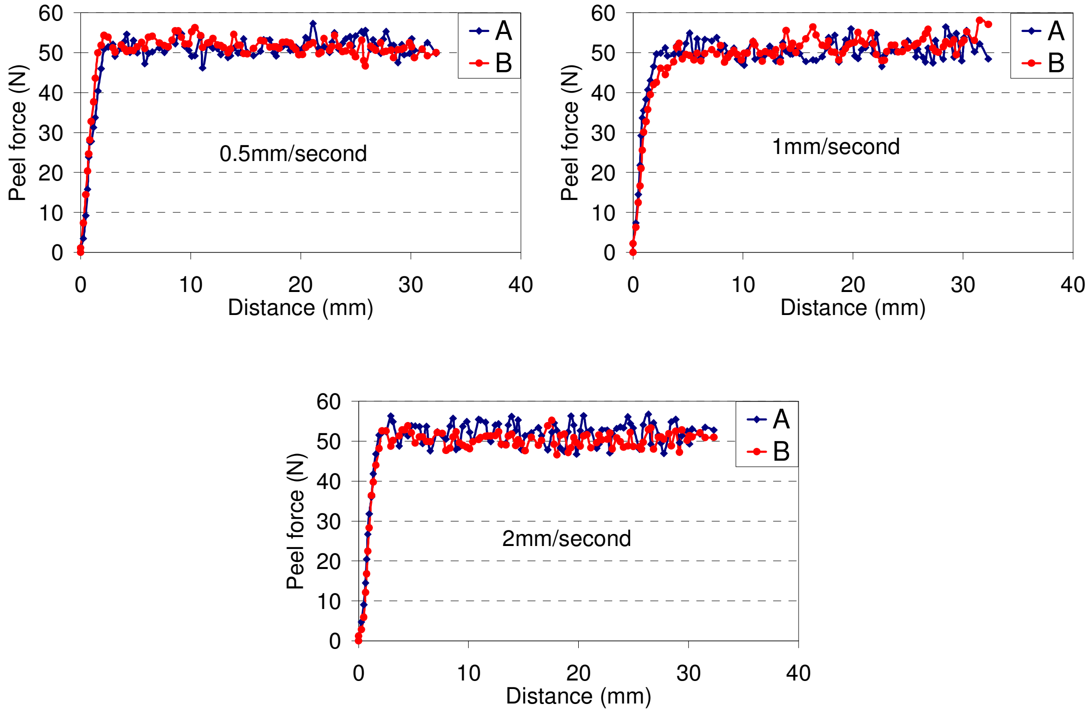


Figure D1: Peel force with peel distance for acrylic coating with different peel speeds

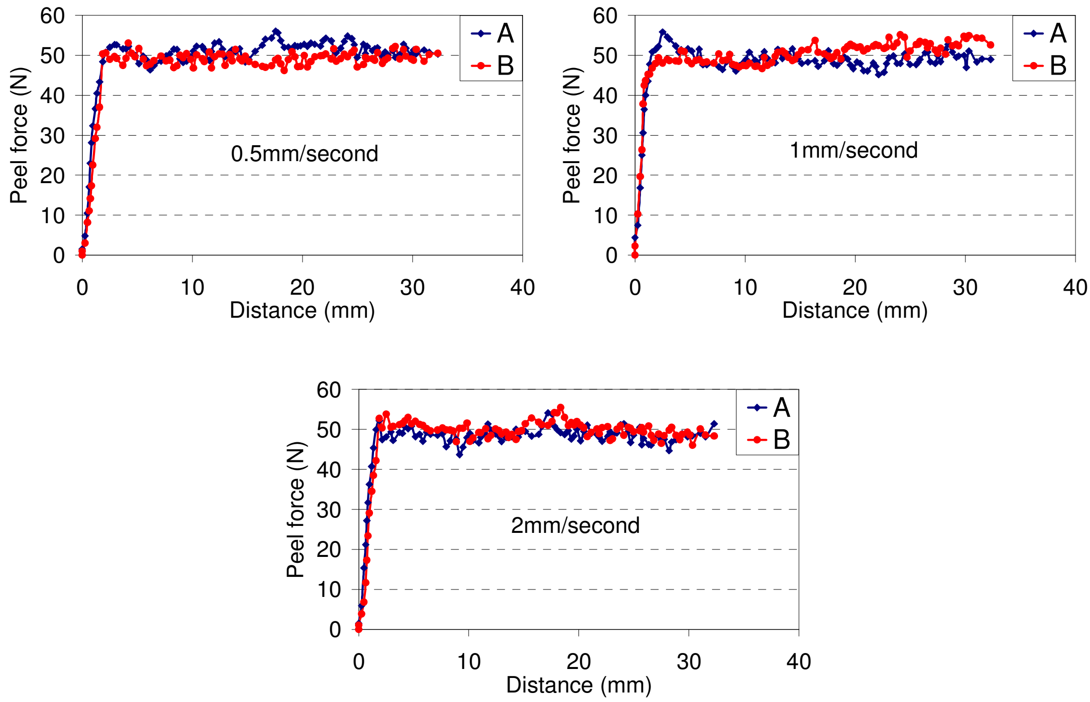


Figure D2: Peel force with peel distance for polyurethane coating with different peel speeds

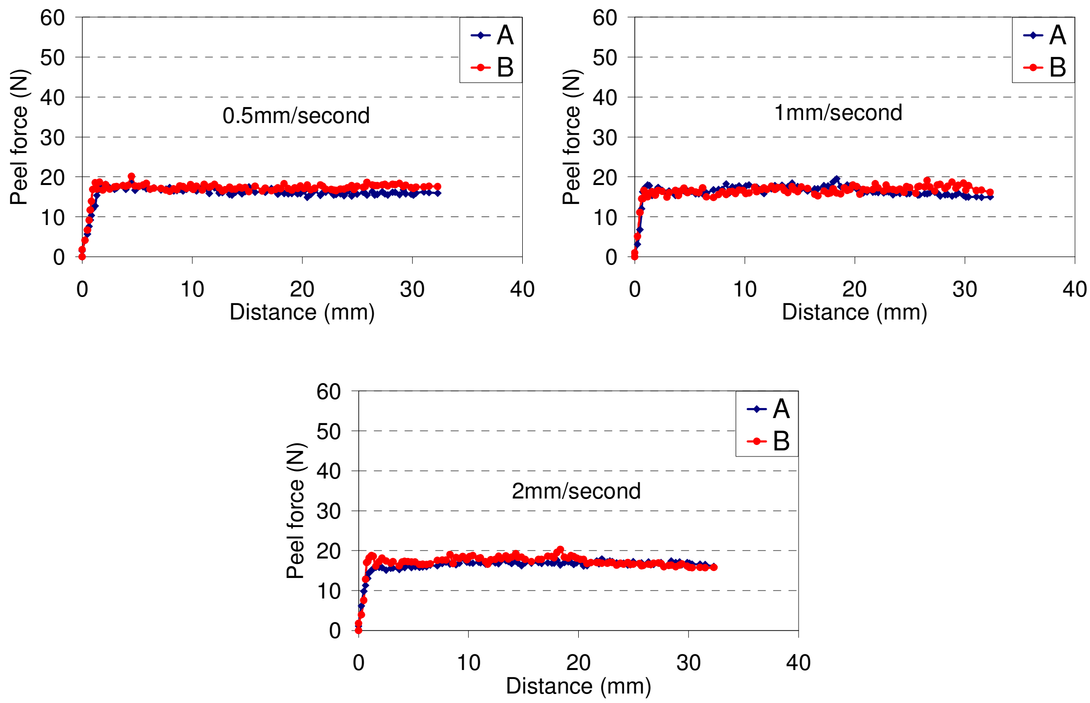


Figure D3: Peel force with peel distance for silicone coating with different peel speeds

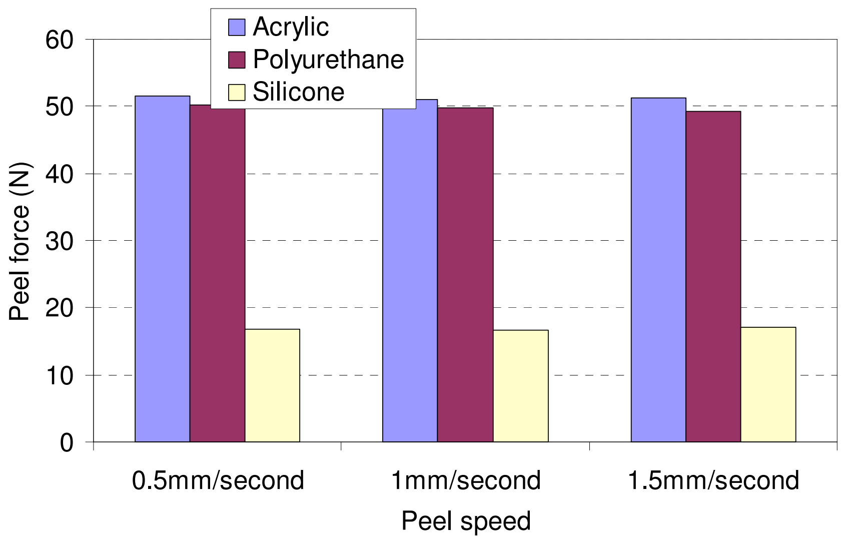


Figure D4: Average peel force from different peel speeds for three type coatings

Appendix E: Effect of tape width on adhesion force

Peel force is a measure of adhesion force in a peel line, as shown in Figure E1, and will be a function of peel width. The relationship of peel force and tape width is reported here.

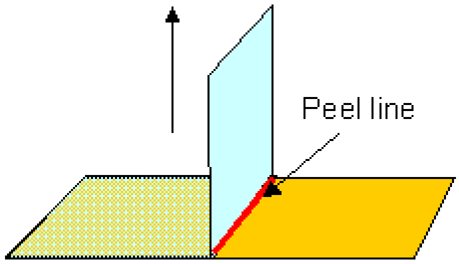


Figure E1: Schematic of tape peel test

E1 Test sample and test condition

The same FR4 PCB and 65% polyester + 35% cotton cloth were used for substrate and peel tape respectively. Three types of coatings and three tape widths were investigated and are listed in Table E1. Peel testing was performed on a Dage4000 machine with 90° peel, and peel distance was 35mm. Two test samples for each coating and each tape width were tested.

Table E1: Test coatings and peel speeds

Coating	Tape width (mm)
Acrylic B	5
Polyurethane	10
Silicone	25

E2 Results and discussions

The peel forces with distance from different tape widths for the three coatings are plotted in Figure E2-E4 respectively. The average peel forces from 5mm to 35mm distance from two samples for each tape width and coating are plotted in Figure E5. The trend lines for three measurement points for three coatings are plotted in solid line, and the formulas for trend lines are shown in the figure. The graph also includes an extrapolated peel force from 25mm test results to 0mm for each coating in dotted line. The results clearly show that the peel force followed an approximate linear relationship with tape width for all coatings, the correlation values are very high for all coatings. As the tape narrowed to zero, there was a small discrepancy in the expected pro-rata peel force. This is attributed to an edge effect and higher forces needed to separate the edge than the central areas of the tape. Therefore, if it is necessary to assume there is a linear response with tape width, then not less than

10mm tape to be used. If not comparing tapes of different width, then less than 10mm width can be used as shown by from the good repeatability from the 5mm tape results.

E3 Conclusions

Peel force has an approximate linear relationship with tape width, but there is edge effect, so this only extends down to 10mm tape width. Finer widths can still be used with good repeatability.

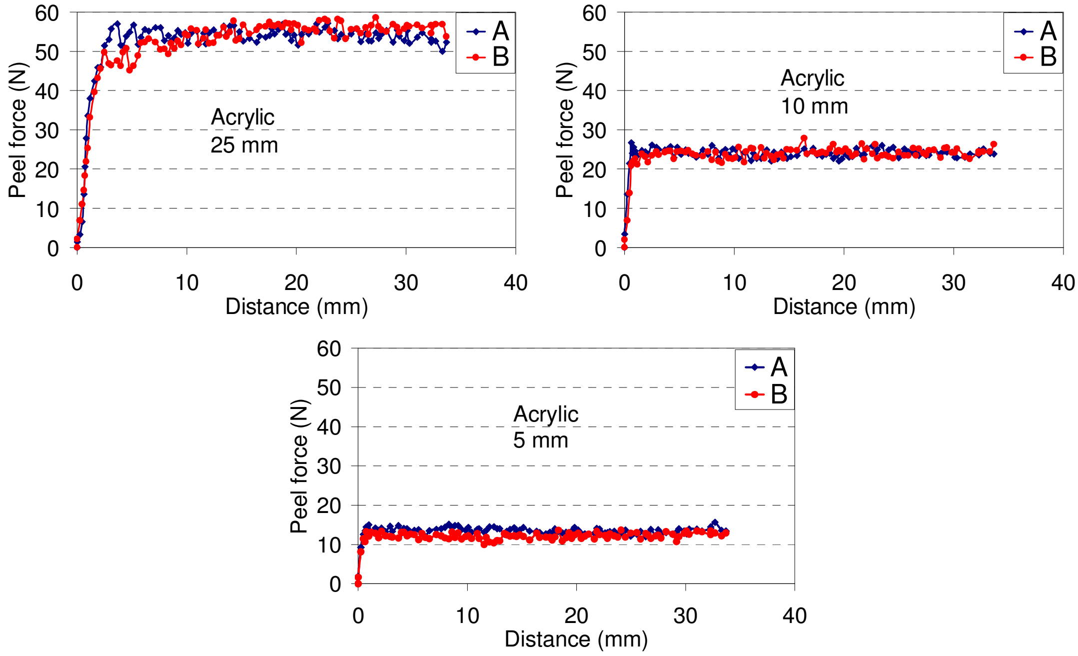


Figure E2: Peel force with peel distance for acrylic coating with different tape widths

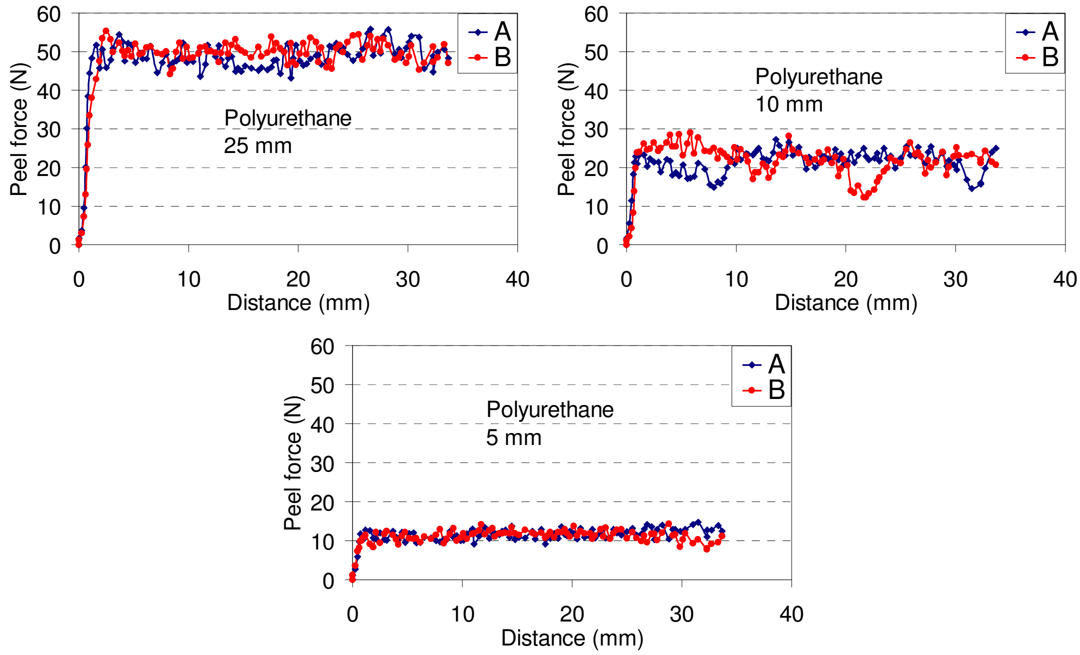


Figure E3: Peel force with peel distance for polyurethane coating with different tape widths

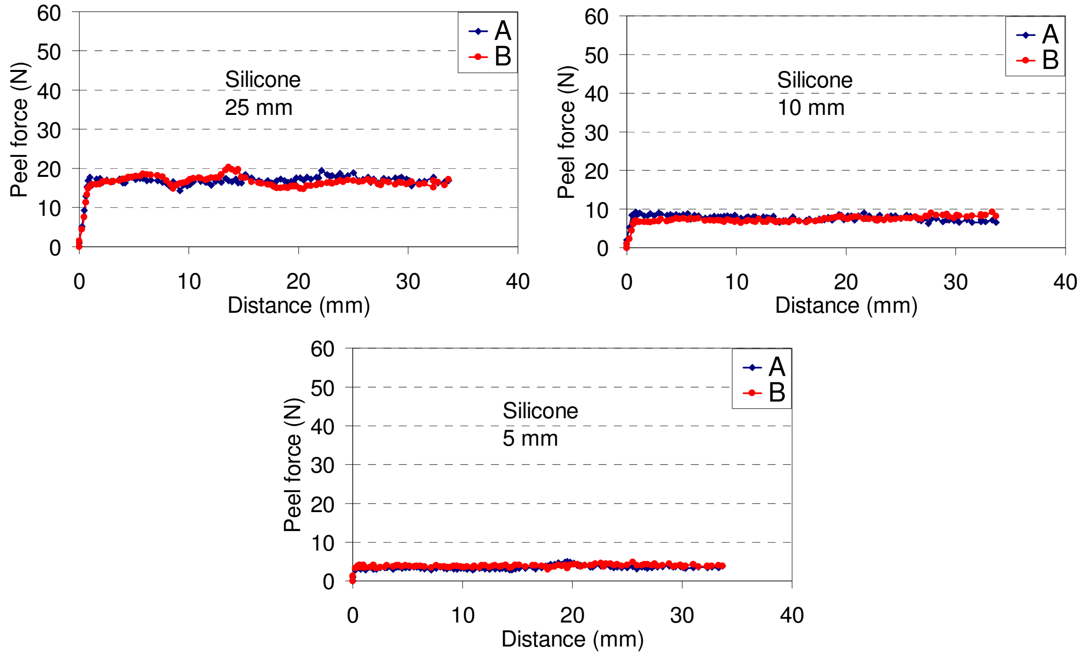


Figure E4: Peel force with peel distance for silicone coating with different tape widths

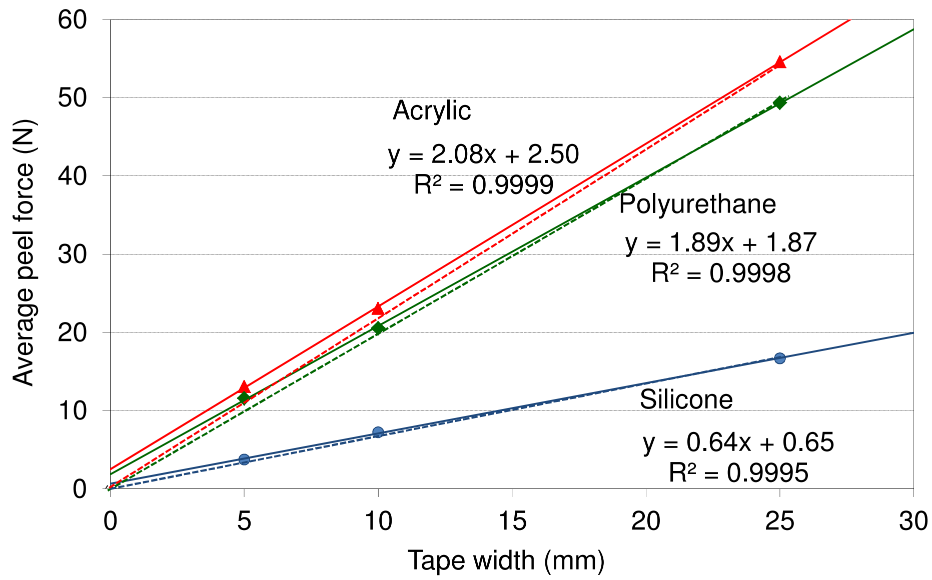


Figure E5: Measured and extrapolated peel force from different tape widths for three coatings

Appendix F: Tape peel test method validation

To verify the tape peel method it was carried out on a range of substrates and components. This included FR4 PCB, double sided PCB copper blank, solder resist, component bodies and wave soldered processed PCB. The wetting angles on these materials were also evaluated to establish if a correlation could be established with peel force. Tape peel testing was also performed on selected areas of two qualification assemblies to assess the suitability of the method on typical assemblies.

F1 Test sample and test condition for tape peel test

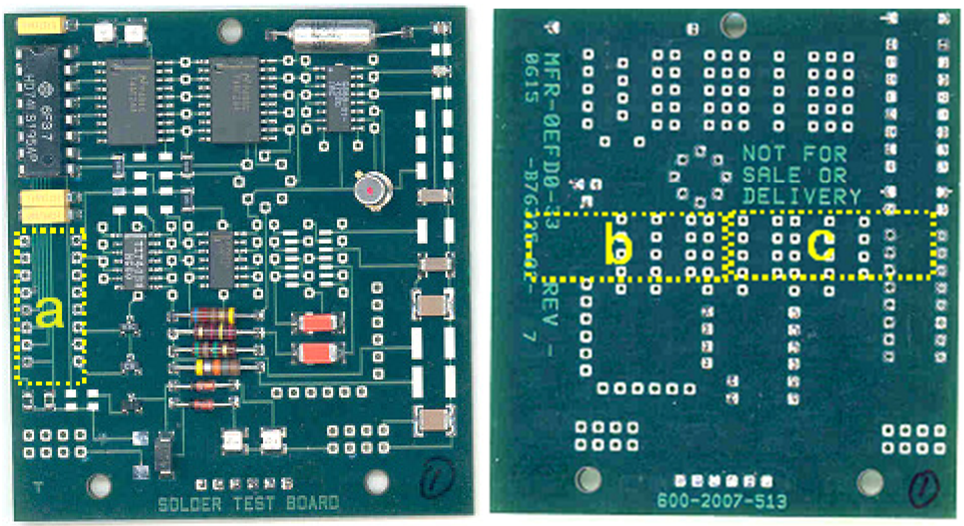
Different materials and assemblies, as detailed in Table F1, were used to validate the tape peel method on three different conformal coatings. Three device component types were tested, PLCC, QFP and BGA, as shown in Figure F1, and from different manufactures. The component body provided at least 20mm peel distance. For wave solder processed PCB, a clean PCB was processed with the flux used set to deliver approximately twice the normal amount, so as to leave high flux residues.
25mm tape was used for FR4 PCB, double-sided PCB copper blank, solder resist and wave soldering processed PCB substrates. For components and assemblies 10mm tape was used due to the space limitation. Peel testing was performed on a Dage4000 machine with 90° peel capability. Two samples for each combination of coating and substrate material were tested.
For two assemblies, A and B, selected areas from the board surface and specific components were tested. On assembly A, the tape peel tests were conducted on three sites, a, b and c, as shown in Figure F2. On assembly B, four sites, a, b c and d, were tested, as shown in Figure F3.

Table F1: Details of substrate materials, coatings and tape width

<table>
<tr><th colspan="3">Substrate material</th><th>Tape width (mm)</th><th>Coating</th></tr>
<tr><td>FR4 PCB</td><td colspan="2"></td><td rowspan="7">25</td><td rowspan="13">Acrylic B
Polyurethane
Silicone</td></tr>
<tr><td>Copper</td><td colspan="2"></td></tr>
<tr><td rowspan="5">Solder resist</td><td colspan="2">A (XV501T-4 curtain)</td></tr>
<tr><td colspan="2">A (XV501T-4 screen)</td></tr>
<tr><td colspan="2">B (Probimer 77)</td></tr>
<tr><td colspan="2">C (XV501 CAWN1287)</td></tr>
<tr><td colspan="2">D (EMP100)</td></tr>
<tr><td rowspan="6">Component</td><td>Component</td><td>Suppler</td><td rowspan="6">10</td></tr>
<tr><td>A (PLCC 68)</td><td rowspan="2">Texas</td></tr>
<tr><td>B (BGA 380)</td></tr>
<tr><td>C (PLCC68)</td><td>EXAR</td></tr>
<tr><td>D (BGA177)</td><td rowspan="2">ANALOG</td></tr>
<tr><td>E (QFP 532)</td></tr>
</table>

	F (QFP 160)	Topline		
	G (BGA 256)	Amkor		
Processed board	PCB wave solder processed with flux A (water based)		25	
	PCB wave solder processed with flux B (solvent based)			
	Assembly A		10	
	Assembly B			

Figure F1: QFP, PLCC and BGA components tested



Top Bottom

Figure F2: Test assembly A (Sn finish)

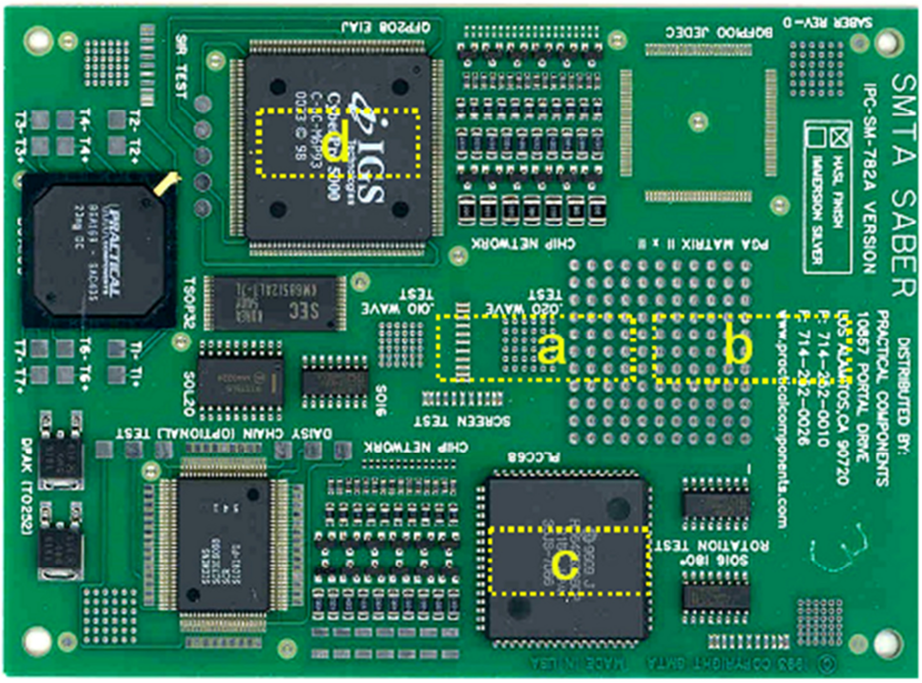


Figure F3: Test assembly B (HASL finish)

Wetting angle measurement on substrate may be some indication for strength of bonding, but the adhesion between coating and substrate can be due to covalent chemical bonding for most of coatings. Therefore it is difficult to predict coating adhesion from substrate surface energy, and wetting angle measurement.
The wetting angles on different substrate material, FR4 PCB, copper, different resists and components, were measured with a DAS 100 using DI water, as shown in Figure F4. A 70pl water drop was used for each measurement. The machine measured wetting angles on both side of each drop, as shown in the figure, and the average reading was taken. There were 9 measurements for each material.

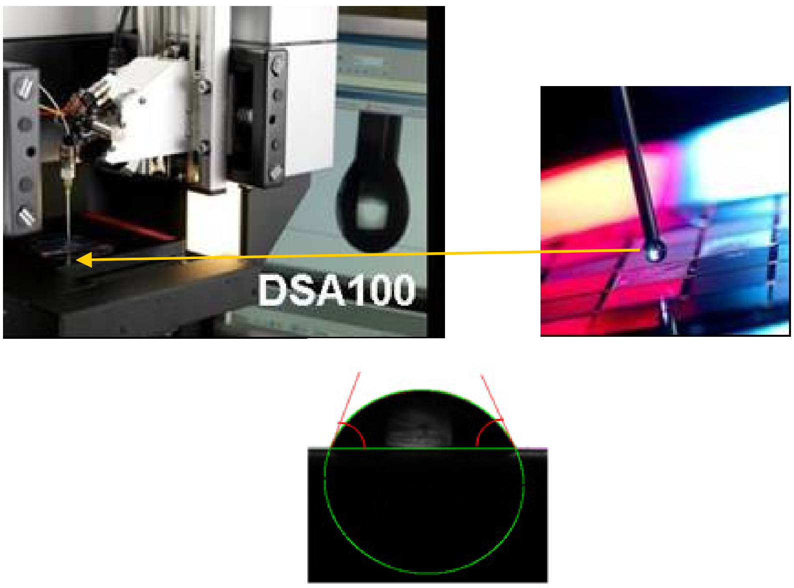


Figure F4: Wetting angle measurement with DSA 100

F2 Results and discussions

The peel forces with distance from PCB, copper and solder resists for three coatings are plotted in Figure F5-F7 respectively. The average peel forces from 5mm to 35mm distance from two samples for each substrate material and coating are compared in Figure F8. Similarly the peel forces with distance from wave solder processed PCB for three coatings are shown in Figure F9, and the average peel forces from 5mm to 35mm distance from two samples for each wave solder flux and coating are compared in Figure F10. The results clearly show that for acrylic and polyurethane coatings, the peel force was lower on copper and some of the resists compared to PCB. For PCB the failure mode was between the tape and coating. Where a reduced peel force was observed, the failure either occurred at the coating/substrate interface, or a mixture between coating/substrate and coating/tape interfaces, as listed in Table F2. However there was no significant difference on peel force for silicone coating between different materials, failure was always occurred at coating/tape interface. For two wave soldered boards failures were at coating/tape interface. This implies that all coatings coped well with wave soldering fluxes.

The peel forces with distance from different components for three coatings are plotted in Figure F11-F13 respectively, and the average peel forces from 5mm to 20mm distance from two samples for each component and coating are compared with FR4 PCB in Figure F14, and clearly show that acrylic coating had very low peel force for all components, and the adhesion was not improved by cleaning in IPA + DI water in ultrasonic machine for 20 minutes. For the polyurethane coating, the peel force was reasonably high (above 10 N) for some components, but for most of the components the peel force was around 5 N. When the force was below 12 N, failure occurred at coating/component interface, as listed in Table F3. For the silicone coating, when the force was below 5 N, failure occurred at coating/component interface.

For two assemblies A and B, the peel forces with peel distance with the three coatings at the different test sites are shown in Figures F15-F21. An image of the peel site is also shown in each figure as an aid to correlate the peel force.

The results clearly show that coating adhesion varied with different materials on the substrates, resist and solder. Different coatings sustained different peel force on the various substrate materials. For example for assembly A site c, the peel force was lower in the resist area than that at the solder area. The force also follows exactly the land patterns for the acrylic and polyurethane coatings, as presented in Figure 17. The difference on peel force between the resist and solder surfaces were not as significant for the polyurethane coating as it was for the acrylic coating. The substrate was inspected after peel testing, as shown in Figure F22 for acrylic coating. The inspection results revealed that the failure occurred at the coating/resist interface in the resist area, but at coating/tape interface in the solder area. There was no significant difference on peel force for different materials on assemblies for the silicone coating.

They all failed at coating/tape interface. This suggests that although the peel force for silicone coating is not high as acrylic and polyurethane coatings, the coating coped well with different materials from assembly.
The wetting angle results for FR4 PCB, copper, different resists and components are listed in Table F4, the peel force on these materials from three coatings are given in the table as well. Since two tape widths were used for peel testing on these materials, the peel forces in the table are given in N/10mm for direct comparison. The results clearly indicate that there was no clear correlation between substrate wetting angles and the peel force. For example, for solder resists sample the peel force was much lower for the curtain version of resist A from both acrylic and polyurethane coatings compared with other resists, but the wetting angle from this resist was not particularly high, it was very close to PCB, which has the highest peel force in all test materials. Although there was significant difference on wetting angle between different components, the peel force for acrylic coating was very low from all components. BGA G had the lowest wetting angle for all test components, but the peel force for this component was high from polyurethane and silicone coatings. BGA B had relatively higher wetting angle, and the peel force for this component is lower. This implies that wetting angle has some indication on peel force, but it is difficult to correlate the wetting angle to peel force directly. While the wetting angle is indicative of substrate surface energy, the composition of coatings with different polymers and solvents makes it impossible to establish a universal correlation between wetting angle and adhesion.

F3 Conclusions

Tape peel method is easy to use and the peel force is capable of discriminating between different substrate materials and coatings found on electronic circuits. All test coatings coped well with production flux residues, but components and some resists show particularly low adhesion for some coatings. The acrylic coating performed poorly on the components, demonstrating very low adhesion forces. Although the silicone coating again did not produce high peel forces, it did cope well with different substrate materials, PCBs, resists and some components. There was no clear correction between wetting angle of substrate and adhesion of coating to substrate.

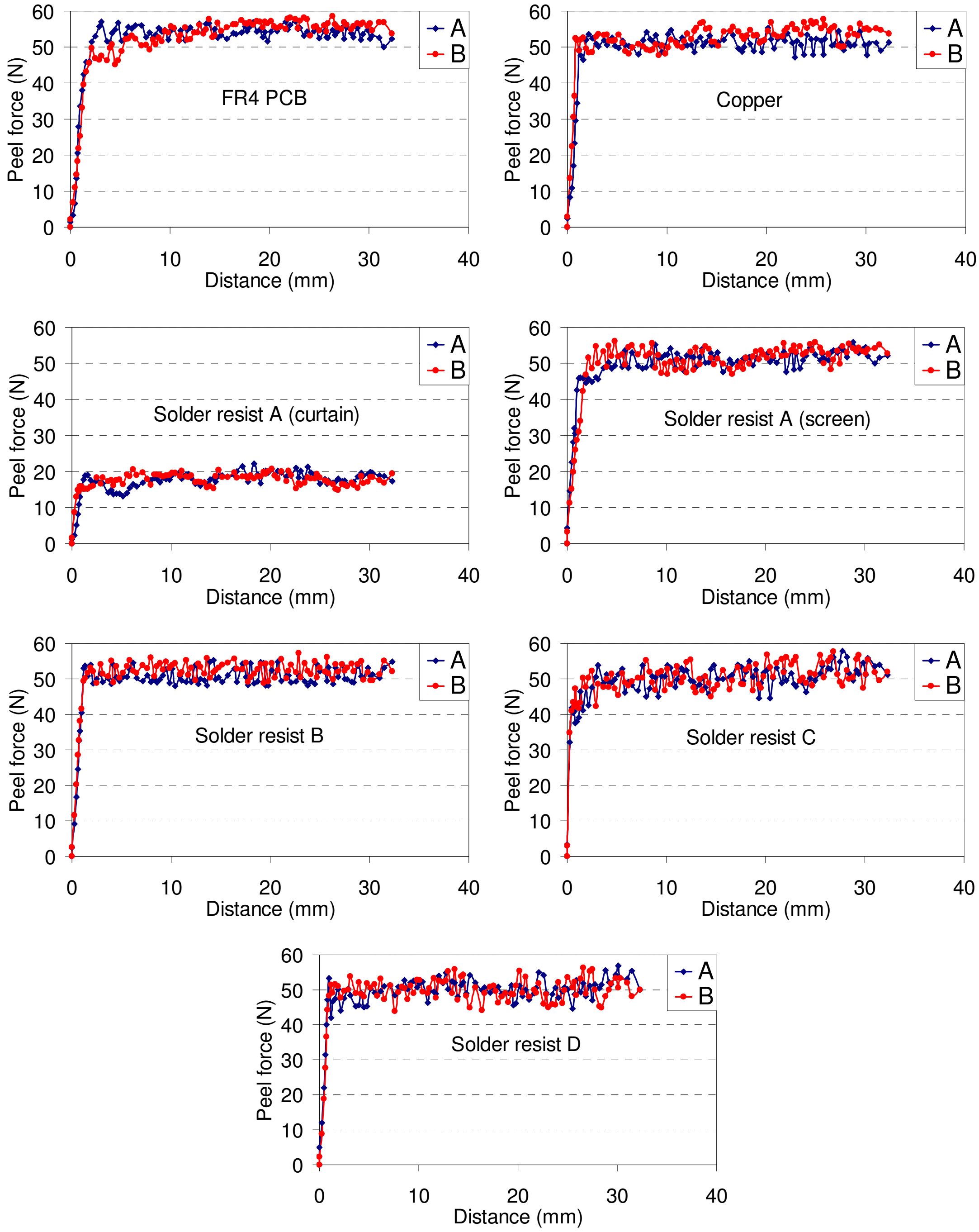


Figure F5: Peel force with peel distance from PCB, copper and solder resists for acrylic coating

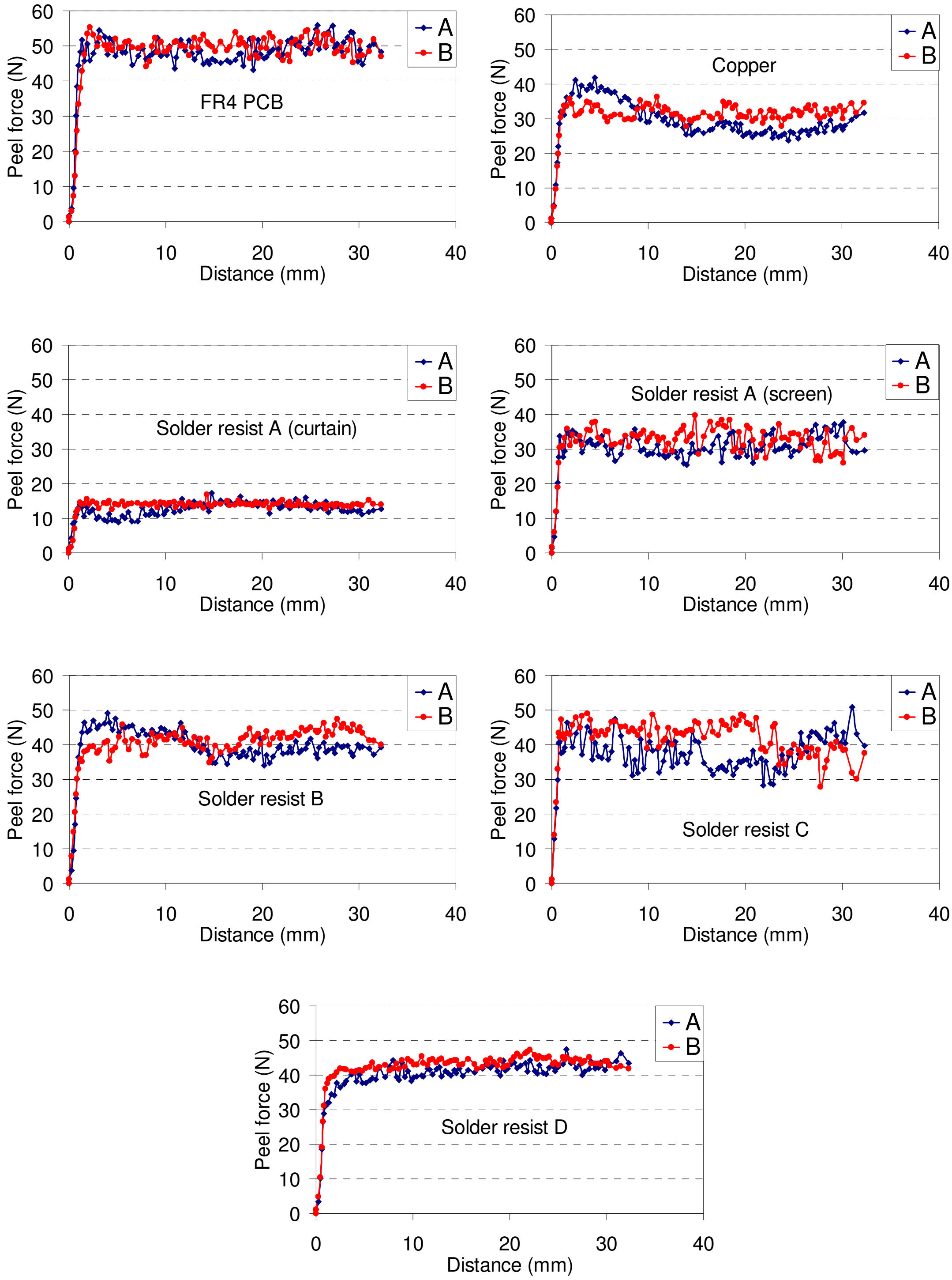


Figure F6: Peel force with peel distance from PCB, copper and solder resists for polyurethane coating

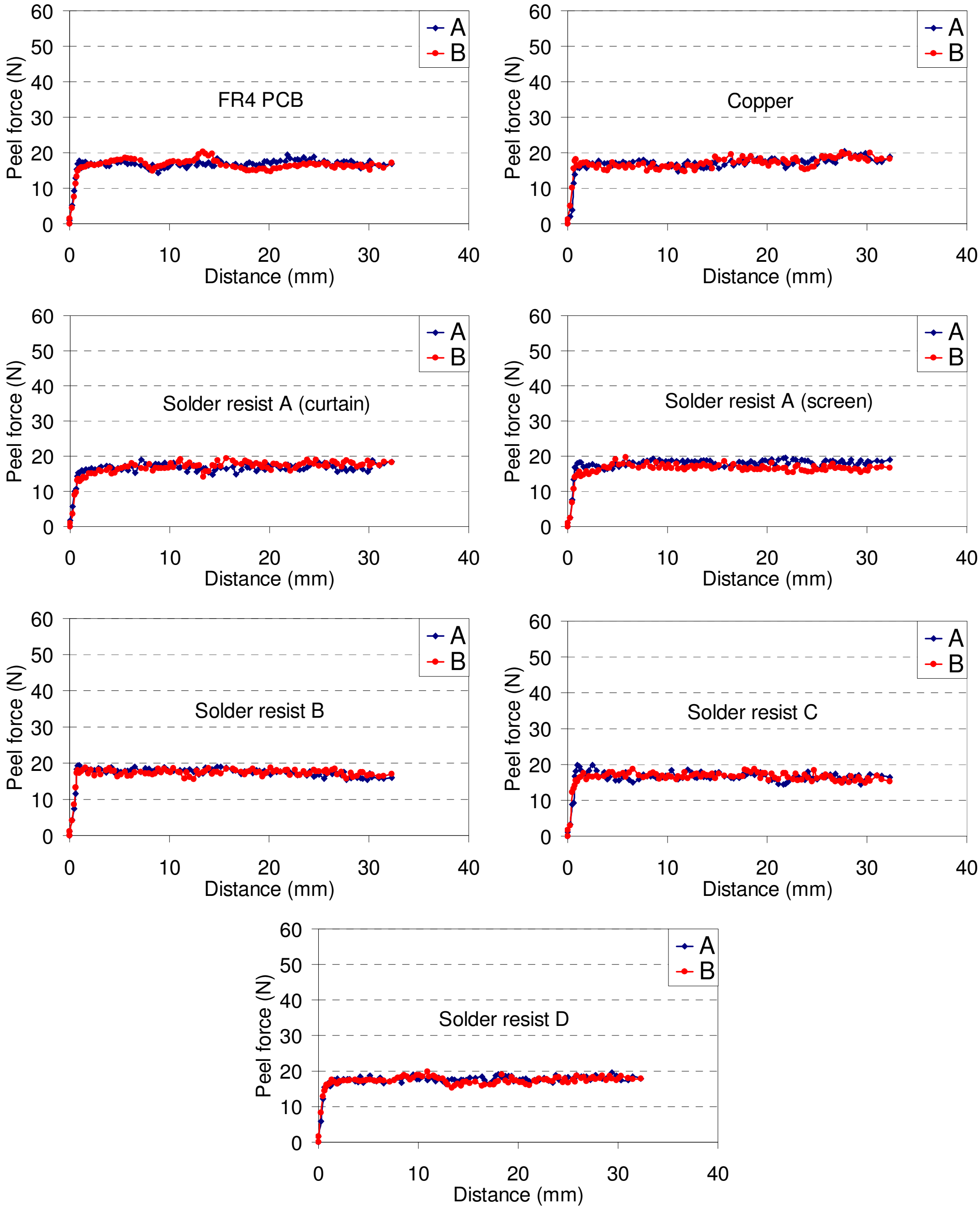


Figure F7: Peel force with peel distance from PCB, copper and solder resists for silicone coating

Table F2: Failure mode from different substrate materials for three coatings

Substrate / Coating	PCB	Cu	Resist A Curtain	Resist A Screen	Resist B	Resist C	Resist D
Acrylic	T	T	S	T	T	T	T
Polyurethane	T	S	S	S	T+S	T+S	T+S
Silicone	T	T	T	T	T	T	T

* T: coating/tape interface S: coating/substrate interface

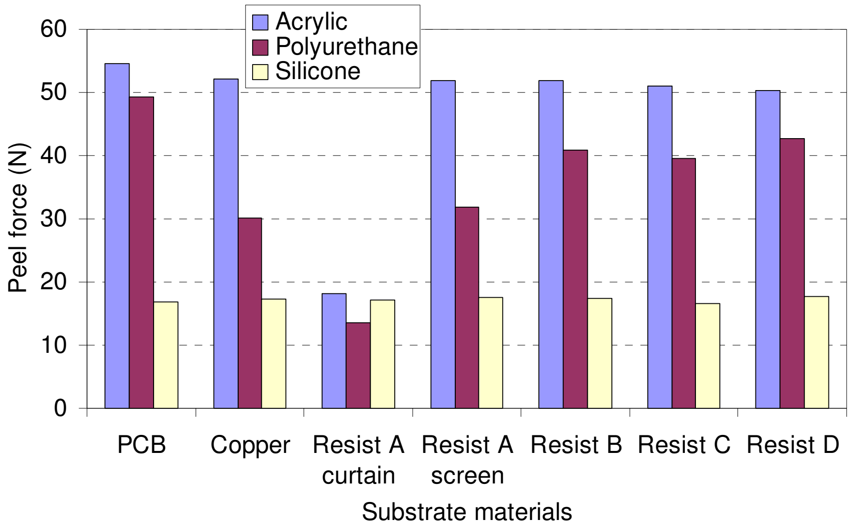


Figure F8: Average peel force from different materials for three coatings

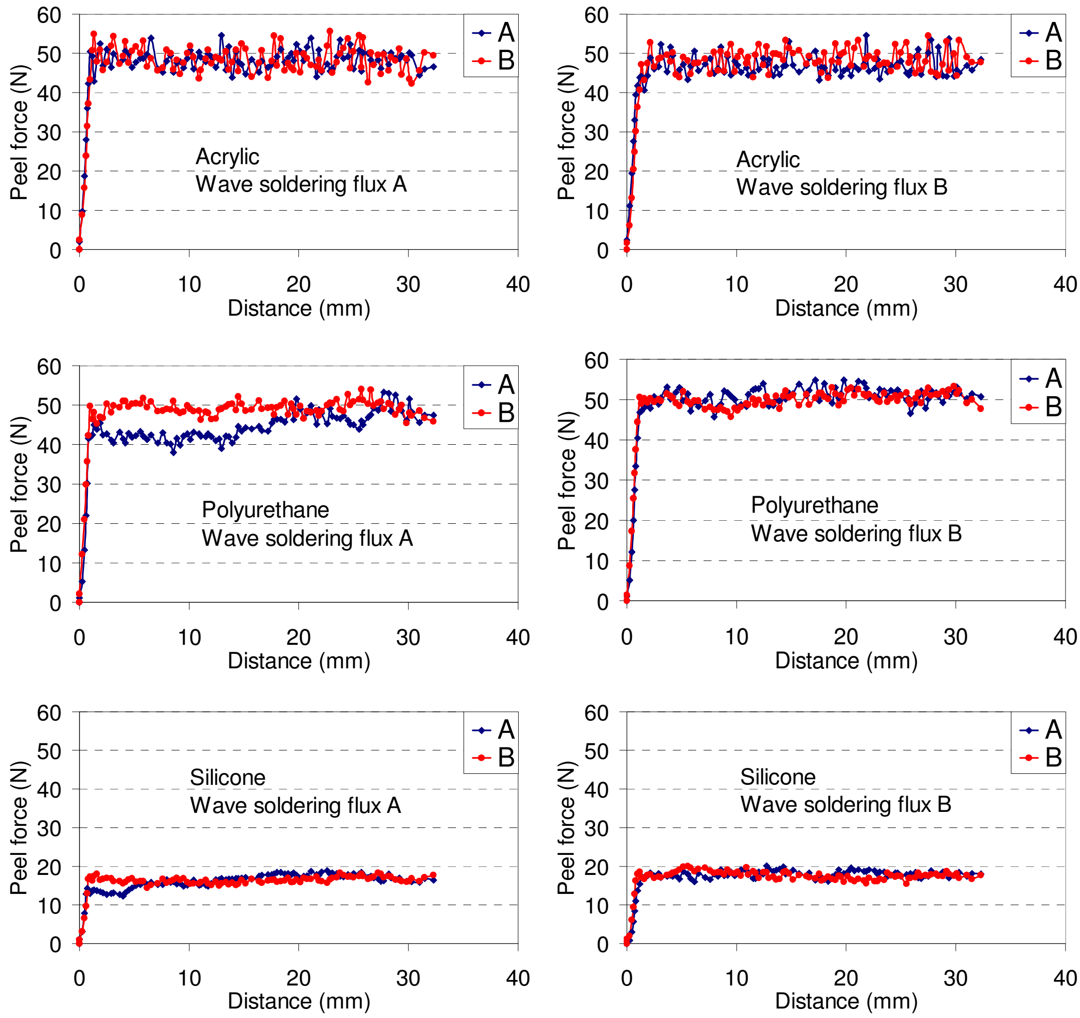


Figure F9: Peel force with peel distance from wave soldering processed PCB for three coatings

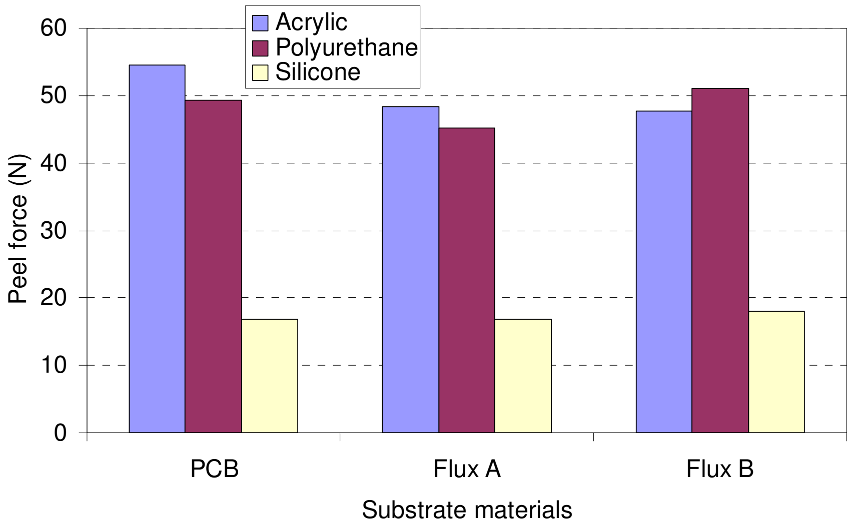
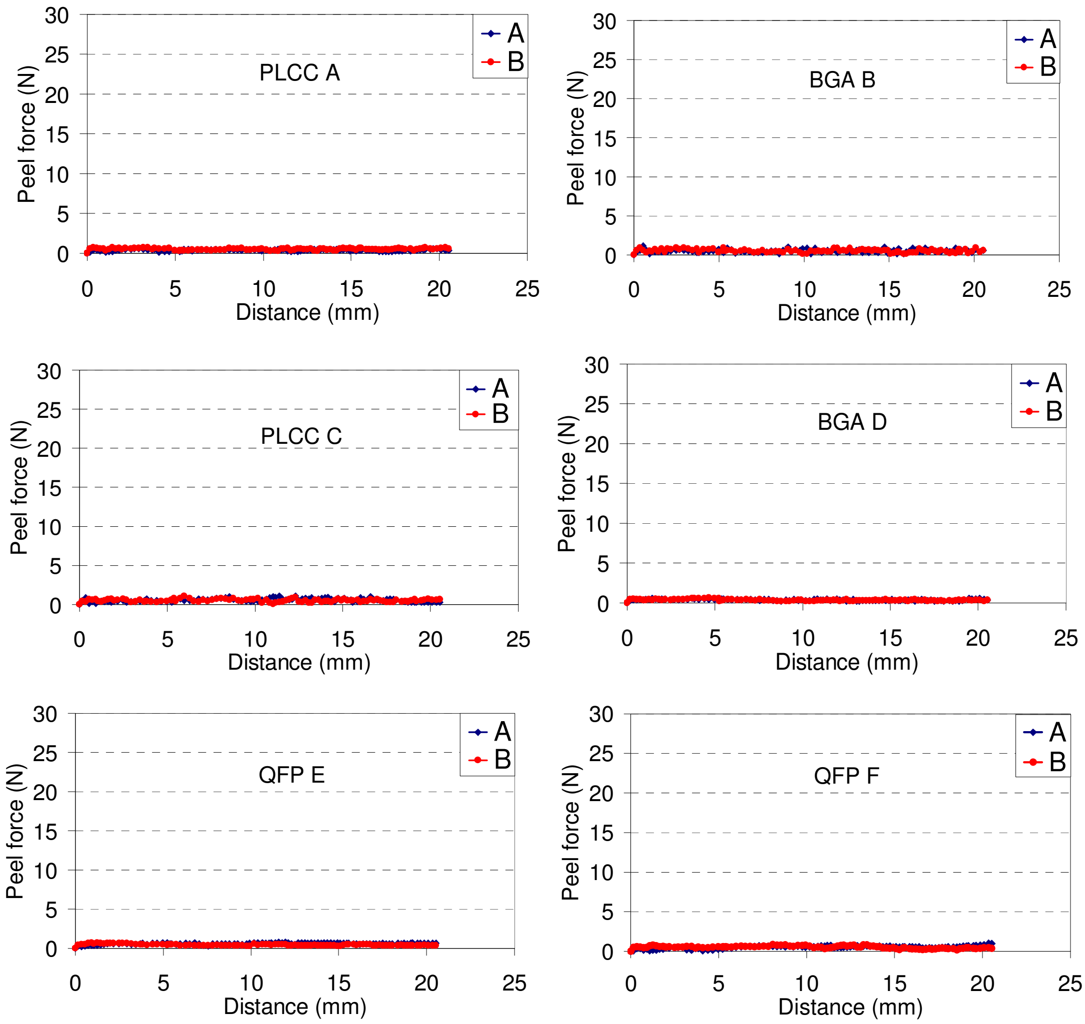


Figure F10: Average peel force from different wave solder fluxes for three coatings



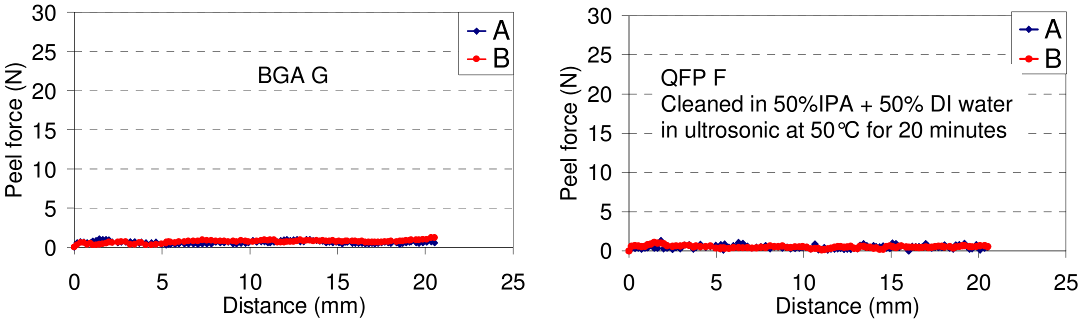


Figure F11: Peel force with peel distance from different components for acrylic coating

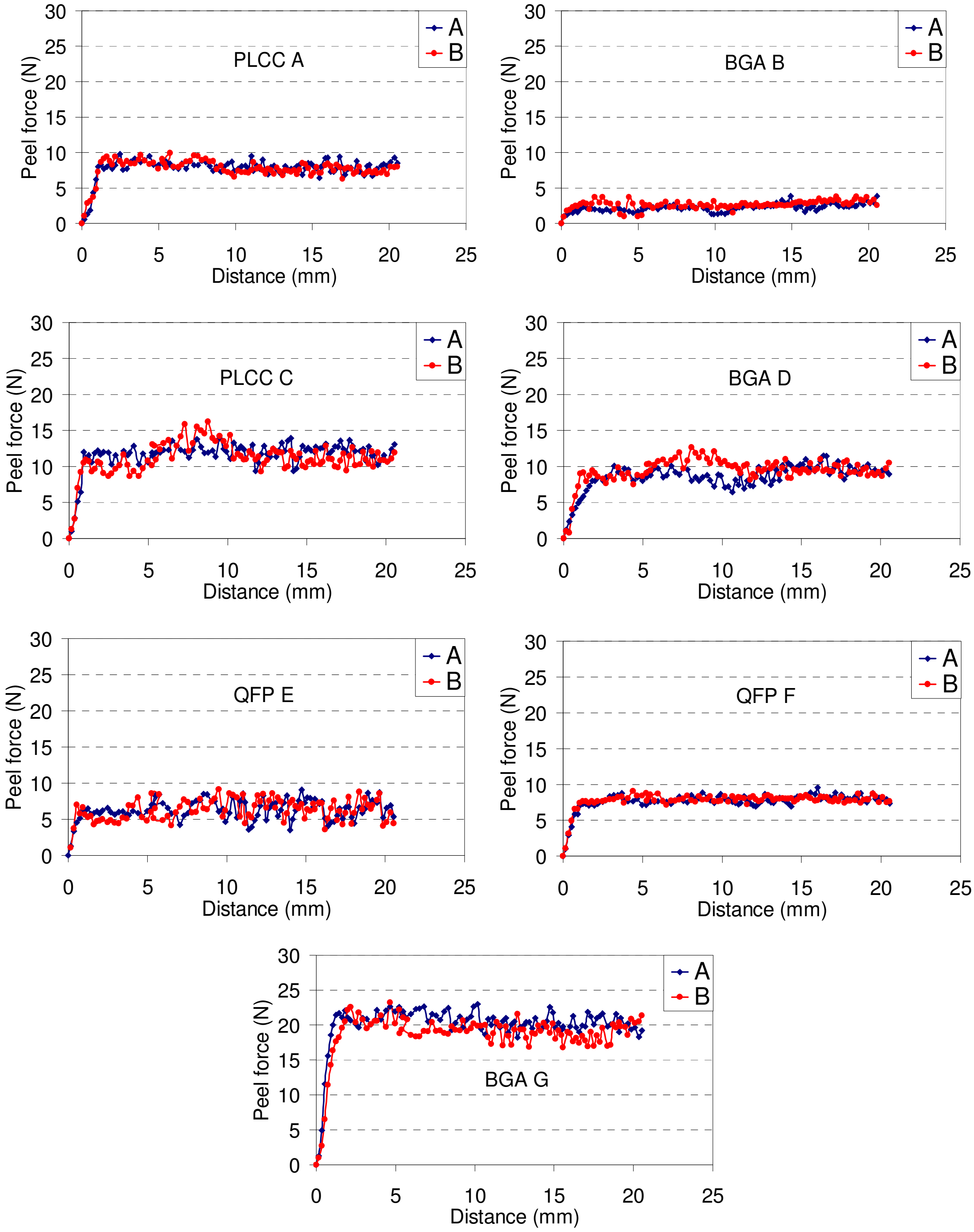


Figure F12: Peel force with distance from different components for polyurethane coating

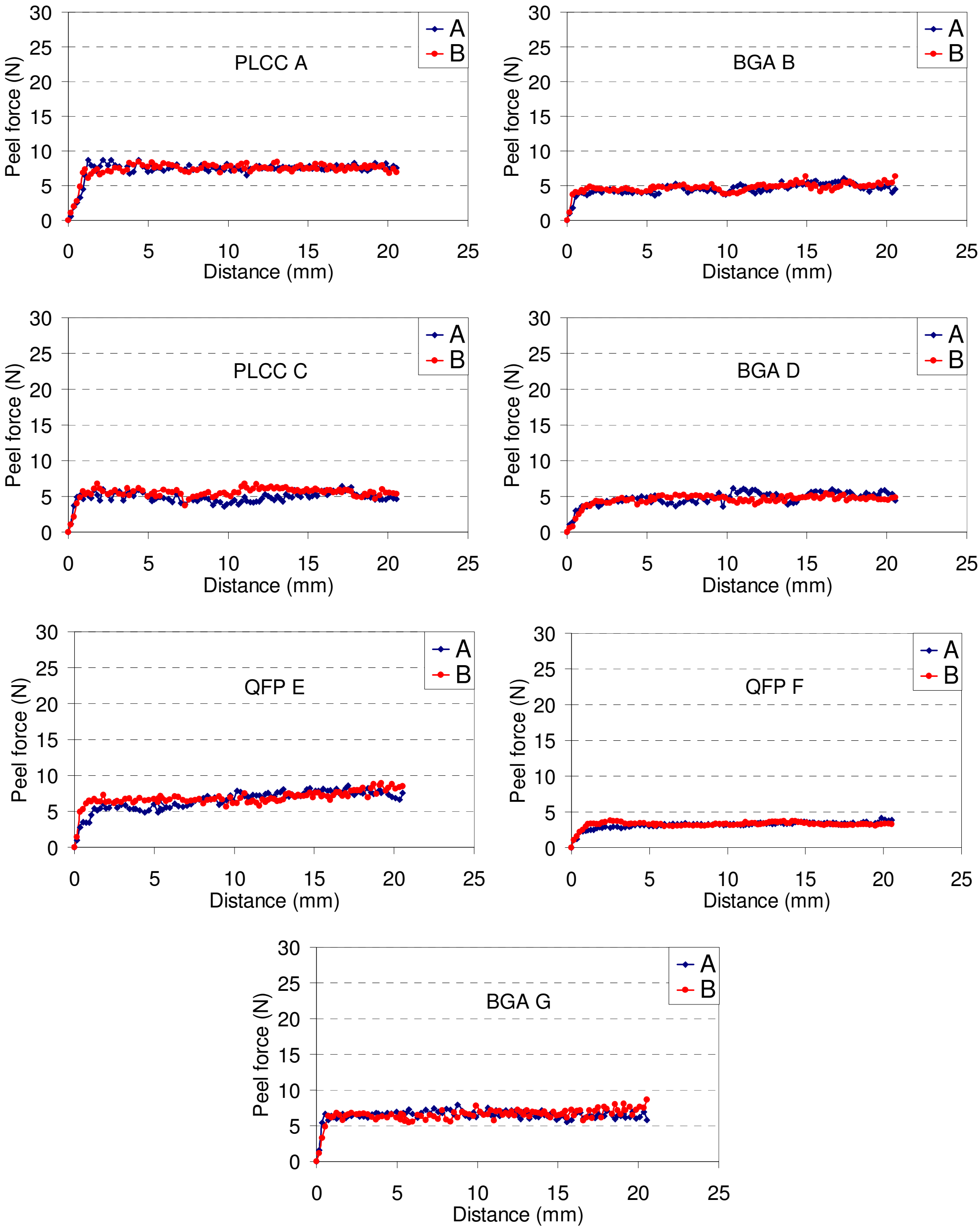


Figure F13: Peel force with peel distance from different components for silicone coating

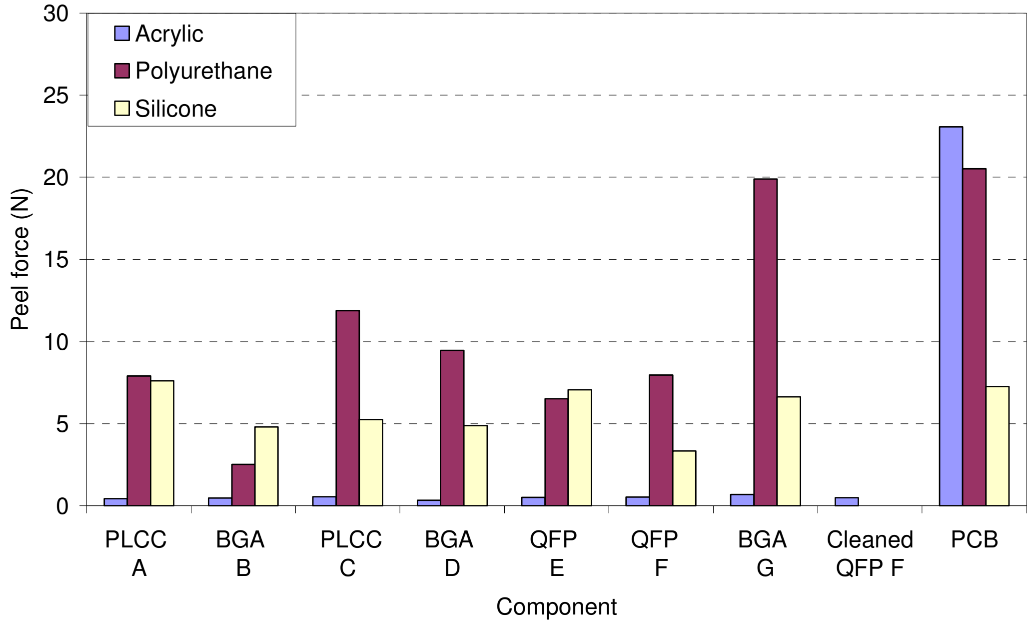


Figure F14: Average peel force from different components for three coatings

Table F3: Failure mode from different components for three coatings

Component / Coating	A	B	C	D	E	F	G
Acrylic	**S**	**S**	**S**	**S**	**S**	**S**	**S**
Polyurethane	**S**	**S**	**T**	**S**	**S**	**S**	**T**
Silicone	**T**	**S**	**T**	**S**	**T**	**S**	**T**

* T: coating/tape interface S: coating/substrate interface

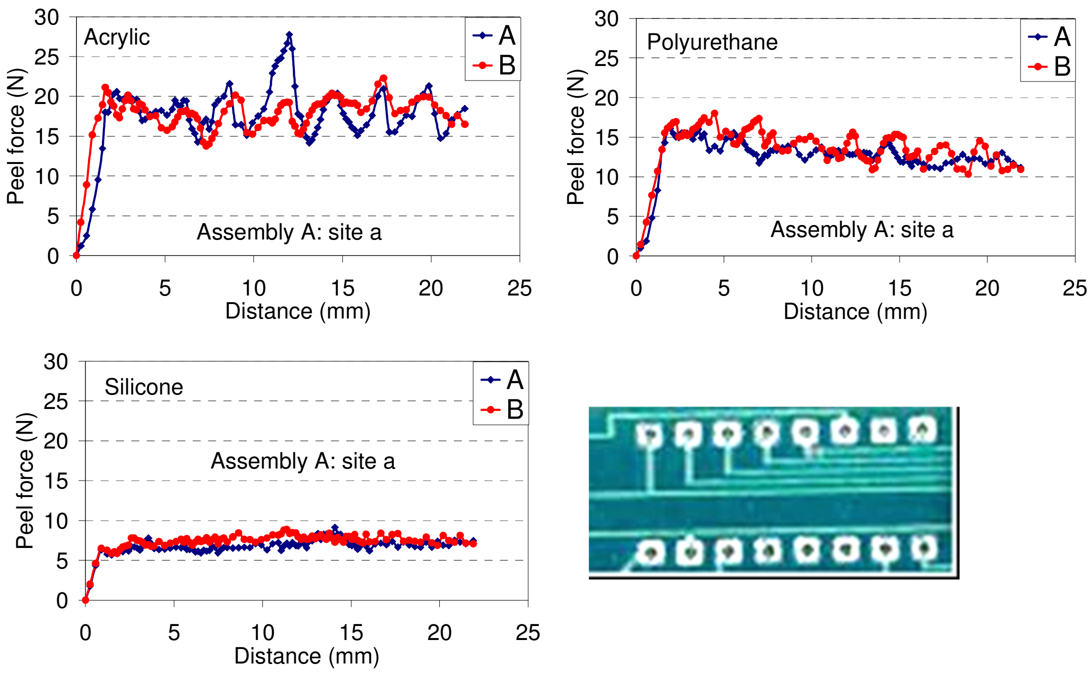


Figure F15: Peel force with peel distance from different coatings for assembly A site a

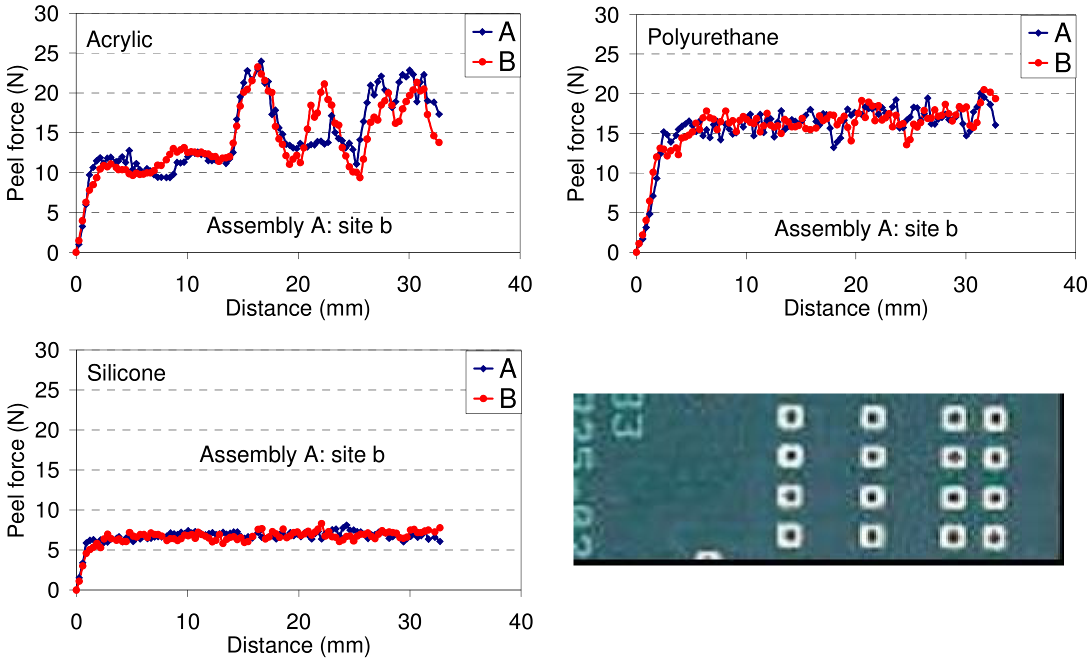


Figure F16: Peel force with peel distance from different coatings
for assembly A site b

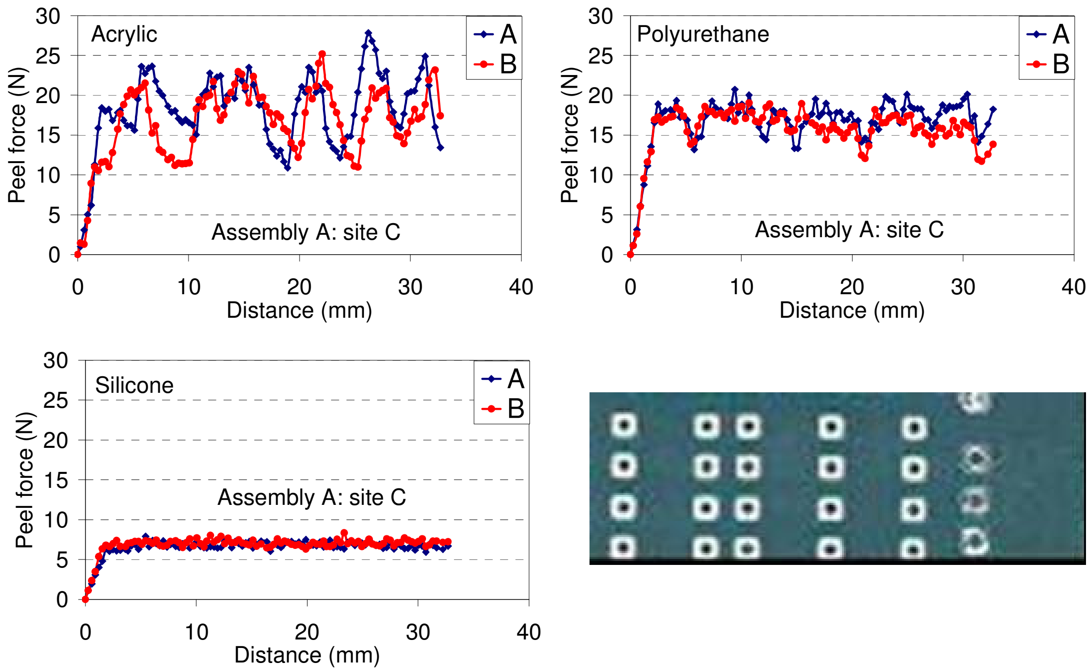


Figure F17: Peel force with peel distance from different coatings
for assembly A site c

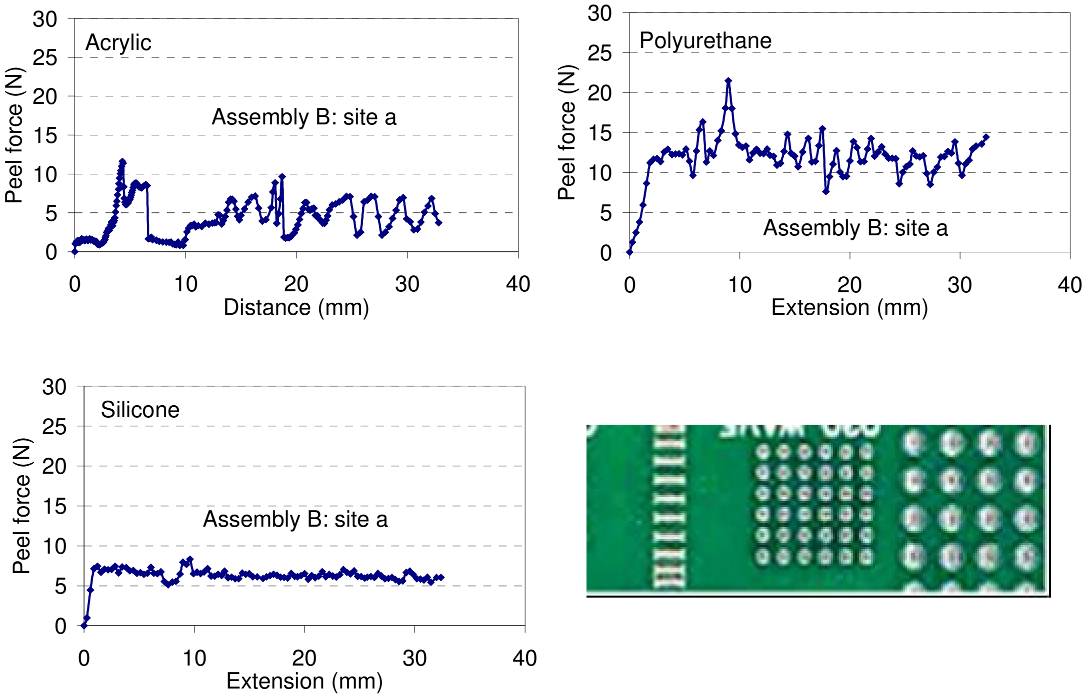


Figure F18: Peel force with peel distance from different coatings for assembly B site a

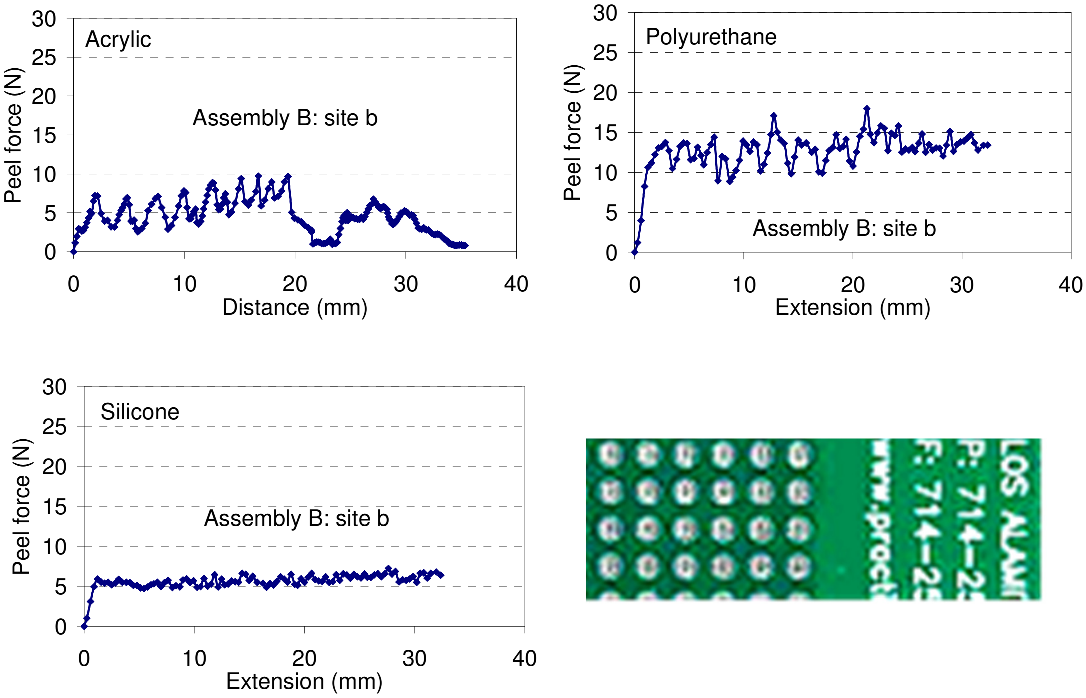


Figure F19: Peel force with peel distance from different coatings for assembly B site b

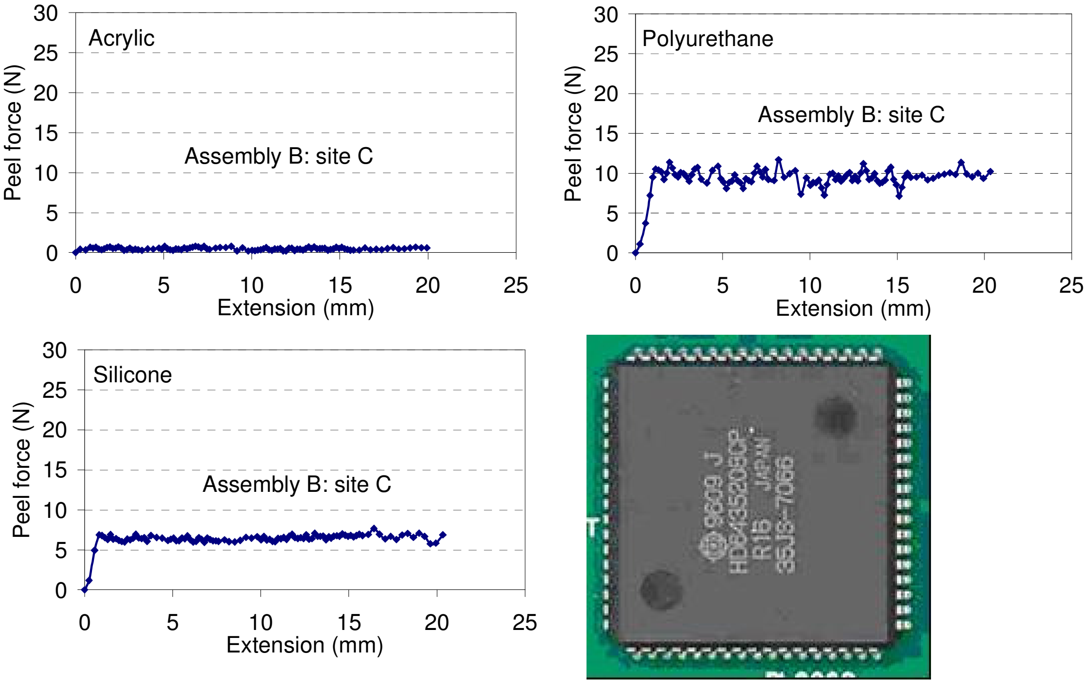


Figure F20: Peel force with peel distance from different coatings for assembly B site c

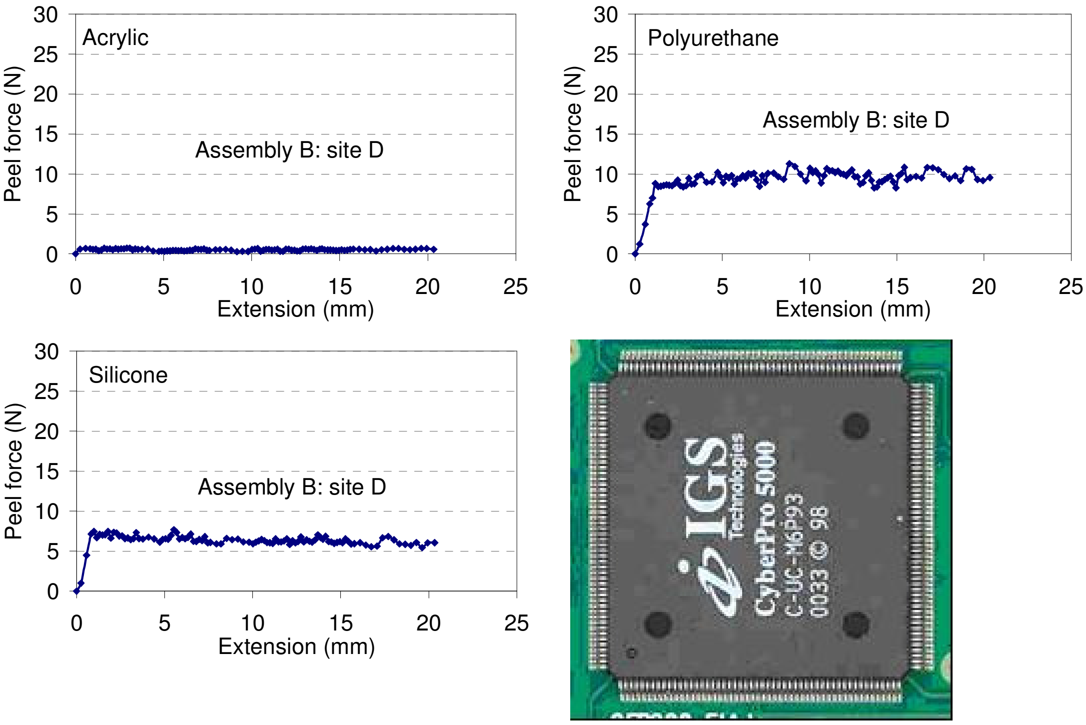


Figure F21: Peel force with peel distance from different coatings for assembly B site d

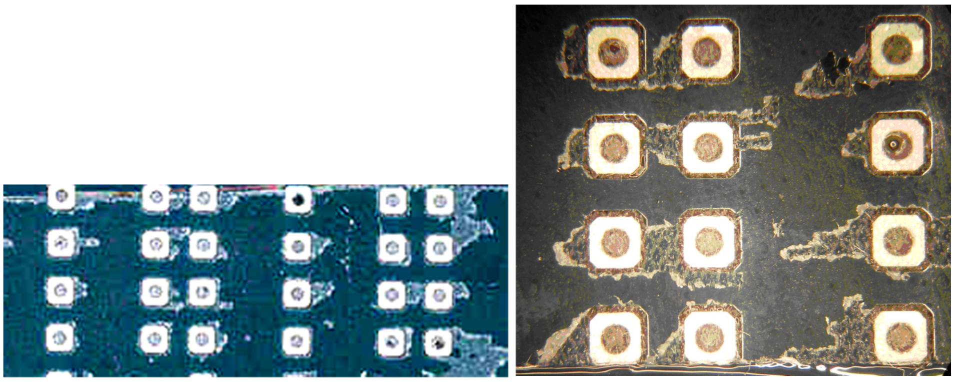


Figure F22: Peel force with peel distance from Assembly A site C for acrylic coating and the substrate after peel

Table F4: Wetting angles of substrate and peel force from three coatings

Substrate material	Wetting angle (°)	Peel force (N/10mm)		
		Acrylic	Polyurethane	Silicone
FR4 PCB	70.0	21.8	19.7	6.7
Copper	86.9	20.9	12.1	6.9
Resist A (Curtain)	70.1	7.2	5.4	6.9
Resist A (Screen)	68.9	20.7	12.8	7.0
Resist B	71.0	20.7	16.4	6.9
Resist C	84.1	20.4	15.9	6.6
Resist D	72.3	20.1	17.1	7.1
PLCC A	91.3	0.4	7.9	7.2
BGA B	86.2	0.5	2.5	4.8
PLCC C	81.1	0.5	11.9	5.3
BGA D	84.6	0.3	9.5	4.9
QFP E	75.0	0.5	6.5	7.1
QFP F	92.9	0.5	8.0	3.3
BGA G	75.5	0.7	19.9	6.6