

Tack of Electronic Adhesives in Tension and Shear

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ABSTRACT

An industry relevant test technique for a full understanding of the tack properties exhibited by conductive and non-conductive electronic adhesives is presented. Uniquely the tack of the adhesive 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 effects of test probe geometry, insertion and withdrawal speed of the probe, and insertion force have all been studied in the work

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

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1 INTRODUCTION

During the production of surface mount technology (SMT) printed circuit assemblies (PCAs) adhesives are used to hold components in place over the wave. In addition, conductive adhesives are becoming valid solder paste alternatives in certain applications. The adhesive must have a rheology suitable for dispensing or printing so it can be applied to the bare circuit board. Once cured the adhesive material must form mechanically (and in the case of conductive adhesives, electrically) sound joints. Further to this, however, the uncured adhesive has a mechanical function in that it must be tacky enough to hold components in place as they are rapidly positioned by robotic 'pick and place' machines. In many examples of pick and place machines the board will move during placement as well as the placement head itself. It is this mechanical requirement of uncured adhesives which tack testing seeks to model. The method of tack testing has historically been applied to solder pastes, but its further application to adhesives is very attractive.

1.1 MEASURING TENSILE TACK

The adhesive 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 adhesive until a controlled force is measured acting back on the probe. As the probe is withdrawn from the adhesive the downward force on the probe is recorded.

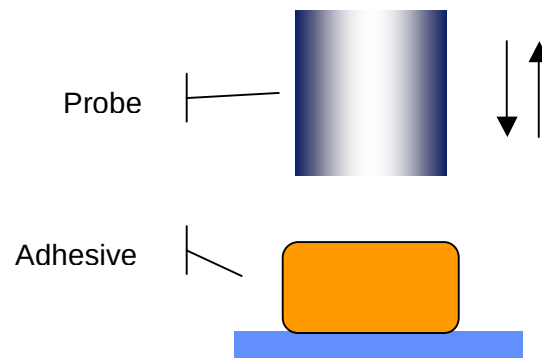


Figure 1. Schematic of tensile tack testing

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.

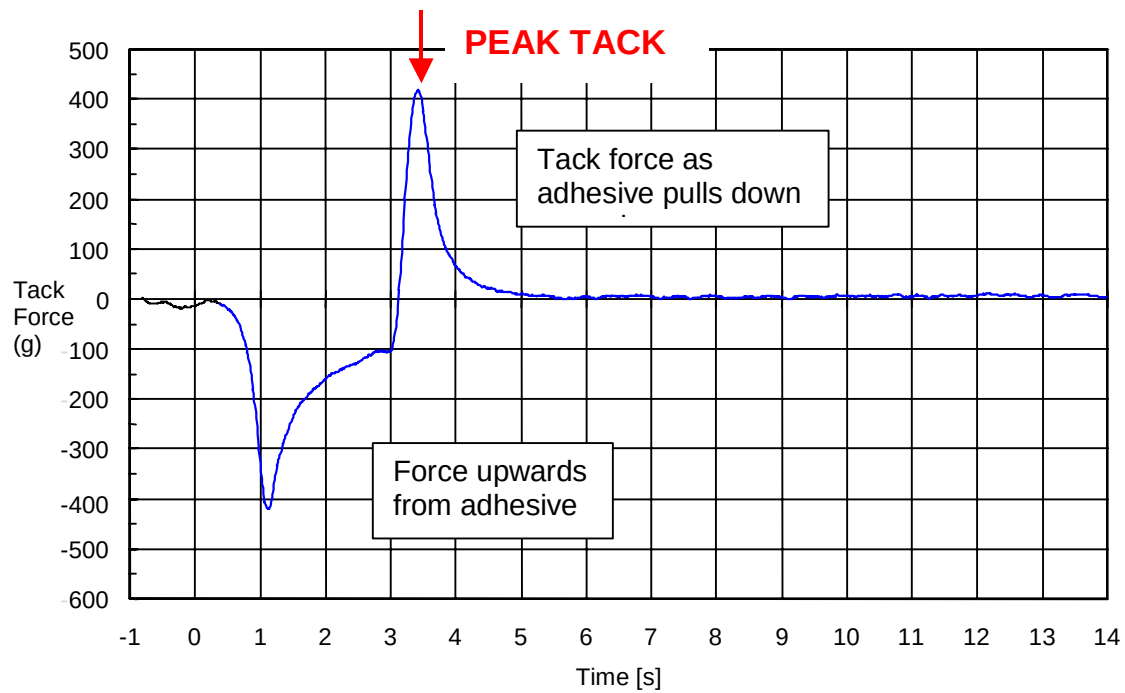


Figure 2. Idealised force - time plot for a tensile tack test

1.2 MEASURING SHEAR TACK

In order to measure the tack force of the adhesive in shear the probe is withdrawn horizontally from the screen-printed deposit, although it is still inserted vertically. In practice this is achieved by moving the adhesive 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.

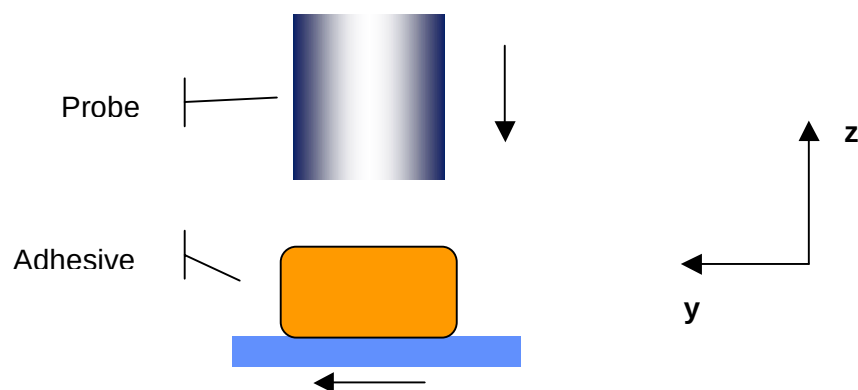


Figure 3. Schematic of shear tack testing

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 adhesive is recorded, as the probe is pulled sideways.

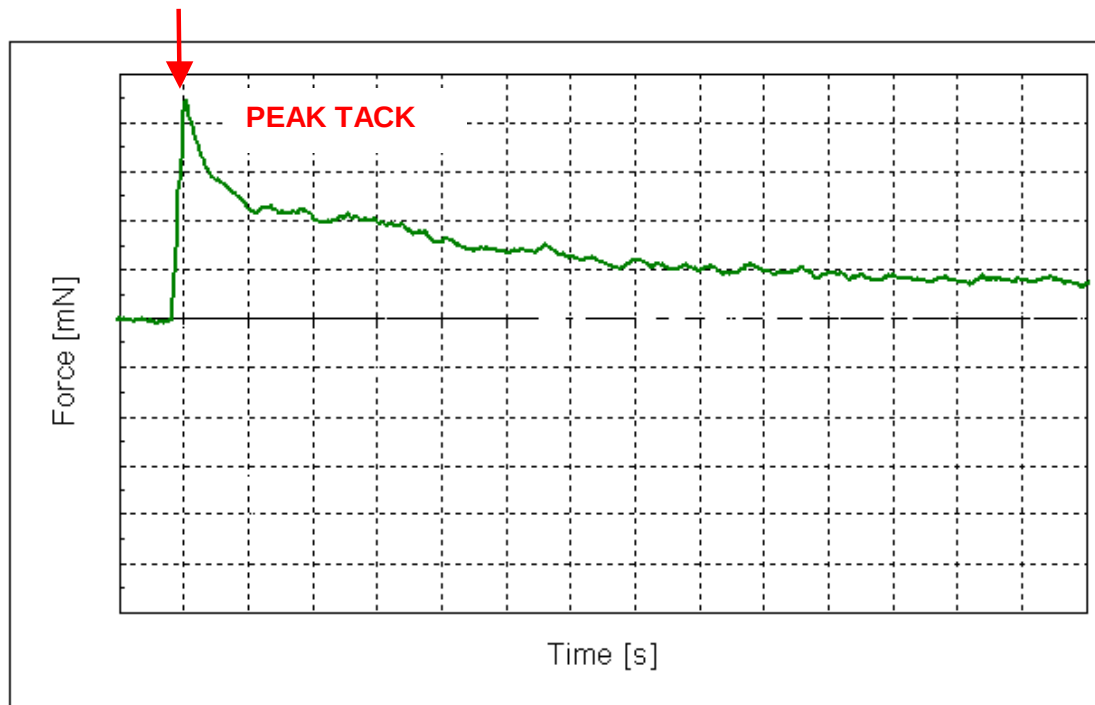


Figure 4. Idealised force against time plot for a shear tack test

1.3 THE TACK TESTER

The equipment used to measure tack in this work was based upon the use of 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 red arrows indicating the location of screw threads attached to stepper motors for the movement and positioning of the probe and sample plate. Blue arrows indicate the load cells, which register the force acting on the probe.

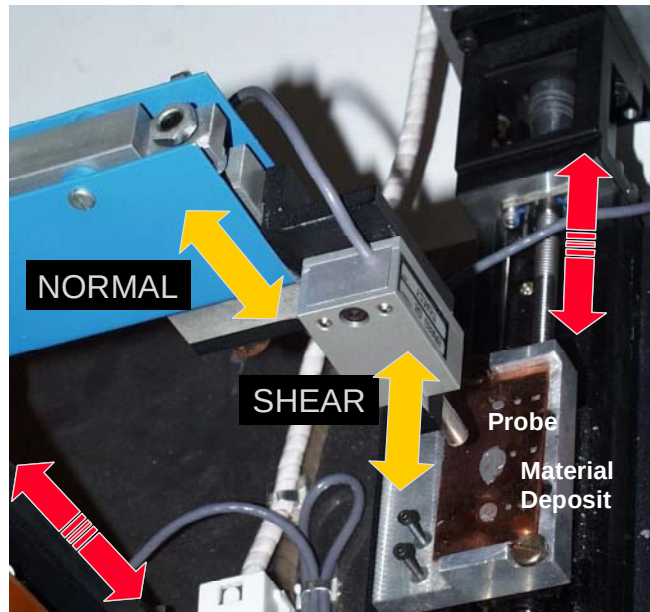


Figure 5. The Multicore-Loctite prototype tack tester

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 ADHESIVES

Three adhesives were selected for test.

- **A** - Heat curable, one part thixotropic adhesive for use in holding components in place during soldering operations of surface mount assemblies
- **B** - Heat curable, one part thixotropic adhesive for holding components in place during soldering operations on surface mount assemblies. Thixotropic properties give high dot profile.

- **C** - A silver-loaded epoxy two-part thermosetting material with an epoxy resin adhesive base, which contains silver flakes.

Adhesives A and B would be classed as traditional SMT adhesives, and C as an isotropic conductive adhesive.

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 were also chosen to be more representative 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:

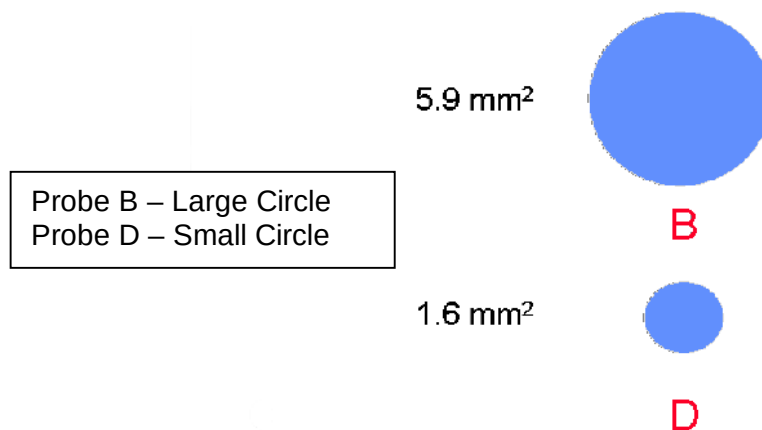
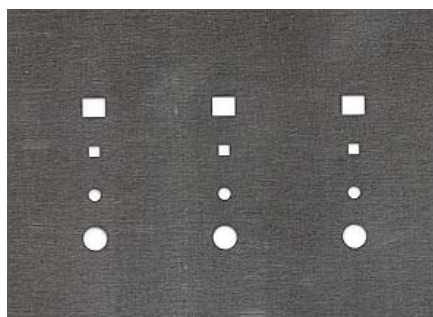


Figure 6. Schematic of cross section of tack testing probes showing surface area

2.3 PRINTING OF ADHESIVE



utilised for solder paste printing¹.

Figure 7. Hand print stencil for application of adhesive deposits

The adhesive 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. The square apertures were not used for the adhesive test work, but were

2.4 USING THE TACK TESTER

The probe was manually aligned with the adhesive deposit prior to starting each test. The stepper motors were used to do this quickly and easily and were controlled via the PC software. 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 adhesive deposit at the designated insertion speed, (or contact speed). As the probe enters the adhesive 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 the adhesive resists release pulling downward on the probe. 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 adhesive deposit horizontally from the probe position. In this case the software logs the output from the horizontal load cell throughout the test.

3 RESULTS

3.1 TENSILE TACK

3.2.1 Effect of Probe Withdrawal Speed

The speed at which the probe is withdrawn from the adhesive sample was shown to have an effect on the peak tack detected during the test. The results for Adhesive 'A' over a range of withdrawal rates are shown in Figure 9.

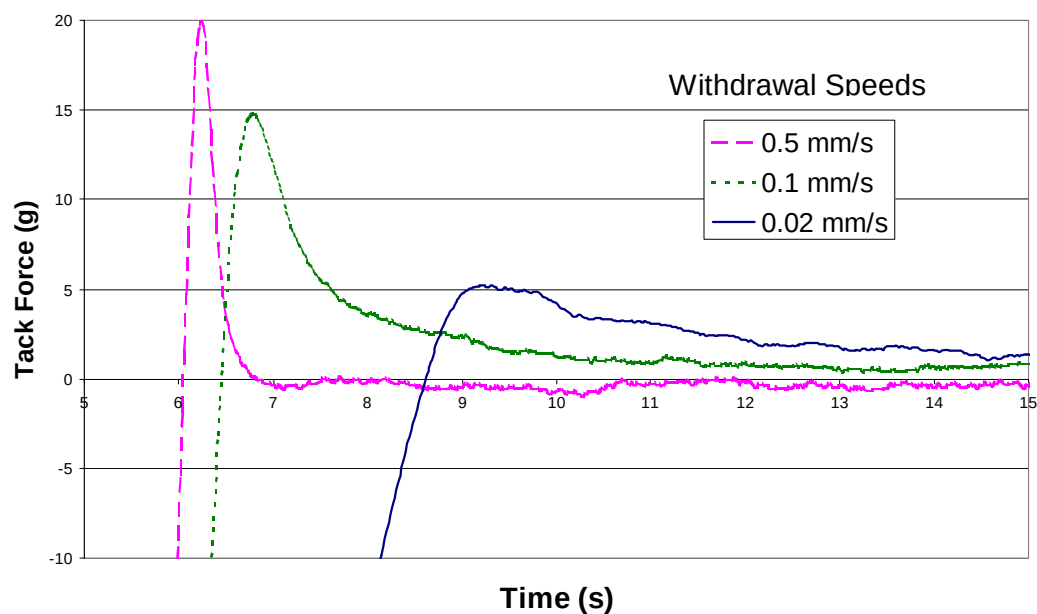


Figure 8. Tack curves for Adhesive A, 0.1mm/s insertion, 50g load, probe B

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

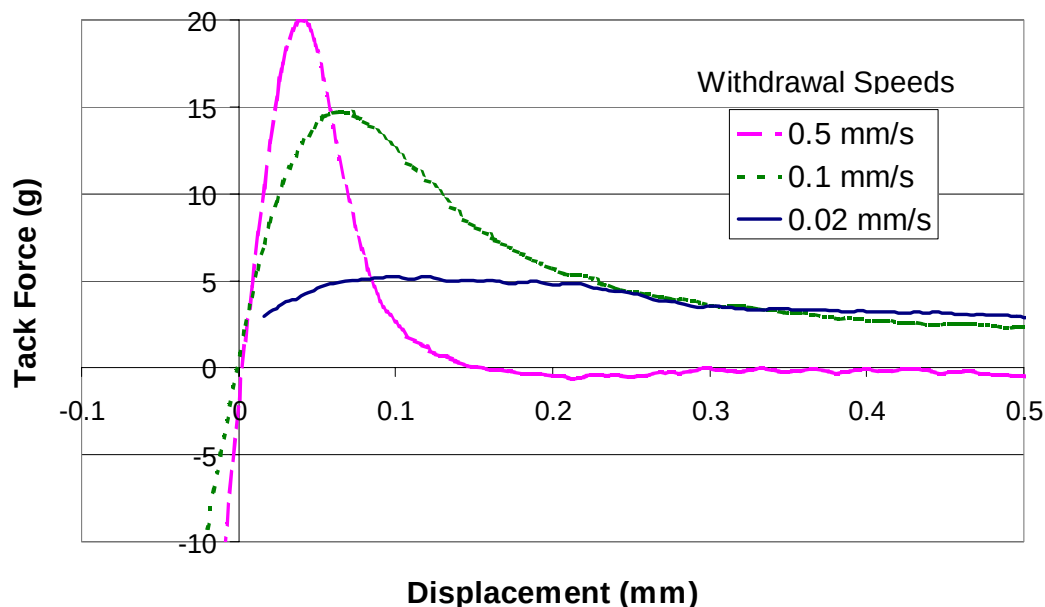


Figure 9. Tack forces for adhesive A, 0.1 mm/s insertion, probe B, 50g load plotted against displacement

It can be seen that as the speed of withdrawal increases the peak tack force achieved by the adhesive increases, but the displacement distance over which the adhesive acts on the probe decreases (Figure 10). This is not generally the case

with solder paste materials for which the deformation during probe extraction is independent of withdrawal rate.

Plotting the peak tack force and the displacement at the peak tack point as a function of withdrawal speed highlights the dependence on withdrawal speed (see Figure 11).

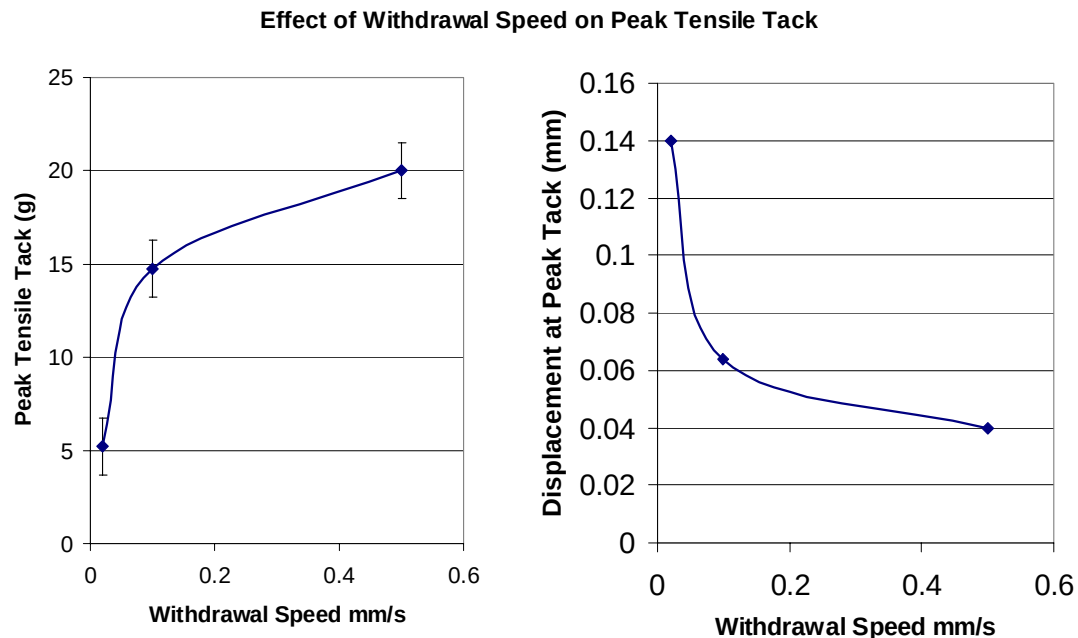


Figure 10. Peak tack force and the displacement at peak tack point against withdrawal speed.

At low speeds, the tack force shown by the adhesive is smaller, possibly due to relaxation of stress in, or necking of, the adhesive before the probe finally exits. At higher speeds of withdrawal the adhesive is beginning to behave in a more brittle-like manner, breaking after less displacement.

3.2.2 Effect of Probe Insertion Rate

The effect of probe insertion speed into the adhesive 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 adhesive 'A'.

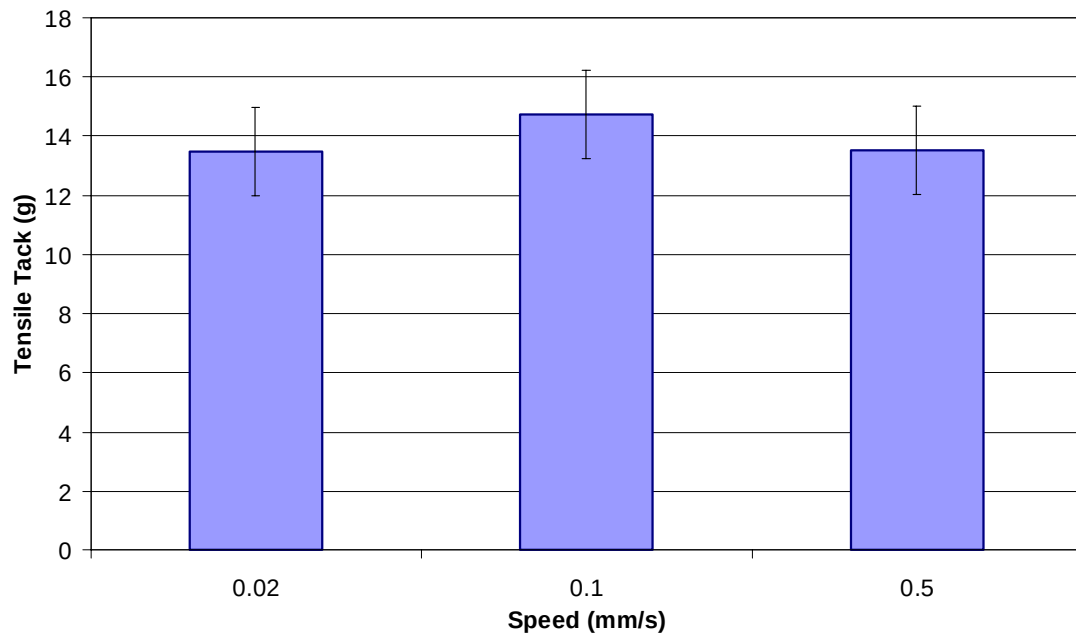


Figure 11. Effect of Insertion rate of probe into adhesive

3.2.3 Effect of Probe Load

The tack tester can apply a pre-set load so that the probe insertion is driven until this force is reached. 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.

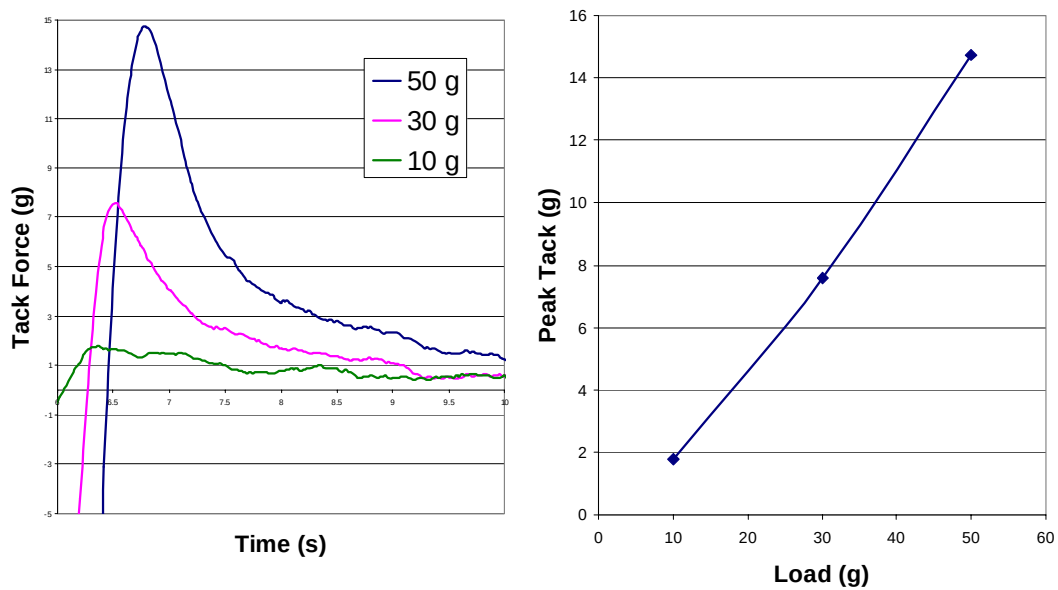


Figure 12. The effect of increasing load on peak tack
(Adhesive A, insertion and withdrawal 0.1 mm/s, probe B)

3.2.4 Effect of Probe Size

It has been demonstrated previously 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. For this reason only probe area was investigated. Probes with larger surface areas always produced a greater peak tack force. A typical example is shown in Figure 14. The relationship between peak tack force and probe area is not a simple one, however. One could predict that tack force might be proportional to area but the tack force for the large probe is greater than would be expected.

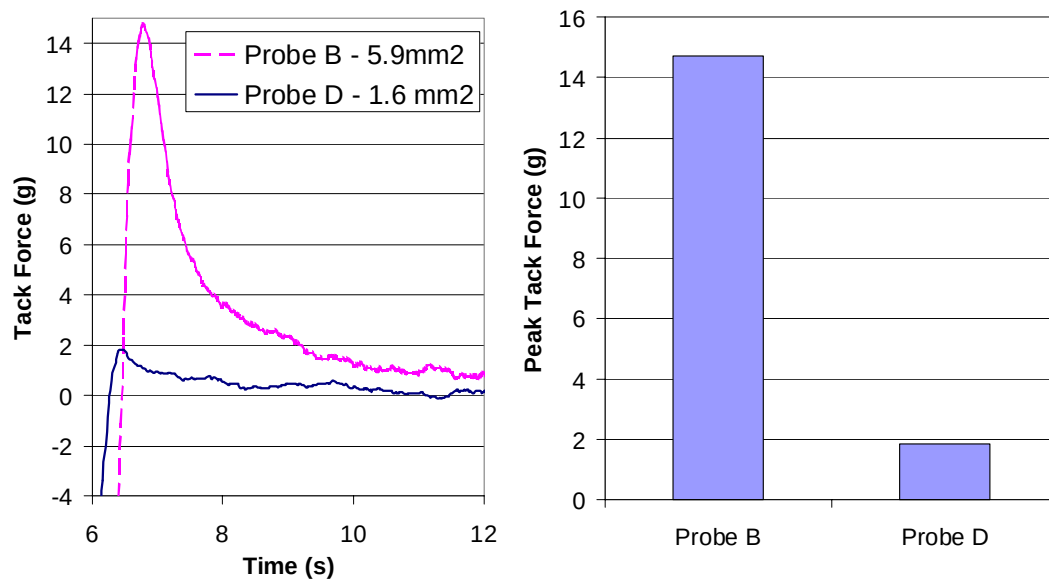


Figure 13. Effect of probe size on tack force.

(Adhesive A, insertion and withdrawal 0.1 mm/s, load 50g)

3.2.5 Differentiation Between Adhesives

Despite the differences in the adhesive products (filled/unfilled, low build/high build) the tack performances proved to be largely similar. The inability of the tensile tack test method to differentiate between the chosen adhesives is highlighted in Figure 15.

Nevertheless the test method is robust enough to repeatably differentiate between the adhesives.

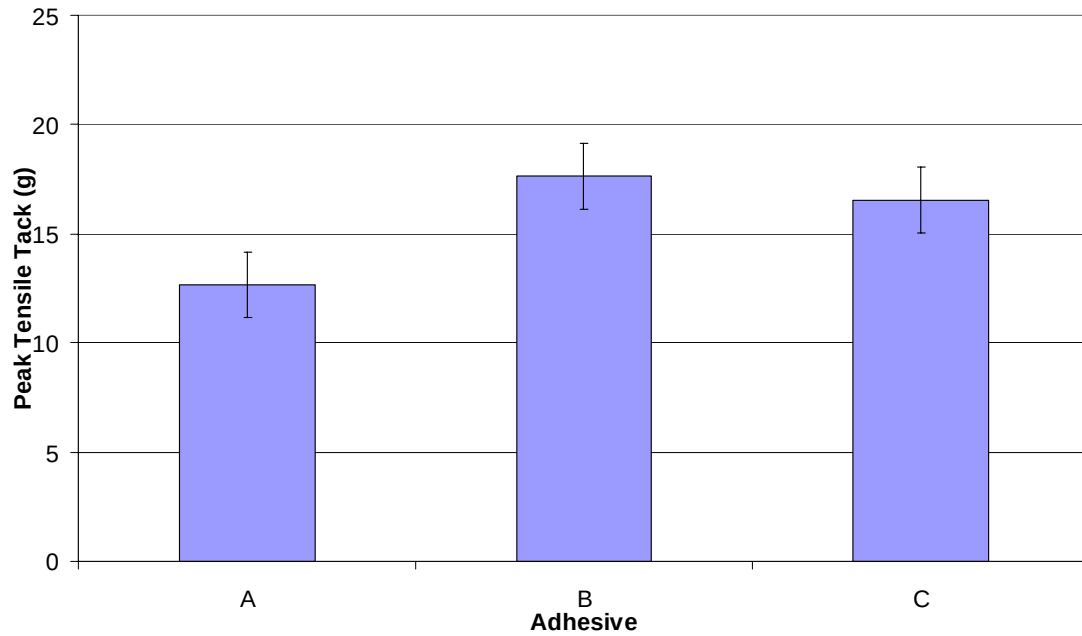


Figure 14. Peak tack force of adhesives
(0.1 mm/s probe speeds, probe B, 50g load)

3.2 SHEAR TACK

3.3.1 *Effect of Probe Shear Speed*

The speed at which the probe is driven in a shearing action through the adhesive sample was shown to have an effect on the peak shear tack force detected during the test. The results for adhesive A over a wide range of shear rates are shown in Figure 16.

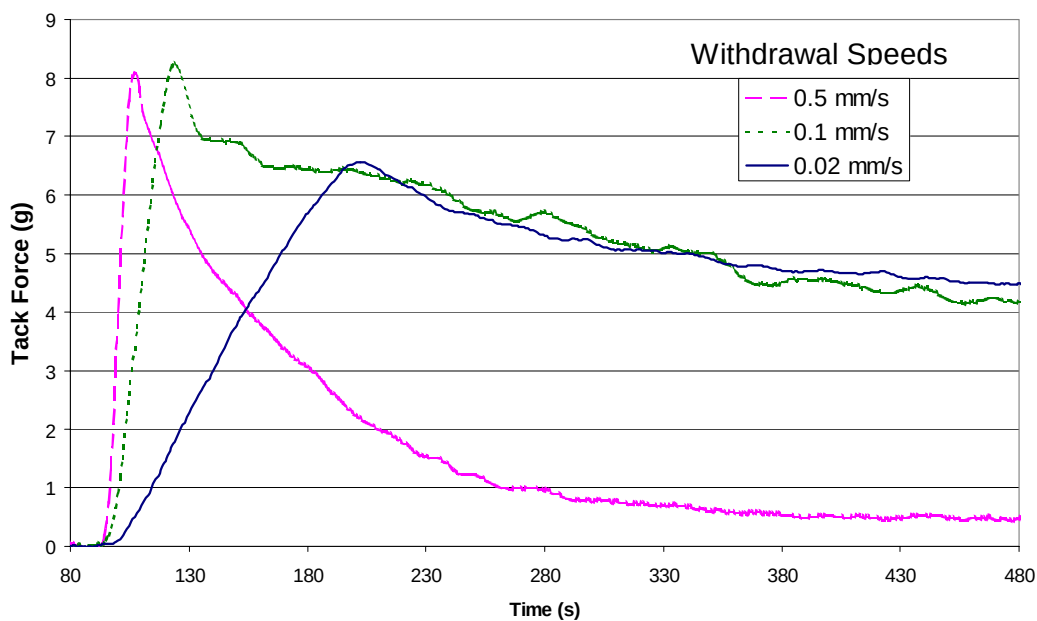


Figure 15. Effect of withdrawal rate on shear tack force
(Adhesive A, 0.1 mm/s insertion, probe B, 50g load)

As with the data collected for vertical withdrawal, we can compare the curves for different shear rates best when plotted against displacement - see Figure 17.

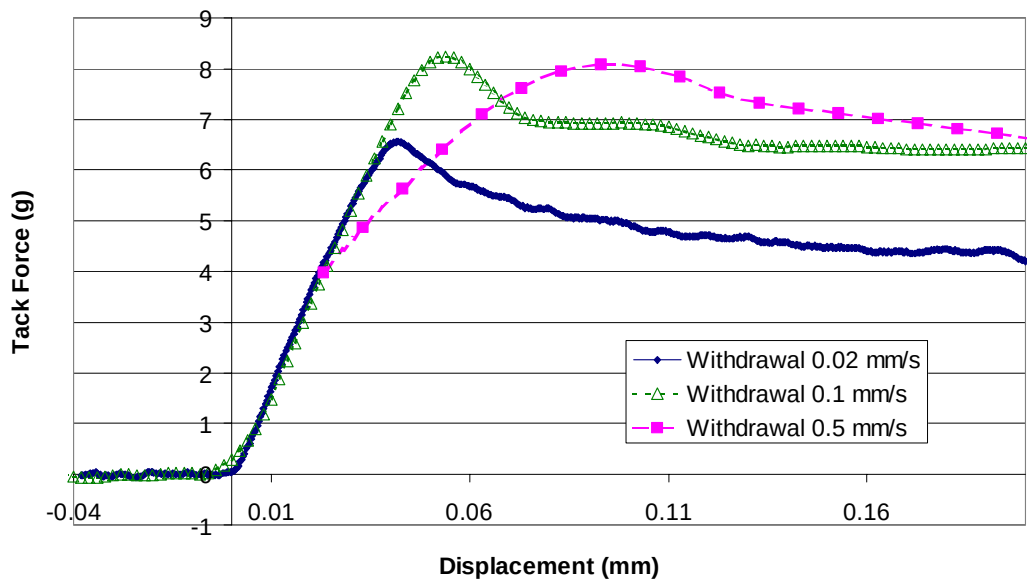


Figure 16. Shear tack curves plotted against displacement.
(Adhesive A, load 50 g, withdrawal 0.1 mm/s, probe B)

It can be seen that the distance the probe moves before the adhesive nature of the material sample is lost increases with increasing withdrawal speed. For the example

shown the displacement before loss of tack is about 50-100 μm , a value comparable to that observed with solder pastes. The peak tack force also increases with shear speed, but reaches an upper limit, in this case of around 8 grams.

Generally the adhesives exhibited greater shear tack as the shear speed was increased up to a limiting peak tack. This trend is shown graphically in Figure 18.

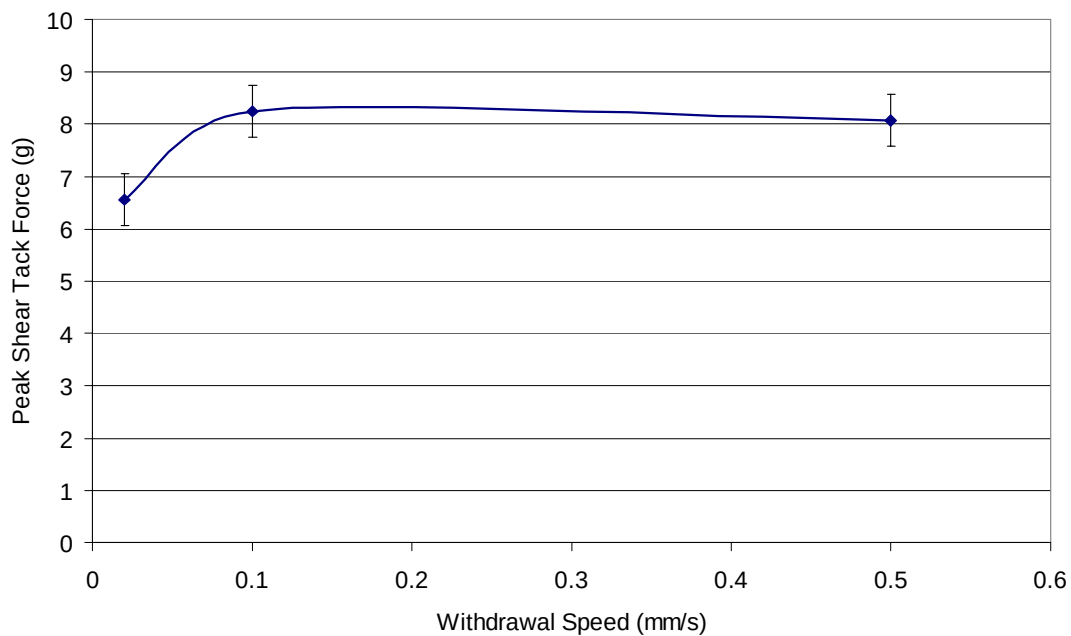


Figure 17. The effect of shear speed on peak shear tack.

(Adhesive A, probe B, insertion 0.1 mm/s, load 50g)

3.3.2 Effect of Probe

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.

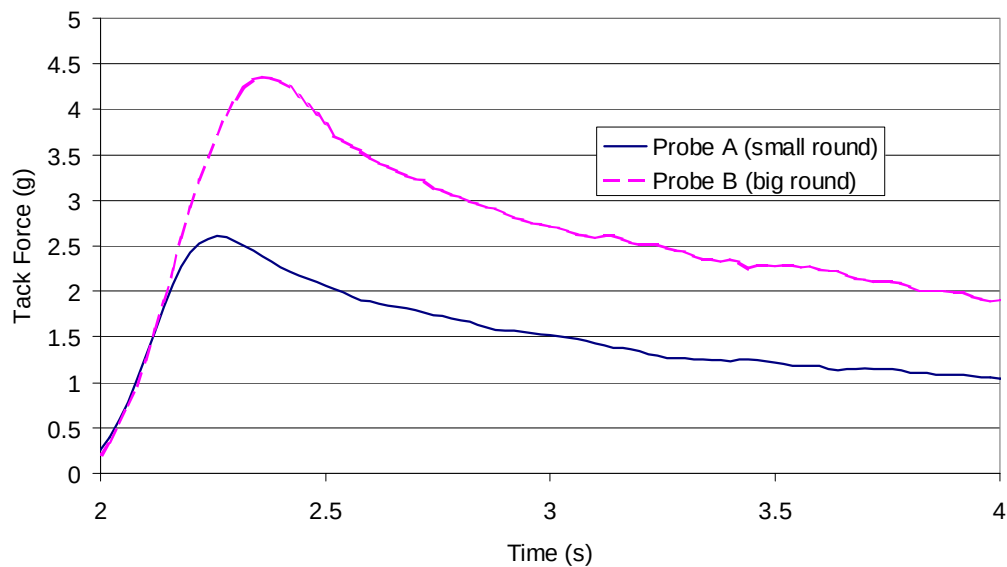


Figure 18. The effect of probe size on shear tack force.
(Adhesive A, load 50 g, withdrawal 0.1 mm/s, probe B)

3.3.3 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 adhesive, the greater the shear force measured. This is illustrated in Figure 20.

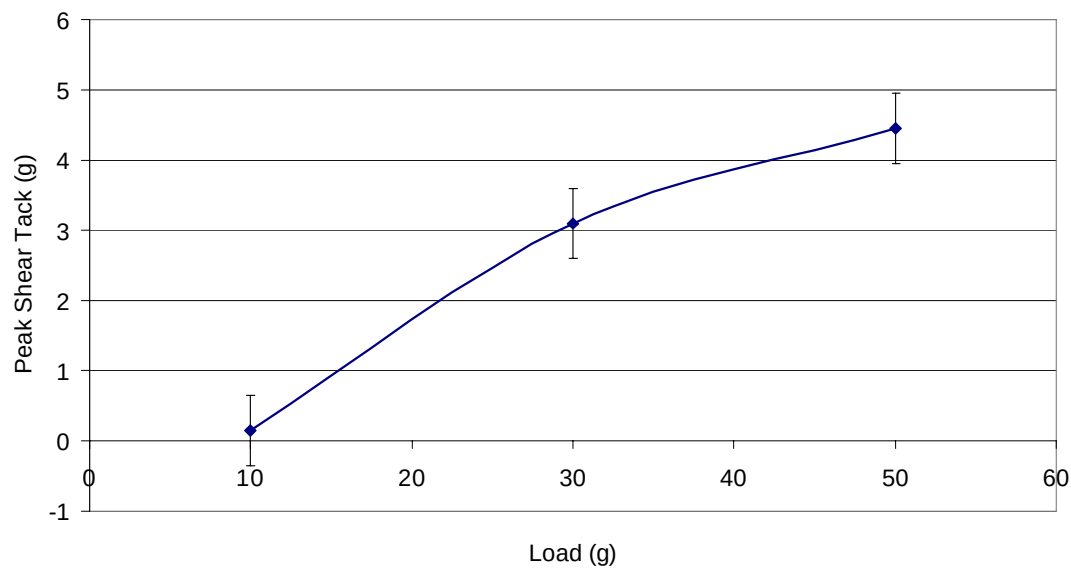


Figure 19. The effect of load on peak shear tack

(Adhesive A, probe B, insertion 0.1 mm/s, withdrawal 0.1 mm/s)

3.3.2 Differentiation Between Adhesives

Testing tack in the shear direction appears to provide a good means of differentiating between loaded and unloaded adhesives. Figure 21 illustrates how adhesive C, containing a high proportion of silver particles, gives almost a ten-fold increase in peak shear tack. The two unloaded adhesives (A and B) gave virtually identical results. It is interesting to note how similar the peak tensile tack forces were for the loaded and unloaded products.

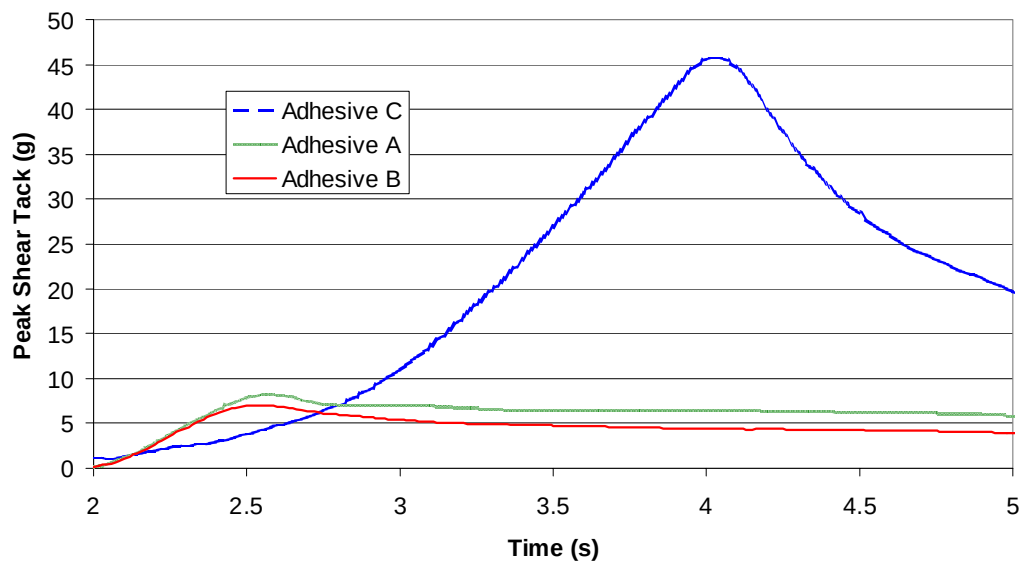


Figure 20. Shear tack differentiation between adhesives A, B and C

(Insertion and withdrawal 0.1 mm/s, load 50 g, probe B)

3.3 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 collected using various test conditions. (Figure 22).

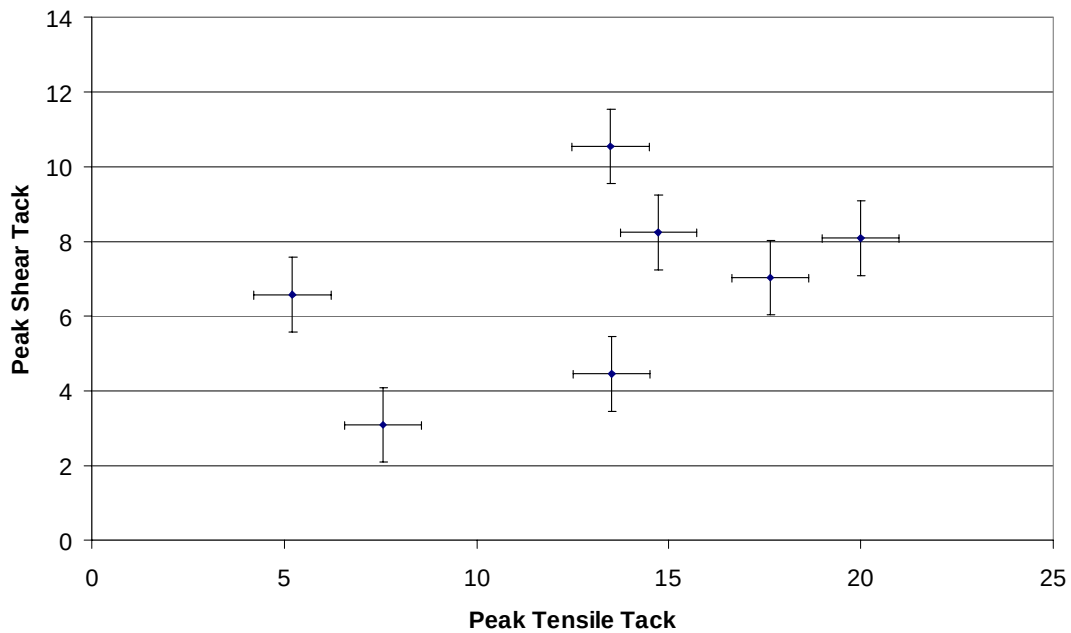


Figure 21. Tensile and shear peak tack for adhesive A over a range of test conditions.

If the same mechanism were being measured in tensile and shear modes one might expect a linear relationship, or some element of proportionality between the results obtained when measuring tack in each direction. It is clear that there is not a strong correlation between shear and tensile measurements. There may be a general trend of shear and tensile tack increasing in magnitude together, but there is significant scatter.

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 22) 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 adhesive structure gives way. Increasing the force applied to the adhesive initially results in minimal distortion to the structure, but at a certain point, 'the peak tack force', the structure of the adhesive begins to collapse, resulting in large displacements.

In the tensile direction the cohesive forces between the adhesive and the probe act in the same axis as the force measurement. For the shear tack measurements there may be other effects. In particular for loaded adhesives the silver particles need to slide past one another for the structure to fail, hence greatly increasing shear tack.

Consequently the results from the loaded adhesive produced significantly elevated tack when in shear, but the tensile tack was similar to that for the standard SMT

adhesive materials. In the tensile tack tests only the cohesive forces supplied by the adhesive vehicle are contributing to the final force on the probe. This force proved to be similar whether the adhesive was loaded or not, but in the shear tests with the conductive adhesive, the metal particles are compacted into and then past one another, so impeding the flow of material.

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 up and down, only positioned beneath the placement head). Components will not move, relative to the board, unless the board is moved too rapidly. If the acceleration is too high the retention forces exerted by the adhesive effectively exceed the peak force of the adhesive and the structure of the adhesive is damaged, releasing the component.

In this respect it is evident that despite the historical use of testing tack of solder pastes and adhesives normal to the surface of the PCA board, a shear test has as much, if not more, relevance to the performance of these products in practice.

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 adhesive materials properly these parameters must be constant.

Larger probes generally provide a means to differentiate between adhesive 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 tack test) has been validated for assessing the potential performance of surface mount and conductive adhesive materials within 'pick and place' equipment. The behaviour of adhesives is different when tested for tack in a direction normal to the PCB surface than parallel to it. It is therefore a significant improvement on paste methods, having great practical sense and mimicking industrial practice. **Hence, shear measurements are strongly recommended to monitor the retention properties of adhesives.**
- Metal-loaded adhesives exhibit higher shear tack performance due to the close proximity of silver particles creating a tougher structure within the adhesive.
- Unloaded adhesives, with no metal content, display tensile tack properties similar to those of loaded adhesives, but a much lower shear tack.
- Care must be taken to control test parameters to ensure test results can be directly compared.

- Further work is available from NPL including a test method for tack testing^{1,2}.

6 ACKNOWLEDGEMENTS

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