

THE PERFORMANCE OF ADHESIVE JOINTS

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to Visco-Elastic/Visco-Plastic Materials**

Report 8

**A Finite Element Model for the Assessment of Loop Tack
for Pressure Sensitive Adhesive Tapes and Labels**

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Head of Centre for Materials Measurement and Technology

**MTS ADHESIVES PROGRAMME 1996-1999
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**PROJECT: PAJ1; FAILURE CRITERIA AND THEIR APPLICATION TO
VISCO-ELASTIC/VISCO-PLASTIC MATERIALS**

**A FINITE ELEMENT MODEL FOR THE ASSESSMENT OF LOOP TACK FOR
PRESSURE SENSITIVE ADHESIVE TAPES AND LABELS**

F Hu, A Olusanya, L A Lay, J Urquhart, L Crocker

ABSTRACT

Adhesive tack is a common property used in a wide range of industrial applications. However its definition is highly dependent upon the industrial sector describing it. The development of tack is strongly influenced by a number of environmental and experimental parameters. The interaction of these variables leads to difficulties when trying to establish a unifying theory describing tack. A review [1] has highlighted the numerous methods and the related standards available to measure 'tack'. These methods are however mutually incompatible and no relationship between the data obtained by these measurement methods has been established. It is to alleviate the experimental difficulties found in defining the measurement scenario across regional borders that an alternative 'virtual testing' solution was envisaged.

This report describes the preliminary attempts to formulate a finite element model of the loop tack test. This work only forms a small part of the overall work plan, and the concept behind its development was to initiate interest for further studies in this area. Mechanical property data for the pressure sensitive adhesive is entered into the model, i.e. the Young's modulus, shear modulus and Poisson's ratio. The output is a tack force - time curve similar to the experimental procedure. An empirical adhesive-surface interaction parameter is being derived by relating experimental test results to the calculated FEA tack values with the surface energies of the adherends. Currently the model predicts the shape of the loop during the tack test correctly. This model gives an insight into the effect of the backing material on the tack- force. It has been found that to analyse all of the physical behaviour occurring in the loop tack test, the adhesive would have to be represented by special user elements. These elements would have a variable contact pressure-clearance relationship. Investigation into the derivation of such elements is now under investigation. Establishment of a model that adequately represents loop tack will aid the conversion of data across measurement techniques.

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1. INTRODUCTION

Tack is a common parameter across a wide range of industrial applications and its definition is highly dependent upon the industrial sector describing it. Physically the development of tack is strongly influenced by a number of parameters. The most important of these are: the adhesive, the contact load, the dwell time, the adherend, temperature and the humidity. The interaction of these variables leads to difficulties when trying to establish a unifying theory describing tack. As part of this programme of work, a review of the industrial methods for determining tack for pressure sensitive adhesives, PSA's, has been carried out [1]. This review has highlighted the numerous methods and the related standards available to measure 'tack'. Tack measurements made using different industrial methods are generally not comparable. Even standard methods tend to be incompatible, for instance, the PSTC (Pressure Sensitive Tape Council) loop tack test gives tack results some 20% lower than the FINAT, Fédération International des Fabricants et Transformateurs d'Adhésifs et Thermocollants sur Papiers et Autres Supports, method for the same PSA. This difference is due to the different materials, glass-FINAT, stainless steel-PSTC for the 'standard' adherend plate. The same problems are found for alternative tack tests, for example, the PSTC and AFERA (Association Des Fabricants Europeens De Rubans Auto-Adhésifs for Europe) probe tack tests also give a different values of tack for similar adhesives [2].

Project PAJ1 is attempting to clarify the measurement of tack through developing a better understanding of the critical test parameters. It focuses on the loop tack test. One objective is to establish techniques to compare data obtained from different methods. As an aid to understanding the processes which are occurring in the loop tack test a 'virtual testing' solution has been developed. This report describes the preliminary attempts to formulate a finite element model of the loop tack test.

2. BACKGROUND

Loop tack is defined as the force required to separate, at a specified speed, a loop of adhesive coated material that has been brought into contact with a specified area of a defined surface. In the FINAT method for measuring loop tack, a strip of material 25 mm wide and at least 175 mm long is formed into a loop and brought into contact, for an area of 25 mm², with a glass plate at 300 mm min⁻¹ and then separated at the same speed. Adhesive tack is a complex function of a number of properties which include; the compliance of the tape which supplies the effective contact force, the flow properties of the adhesive, the surface energy of the adhesive and the adherend, a surface interaction parameter, the rate of separation, angle of separation (peel angle), temperature, humidity, etc. A round robin exercise co-ordinated by PIRA International (the Packaging Industries Research Association) [3] has been investigating the reproducibility and repeatability of the FINAT [1] loop tack test with fifteen industrial participants.

Three adhesives were distributed which were designated by the manufacturer to exhibit low, medium and high tack.

Preliminary results indicate that only 50% of the participants were able to rank the adhesives correctly, Table 1. Difficulties that arose in testing included; the manipulation of the test material, variable response of the test material and the response of the test equipment. All these factors effect the accuracy and precision of the test. Despite these qualifications, the loop tack test remains a popular method for qualitative measurement, providing a basis for ranking adhesives within an organisation, being cheap, easy to use and set-up. Frequently ‘in-house’ testing is not carried out strictly in accordance with the FINAT procedures but with a ‘local’ procedure which ‘suits’ the product and the local application. It is due to these experimental difficulties that an alternative ‘virtual testing’ solution seems appropriate to aid the understanding of the physical test results.

Table 1 compares some of the data from the round robin exercise managed by PIRA [3] to the results from the FE model.

| Test House | Tack Force (N) | |
|--------------------------|------------------------------------|--------------------------------|
| | Polypropylene 1240 0.5 mm thick | Polyester 1627 0.1 mm thick |
| NPL | 23.00 ± 2.83 | 14.80 ± 0.65 |
| PIRA | 17.19 ± 2.40 | 12.69 ± 0.31 |
| A | 18.60 ± 2.00 | 14.60 ± 0.79 |
| B | 20.38 ± 2.18 | 11.83 ± 1.02 |
| C | 11.64 ± 3.51 | 12.96 ± 0.94 |
| D | 28.13 ± 7.36 | 19.85 ± 3.1 |
| E | 12.20 ± 2.66 | 12.80 ± 0.87 |
| F | 10.99 ± 0.68 | 13.38 ± 1.44 |
| G | 20.80 ± 0.87 | 13.10 ± 1.21 |
| Average Test Data | 18.10 ± 2.72 | 14.00 ± 1.15 |

Table 1: Comparison of loop tack values from experimental tests [3]

The variation in the experimental results can be seen in Table 1. As discussed previously the variation in the tack value from the FE analysis can be reduced by increasing the elements in the contacting zone. Further details of the backing material’s properties are required and the model has to be modified to take into account measured adhesive properties.

3. EXPERIMENTAL

The data for input into the FEA model was measured using in-house equipment. The basic test device was similar to that employed to develop the NPL/SATRA hot tack tester [4]. A Mecmesin M2500 motorised test stand was used to drive the loop of tape in the vertical direction. The stand had a maximum speed in the vertical plane of $\pm 500 \text{ mm min}^{-1}$. The speed of the test stand was set to 300 mm min^{-1} to comply with the FINAT standard. The force applied by the tape loop and the detachment force was measured by a Mecmesin AFG-50N force gauge. This gauge has a range of $\pm 50\text{N}$ with a resolution of 0.01N.

Adhesive tapes, crepe masking tape Code No. 2566, polyester splicing tape, Code No. 1627 described as “a film with a heavy coating of a specially formulated silicone adhesive”. The adhesive is approximately four times thicker than that of conventional tapes” and a clear polypropylene packaging tape, Code No. 1240, described as “coated with a high adhesion pressure sensitive adhesive” were sourced from Scarpa Tapes. The PSA’s that were sourced from Scarpa Tapes were:

The adhesive tape 175 mm x 25 mm was formed into a loop with 10 mm at either end drawn together and clamped. The acetone/alcohol cleaned glass plate was fixed into position and the test was ready to commence. It was found that after storage of the tape for any period of time, in order to maintain consistency in the measured tack force the initial metre of tape off the roll was discarded. It is assumed that the penetration of moisture into the tape occurs over time which results in this initial portion of the tape exhibiting large variation in tack.

Bulk storage of tape samples in a controlled environment e.g. dessicators, is impractical at the present time, however an elaborate controlled storage and test environment is planned if further work is carried out on tack measurement. The resultant output of this test is a force-time curve showing the detachment force or tack of the PSA/adherend combination. The experimental equipment is shown in Figure 1.

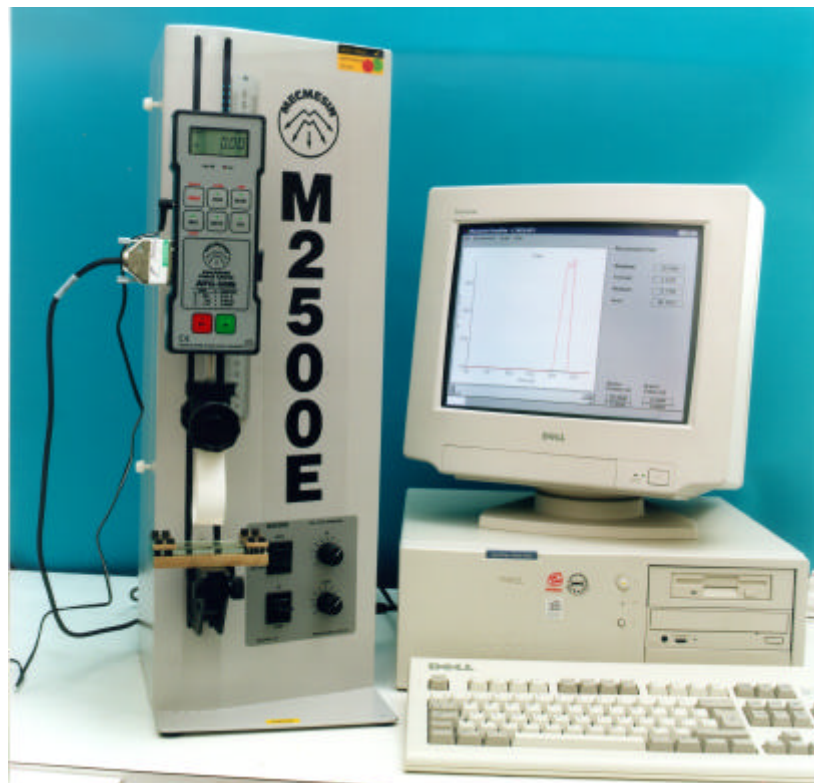


Figure 1:NPL Loop Tack Testing Equipment

The output of the test, tack force - time data can be collected from the force gauge by a number of methods. It was observed that the method used to collect data affected the values recorded. This variation in data was traced to the response time of the recording equipment verified by the connection of multiple collection devices, a chart recorder, and a computer to the data logging AFN-50N force gauge. It was found in general that;

- i) data from the chart recorder was on average 2% lower than that captured on the force gauge
- ii) data captured by the data-plot software was 3% lower than the chart recorder.

The response of the force gauge is 1200 samples s^{-1} , the chart recorder is of the order of 800-1000 s^{-1} and the data-plot software is 20 samples s^{-1} . This effect of recording method needs to be taken into consideration when comparing results across test houses. Data recording devices that have sampling rate comparable with the AFN-50N force gauge will give the most reliable records.

A typical tack plot using Mecmesin's proprietary computer aided data logging system is shown in Figure 2. The contact pressure is not registered by the dataplot or chart recorder systems and has only been registered by using the AFN-50N force gauge and is only 0.2N. This value is at the measurement limit of the force gauge.

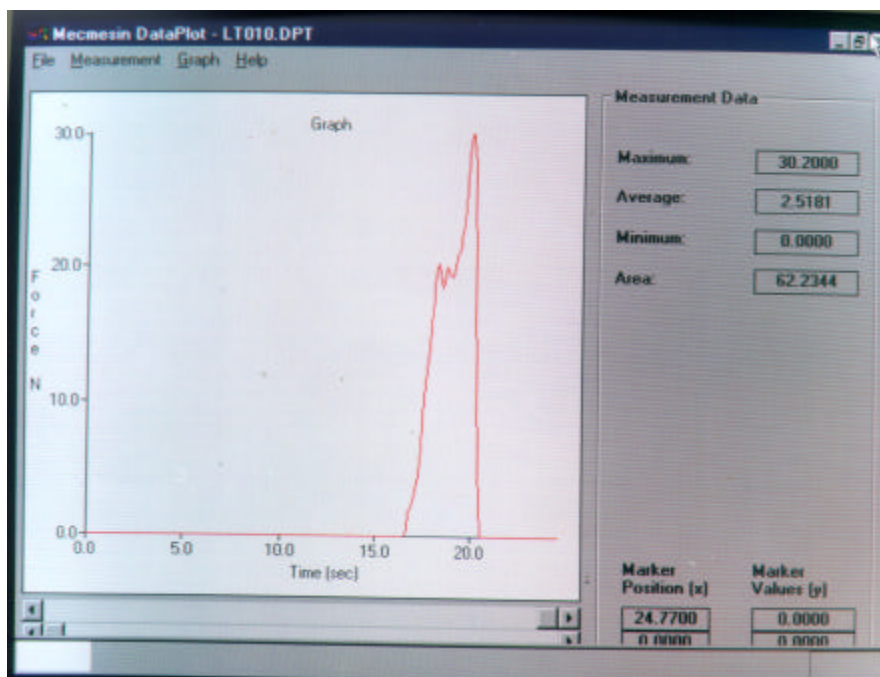


Figure 2: A typical force-time curve showing the tack of a PSA using Mecmesin's dataplot software.

4. THE FINITE ELEMENT MODEL

Finite element modelling has been used to represent the tape material with the adhesive layer being modelled using a contact relationship with the adherend. The mechanics of the loop tack test has been broken down into a number of stages. This approach highlights four key stages in a loop tack test:

- i) formation of the loop. The length of adhesive tape is formed into a loop by clamping the final 10 mm of tape. The shape of the loop formed is mainly dependent upon the compliance of the carrier material. It is this compliance that determines the effective load when the loop is brought into contact with the adherend.
- ii) the loop is lowered at 300 mm min^{-1} and brought into contact with the adherend, a clean glass plate. The rate at which the adhesive bond is created is dependent on the rheological (flow) properties of the adhesive and the compatibility between the adhesive and the surface. The loop continues downwards until 25 mm^2 of the loop is in contact with the adherend and then the direction is reversed. The contact time is dependent upon the compliance of the backing tape.
- iii) the direction of the loop is reversed and the adhesive detaches itself from the adherend. This detachment force is measured and the peak value is regarded as a measure of the loop tack of the tape.
- iv) the loop is detached from the adherend.

These four steps, loop formation, clamping of the tape ends, compression of the loop onto the adherend and the detachment of the loop are shown in Figures 3a to 3d.

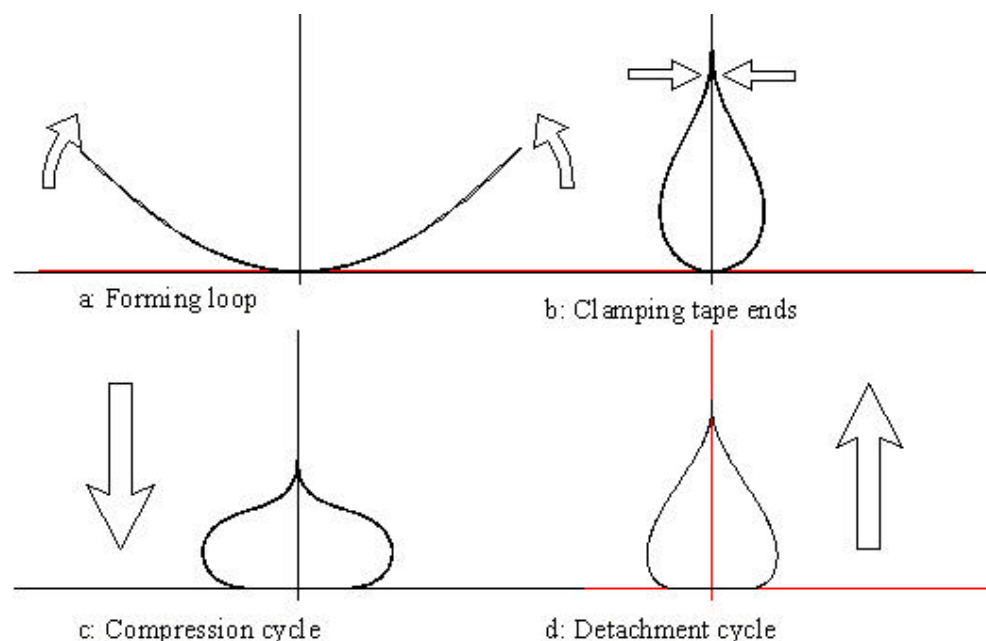


Figure 3a-3d: Schematic of the basic steps in a loop tack test

To verify this sequence of events a typical loop tack test was recorded onto video tape. This recorded sequence was converted to a digital format suitable for playback on a PC (Microsoft AVI, Apple Quicktime). The FE sequence was also converted to a similar format. The two 'digital sequences' were then compared. The correlation between the shape of the model and the test material was very good. A demonstration CD-ROM is to be made available that contains these digital sequences for review on request.

5. FINITE ELEMENT MODELLING RESULTS

For modelling purposes the PSA tape is represented using a 2 node linear, in plane beam elements. A beam element is a one-dimensional element in three-dimensional space. Beam theory is a simplification that allows a three dimensional continuum to be represented in one dimension. Elements of this type have a stiffness associated with the deformation of the beam's axis in the X-Y plane. The deformations can be axial stretching, bending and in space (3D), torsion. Further discussion of beam elements and associated theory can be found in the ABAQUS/Standard User's Manual Volume II [5].

For the initial formation of the loop, the response of the beam is determined by a number of factors, the area of the section, the moments of bending about the two axes of the section, the moment of bending for cross-bending, which for this model is zero and the torsional rigidity. Mechanical property data for the PSA is also required such as, the Young's modulus, shear modulus and Poisson's ratio. In the current FEA model all these mechanical properties relate solely to the backing material. The mechanical property data was sourced from the Goodfellow materials catalogue 1997/98 [6] with a typical value of Poisson's ratio for elastomers, 0.37, being used. A major problem with the mechanical property input data of the carrier material is the variance due to the method of manufacture. For example, the quoted Young's modulus for high density polyethylene ranges from 0.5 - 1.2 GPa. and for cellulose acetate, 1 - 4 GPa. The Young's modulus data quoted for polypropylene, ranges from 0.9 - 1.5 GPa. for an extruded material, to 2.2 - 4.2 GPa. for a biaxially blown film. In the further development of the FE model the modulus of the tape will be measured directly at a rate equivalent to the loop tack test.

The current model does not have an element set relating to the 'adhesive', the adhesive contact between the tape and the adherend is represented using the *SURFACE BEHAVIOUR subroutines in the ABAQUS FEA solver. This routine requires the input of a pressure parameter which defines how well the two surfaces combine during contact. Initially an arbitrary value for this pressure is chosen and then modified to match the experimentally derived tack force. Currently the same contact pressure is used for all backing materials i.e. the same adhesive, however in reality we have been unable to source any products which have the same adhesive but different backing materials.

The loading of the loop is achieved by moving the loop on to the contacting surface at 300mm min^{-1} where the compliance of the backing material transfers this load to the adherend. Figure 4 shows a representative tack force - time curve for the FEA model using the material properties of polypropylene.

Typical values of tack obtained in NPL loop tack tests were 23.0 N for a contact force of approximately 0.2N, Table 1. The oscillation of the FE results are due to the release of energy when the contacting node of the tape breaks from the contacting node of the adherend (in ABAQUS terminology, “master/slave surfaces”.) This oscillation is an artefact of the finite element method. The magnitude of this oscillation can be reduced by increasing the nodes in the contact zone. Of course, in reality the detachment of the adhesive from the adherend is a continuum process. An estimate of the tack force calculated by the finite element analysis can be obtained by taking the average of the displayed tack force - time data.

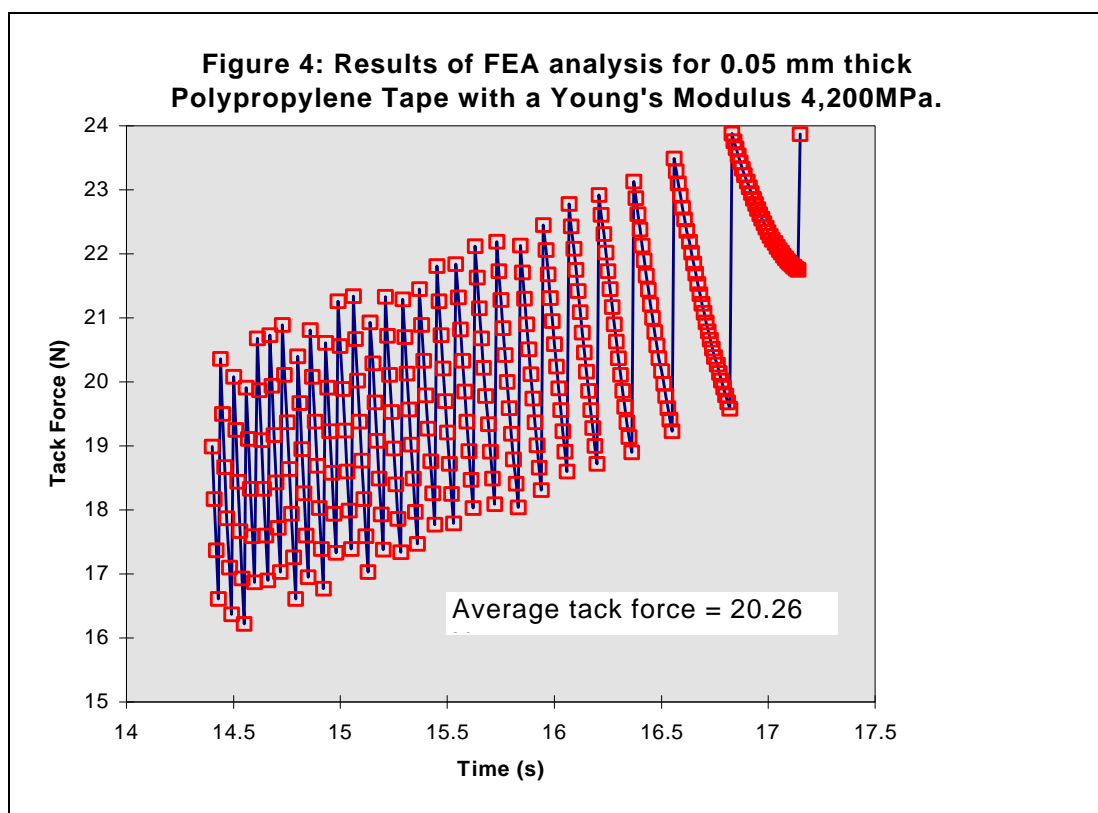


Figure 5 shows the relationship between the average tack force and tape thickness for range of carrier materials. This shows that as the tape thickness increases the tack force for the standard FE adhesive decreases. This simulates the opposing effects of contact pressure and flexibility of the adhesive carrier e.g. for a stiffer adherend the contact pressure at any point will be higher but its ability to form a loop and spread the adhesive across the surface is reduced, thus a lower tack force is observed. In practise this effect may be masked by the adhesive’s flow characteristics, the degree by which the adhesive is able to ‘wet’ the adherend will then be the critical factor which determines the tack force.

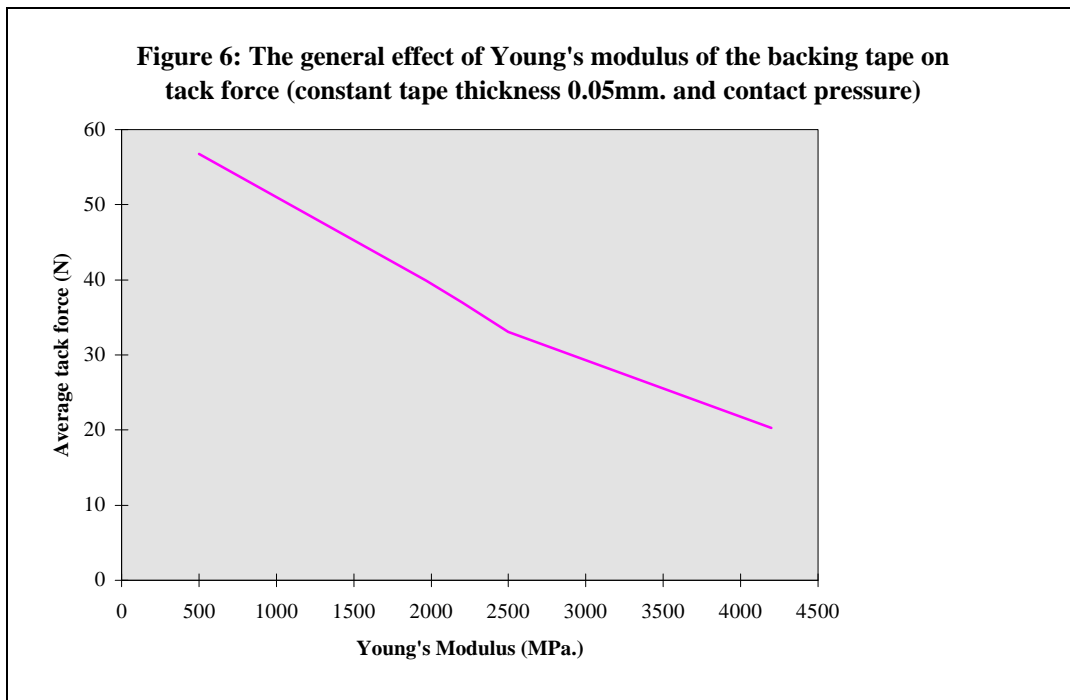
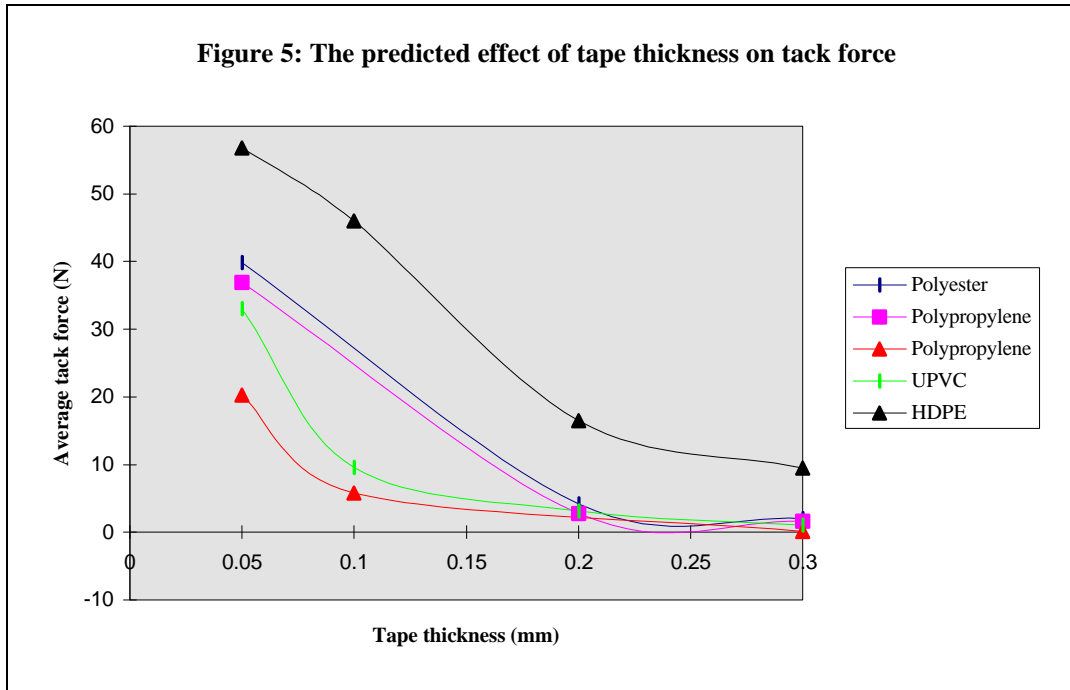


Figure 6 shows the general relationship between the predicted tack force and Young's modulus for range of carrier materials showing that increasing the stiffness of the material lowers the tack force for a specific adhesive ignoring the flow characteristics of the adhesive.

At the present the model described in this report does not include an element layer that corresponds to the adhesive but simulates the adhesive by use of a *SURFACE BEHAVIOUR routine from the ABAQUS finite element solver.

Future developments of the model will use an element layer which corresponds to the adhesive and will allow the input of physical property data such as the rheological properties for the adhesive and the variance of tack force with contact pressure. This latter physical manifestation of tack requires the generation of a special set of finite elements, so-called user defined elements as none of the 'standard' elements supplied in the ABAQUS system are capable of such a response. The generation of elements which have such a relationship is being investigated and will be reported in another document.

6. CONCLUSIONS

This FEA model is the initial attempt at modelling a complex experimental system. The geometry of the tack test has been successfully described by the FE model. Getting the shape of the loop correct enables the determination of the dynamic peel angle at the adhesive-adherend interface thus allowing the resolution the peel forces as the loop is removed from the surface. A relationship between the tack force and the physical properties of the backing tape has been shown by the model. The response of the adhesive is based on defining a contact pressure within the FE code. To analyse all of the physical behaviour occurring in the loop tack test the adhesive would have to be represented by special user elements which have a variable contact pressure-clearance relationship [7]. The alternative arrangement that of establishing an adhesive/surface interaction factor provides a route for the conversion of results by use of a look up table to provide the relationship between contact pressure and tack force. The capability to model tack in this way will allow conversion between the different measurement standards. The requirement for material data for input into the model has highlighted the wide range of mechanical properties displayed by the materials used to make pressure sensitive tapes and labels. The large coverage of physical property data by any one material and the relationships highlighted by the FE model would seem to indicate that the tack values may be altered by the simple expedient of altering the batch of backing material assuming compatibility of the adhesive with the application.

Development of models such as these will enable the manufacturer to tailor his products to suit specific applications and go some way to solve the variation in tack values obtained by the numerous testing methods.

It is noteworthy that one of the driving forces to develop a FE model was to reduce experimental error in testing, however there is now a need to source materials property data from products made by differing manufacturing routes. It is hoped that further development of this model can be achieved in a subsequent project.

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