NPL Report No CMMT(A)176
May 1999

An Intercomparison of Tack Measurements

B C Duncan and L A Lay

Performance of Adhesives Joints
Project PAJ1: Failure Criteria and their Application to Visco-Elastic/Visco-Plastic Materials

Report No 11
(Milestone 11)

May 1999

Summary

Adhesive tack is critical in the initial formation of an adhesive bond. However, tack is not a unique property of the adhesive but also depends on the properties of the adherends, the bonding process. Measured tack values will also depend on the test method and conditions. Loop tack, probe tack and rolling ball tests are all commonly used to measure tack for a variety of purposes. A comparison of these methods is presented. The rolling ball test results were significantly different. .Loop and probe tack tests give similar relative rankings of adhesive tape performance. These differences may be explained by differences in the test methods. Experimental studies to illuminate the influence of test variables, such as contact pressure, dwell time, test speed, temperature and adherend stiffness, are discussed. A Finite Element modelling approach was used to study the influence of the stiffness of the backing material in the loop tack test.

NPL Report No CMMT(A)176
May 1999

ISSN 1361-4061

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1. INTRODUCTION

Tack is a measure of how 'sticky' a substance is. It is the property of a material that enables it to form a bond immediately on contact with another surface which may be an adherend or another layer of adhesive. Although not all adhesives (e.g. film epoxies) will necessarily do this, tack is of great relevance to industries such as packaging and footwear where rapid processing is essential. Tack is often measured as part of the quality control procedures of an adhesive manufacturer or user. The simplest 'instrument' for determining if something is tacky is the thumb. Obviously, this is rather subjective and, depending on the adhesive or processing conditions, is potentially hazardous to the operator.

Control of tack is important so that the right level of initial bond strength is achieved. If the tack is too low then the bond may rupture during manufacture or if the tack is too high then repositioning of substrates may be difficult. The measurement of tack is normally specific to a particular application. Different measurement standards and methods have evolved within industries. Tack is not a fundamental material property but depends on a wide range of factors including the method of testing. Therefore, the results from these tests are unlikely to be directly comparable.

Within Project PAJ1 of the DTI Performance of Adhesives Joints Programme, research has been undertaken into factors influencing the measurement of tack. This work concentrated primarily on the tack of pressure sensitive tapes used in packaging and heat activated adhesives for the footwear industries. The project was managed by the National Physical Laboratory (NPL) and the research on tack was carried out by NPL, SATRA and Pira International. This report describes the main findings of the work.

2. THEORY

Tack is normally determined from the force required to separate two components joined by a soft visco-elastic bonding material. It is a concept normally applied to the initial stages of bonding but is relevant for longer periods in certain applications such as adhesive tapes where the adhesive remains sticky. The tack of an adhesive has been defined as the property that enables it to form a bond with the surface of another material upon brief contact under light pressure. To do this, the adhesive needs to wet the surface and spread to form a continuous interface between the surfaces. High wetting energies are associated with strong adhesion to the surface. High tack forces on separation are associated with effective wetting of the surface. Thus, tack gives an indication of how quickly an adhesive can wet and make intimate contact with a surface.

Tack depends on the surface energies of the adhesive and surface where bonding takes place and on the cohesive strength of the adhesive (or the cohesive strength of the substrate). Classic theories of tack assumed that it occurs in two phase systems due to the disperse phase acting as a viscous liquid that wets the substrate with an elastic continuous phase providing the strength(1). This does not account for tack of modern single phase systems. Current theories suggest that tack is due to visco-elasticity. For a material to be tacky, the glass transition temperature of the adhesive should be substantially below the application temperature. Zosel[2,3] reported that the highest tack levels are achieved when the application temperature is around 50-70°C above T_g. Zosel also reported that high tack strength was also associated with the formation of filament structures in the adhesive as the adherends are pulled apart. Recently reported research[4] has suggested that the presence of air bubbles at the interface play a role in the tack forces. The assumption is that deformation of 'macro-bubbles' provides a suction force. However, in most practical measurement methods many other factors will significantly influence the measured tack strength.

The adhesive must fully wet the two surfaces to form a continuous film to achieve maximum tack strength. Therefore, the tack will depend on the pressure applied, the time history of the applied pressure and on the flow (or rheological) properties of the adhesive. These in turn imply that the rate at which the surfaces are brought together and separated will influence the measured tack force. Since the properties of the adhesive, substrate or interface may change with time, the dwell time will also be important.

The stresses experienced by the tacky adhesive will be influenced by the geometry of the test method. The mechanical properties of the substrates are important since they may also deform during the test, changing the stress distribution in the bond.

A number of methods for measuring tack have been developed over the last 50 years or so, and these involve different dwell times and pressures, different surfaces and different geometries. Consequently there is no agreement in ranking order between the different methods.

3. EXPERIMENTAL METHODS

The general subject of tack measurement has been reviewed by Johnston[5,6,7] and Hammond[8,9]. Specifically for this project, the test methods used by UK pressure sensitive adhesive and adhesive tape manufacturers and users were reviewed[10]. Tack measurement methods vary from industry to industry. Discounting industry stick-on tests, such as the SATRA sole-upper adhesion test[11], the most widely used methods for measuring tack are:

- loop tack test, used for tapes and pressure sensitive adhesives;
- probe tack test;
- rolling ball test.

These methods are outlined in more detail below.

3.1 LOOP TACK TEST FOR ADHESIVE TAPES

This method involves lowering a loop of the tape being tested on to a plate until it makes contact over a known area. The direction of travel is then reversed and the force required to separate the loop from the plate is measured. Depending on the method used, the adhesive can be applied to either the tape or the plate.

There are two British Standard specifications[12,13] which include loop tack testing. BS 7116: 1990[12] deals with double sided pressure sensitive adhesive tapes, and is not applicable to single sided tapes. It involves applying the tape to a flat plate and applying a standard load, and then lowering a loop made of 23 µm thick polyester film on to the sample. BS EN 1719: 1994[13] deals with tack measurement for pressure sensitive adhesives rather than adhesive tapes, and involves coating the adhesive on to polyester film under standardised conditions. A survey of industrial organisations undertaken as part of this project concluded that these British Standard methods are not widely used[10].

The most widely used method in the UK is FINAT Test Method Number 9 (FTM9), "Quick-Stick" tack measurement[14]. The loop is made from a strip of tape 25 mm wide and at least 175 mm long. The plate is made of "Float Process" glass 25 mm wide, so that the area of contact is 25 mm square. A tensile tester or similar machine is used. The cross-head speed should be 300 mm per minute with an accuracy of ± 2%, and the force measuring device should be capable of measuring up to at least 20 Newtons with an accuracy of ± 2%.

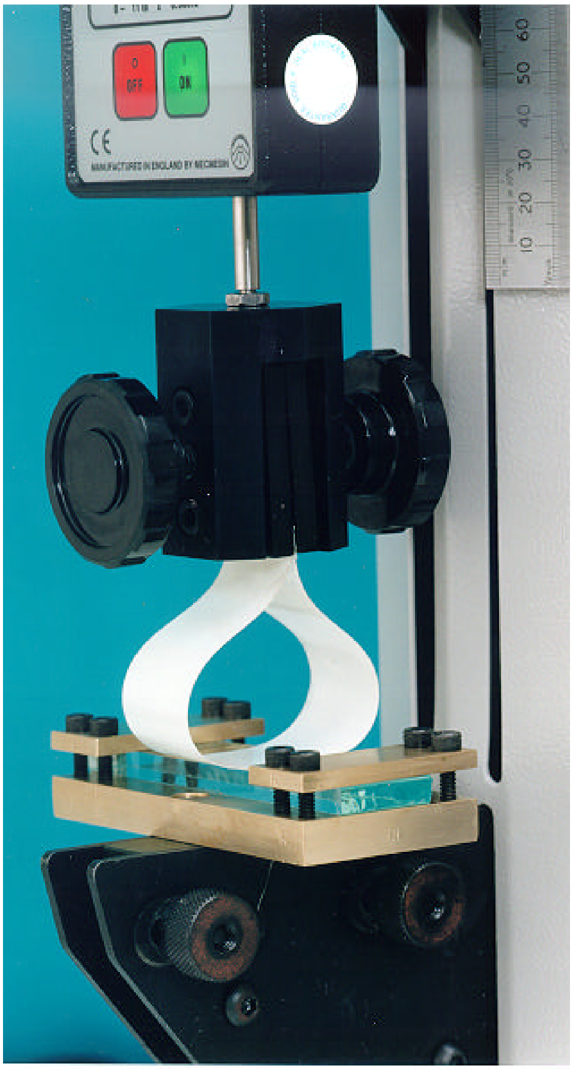


Figure 1: Loop tack test

Before setting up equipment, two commercial loop tack testers were examined. They were considered unsuitable for the programme because they were not capable of measuring the contact force, and this was considered to be an important parameter. The equipment used is shown in Figure 1. It consists of a force gauge capable of measuring compressive and tensile forces up to 50 N with a resolution of 0.01 N, and a motorised stand that lowers and raises the loop. The force gauge records the maximum compressive and tensile forces, and is connected to a computer based logging system that allows the data to be recorded. The gauge, stand and Dataplot software used for data acquisition were supplied by Mecmesin.

In addition, the force gauge can be connected through a junction box to a chart recorder and the computer at the same time. This enables the peak force from a single test to be recorded in three different ways: by the force gauge, by the computer and by a chart recorder. The results from a series of tests carried out to compare the measuring techniques are given in Table 1.

Table 1. Comparison of loop tack results obtained using different measuring devices

Test code	Maximum recorded tack force in Newtons		
	Force gauge (AFG)	Chart recorder	Computer (Dataplot)
LT114	27.56	26.85	27.02
LT115	27.35	27.12	27.04
LT116	27.74	27.21	26.68
LT117	28.04	27.66	27.51
LT118	26.62	26.31	26.33
LT119	27.95	26.85	26.49
LT120	25.83	25.60	25.47
LT121	28.13	27.30	26.56
LT122	25.94	25.51	25.10
LT123	26.37	26.04	25.97
Mean	**27.15**	**26.65**	**26.42**
Ratio	**100**	**98.2**	**97.3**

These tests were carried out using a double sided adhesive tape with the backing paper attached. The backing provided stiffness and made the tape convenient to handle. The equipment used were a Mecmesin Advanced Force Gauge (AFG) which took 1200 readings per second, a Kipp and Zonen model BD112 chart recorder and the Mecmesin Dataplot data acquisition system that took 10 readings per second.

The force gauge always gave the highest value. The Dataplot system always gave a lower value than the force gauge. The average of the Dataplot results was within 3% of the AFG average. The chart recorder also always gave a lower value than the force gauge, but usually gave a higher value than the Dataplot. The average of the chart recorder results was within 2% of the AFG average. The disbonding of the tape from the substrate is a dynamic process. Plots of force against time typically show a sharp peak followed by an almost instantaneous drop to zero force. The faster the force reading is sampled the closer the reading should be to the actual peak force. Thus the force gauge which has a high sampling rate would produce the highest peak force. The data measured will be dependent on the recording devices used.

The loop tack test presents a number of areas of uncertainty that may influence test reproducibility. The results of an intercomparison exercise for the FINAT No 9 test are discussed in a later section.

The specimen is tested in the form of a loop. If the backing material has little stiffness then there may be difficulties in forming the loop into a repeatable shape. This can be compounded by static electricity effects. Alignment of the loop with respect to the substrate plate is another potential problem particularly with low stiffness tapes which may be prone to twisting. There is a degree of subjectivity in the decision as to when the tape is in full contact with the plate to reverse the direction of the machine. Thus the contact area and/or dwell time may vary.

The downwards contact pressure exerted through the loop will depend on the stiffness of the tape. Thus different tapes will give different contact pressures that will lead to different measured tack strengths even if the adhesive is the same. In the absence of a suitable range of tapes having the same adhesive but different backing materials, a mathematical approach utilising Finite Element Analysis was used to investigate the role played by the stiffness of the backing material. This is discussed in a later section. BS 7116, by utilising the same loop tape material, overcomes the variability due to the stiffness of different backing materials. However, the polyester material specified is rather flimsy and difficult to handle which may account for the low popularity of the method.

3.2 PROBE TACK

The probe tack test is based on ASTM Standard Test Method D 2979 - 95[15]. The equipment was initially developed in the 1950s, and is commercially available from Testing Machines Inc[16]. It is shown in Figure 2. The tape specimen is applied to an annular weight, and positioned above the cylindrical probe. The probe is raised to make contact with the specimen, held for a fixed time, and then the force required to cause separation is measured. The machine enables systematic studies of tack to be performed. Tack can be studied as a function of contact pressure, dwell time, probe speed and probe material.

Figure 2: Probe tack tester

The equipment used in this work had a 5 mm diameter probe and a contact area of 0.196 cm^2. Peak detachment forces were displayed in grams weight. One potential problem with the probe tack test is entrapment of air between the probe and adhesive. To overcome this, a slightly domed probe was used. Although the contact pressure and area are less easily defined, the tack measurement conditions have better reproducibility which is more important for comparison studies or quality control measurements.

Probe tack measurements ought to be inherently more reproducible than loop tack measurements as there is less scope for operator subjectivity in the procedure. However, the smaller area of contact may require that more measurements are made to ensure statistical accuracy. The problems with handling flimsy loops and the subjectivity regarding loop alignment and test reversal are eliminated. However, the equipment required is more expensive and less versatile than the loop tack equipment. Probe tack testing is thus less widely adopted than loop tack testing.

3.3 ROLLING BALL

This ASTM method(17) is simple to carry out and the equipment (Figure 3) is inexpensive. A ball is rolled down an incline on to the tape being tested. Tack is related to the inverse of the distance rolled before the ball is stopped by the tape. The method becomes less accurate at longer travel. The test can be varied by choosing different incline angles, incline heights or type of ball to suit the type of tape being tested. For example, table tennis balls have been suggested to minimise pressure[5]. However, results from different test equipment will not be comparable. The rolling ball test is intended primarily as a comparative method for quality control.

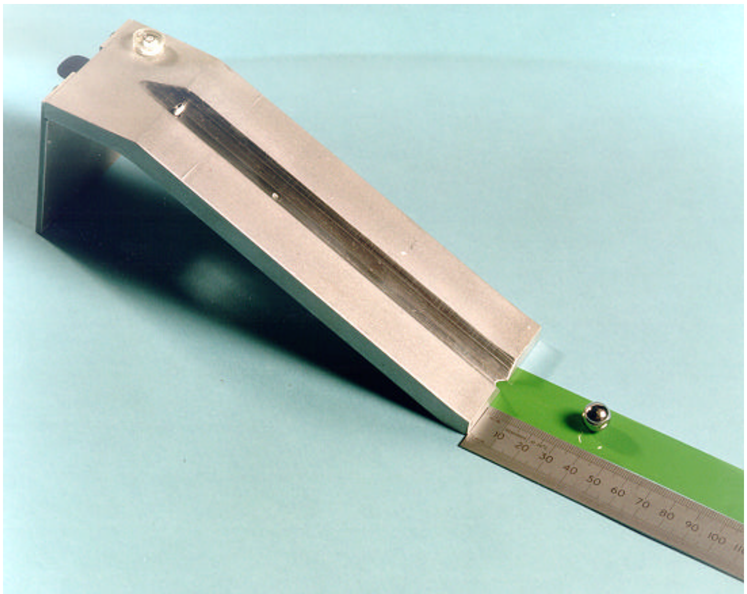


Figure 3: Rolling ball tack test

The results from this test can be significantly influenced by the backing material of the tape or the thickness of the adhesive layer. A thick, ‘soft’ backing or a thick layer of adhesive will absorb a significant proportion of the kinetic energy of the ball and thus bring it to a stop earlier. Where the adhesive coating is thin, the area of contact between the ball and adhesive will be small (as the ball will not sink as deep) and the stopping distance will be longer.

3.4 ALTERNATIVE METHODS

3.4.1 Spherical Probe Method

A recent paper(18) describes the use of equipment having a spherical probe to characterise the behaviour of pressure sensitive adhesives. The equipment was developed by Stable Microsystems Ltd of Godalming, Surrey, UK for analysing the texture of food products, and was adapted by the authors for adhesive testing(18). They claim that the equipment has a number of advantages over traditional probe tack testers and can generate much more information.

3.4.2 Tack Wheel Method For Measuring Pressure Sensitive Tack

This equipment(19) was developed and evaluated in the USA by Chemsultants International, who specialise in adhesive testing. The method involves running a spoked wheel (having a load cell attached) across the surface of the adhesive, and analysing the patterns of force generated. The work was reported in 1994 but no current information on commercial development of this instrument was available.

3.4.3 SATRA/NPL Shoe Adhesive Tack Tester

This instrument was jointly developed by SATRA and NPL to perform tack measurements in the footwear industry[11]. The design (Figure 4) is based around a motorised test stand and force gauge similar to that used in the loop tack test. The more rigid clamping enables contact pressure to be controlled. A heating unit is incorporated to allow heat activation of the adhesives commonly used in the footwear/leather industry. Developments to the instrument have enabled different test surfaces to be clamped which improves versatility. Investigations into factors influencing tack of two heat activated adhesives carried out as part of this project were reported by Barraclough[20]. This work showed that the measured tack was influenced by many factors:

Figure 4: Shoe tack tester

- temperature: there is a characteristic temperature where tack is highest;
- thermal history: the effects of heating the adhesive above the activation temperature may have either beneficial or detrimental effects on the tack depending on the adhesive type;
- substrate clamping: measured tack is greatest where the clamps are set to minimise the compliance of the substrate as this reduces peel stresses at the ends of the bond;
- substrate flexibility: increasing the substrate thickness, reducing compliance, leads to larger measured tack;
- test rate: tack is greater at low test rates mainly because dwell time is greater;
- contact pressure: tack increases with pressure until a maximum tack is achieved;
- coating weight: increased layers of adhesive can improve tack provided that sufficient drying is allowed between layer application;
- drying time: the interval between applying adhesive and forming the bond can have significant influence on tack strength. As with temperature, there is an optimum drying time.

The work carried on the tack tester demonstrated the versatility of the instrument. The results help identify optimal processing procedures for manufacturing footwear.

4. LOOP TACK TEST RESULTS

4.1 REPEATABILITY OF FINAT LOOP TACK TESTS

These tests were carried out using a reel of double sided tape on different days in order to examine repeatability. The tests were carried out with the adhesive tape attached to the backing paper. The stiffness of the backing paper enabled loops of fairly regular shape to be formed. These behaved reliably when lowered on to the plate. In later work with more flimsy tapes there were severe difficulties in handling. Therefore, the repeatability of the results was much worse. The results in this section therefore gave the lowest scatter in loop tack results obtained in the programme. Before each set of tests the outer three turns of the roll were cut off and discarded. The glass plate was cleaned using methanol on a paper towel before each test. The results given are the maximum tensile values (F) recorded by the force gauge. The maximum compressive forces were in the range 0.12 to 0.16 N. The room used for the tests was temperature controlled, but there was no control over humidity.

The results shown in Table 2 indicate that the repeatability of the FINAT test method for this tape is relatively good. The coefficient of variation (Cv), defined here as the standard deviation divided by the mean, is small. The results are repeatable on different days within the scatter of data. The difference in tack between 50 % RH and 60 % RH is insignificant.

Table 2. Repeatability of FINAT loop tack tests on a double sided adhesive tape

30/7/97		31/7/97		4/8/97		20/8/97	
Test	F (N)	Test	F (N)	Test	F (N)	Test	F (N)
LT039	25.37	LT054	27.51	LT064	25.86	LT069	25.68
LT040	25.69	LT055	25.98	LT065	26.16	LT070	25.99
LT041	27.63	LT056	26.47	LT066	25.30	LT071	26.24
LT042	26.38	LT057	26.67	LT067	26.85	LT072	27.62
LT043	26.47	LT058	25.34	LT068	27.51	LT073	26.23
LT044	26.28					LT074	27.09
LT045	24.89					LT075	26.85
LT046	27.69					LT076	27.03
LT047	26.07					LT077	26.62
LT048	26.27					LT079	26.79
Mean	**26.27**		**26.39**		**26.34**		**26.61**
St. devn.	**0.88**		**0.81**		**0.86**		**0.58**
Cv	**0.03**		**0.03**		**0.03**		**0.02**
°C	21.9		21.3		21.9		21.7
% RH	60.0		50.1		61.2		50.2

4.2 COMPARISON OF FINAT LOOP TACK RESULTS

The results given in this section compare four tapes:

(a) The double sided tape described in Section 3.1
(b) A clear polypropylene packaging tape, code 1240, manufactured by Sellotape. Described as "coated with a high adhesion pressure sensitive adhesive".
(c) Green polyester splicing tape, code 1627, manufactured by Sellotape. Described as "polyester film with a heavy coating of specially formulated silicone adhesive".
(d) Black crepe masking tape, code 2566, manufactured by Sellotape. Described as a "medium creped paper coated with a rubber resin adhesive".

The last three were used for the loop tack round robin organised by PIRA (Packaging Industry Research Association) in collaboration with NPL(21). The maximum compressive force for the double sided tape was 0.12 to 0.16 N. The other three tapes were much less stiff and the compressive 'push down' force was much lower, around 0.01 or 0.02 N.

Table 3. Comparison of FINAT loop tack results from four different tapes

Double sided		1240, clear		1627, green		2566, black	
Test	F (N)	Test	F (N)	Test	F (N)	Test	F (N)
LT039	25.37	LT100	24.96	LT080	15.11	LT090	9.48
LT040	25.69	LT101	16.18	LT081	13.78	LT091	10.29
LT041	27.63	LT102	23.65	LT082	14.54	LT092	9.49
LT042	26.38	LT103	25.48	LT083	14.48	LT093	10.99
LT043	26.47	LT104	25.28	LT084	14.96	LT094	8.80
LT044	26.28	LT105	23.83	LT085	14.80	LT095	8.62
LT045	24.89	LT106	23.43	LT086	14.55	LT096	8.93
LT046	27.69	LT107	20.16	LT087	14.27	LT097	9.25
LT047	26.07	LT108	24.00	LT088	16.11	LT098	8.23
LT048	26.27	LT109	23.15	LT089	15.41	LT099	8.37
Mean	**26.27**	**Mean**	**23.01**	**Mean**	**14.80**	**Mean**	**9.25**
St. devn.	**0.88**	**St. devn.**	**2.83**	**St. devn.**	**0.65**	**St. devn.**	**0.87**
Cv	**0.03**	**Cv**	**0.12**	**Cv**	**0.04**	**Cv**	**0.09**
°C	21.9	°C	21.9	°C	21.5	°C	21.8
%RH	60.0	%RH	62.6	%RH	55.0	%RH	52.6

The double sided tape gave the lowest coefficient of variation, and the 1240 clear packaging tape the highest. The difficulty in handling the more flimsy tapes is believed to be a major factor in causing increased scatter in the results.

4.3 INFLUENCE OF THE PLATE MATERIAL

The FINAT loop tack test method specifies a flat plate made of “Float Process” glass or equivalent plate glass[14]. An old American Pressure Sensitive Tape Council (PSTC) loop tack test method (which is not included in the current handbook of test methods) specified a stainless steel test panel. This was made from 304 bright annealed stainless steel with a surface height roughness of 2 ± 1 micro-inches (0.05 ± 0.025 µm). The experiments described here were carried out to compare the results obtained using the two different types of plate.

The tape used was Tesa type 7158, which is a double-sided splicing tape equipped with a non-woven backing and coated with an acrylic resin of very high tack. This was chosen because, when tested while attached to the backing, it is convenient to handle and forms loops having fairly regular shapes. Thus, it gives reasonably consistent results. The tests were carried out at the standard FINAT speed of 300 mm/minute. The plates were cleaned using acetone on cotton wool before each set of five tests, but not between tests.

Four sets of five tests were carried out on each of the two plates:
Set 1. Five tests were carried out using the stainless steel plate, followed by five tests using the glass plate
Set 2. The same as Set 1.
Set 3. A test was carried out using the stainless steel plate, followed by a test using the glass plate. Four further tests were carried out on each type of plate, alternating the plate type. The reason for doing this was to overcome any systematic “drifts” in the results due to variations in the tape, or variations in ambient conditions.
Set 4. The same as Set 3.

The results are summarised in Table 4. Both the tensile ‘tack’ force (F) and compressive, ‘push-on’ force (C) are given. The test conditions are given in Table 5.

Table 4. Mean Tack Measurements.

	Stainless steel plate				Glass plate			
SET	F (N)	St dev	Cv	C (N)	F (N)	St dev	Cv	C (N)
1	16.58	1.01	0.06	-0.15	17.61	2.21	0.13	-0.19
2	13.02	0.69	0.05	-0.16	17.83	0.84	0.05	-0.17
3	13.53	0.64	0.05	-0.17	18.86	1.90	0.10	-0.17
4	13.79	1.39	0.10	-0.16	16.57	1.48	0.09	-0.17
Mean	**14.38**	**1.93**	**0.13**	**0.16**	**17.72**	**0.94**	**0.05**	**0.17**

Table 5: Test Conditions for Tests in Table 4

SET	Temperature	Relative Humidity
1	21.6 °C	53.5 %
2	20.9 °C	48.7%
3	20.8 °C	51.3%
4	21.6 °C	50.7%

The scatter in results makes it difficult to draw firm conclusions. However, the fact that all four sets of results gave higher mean values from the glass plate than from the stainless steel plate suggests that there is a real difference. Taking the averages from all the results, the values obtained using the stainless steel plate are about 20% lower than those from the glass plate.

4.4 INTERCOMPARISON OF THE LOOP TACK TEST

An intercomparison exercise to investigate the reproducibility of the FINAT No 9 method was organised by Pira International[21]. Thirteen laboratories took part in the round robin. Each of the participants was supplied with 3 adhesive tapes (1240, 1627 and 2566 described above) and the test method. Results were produced from 10 repeats.

In general, the repeatability of measurements carried out within laboratories was reasonable. This suggests that there should be few problems with using the method for quality control purposes. However, reproducibility between laboratories was poorer. Thus, there may be problems with using the method to generate data for design or qualification purposes. Out of the 13 laboratories only 9 ranked the three tapes in the same order (1240 > 1627 > 2566). Where ranking order differed this was due to lower tack values produced for the thinnest tape (1240) which normally had the largest tack. This confirms the opinion that the reliability of the loop tack test is worst for the most compliant tapes.

4.5 MODELLING THE LOOP TACK TEST

The loop tack test as described is not particularly amenable to studies to determine the influence of testing parameters on tack strengths. Dwell time is not well defined nor is contact pressure. While test speed can be varied, it was felt that there was insufficient ability to vary other factors to make a study of the effect of this worthwhile. Contact pressures, dwell times and separation speeds were variables studied using the probe tack tests.

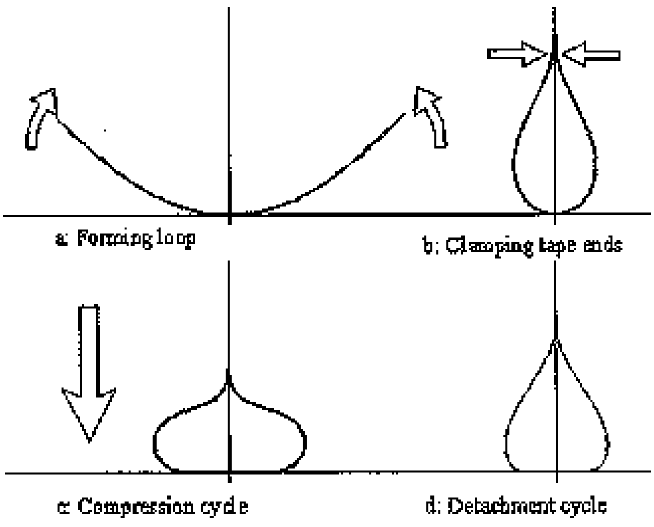


Figure 5: Stages in the loop tack test

The backing tape was considered to have significant influence on the measured tack. Test measurements to assess the influences of different backing tapes on adhesive tack were considered. However, contacts with tape suppliers revealed that the normal practice was to match adhesive type with tape material. As a consequence, different tapes (whether different material or thickness) tended to use different adhesive and there was no standard range of tapes available with different backings to the same adhesive.

As an alternative to physical experiments, a virtual experiment approach was undertaken. A Finite Element model was created of the tape loop and surface using ABAQUS(22). The beam was modelled using 2 node linear, in-plane beam elements. The mechanical properties of the backing tape material were used to define the stiffness of the tape.

The FE model runs through the four steps of the tack test as illustrated in Figure 5. The shapes of the loop throughout the virtual test agreed very well with digitised video images of an actual test.

In the original model the interaction between the adhesive and the plate was represented using the *SURFACE BEHAVIOUR(23) subroutines in the ABAQUS FEA solver. The pressure parameter required to describe the combination of the surfaces was an arbitrary value chosen to give reasonable agreement between measured and predicted 'tack' forces. Once this value was selected, it was possible to run predictions of the effect of varying the material and thickness of the backing tape on the tack forces.

Figure 6 FE Predictions of Influence of Tape Properties

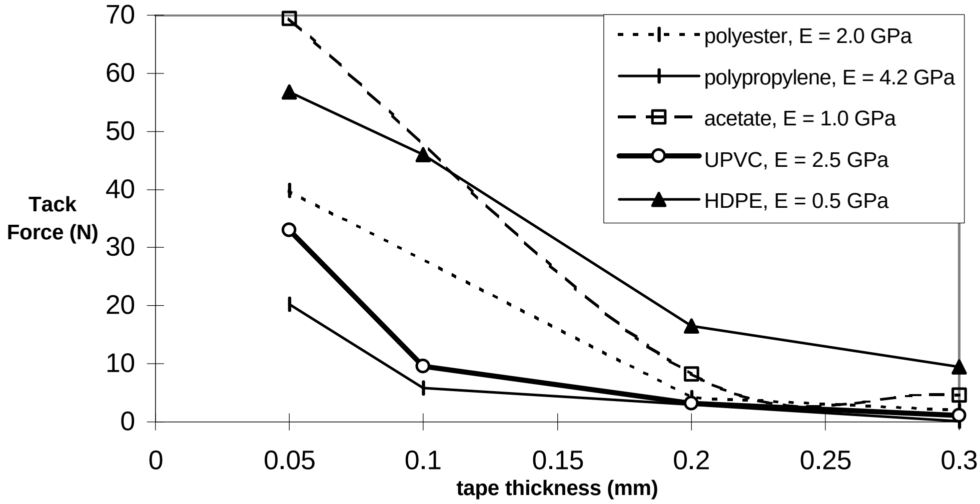
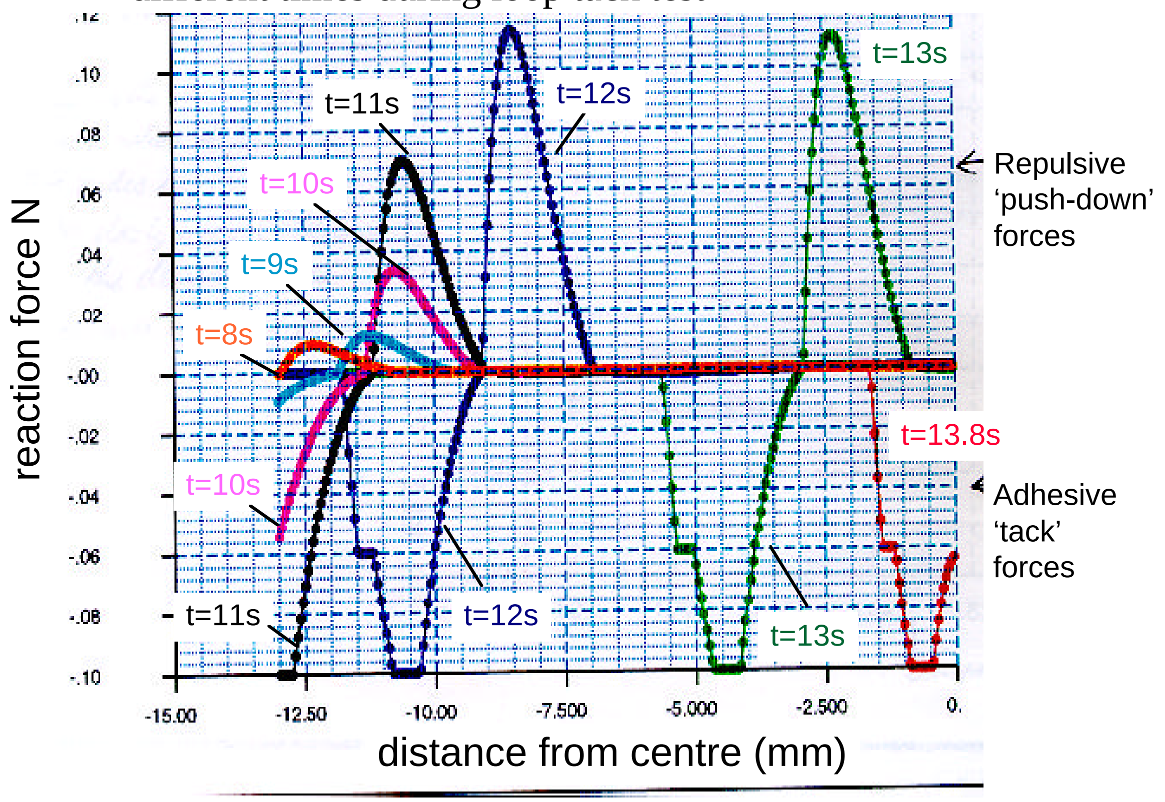


Figure 6 summarises the initial predictions made. The main trend is that the measured force will decrease as the stiffness of the tape increases. This does not take into account the higher contact pressures produced by the stiffer tapes that would tend to increase the measured tack.

The FE model was further improved by adding a specifically written user element to model the adhesion properties. The element allows specification of distance dependent adhesion properties - in essence the strength and range of the adhesion forces can be specified in this element. This provides advantages over the *SURFACE BEHAVIOUR routines used previously. The adhesion force is now a tension pulling the tape and plate together rather than a compressive pressure being released. This is a much better physical representation of the system. The alterations to the model allow for analysis of the forces between the tape and plate along the interface.

Figure 7 shows the predicted forces along the tape-plate interface at different times during the test. The model is symmetrical so only half the tape is shown (the centre of the tape is at the right hand end). The analysis results indicate that a zone of increased contact pressure advances in front of the peeling edge of the tape. This pressure is due to the elastic response of the tape resisting bending. This acts to force the tape against the plate. Away from the area where the tape is curved, contact pressure is virtually zero. The FE analysis also shows that the adhesive is under stress only in the region around the edges of the bond. For much of the test there are no forces acting on the centre of the loop. The tape detaches from the plate after 13.8 s. Dynamic elastic analysis predicts that the loop will vibrate following detachment. However, the viscous response of the tape and adhesive would act to damp these vibrations.

Figure 7:Predicted interfacial forces at different times during loop tack test



5. PROBE TACK RESULTS

These tests were carried out using the probe tack tester described earlier to investigate the effects of varying contact pressure, dwell time and probe speed on tack force. The three adhesive tapes [(b), (c) and (d) from the previous section] used in the loop tack round robin exercise were studied to provide further information on these samples.

The following test conditions were used.

(a) Standard conditions: Pressure 100 g/ sq cm (= 0.98 N/cm), time 1 sec, speed 1 cm/sec.
(b) Variable pressure: Used 20 and 500 g/ sq cm, time 1 sec, speed 1 cm/sec.
(c) Variable time: Used 0.1, 10 and 100 sec, pressure 100 g/ sq cm, speed 1 cm/sec.
(d) Variable speed: Used 0.02, 0.1 and 5 cm/sec, pressure 100 g/ sq cm, time 1 sec.

5.1 INFLUENCE OF CONTACT PRESSURE

Ten tests were carried out for each set of conditions. Pressures are expressed in grams weight per sq. cm (g/sq. cm). The contact pressures can be calculated through the relationship 1 g/sq. cm = 0.98 Pa. Results for tack are given in grams force (g). Tables 6a-6c show the effects of varying pressure at constant dwell time and probe speed for each tape. These results are shown in Figure 8. As expected, all the tapes show increasing tack strength with increasing contact pressure. The repeatability of the measurements at the lowest contact pressure is significantly worse than the at the higher pressures. The slope of tack against contact pressure is similar for each tape. Tape 1240 has significantly higher tack than tapes 1627 and 2566. Tapes 1627 and 2566 have very similar tack strengths.

Table 6a. Tape 1240, Probe tack as a function of pressure
Time 1 second, speed 1 cm/sec.

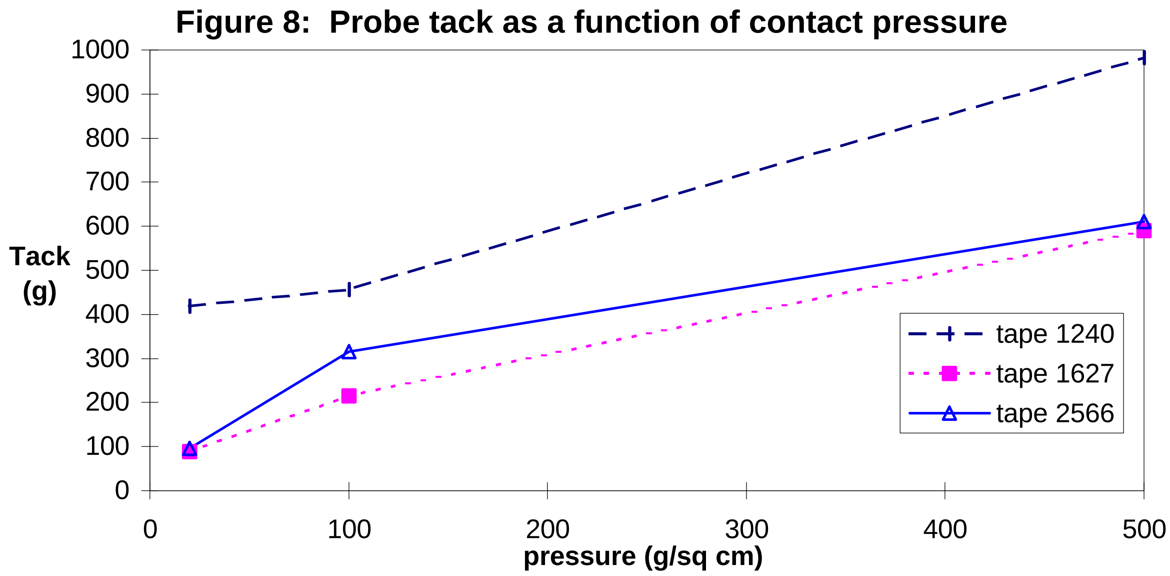
pressure	**20 g/ sq cm**	**100 g/ sq cm**	**500 g/ sq cm**
Mean	418	456	982
Std devn	145	108	231
Cv	0.35	0.24	0.24
°C	22.3	22.1	22.0
%RH	42.6	43.9	45.6

Table 6b. Sellotape 1627: Probe tack as a function of pressure
Time 1 second, speed 1 cm/sec

	20 g/ sq cm	**100 g/ sq cm**	**500 g/ sq cm**
Mean	88	215	590
Std devn	33	16	50
Cv	0.38	0.07	0.08
°C	21.3	21.8	21.4
%RH	33.0	42.8	40.0

Table 6c. Sellotape 2566: Probe tack as a function of pressure
Time 1 second, speed 1 cm/sec

	20 g/ sq cm	**100 g/ sq cm**	**500 g/ sq cm**
Mean	96	315	610
Std devn	14	28	33
Cv	0.15	0.09	0.05
°C	20.9	21.9	21.4
%RH	30.0	53.4	50.3



5.2 INFLUENCE OF DWELL TIME

The results from tests carried out to study the influence of dwell (or contact) time on tack strengths are shown in Tables 7a - 7c and Figure 9. Tack strength typically increases with dwell time. Tape 1240 is again significantly more ‘tacky’ than the others. The influence of dwell time shows differences between the other two adhesives. Tape 1627 is more sensitive to dwell time than tape 2566. Furthermore, between 1 s and 10 s dwell time, the ranking of the tapes changes.

Table 7a. Tape 1240, Probe tack as a function of dwell time
Pressure 100 g/sq cm, speed 1 cm/sec

dwell time	**0.1 s**	**1 s**	**10 s**	**100s**
Mean	560	456	752	993
Std devn	139	108	156	159
Cv	0.25	0.24	0.21	0.16
°C	21.5	22.1	21.6	21.1
%RH	39.4	43.9	46.3	26.1

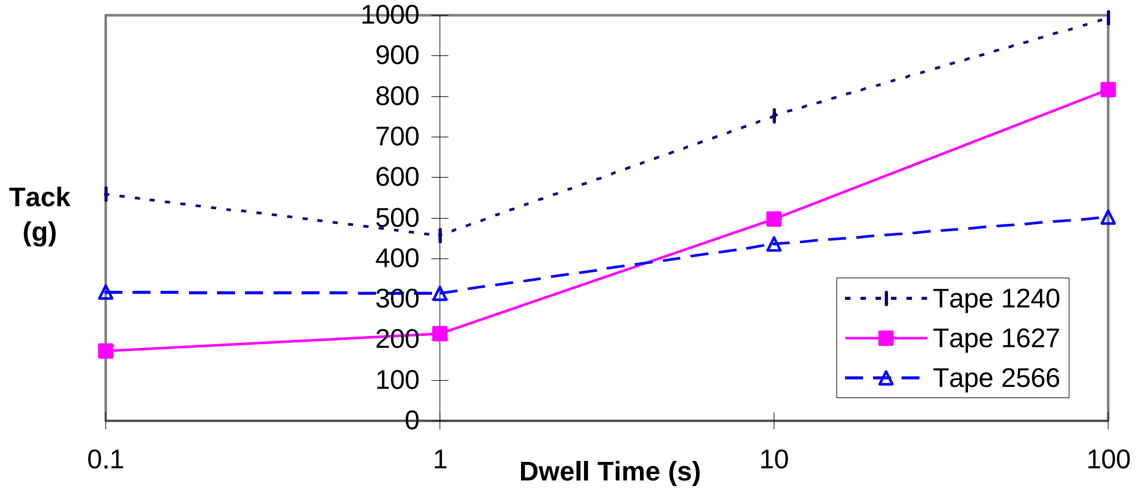
Table 7b: Sellotape 1627: Probe tack as a function of dwell time
Pressure 100 g/sq cm, speed 1 cm/sec

	0.1 s	**1 s**	**10 s**	**100 s**
Mean	172	215	497	816
Std devn	28	16	57	55
Cv	0.16	0.07	0.11	0.07
°C	21.4	21.8	21.4	21.0
%RH	43.5	42.8	44.5	32.4

Table 7c. Sellotape 2566: Probe tack as a function of dwell time
Pressure 100 g/ sq cm, speed 1 cm/sec

	0.1 s	**1 s**	**10 s**	**100s**
Mean	318	315	436	503
Std devn	32	28	28	45
Cv	0.10	0.09	0.06	0.09
°C	21.4	21.9	21.6	21.2
%RH	48.3	53.4	57.3	45.5

Figure 9: Probe tack as a function of dwell time



5.3 INFLUENCE OF TEST SPEED

The effect of varying the separation speed on tack strength is shown in Tables 8a - 8c and Figure 10. The variability of the test results on tape 1240 is much higher at the fastest speed (where the tack strength is extremely low). The tack of tapes 1240 and 1627 falls as the test speed increases. In contrast, the tack strength of tape 2566 increases with test speed. The three tapes all use different types of adhesives. It is likely that the results reflect the different response of these materials to test speed. The trend in the results on tape 2566 agrees with those reported by Hammond[8] on tapes coated with similar rubber resin adhesives. Other researchers have tended to report increasing tack with increasing separation speed. Bates[24] suggested that tack strengths could be represented by an Arrenhius function:

$$\text{tack, } T = Ae^{mx}$$

where x is the rate of separation, A and m are constants depending contact pressure and dwell time.

From a perspective that only considers the visco-elastic response of the adhesive, increasing the strain rate should increase the modulus of the adhesive and, hence, the tack strength. However, this argument ignores other features of the test. The properties of the backing tape will also be rate dependent. Furthermore, tack strength is not simply due to the elastic modulus of the adhesive but also depends on the viscous modulus and deformation prior to rupture. Zosel[2,3] demonstrated that tack strength is improved if the adhesive is capable of forming filaments linking the separating substrates. Increasing the test speed may lead to premature rupture of these structures in some adhesives and thus lower tack..

Also linked to lower test speeds are increased dwell times, over and above the set dwell time. The tack strengths of tapes 1240 and 1627 are more sensitive to dwell time than 2566. Any effects of increased separation speed for these systems may be swamped by the differences in dwell time. This decrease of tack with increasing test speed was also found for shoe adhesives[20].

Table 8a. Tape 1240, Probe tack as a function of rate of separation
Pressure 100 g/ sq cm, time 1 second

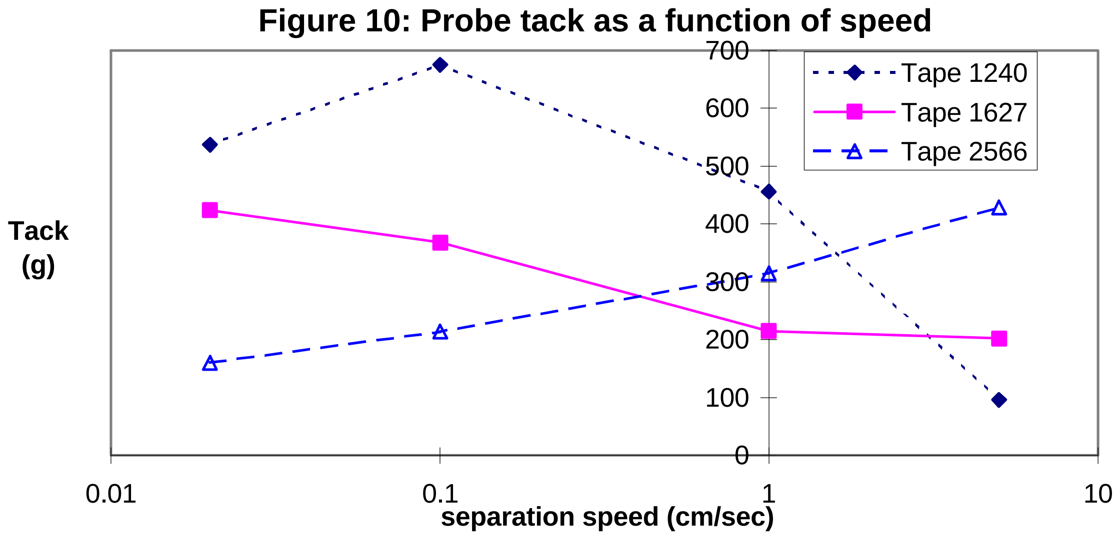
	0.02 cm/sec	**0.1 cm/sec**	**1 cm/sec**	**5 cm/sec**
Mean	537	675	456	96
Std devn	143	128	108	56
Cv	0.27	0.19	0.24	0.58
°C	22.0	22.1	22.1	21.3
%RH	39.4	41.2	43.9	37.5

Table 8b. Sellotape 1627: Probe tack as a function of rate of separation
Pressure 100 g/sq cm, time 1 second

	0.02 cm/sec	**0.1 cm/sec**	**1 cm/sec**	**5 cm/sec**
Mean	424	368	215	202
Std devn	48	38	16	20
Cv	0.11	0.10	0.07	0.10
°C	20.7	21.9	21.8	21.7
%RH	31.1	43.0	42.8	40.9

Table 8c. Sellotape 2566: Probe tack as a function of rate of separation
Pressure 100 g/sq cm, time 1 second

	0.02 cm/sec	**0.1 cm/sec**	**1 cm/sec**	**5 cm/sec**
Mean	160	214	315	429
Std devn	12	15	28	14
Cv	0.08	0.07	0.09	0.03
°C	21.2	21.7	21.9	20.8
%RH	46.0	54.8	53.4	38.7



6 ROLLING BALL TACK TESTS

This study was carried out on the three tapes used in the round robin study. The test method is described in PSTC-6 (Pressure Sensitive Tape Council Test Method 6, dated 8/89)(25) and ASTM 3121-94(17), Standard Test Method for Tack of Pressure-Sensitive Adhesives by Rolling Ball. A steel ball (11.1 mm diameter) rolls down an incline (height 65 mm, inclined at 21.5° to the horizontal) on to the tape. The ball was cleaned using acetone before the first test in each series, but not between tests. The distance travelled by the ball before stopping is measured. It is inversely related to tack.

The results given in Table 9 are the distances travelled by the ball in millimetres. The higher the distance rolled, the lower the tack is. It is clear from these results that there is no correlation between rolling ball and loop or probe tack results. Loop tack and probe tack measurements indicate that the clear tape 1240 has the highest tack, whereas rolling ball results indicate that it has the lowest tack.

Table 9. Distance travelled by rolling ball in millimetres

	Clear, 1240	Green, 1627	Black, 2566
1	732	13	173
2	622	15	159
3	693	17	176
4	675	19	210
5	438	22	180
6	681	37	210
7	624	20	185
8	658	19	208
9	634	20	204
10	760	29	199
Mean	**652**	**21**	**190**
Std. Devn.	**88**	**6.7**	**18**
Cv	**0.13**	**0.32**	**0.10**

ASTM D 3121 discusses the significance and use of the rolling ball test method, and points out that results are influenced by adhesive film thickness, bond of adhesive to backing and backing rigidity. The test is intended primarily for quality control, and is able to detect batch-to-batch variations if adhesive film thickness is held constant. It is not intended for investigating applications of adhesives, since the results do not correlate well with behaviour in service.

It is probable that the green tape 1627 gives a high tack result from the rolling ball method because the coating of adhesive is very thick. Much energy is required to push the adhesive out of the ball's path. The black tape 2566 may give a higher tack value than the clear tape 1240 because of greater area of contact. The ball will tend to sink into the thicker paper tape 2566. Whereas there will be less contact with the thinner clear tape 1240 that has a thin coating of adhesive.

7. COMPARISON BETWEEN METHODS

7.1 COMPARISON BETWEEN FINAT LOOP TACK AND PROBE TACK RESULTS

FINAT loop tack tests and probe tack tests were carried out on a number of adhesive tapes and the results were compared. Two aspects were of particular interest:

(a) Whether the two methods would give similar ranking orders.
(b) The scatter in results.

The tapes tested were manufactured by Sellotape and Tesa. They incorporate a range of types of adhesives, including rubber resin, acrylic and silicone. Tapes 1-3 were those used in the round robin comparison:

1. 1240 Clear polypropylene packaging tape, made by Sellotape, supplied by PIRA.
2. 1627 Green polyester splicing tape, made by Sellotape, supplied by PIRA.
3. 2566 Black crepe masking tape, made by Sellotape, supplied by PIRA.
4. Tesa 4316 creped paper masking tape, supplied by Radiospares (RS).
5. Tesa 4965 double sided polyester tape with modified acrylic adhesive. Supplied by RS.
6. Tesa 4970 double sided PVC tape with modified acrylic adhesive to give very high adhesion values. Supplied by RS.
7. Tesa 51968 "high-strength bonding double sided tape". Polypropylene tape with modified acrylic adhesive. Supplied by RS.
8. Tesa glass fibre reinforced polypropylene strapping tape. Supplied by RS.

Ten FINAT No 9 tests were carried out on each tape. One metre of tape was discarded before the first specimen was cut. The double sided tapes were tested while attached to the backing materials. They were stiffer than the single sided tapes and, hence, had higher contact pressures as shown in Table 10a. The glass plate was cleaned using acetone on cotton wool before the first test on each tape, but not between tests. The results in Newtons were obtained from the force gauge.

Ten probe tack tests were carried out on each tape using the standardised test conditions of 1 cm/sec for descent and ascent of the specimen holder, 1 s dwell time and 100 g/ square cm pressure. The instrument gave results for the tack force in grams, and these have been converted to Newtons (1 g = 0.0098 N).

The results are summarised in Table 10b. The ranking order of the tapes is shown in Table 10c.

Table 10a. Loop test, maximum compression forces in Newtons

	Tape							
Test	1	2	3	4	5	6	7	8
Mean	0.014	0.015	0.017	0.042	0.17	0.27	0.34	0.06
Std. Devn.	0.005	0.005	0.011	0.015	0.03	0.02	0.05	0.014
Cv	0.36	0.33	0.59	0.36	0.19	0.07	0.15	0.23

Table 10b. Comparison of loop tack and probe tack

	Loop			Probe		
Tape	Mean	St. dev.	Cv	Mean	St. dev.	Cv
1 (S)	23.01	2.83	0.12	5.33	1.52	0.28
2 (S)	14.80	0.65	0.04	2.13	0.35	0.17
3 (S)	9.25	0.87	0.09	3.21	0.32	0.10
4 (S)	7.87	1.61	0.20	1.26	0.23	0.18
5 (D)	35.70	5.48	0.15	10.61	1.70	0.16
6 (D)	35.12	4.64	0.13	9.37	1.52	0.16
7 (D)	43.64	3.38	0.08	9.04	1.29	0.14
8 (S)	18.46	2.27	0.12	3.96	0.63	0.16

(S) indicates single sided, (D) double sided

Table 10c. Comparison of ranking order of tapes from loop and probe measurements

	Loop	Probe
Highest tack	Tape 7 (43.64 N)	Tape 5 (10.61 N)
	Tape 5 (35.70 N)	Tape 6 (9.37 N)
	Tape 6 (35.12 N)	Tape 7 (9.04 N)
	Tape 1 (23.01 N)	Tape 1 (5.33 N)
	Tape 8 (18.46 N)	Tape 8 (3.96 N)
	Tape 2 (14.80 N)	Tape 3 (3.21 N)
	Tape 3 (9.25 N)	Tape 2 (2.13 N)
Lowest tack	Tape 4 (7.87 N)	Tape 4 (1.26 N)

These results show that the two measurement methods give generally the same ranking orders for the tapes tested. Where there are discrepancies between the two methods these usually occur due to the difficulties in discriminating between the tapes that have similar levels of tack. The methods distinguish the highest and the lowest tapes reliably.

There are a number of differences between the two test methods which are summarised in Table 11 that may account for the discrepancies in ranking. The loop tack test involves a considerably longer dwell time than the standard conditions for the probe tack test. If tapes 1627 and 2566 are considered, probe tack measurements at different dwell times (Figure 9) indicate that the ranking of the two tapes reverses at higher dwell times (above 10 s). If the probe tack tests were reported for 10 s dwell times then the rankings produced by the tests would agree for 1627 and 2566.

Table 11. The practical differences between the loop tack and probe tack methods

	Loop	Probe
Adherend surface	Glass	Stainless steel 304
Adherend roughness	Smooth	280 grit abrasive finish
Contact area	625 square mm	20 square mm (approx.)
Contact pressure	About 0.2 - 5.0 g/ sq. cm	100 g/ sq. cm
Dwell time	Variable, 20 - 30 s	Fixed, 1 s
Speed of separation	5 mm/sec	10 mm/sec

In view of the differences between the two methods, it is not surprising that a range of tapes having different types of adhesive gives slightly different ranking orders. The loop tack method shows similar repeatability to the probe method. However, both methods give a fairly large scatter, so it is essential to carry out a reasonable number of tests to improve data accuracy. Both methods show the ability to discriminate between high and low tack products.

7.2 DISCUSSION OF THE INFLUENCE OF TEST VARIABLES

The Probe Tack Tester allows tack force to be investigated as a function of contact pressure while the other parameters are held constant. The three tapes tested showed increasing tack at higher pressures, and were in accordance with the results reported elsewhere(2,8,24) which suggest that this is a universal trend. Tack is an indication of how quickly an adhesive can wet and come into intimate contact with a surface. Initially, contact is established in isolated spots, and these increase in size and number by flow and wetting. It is to be expected that increasing pressure will increase flow and wetting, giving higher tack. However, the study of the tack of a heat activated adhesive(20) showed that there can be a maximum tack that can be achieved. The adhesive is believed to have fully wetted the surfaces and additional pressure gives no further increase in tack.

Probe tack results on the three tapes tested showed increasing tack with increasing dwell times. Again the results agree with results reported elsewhere. Increasing time of contact would be expected to increase wetting and therefore to always give higher tack (until the time at which full wetting is achieved).

Probe tack measurements carried out to investigate the effects of varying separation speed do not show a universal trend. Other studies have reported increasing tack values with increasing rate of separation for commercial adhesive tapes. NPL tests on tape 2566 showed a similar trend, but the two other tapes tested (1240 and 1627) showed decreasing tack force values with increasing rates of separation. Different types of adhesives were used on these tapes. The influence of separation speed therefore appears to depend on the composition and properties of the adhesive coating, and may also be affected by coating thickness. It may be that different adhesives exhibit different mechanisms of adhesive rupture. Zosel(2,3) has used high-speed photography to examine the deformation of polymers during bond separation. It was reported that polymers with high tack split up into filaments, which are able to store and dissipate a large amount of deformation energy.

The substrate material influences the measured tack force. Finite Element modelling suggests that the stiffness of the backing tape can have significant effects of the results. Higher tack values were predicted with the less-stiff backing tapes. This contrasts with the SATRA/NPL tack tester where stiffer adherends give the highest tack measurement(20). The surface properties of the adherends are also important. Measurements made suggest that glass and steel plates give tack values that differ by 20% for one of the tapes tested.

8. CONCLUSIONS

Adhesive tack is a complex quantity depending significantly on the properties of the adhesive, the adherends, the bonding process and the test conditions. Tack is primarily a visco-elastic phenomenon but rupture behaviour also plays a significant role. This leads to varying dependencies of the measured tack of different types of adhesive on temperature, testing rate, dwell time and contact pressure. Thus tack is not a unique property of the adhesive. Tack measurements should be made under conditions approximating to use.

Three standard test methods have been evaluated. The loop tack and probe tack tests give reasonable agreements in the rankings assigned to the tapes studied in this work. This agreement improves if differences between the methods (such as dwell time) are considered. These tests are suitable for both quality control and adhesive selection or qualification purposes. Both the loop and the probe tack tests normally give similar degree of scatter in the measured data. However, as the round robin exercise demonstrated, the loop tack test can give variable results particularly if the tape lacks stiffness.

The rolling ball test gives significantly different results to the other tests. This test may be used for quality control purposes but is unsuitable for more sophisticated purposes.

9. ACKNOWLEDGEMENTS

The funding for this work from the DTI Performance of Adhesive Joints programme is gratefully acknowledged. Thanks are also due to Abayomi Olusanya, Roger Hunt, Louise Crocker, Jeannie Urquhart, Roger Hughes and Fangzong Hu (NPL), Steve Abbott, Phil Barraclough and Andy Bingham (SATRA) and Richard Roberts (PIRA). The authors also wish to thank all the organisations who took part in the round robin.

10. REFERENCES

1. Goulding, T.M., Pressure Sensitive Adhesives, Handbook of Adhesive Technology, edited by Pizzi, A and Mittal, K.L., New York, Marcel Dekker, 1994.
2. Zosel A. Adhesive failure and deformation behaviour of polymers. *J. Adhesion*, 1989, **30**, 135-149.
3. Zosel A. Adhesion and tack of polymers: influence of mechanical properties and molecular structure. *Double Liaison*, 1991, **38**, [431/432], III-XI.
4. Gay C. and Leibler L. Sticky secrets disclosed, Physics World, March 1999, 5.
5. Johnston, J. Tack: Known by many names, it's difficult to define. I. *Adhesives Age*, 1983, **26**, [12], 34-38.
6. Johnston J. Tack: Probe testing and the rate process. II. *Adhesives Age*, 1983, **26**, [13], 24-28.
7. Johnston J. Physical testing of pressure-sensitive adhesive systems. Handbook of adhesive technology, edited by Pizzi, A and Mittal, K.L., New York, Marcel Dekker, 1994, 93-112.
8. Hammond, F.H. Jr. Polyken probe tack tester. *ASTM Special Technical Publication* No. 360, 123-134.
9. Hammond, F.H. Jr. Tack. Handbook of pressure sensitive adhesive technology, edited by Satas, D., New York, Van Nostrand Reinhold, 1989, 38-60.
10. Roberts R.A., Review of methods for the measurement of tack, PAJ1 Report No 5, September 1997.
11. Olusanya A. and Lay L.A., An instrument for the measurement of "tack" for the footwear industry, NPL Report CMMT(B)91, September 1996.
12. BS 7116: 1990, British Standard Specification for Double sided pressure sensitive adhesive tapes.
13. BS EN 1719 1994, Adhesives - Tack measurement for pressure sensitive adhesives - Determination of loop tack.
14. FINAT Technical Handbook, 4th Edition, 1995. [FINAT stands for Federation International des Fabricants et Transformateurs d'Adhesifs et Thermo Collants sur Papiers et Autres Supports].
15. ASTM D 2979 - 95, Standard Test Method for Pressure-Sensitive Tack of Adhesives Using an Inverted Probe Machine.
16. Testing Machines Inc., New York, USA.11.
17. ASTM D 3121 - 94, Standard Test Method for Tack of Pressure-sensitive Adhesives by Rolling Ball
18. Chuang, H.K. and others. Avery adhesive test yields more performance data than traditional probe. *Adhesives Age*, 1997, **40**, [10], 18-23.
19. Muny, R.P. and Miller, J.A. A new method for measuring pressure sensitive tack. *European Adhesives and Sealants*, 1994, **11**, [1], 7-13.
20. Barraclough P., Study of a range of variables on tack of heat activated adhesives, PAJ1 Report No 9, February 1999.
21. Roberts R.A., Loop tack round robin, PAJ1 Report No 10, February 1999.
22. Hu F., Olusanya A., Lay L.A., Urquhart J. and Crocker L.E., A Finite Element model for the assessment of loop tack for pressure sensitive adhesive tapes and labels, NPL Report CMMT(B)129, PAJ1 Report No 8, August 1998.
23. ABAQUS User Manual, HKS Ltd..
24. Bates, R., Studies in the nature of adhesive tack, *J. Applied Polymer Sci*., 1976, **20**, 2941-2954.
25. Pressure Sensitive Tape Council, Test Methods for Pressure Sensitive Tapes, 1996.