

Measurement of Solder Paste Tack in Tension and Shear

**Alan Brewin, Ling Zou and Christopher
Hunt**

February 2001

February 2001

Tack Testing of Solder Paste in Tension and Shear

Alan Brewin, Ling Zou & Christopher Hunt
Materials Centre
National Physical Laboratory
Teddington, Middlesex
UK. TW11 0LW

ABSTRACT

An industry relevant technique for a full understanding of the tack properties exhibited by solder pastes is presented. Uniquely the tack of paste in the direction normal to the printed circuit assembly (PCA) surface, and parallel to it, has been studied proving an easy method of differentiating and classifying materials. The method has been shown to be sensitive enough to monitor ageing of pastes and the effects of test probe geometry, the insertion and withdrawal speed of the probe, and insertion force have all been studied in the work.

© Crown copyright 2001
Reproduced by permission of the Controller of HMSO

ISSN 1361-4061

National Physical Laboratory
Teddington, Middlesex, UK, TW11 0LW

Extracts from this report may be reproduced provided the source is
acknowledged and the extract is not taken out of context.

Approved on behalf of Managing Director, NPL, by Dr C Lea,
Head, Centre for Materials Measurement and Technology

CONTENTS

1	INTRODUCTION	5
1.1	MEASURING TENSILE TACK.....	5
1.2	MEASURING SHEAR TACK.....	6
1.3	THE TACK TESTER	7
2	EXPERIMENTAL.....	8
2.1	SELECTION OF PASTES.....	8
2.2	DESIGN OF TEST PROBES.....	9
2.3	PRINTING OF PASTE.....	9
2.4	USING THE TACK TESTER.....	9
3	RESULTS	10
3.1	TENSILE TACK	10
3.1.1	Effect of Probe Withdrawal Speed.....	10
3.1.2	Effect of Probe Insertion Rate	12
3.1.3	Effect of Probe Load.....	13
3.1.4	Effect of Probe Geometry.....	14
3.1.5	Differentiation Between Pastes	15
3.2	SHEAR TACK	15
3.2.2	Effect of Probe Shear Speed.....	15
3.2.3	Effect of Load.....	19
3.3.4	Differentiation Between Pastes	19
3.4	AGEING OF PASTE	20
3.5	CORRELATION OF TENSILE AND SHEAR TACK.....	21
4	DISCUSSION	22
4.1	COMPARISON OF TENSILE AND SHEAR METHODS	22
4.2	TEST VARIABLES.....	22
5	CONCLUSIONS	23
6	ACKNOWLEDGEMENTS	23
7	REFERENCES.....	23

1 INTRODUCTION

Solder paste is a complex material with many properties. The paste is a suspension of solder spheres of $\approx 25\mu\text{m}$ diameter suspended in a flux vehicle. The flux vehicle has a number of components: activators, solvents, rheology modifiers, and gelling agents. The principal role of the paste is to attach a component to the substrate, a printed wiring board (PWB), during a heating cycle. The rheology of the paste is critical. The paste (when designed for a screen-printing application) must have three seemingly conflicting characteristics

- i) be able to flow rapidly into apertures
- ii) not to slump as the stencil is removed and
- iii) be sufficiently tacky to retain the components following its placement. Having met these mechanical requirements the paste must also contain a flux to ensure good wetting during reflow.

It is the mechanical function of the paste being tacky, and holding components in place as robotic 'pick and place' machines rapidly position them, that is evaluated in this study.

1.1 MEASURING TENSILE TACK

There are existing standards for the measurement of tensile tack for solder pastes, but these are inadequate for a number of reasons. For a justification of the requirement to develop a new tack test method see NPL Report CMMT (A) 253¹.

During a tack test the paste is screen printed onto a test panel in a pattern to match the geometry of the test probe. The test probe is moved downwards into the paste until a controlled force is measured acting back on the probe. As the probe is withdrawn from the paste the downward force on the probe is recorded.

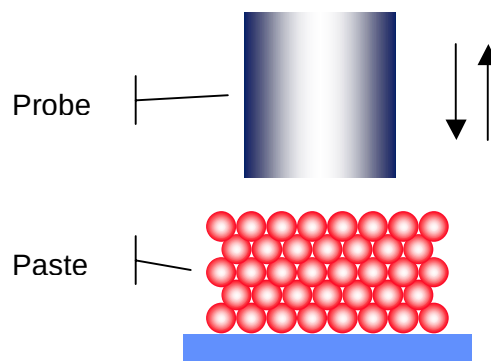


Figure 1. Schematic of tensile tack testing

The data are then viewed as a plot of force against time, and will ideally have the shape of curve shown in Figure 2. The tack force is defined as the peak force in the force-time curve shown.

The probe is driven into the paste until the required force is met at the point marked 'A'. The system dwells at this point and the paste relaxes with the force diminishing to point 'B'. At point 'B' the probe is withdrawn, the paste is extended and the maximum cohesive force in the paste is reached at point 'C'. After this the paste necks, and the neck breaks and the force falls to approximately zero at point 'D'.

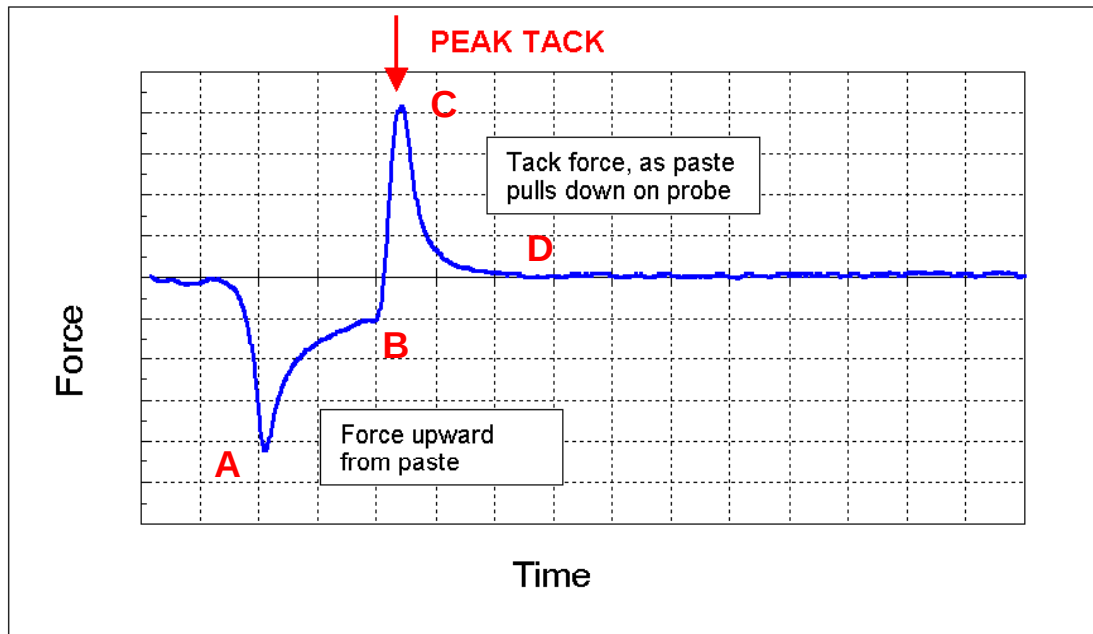


Figure 2. Idealised force - time plot for a tensile tack test

1.2 MEASURING SHEAR TACK

In order to measure the tack force of the paste in shear the probe is withdrawn horizontally from the paste, although it is still inserted vertically. In practice this is achieved by moving the paste sample plate horizontally. The force monitored during the process is the force on the probe in the y-horizontal axis, not the z-vertical axis, although the z-axis force is still used as the controlling parameter for limiting the insertion depth of the probe.

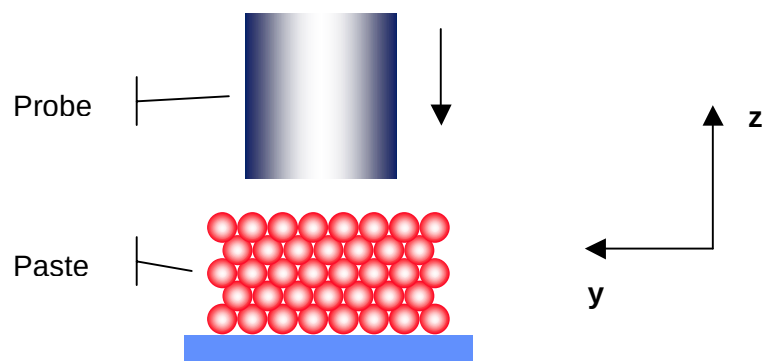


Figure 3. Schematic of shear tack testing

The force against time plot for the shear tack test is different from that in the case of vertical withdrawal. There is no negative displacement due to the insertion force of the probe since this force is not in the horizontal plane. Only the force resulting from the shearing of the paste is recorded, as the sample is pulled sideways. Hence in Figure 4 there is only a positive curve. The maximum force at point 'A' is reached again when the maximum cohesive force in shear is reached. Thereafter the paste necks and breaks, with a final residual force being present with remnant paste on the probe being rubbed over the substrate, point 'B'. The shear tack force is defined as the peak force i.e. point A.

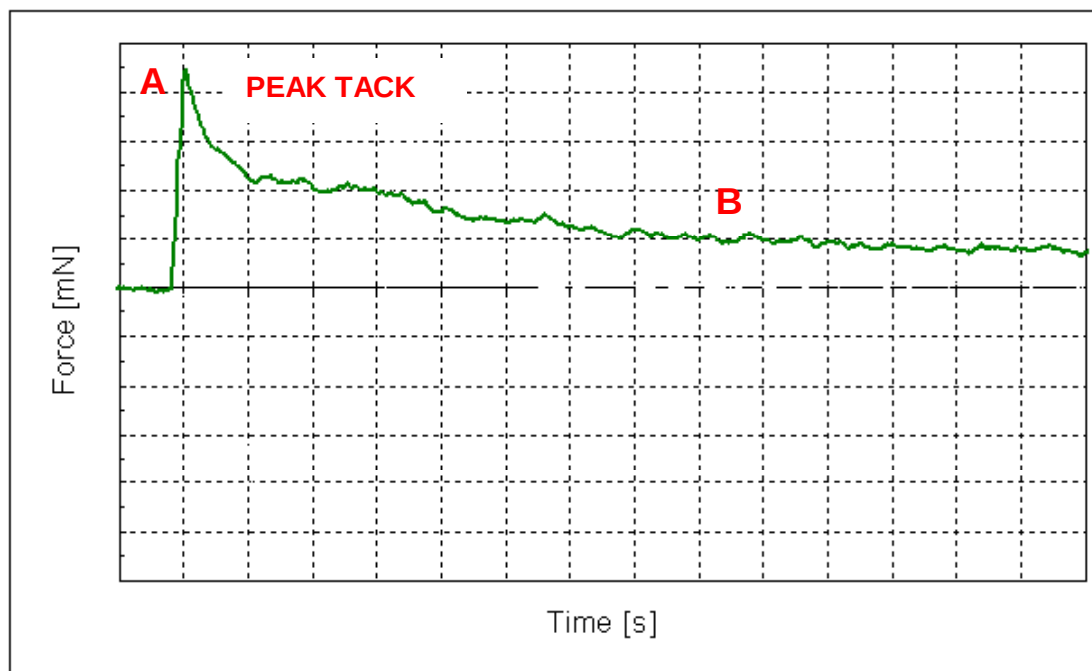


Figure 4. Idealised force against time plot for a shear tack test

1.3 THE TACK TESTER

The equipment used was a prototype machine provided by Multicore-Loctite. The instrument uses load cells to measure the forces applied, and stepper motors to move the test probe and test plate. Figure 5 shows the tack tester, the broken arrows indicating the location of screw threads attached to stepper motors for the movement and positioning of the probe and sample plate. The yellow arrows indicate the load cells, which register the force acting on the probe.

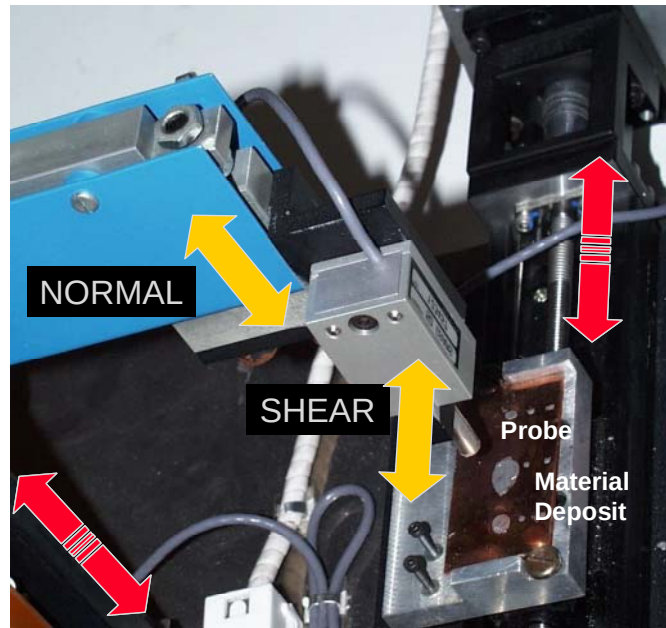


Figure 5. The Multicore-Loctite prototype tack tester

The system is computer controlled with the software allowing flexibility of motor speeds, and insertion load.

	Tensile Mode		Shear Mode	
	Minimum	Maximum	Minimum	Maximum
Contact Speed	0.001 mm/s	20 mm/s	0.001 mm/s	20 mm/s
Withdrawal Speed	0.001 mm/s	20 mm/s		
Contact Load	10 g	500 g	10 g	500 g
Contact Timing	2 s	3600 s	2 s	3600 s
Shear Speed			0.001 mm/s	10 mm/s

Table 1. Parameter ranges for tack tester

2 EXPERIMENTAL

2.1 SELECTION OF PASTES

In order to study the effects of different paste rheologies three pastes with different metal contents were selected.

Paste X – 89% Metal Content
 Paste Y – 89.5% Metal Content
 Paste Z – 90% Metal Content

All the pastes were based upon rosin flux technologies.

2.2 DESIGN OF TEST PROBES

The probes utilised in the work were designed to allow the effect of surface area and shape to be investigated. They also included more representative designs of realistic component leg geometries than some of the larger probes historically used. The probes can be easily interchanged on the tack tester. The probe dimensions were as follows:

Probe A – Large Square
 Probe B – Large Circle
 Probe C – Small Square
 Probe D – Small Circle

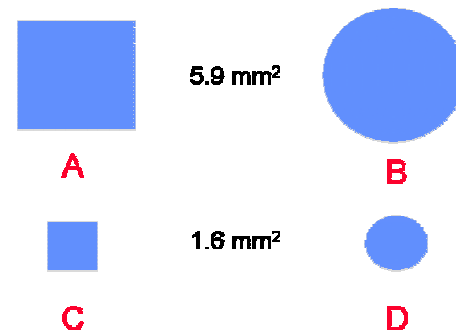


Figure 6. Schematic of cross section of tack testing probes showing surface area

2.3 PRINTING OF PASTE

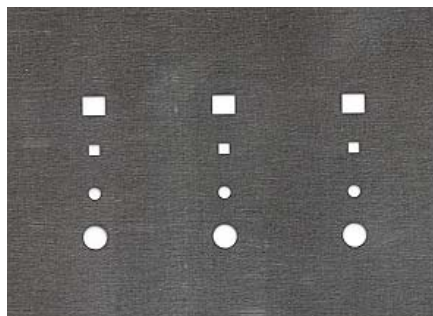


Figure 7. Hand print stencil for application of paste deposits

The paste was hand printed onto a copper test panel using a small stencil with apertures corresponding to the probe dimensions. The stencil thickness was 200 μ m.

The stencil was designed to place three rows of deposit to enable tests to be repeated more easily.

2.4 USING THE TACK TESTER

The probe was manually aligned with the paste deposit prior to starting each test. The stepper motors were used to do this quickly and easily and were controlled via the PC software. In addition, the parameters for the test must be set in the software; these are shown in Table 1. Shear load was not utilised at all in this work, since insertion of the probe was always in the vertical axis. The fields for probe size data had no practical effect on the test, but the information was logged as part of the data file.

Once the test is started the probe is driven down into the paste deposit at the designated insertion speed, (or contact speed). As the probe enters the paste the vertical displacement load cell registers the force upwards on the test probe and once this reaches the defined contact load the insertion is halted. The machine then waits for two seconds before withdrawing the probe. All tests were performed with two-second contact times as standard.

For a tensile tack test the probe is withdrawn vertically and so the vertical displacement load cell detects any tack force as work is done in partitioning the paste and exceeding its cohesive strength. The software logs the readings from this load cell against time for the duration of the test.

For a shear tack test the horizontal lead screw is activated to slide the paste deposit horizontally from the fixed probe position and the shear load cell measures the sideways drag. In this case the software logs the output from the horizontal load cell throughout the test.

3 RESULTS

3.1 TENSILE TACK

3.1.1 Effect of Probe Withdrawal Speed

The speed at which the probe is withdrawn from the paste sample was shown to have an effect on the peak tack detected during the test. The output data from the tack tester software for Paste X over a wide range of withdrawal rates are shown in Figure 9.

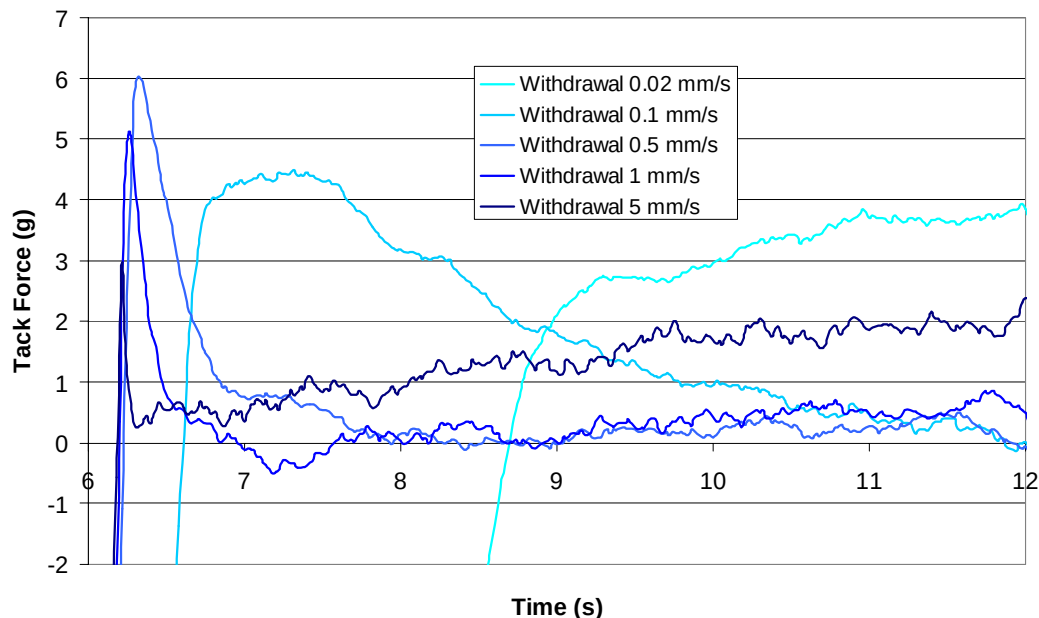


Figure 8. Tack curves for paste X, 0.1mm/s insertion, 50g load, with probe B

Plotting the tack force data against displacement instead of time allows the tack curves to be compared more easily, as in Figure 10.

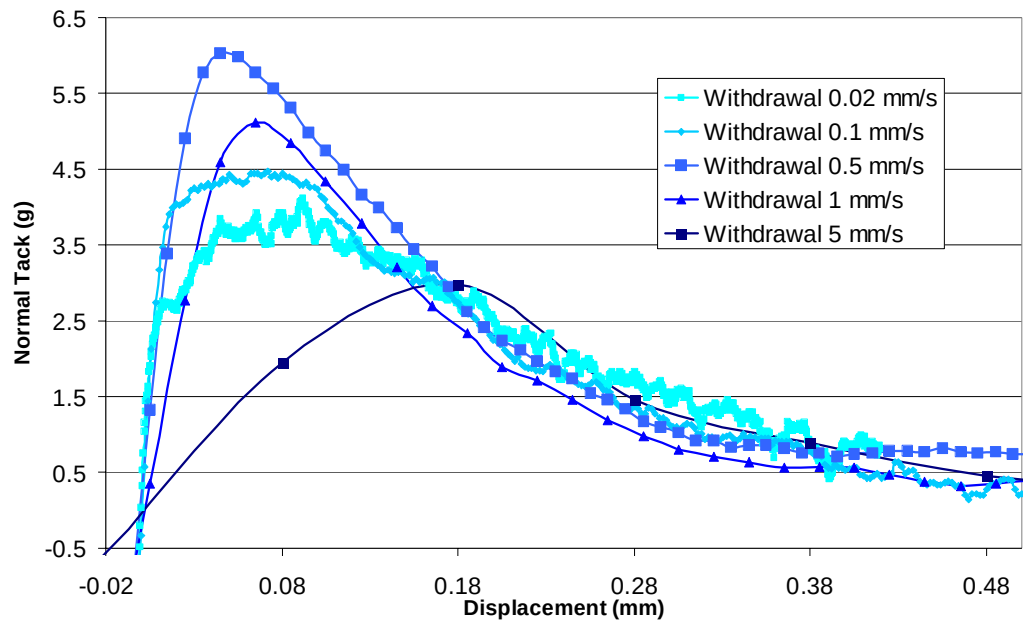


Figure 9. Tack forces for paste X plotted against displacement

It can be seen that although the peak tack varies with the speed of withdrawal the distance over which the tack force is able to act on the test probe is relatively constant. This would suggest that the deformation or maximum extension of the paste is similar in each case despite the faster movement of the probe from the paste deposit. After the maximum is reached the paste begins to neck and the force drops.

Plotting the peak tack force against withdrawal speed highlights the dependence of peak tack on withdrawal speed (Figure 11).

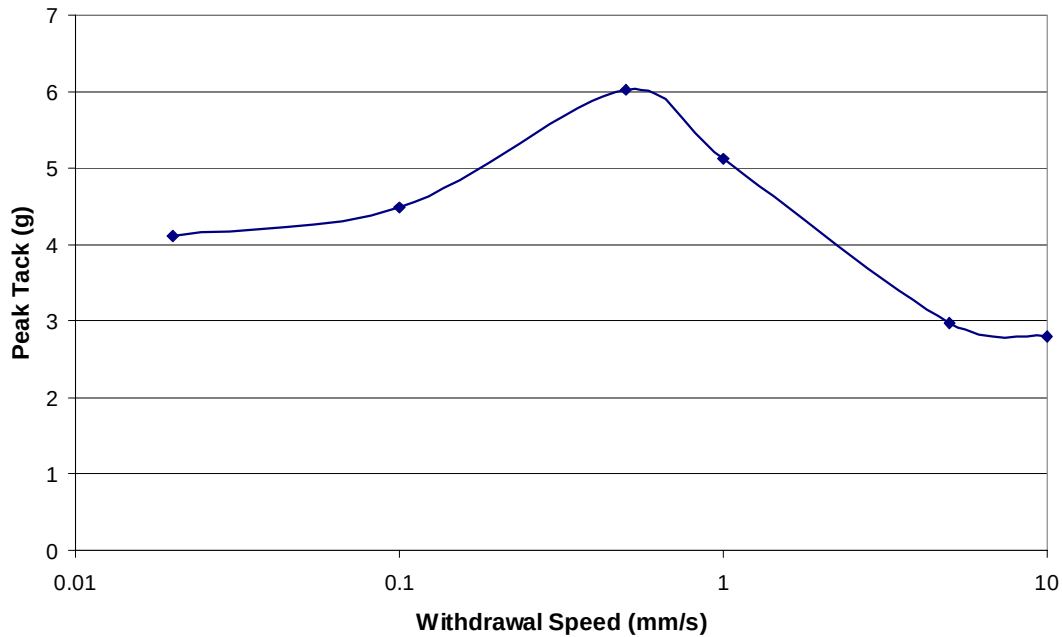


Figure 10. Trend of peak tack with increasing withdrawal rate for paste X

At low speeds, decreasing the withdrawal speed further reduces the tack force from the paste, possibly due to relaxation of stress in, or sagging of, the paste before the probe finally exits. At higher speeds of withdrawal, increasing the speed further results in a lower tack force. In these cases the paste is beginning to behave in a more brittle manner. Thus the peak tack force reaches a maximum level at a certain withdrawal speed. It is evident that the choice of withdrawal speed can have a significant effect on the peak tack value measured. The position of the maximum peak tack point will be different for different paste products.

3.1.2 Effect of Probe Insertion Rate

The effect of probe insertion speed into the paste deposit was shown to have very little effect upon the subsequent tack force. This can be seen in Figure 12, in which peak tack is plotted against insertion speed for paste X.

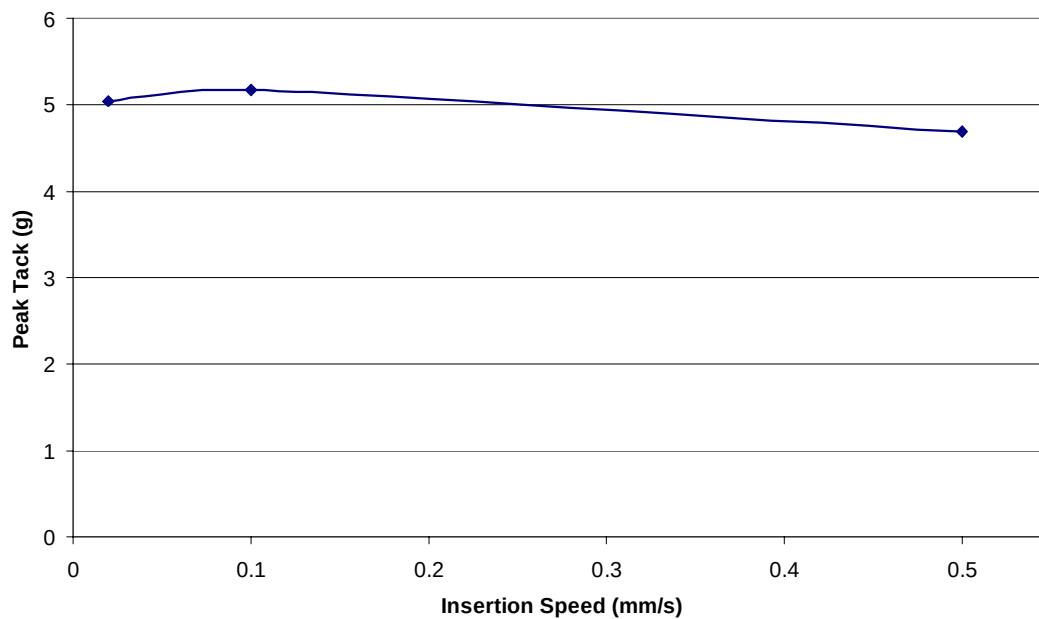


Figure 11. Effect of insertion rate of probe.

(Paste X, probe B, 0.1mm/s withdrawal, 50g load.)

3.1.3 Effect of Probe Load

The tack tester will apply a designated load to the probe so that it enters the body of the paste deposit. As this load is increased the tack force measured as the probe is removed also increases. It has been noted that higher forces on the probe mean a greater insertion depth in practice, and so this may help explain the relationship shown in Figure 13. Load force is an important parameter in tack testing and must be considered when reporting results.

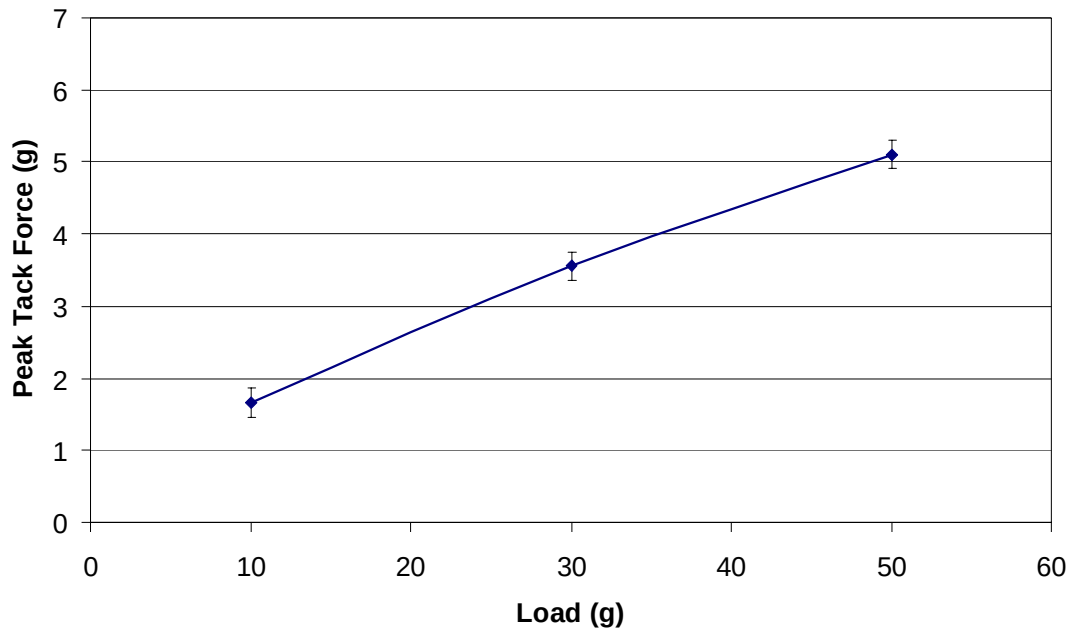


Figure 12. The effect of increasing load on peak tack
(Paste X Withdrawal 0.1 mm/s, , probe B, load 50)

3.1.4 Effect of Probe Geometry

The results of this study demonstrated that the shape of the test probe has a negligible effect on the measured tack force providing the surface area of the probe is the same. However, test probes with larger surface areas always produced a greater peak tack force. A typical example is shown in Figure 15.

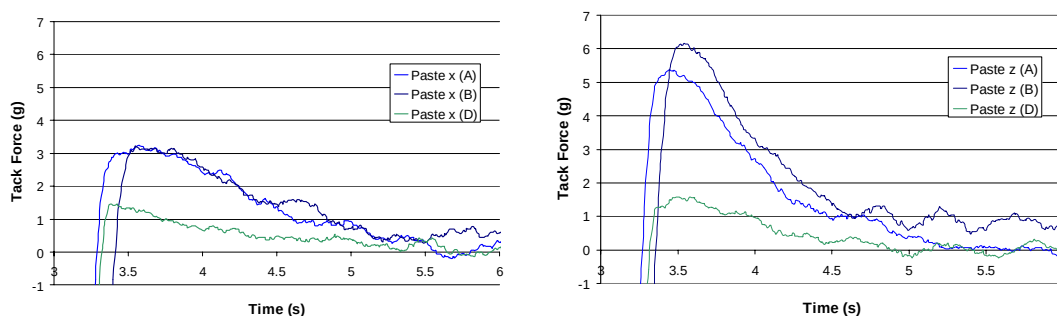


Figure 13. Tack curves for pastes X and Z, with three probe geometries, 0.1 mm/s probe speeds, 50g load

The two lines showing the greatest tack in each graph represent the larger probes, A & B, with a surface area of 5.9 mm^2 , and the green line is a smaller round probe with 1.9 mm^2 horizontal surface area. It is clear that the larger probes are able to produce a greater tack, as might be expected, although the relationship between peak tack force and area is not a simple one. It can also be seen that the larger probes allow better differentiation for different paste products. In Figure 15, for example, the higher metal content paste Z gives almost twice the peak tack reading

than paste X when tested with the large area probes. Testing with the smaller probe is unable to differentiate between the two materials. The smaller probe is more representative of components leg geometries. Further work is required to understand this effect.

3.1.5 Differentiation Between Pastes

The ability of the larger probes to differentiate between pastes with different metal contents in terms of tack force was mentioned in 2.2.4, and in Figure 16 data are presented for the three solder pastes.

It appears that pastes X and Y (89 and 89.5% metal content respectively) exhibit very similar tensile tack properties, but an increase to 90% metal content as in paste Z provides a marked increase in tack. This higher tack is not detected if the smaller (1.6mm² area) probe D is used.

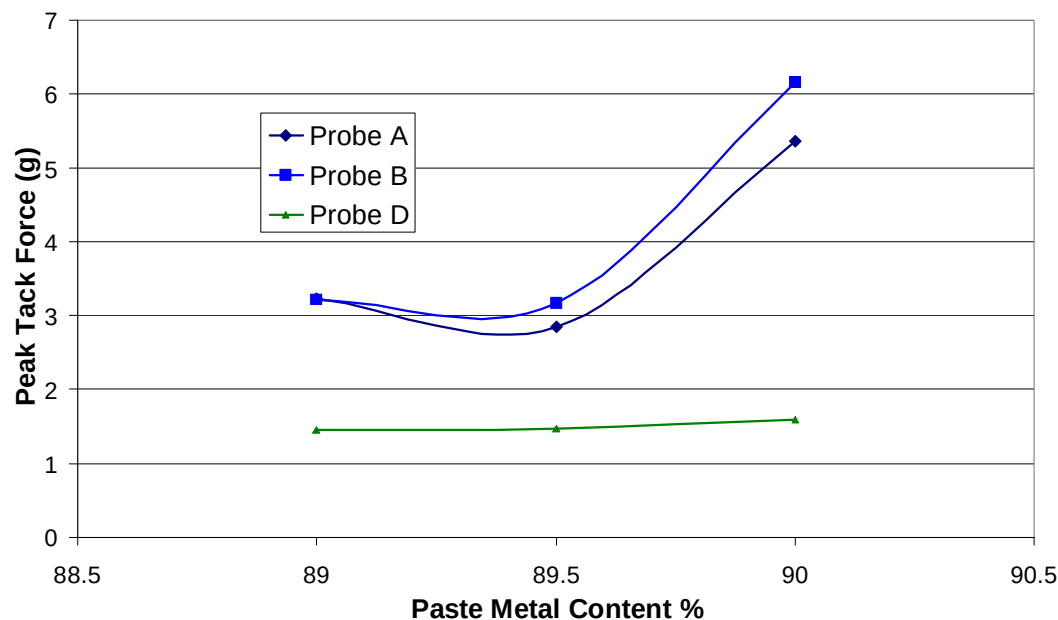


Figure 14. Differentiation between pastes using different probes

3.2 SHEAR TACK

A similar set of experiments was conducted in shear, varying speed, probe size and load.

3.2.2 Effect of Probe Shear Speed

The speed at which the probe is pulled in a shearing action through the paste sample was shown to have an effect on the peak shear tack force detected during the test. The output data from the tack tester software for paste X over a wide range of shear rates are shown in Figure 17.

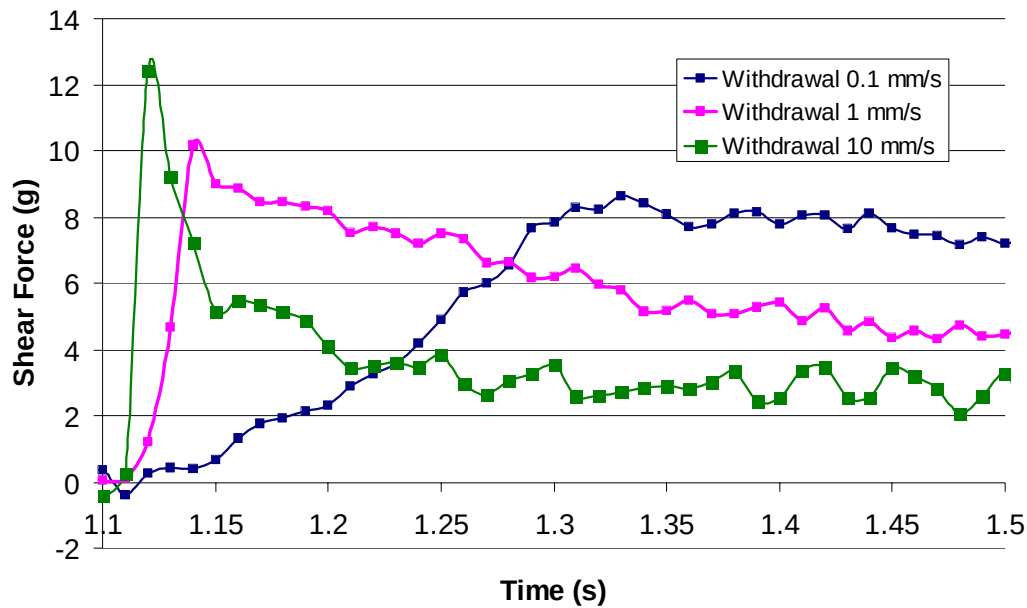


Figure 15. Shear tack curves for paste X

(Probe B, 0.1 mm/s insertion, 50g load)

As with the data collected for vertical withdrawal, we can compare the curves for different shear rates best when plotted against displacement - see Figure 18.

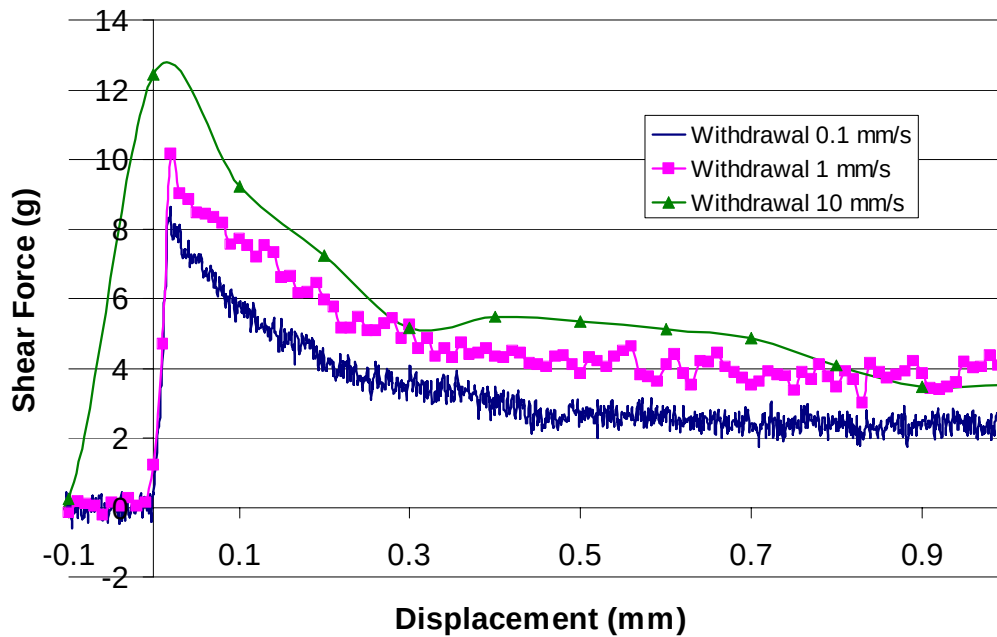


Figure 16. Shear tack curves for paste X, plotted against displacement of probe, 1mm/s insertion, 50g load

The residual force in shear after 0.5mm displacement may be due to remnant particles captured under the probe and causing drag as the probe continues to be driven.

It can be seen that the distance the probe moves before the adhesive nature of the paste is lost is quite constant even when the speed of shear is increased by a factor of 100. In Figure 18 the peak tack force occurs after approximately 20 μ m displacement. For the higher rheology and metal content Paste Z the displacement was a little greater ranging from 80 to 120 μ m, the results are shown in Figure 19.

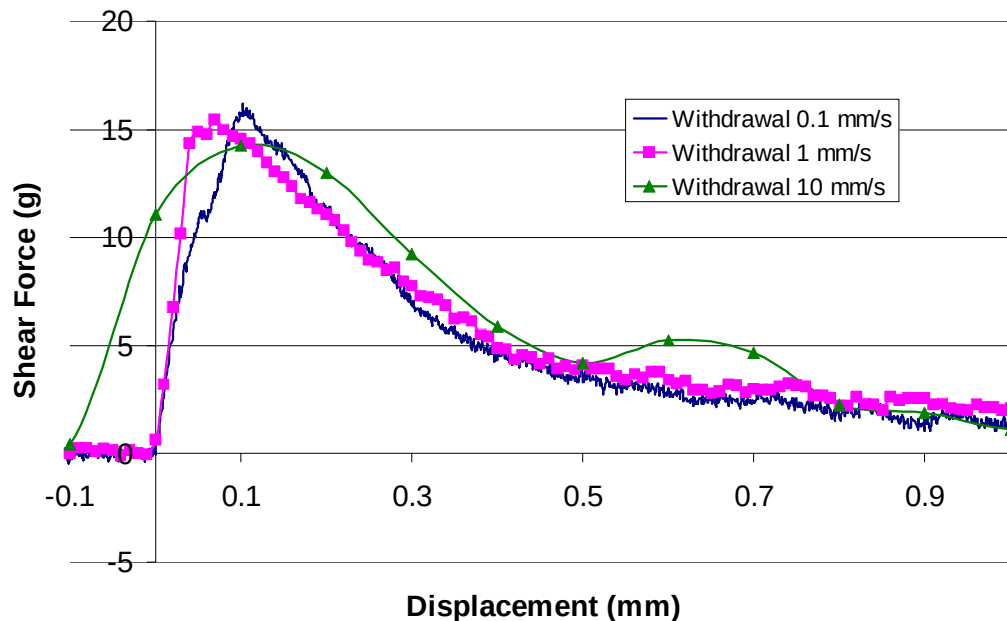


Figure 17. Shear tack curves for Paste Z, plotted against displacement of probe 1mm/s insertion, 50g load

In Figure 18 the peak tack is plotted against shear speed for pastes X and Z. Clearly for both pastes the shear tack rapidly increases up to a shear speed 1mm/s, subsequently there are more gradual changes.

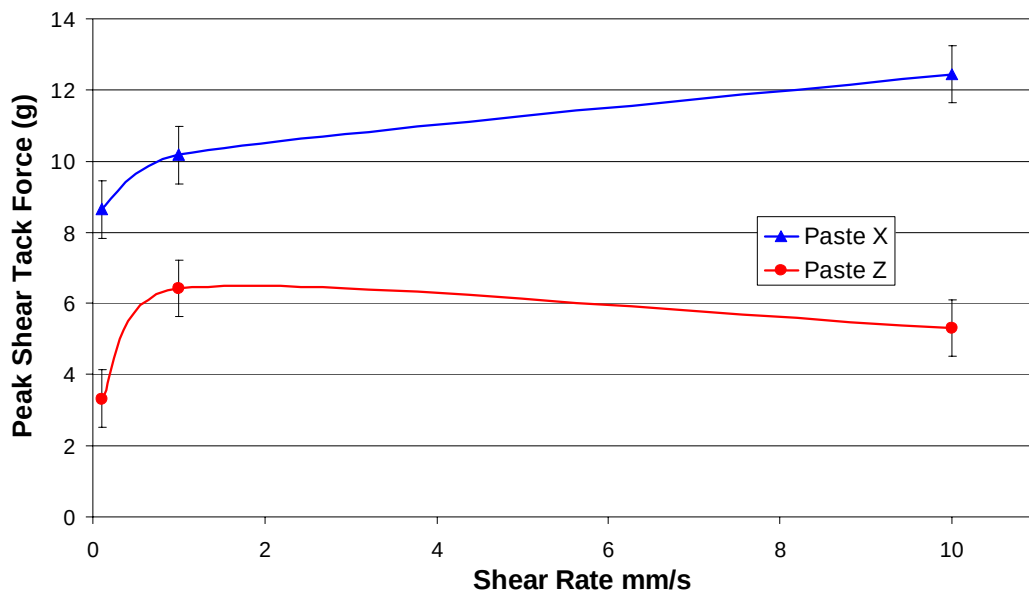


**Figure 18. The effect of shear speed on peak shear tack
(1mm/s insertion, 50g load)**

Figure 19 illustrates the finding that a larger probe size produces a greater peak shear tack, although the difference is not as marked as in the case of tensile tack measurements. This may be due to the fact that although there is greater contact area with the larger probes, the smaller probes will be exerting a greater pressure for the same load.

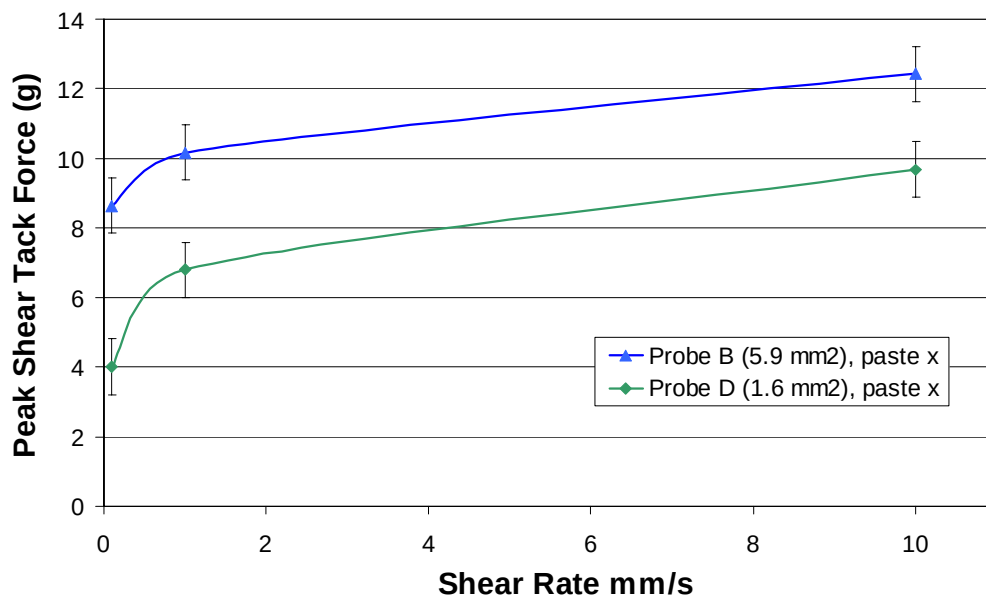


Figure 149. The Effect of probe size on shear tack, with round probes

3.2.3 Effect of Load

The results of this investigation proved that the greater the load applied to the probe prior to shearing the probe from the paste, the greater the shear force measured. This is illustrated in Figure 20.

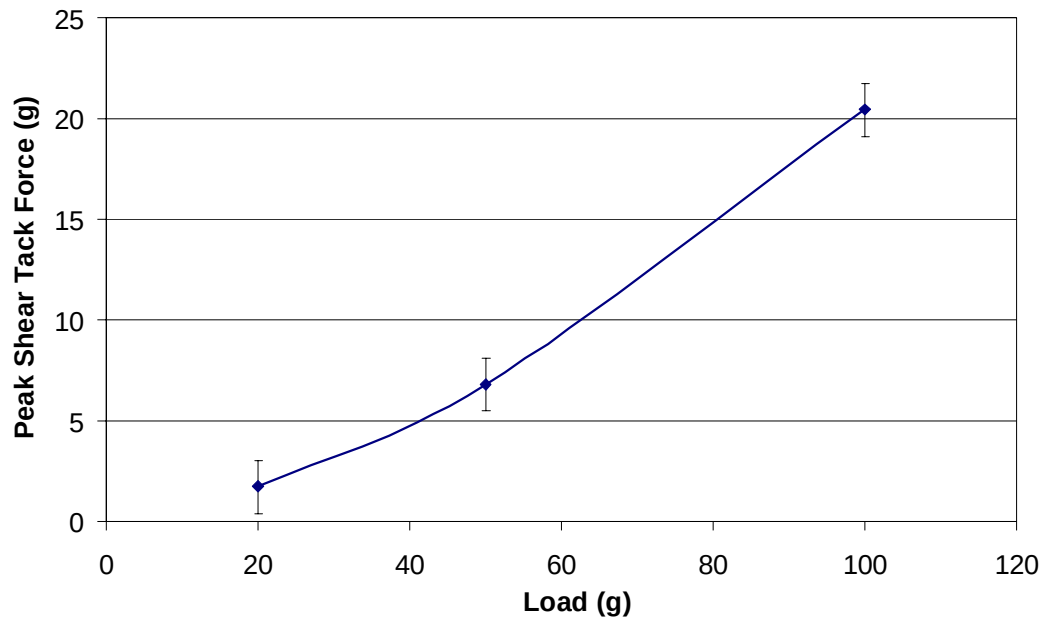


Figure 2015. The effect of load on peak shear tack
(Paste X, 1mm/s probe speed, probe D)

3.3.4 Differentiation Between Pastes

Testing tack in the shear direction provided a good means of differentiating between paste materials. Figure 21 illustrates how paste X consistently had higher shear tack over a wide range of test conditions. It is worth noting that paste Z produced a higher tensile tack than paste X, but a lower shear tack.

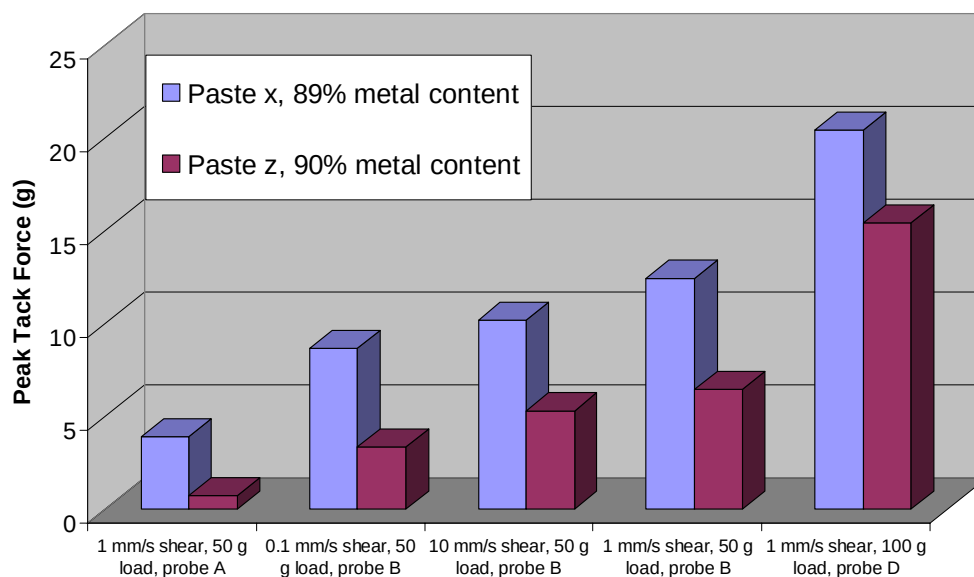


Figure 21. Differentiation between pastes X and Z

3.4 AGEING OF PASTE

Data were collected to determine whether the methods of tensile and shear tack testing were able to detect any effects of ageing on pastes. Pastes X and Z were used as before, and from the same pot. However, the pastes in this experiment were two months older than the samples used in previous work. The paste was printed and then left for various times (up to 8 hours) delays at ambient conditions before testing. The results are shown in Figure 22.

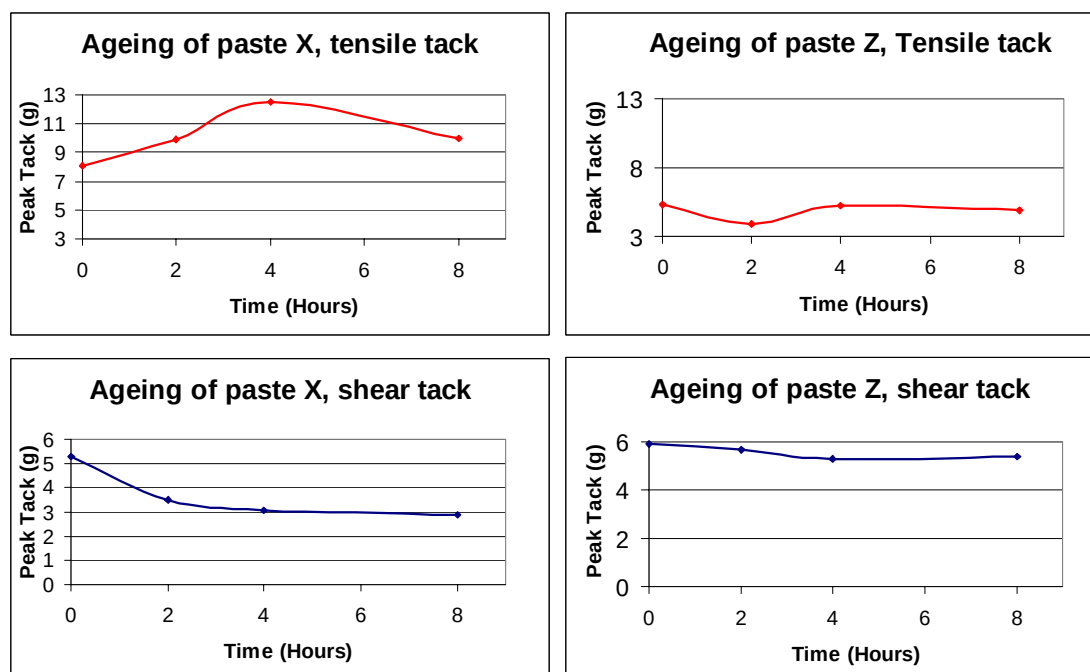


Figure 22. The effect of ageing on pastes X and Z

It can be seen that paste X, with a greater flux medium content is more susceptible to ageing than paste Z. As Paste X ages it produces a lower peak shear tack, but a higher tensile tack. After 8 hours of ageing, however, the tensile peak tack of paste X drops. The initial increase in tensile tack is probably due to an increase in viscosity, and then the drop after 4 hours occurs as the paste begins to dry out completely.

The ageing effects on paste Z after 8 hours are minimal and within the experimental error of the tack measurements.

3.5 CORRELATION OF TENSILE AND SHEAR TACK

There is no direct relationship between tensile and shear tack, as can be seen from plotting the tensile and shear tack results (at fixed conditions) from the ageing test, in Figure 23.

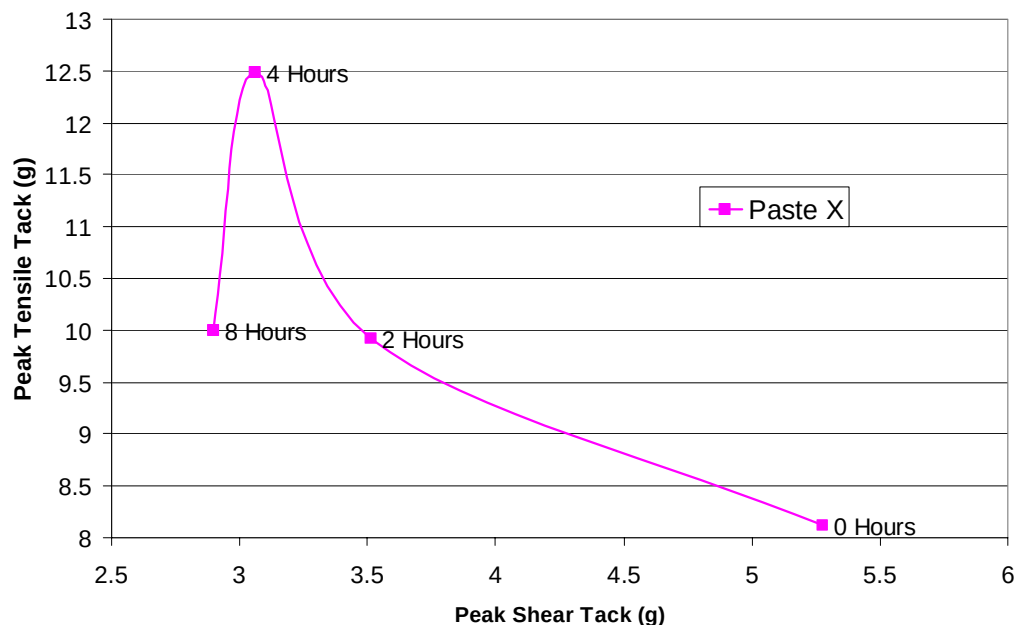


Figure 23. Correlation between tensile and shear peak tack for ageing paste X

If the measurement methods in the two axes measure the same property of the paste, it would be expected that the two measurements should have a similar dependence on the paste ageing mechanism. Hence a linear relationship, or some element of proportionality between the results obtained when measuring tack in each direction would have been expected. It seems evident that different mechanisms are in effect in each mode. Hence, since it is the shear tack measurements that are critical in component placement, measuring tensile tack can be misleading.

4 DISCUSSION

4.1 COMPARISON OF TENSILE AND SHEAR METHODS

Comparing the tensile and shear peak tack results directly for a set of test conditions (Figure 25) suggests that there are different mechanisms taking place in each case.

In both instances plots of tack against displacement have indicated that there is a 'break point' at which the paste structure gives way. In effect an increasing force is applied to the paste resulting in a minimal distortion to the structure. At the point of peak tack force, however, the paste releases the probe.

In the tensile case the cohesive forces between the solder particles and paste medium and the probe itself are acting in the axis of force measurement.

For the shear tack measurements there may be other effects. The solder balls will have to slide past one another for the structure to fail.

These observations may begin to explain why the lower metal content paste provided higher tensile peak tack readings, and the high metal content paste higher shear peak tack readings. In the tensile tack tests only the cohesive forces supplied by the liquid paste vehicle are contributing to the final force on the probe. Thus the paste with the larger content of flux medium gave higher tack forces.

In the shear tests the force applied will push solder balls into and then past one another. In the higher metal content paste the balls will be more compacted and so this will require a greater force.

When surface mount components on a PCA are moved in 'pick and place' handling it is clear that the main forces will be in the plane of the board (it is not moved in the vertical axis, only positioned beneath the placement head). In practice electronic components are dislodged from the paste if the board is moved too rapidly. At this point the forces are effectively exceeding the peak force of the paste and the structure of the paste is damaged, releasing the component.

In this respect it is evident that despite the historical use of testing tack of solder pastes normal to the surface of the PCA board, the shear test should be adopted, as it provides data of more relevance to the performance of solder pastes.

4.2 TEST VARIABLES

The data collected clearly show the effects of probe size, insertion load, withdrawal and shear speed on the peak tack measured. In order to compare paste materials properly these parameters must be constant.

Larger probes generally provide a means to differentiate between paste types, and the larger forces detected give a better signal to noise ratio. Using slower speeds also helps reduce noise and gives more repeatable results.

Insertion speed, whilst having a smaller effect on results, should also be held constant.

5 CONCLUSIONS

- The use of a shear tack test method (rather than a tensile test) to assess the potential performance of solder paste materials within 'pick and place' equipment has been shown to be necessary. The behaviour of solder paste is different when it is tested for tack in a direction normal to the PCB surface than parallel to it. Both tests can be used in parallel if desired to ensure better understanding of paste properties and correlation to existing data.
- Pastes with higher metal contents exhibit higher shear tack performance due to the closer proximity of solder particles creating a tougher structure within the paste.
- Pastes with lower metal content display higher tensile tack properties, possibly due to the higher proportion of flux medium within the paste volume leading to more cohesive strength in tensile stress.
- Care must be taken to control test parameters to ensure that test results can be directly compared. Choice of probe area is critical. Smaller probes, although more representative of SM components are not as useful in differentiating between different paste conditions.
- The tack measurement is clearly sensitive to paste ageing and can be used to monitor the condition of the paste. Shear measurements are more sensitive and relevant than tensile measurements.
- Further work is available from NPL including a test method for tack testing^{2,3}.

6 ACKNOWLEDGEMENTS

The authors would like to thank Multicore-Loctite for providing the prototype tack testing equipment used in the work. The authors also gratefully acknowledge Milos Dusek for preparing the equipment, and for writing the data manipulation software.

The work was carried out as part of a project in the Materials Processing Metrology Programme of the UK Department of Trade and Industry.

7 REFERENCES

1. NPL Report CMMT (A) 253 – 'Tack testing: Critique and Recommendations for a New Test', Christopher Hunt.
2. NPL Report MATC (A) 30 – 'Tack of Adhesives in Tension and Shear', Alan Brewin, Ling Zou and Christopher Hunt.

3. NPL Report MATC (A) 31 – 'Test Method for the Measurement of Tensile and Shear Tack for Electronic Solder Pastes and Adhesives' – Alan Brewin and Christopher Hunt.