

Test Methods for Determining Hyperelastic Properties of Flexible Adhesives

Summary

Finite Element Analysis (FEA) is used extensively in the design of structures and sub-components. Accurate predictions of component properties require both suitable material models and accurate material properties data. Highly extensible materials, such as flexible adhesives, cannot be accurately modelled using conventional elastic-plastic material models. These materials require the so called Hyperelastic models [1]. The classical Mooney-Rivlin model is an example of a Hyperelastic model that is implemented in FEA packages such as ABAQUS [2].

Accurate modelling of Hyperelastic materials requires material properties data measured to large strains under different states of stress. In Hyperelasticity the strain energy density is modelled as a function of the deviatoric (shear) and volumetric components of the strain tensor. A common assumption made, particularly for rubbers, is that the material is incompressible. Therefore, the volumetric terms can be set to zero. Only the shear terms need be considered. However, this assumption may not strictly hold for all flexible materials.

Test data are required under conditions of plane stress (uniaxial tension), plane strain (planar tension) and equi-biaxial stress (equi-biaxial tension) in order to accurately model the Hyperelastic materials under multi-axial states of stress. These techniques are only referred to briefly in the FEA manuals. Therefore NPL have developed test methods for obtaining reliable input data for Hyperelastic modelling [3]. The cure state of the bulk test specimens used to obtain the mechanical properties data should be similar to that of the adhesive in the bonded structure. Cure schedules should be selected to ensure that the thermal history of the materials are similar in each case. Dynamic Mechanical Thermal Analysis (DMTA) measurements can be made to compare the state of cure of the materials.

B.C. Duncan

October 1999

The Uniaxial Tension Test

The low stiffness and large potential extensions of uniaxial test specimens of flexible adhesives preclude the use of conventional, clip-on extensometry (or strain gauges) for the measurement of strain. Instead, non contacting strain measurements must be made.

Video extensometry is the obvious choice for determining the large strains in flexible materials. Key to obtaining reliable data is a sharp contrast between the gauge mark and the background (Figure 1). Changing contrast levels can be read erroneously as strain. Therefore, uniform illumination is critical. Further problems may occur if the colour of the specimen changes at high strains (e.g. through stress whitening caused by the formation of crazes). The specimen surface can be painted white to overcome this and to improve contrast.

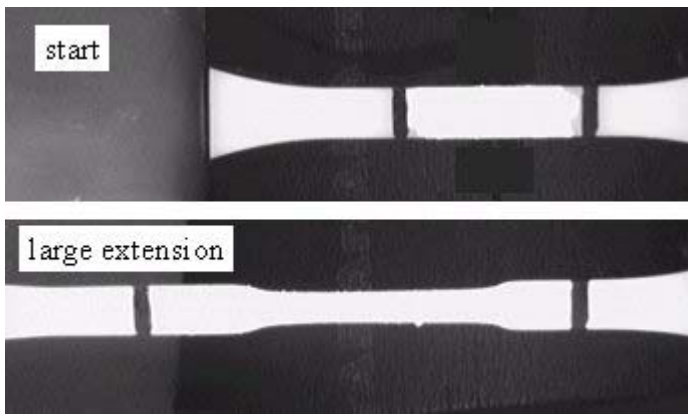


Figure 1: Video extensometry can be used to measure both tensile strain and transverse contractions at large extensions. For example this allows the study of necking behaviour.

Modern video extensometers are versatile instruments capable of simultaneously measuring strains in perpendicular directions. This enables determination of Poisson's ratio. However, the video extensometer strain measurements may be less accurate at low strains than conventional clip-on techniques. Part of the reason for this may be bending of the specimen as the low loads are applied. This will be seen as strain by the video extensometer. Averaging measurements from both faces of the specimen to correct for this is not usually possible with video extensometry. Accuracy could be improved by applying small pre-loads prior to testing.

Planar Tension Test

The planar tension test imposes plane strain conditions on the test specimen by preventing the edges of the specimen from contracting. This is achieved through the use of test specimens with high aspect ratios (large width to length). In the current work, 200 mm wide specimens were clamped with a grip separation of 40 mm using the wide grips shown in Figure 2.

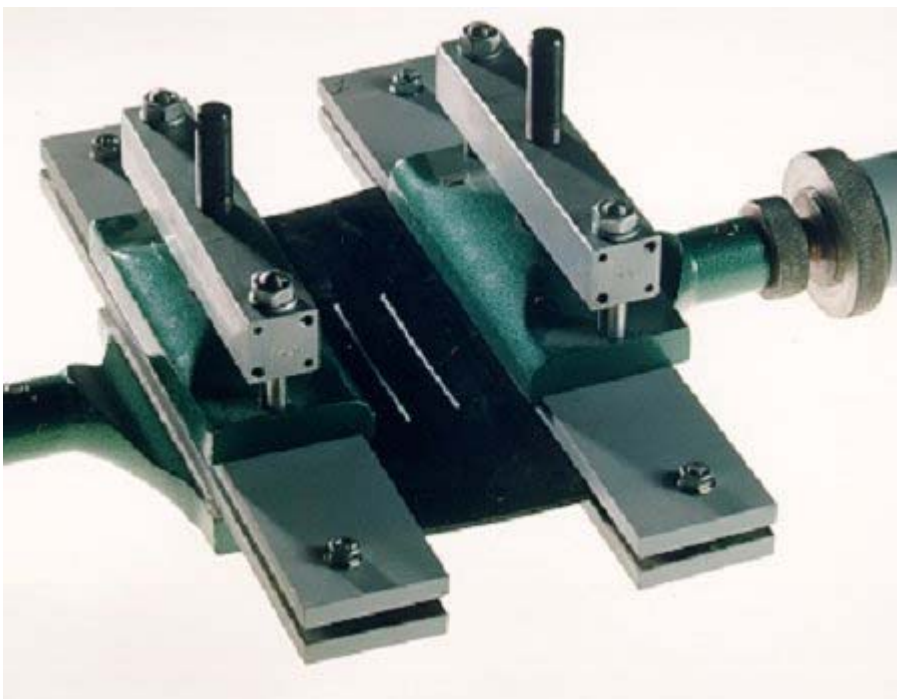


Figure 2: Wide grips and small gauge length impose a plane strain state on the planar tension test specimen.

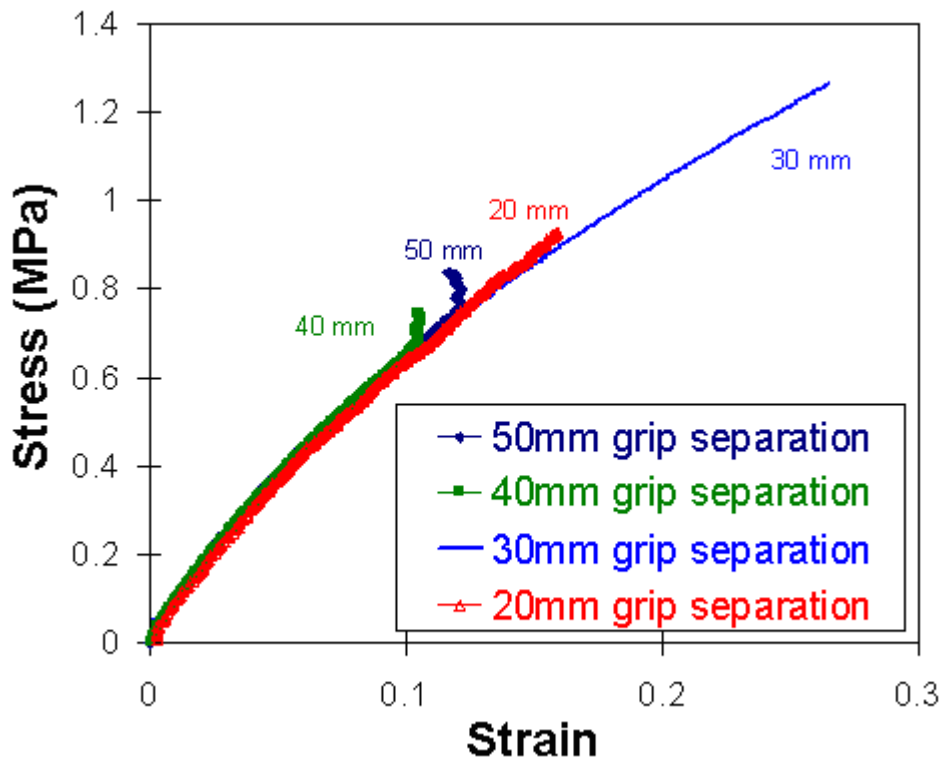


Figure 3: The planar test results are relatively insensitive to the grip separation.

Strains are determined from the extensions of two contrasting gauge marks on the specimen surface using video extensometry. Tests confirmed that plane strain conditions are achieved in the test specimen. As [Figure 3](#) shows, the stress-strain behaviour is essentially independent of the grip separation. Strain measurements made orthogonal to the extension confirmed that lateral strains were minimal.

Biaxial Tension Test

Biaxial tension is produced through deforming a specimen simultaneously in two directions. Mechanical testing machines with two independent axes are rare in test laboratories owing to their expense. A test fixture has been developed to enable the performance of equi-biaxial tension measurements in uniaxial test machines ([Figure 4](#)).

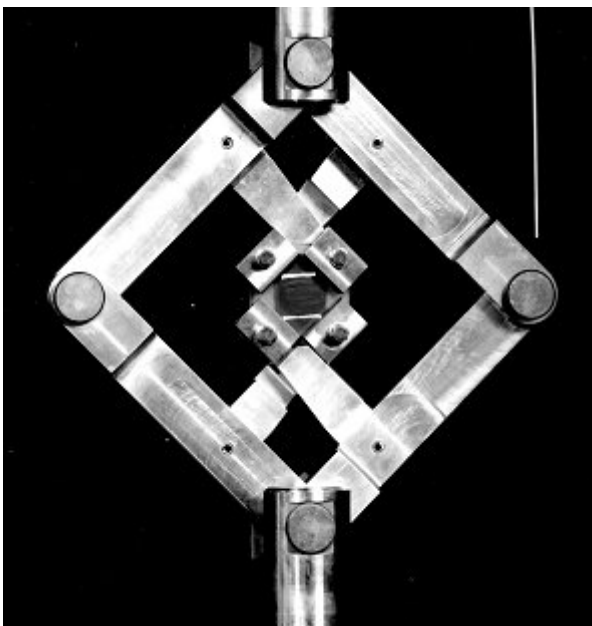


Figure 4: Biaxial test fixture.

The test fixture consists of pivoted scissor arms that resolve the machine crosshead movement into extension of the test specimen at $\pm 45^\circ$ to the axis of the test machine. The total force measured on the pull rod of the test machine can be resolved into biaxial components through a geometrical correction factor. Strain is measured (using video extensometry) from the extension of two gauge marks in the axis of the test machine. In equi-biaxial tension this strain is equivalent to the biaxial strain.

Measurements were made that demonstrated the biaxial nature of the strain in the centre of the testpiece. FEA analysis of the test specimen also proved that the stress and strain distributions in the centre of the specimen were equi-biaxial. However, there are stress concentrations at the corners of the specimen where failure will initiate (Figure 5).

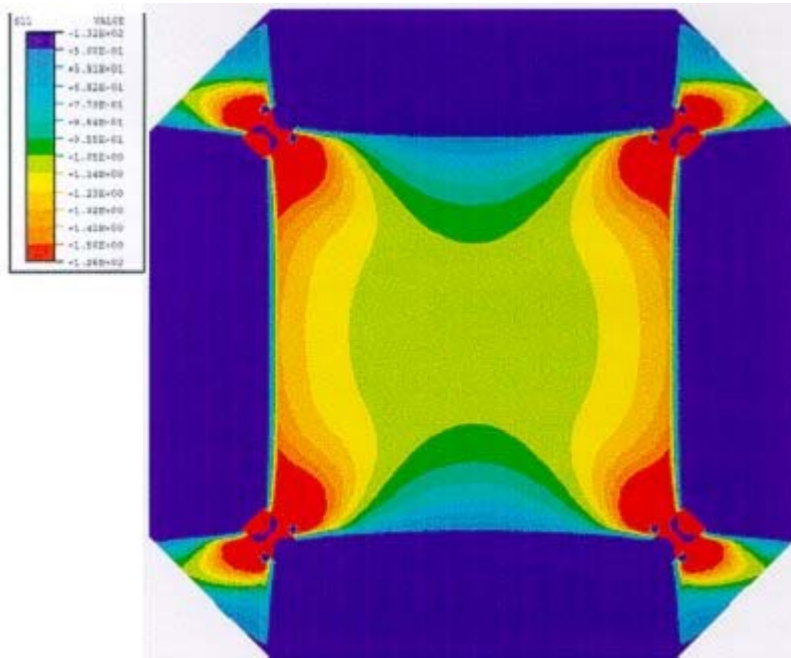


Figure 5: FEA of stress distribution in the biaxial specimen.

Hyperelastic Properties

FEA programmes such as ABAQUS use least squares fitting routines to calculate the model coefficients that describe the Hyperelastic behaviour. The accuracy of the model can be tested through single element tests (Figure 6). Poor agreement between the model and the test data may indicate that the model chosen is unsuitable. The accuracy of the model may sometimes be improved by restricting the range of the input data.

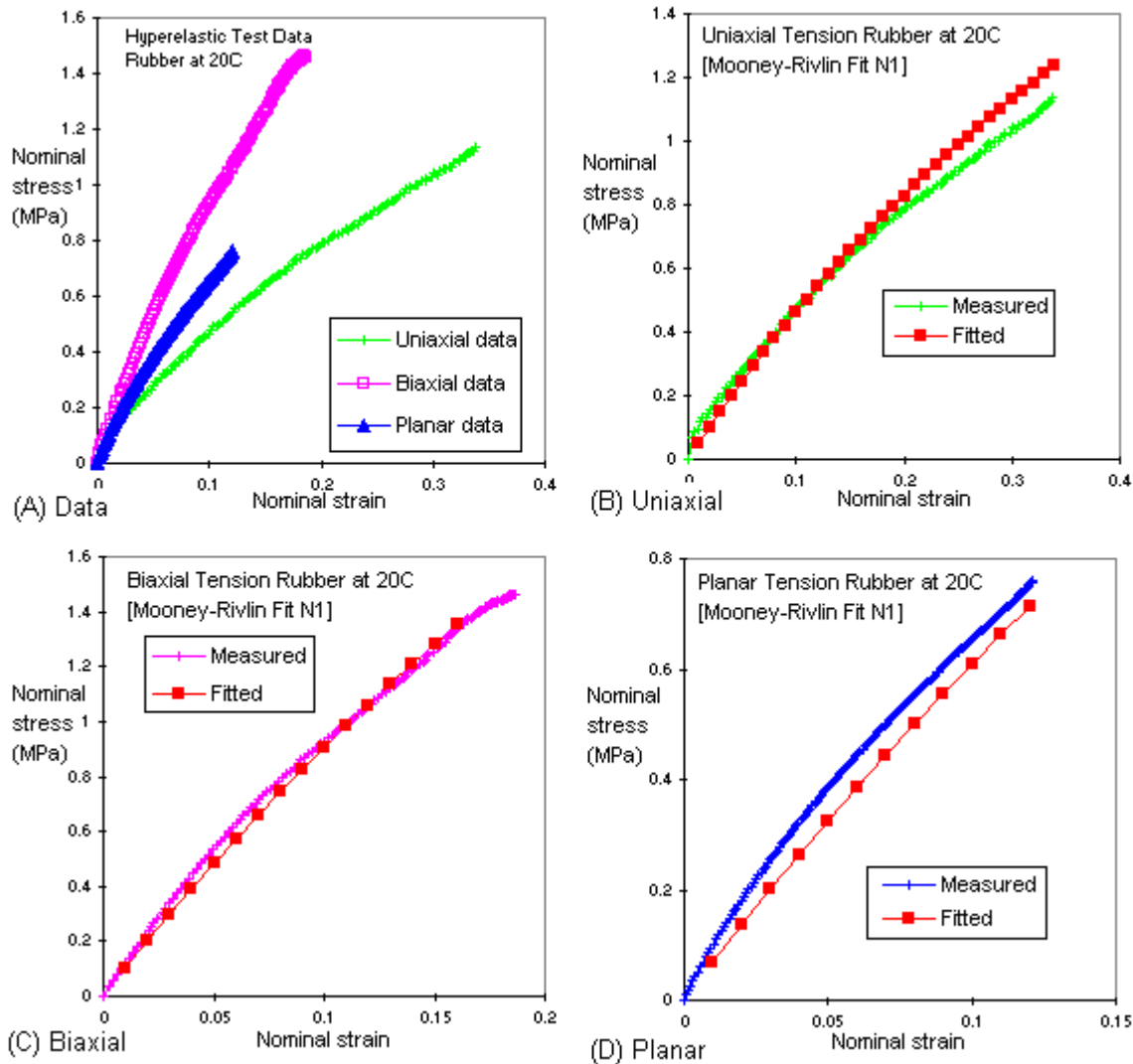


Figure 6: Hyperelastic data for a flexible material.

Concluding Remarks

The behaviour of flexible adhesives is described by different material models to those used for structural adhesives. Therefore, characterising flexible adhesives requires different measurement techniques.

- The uniaxial test combined with video extensometry can produce accurate stress-strain and Poisson's ratio data at large extensions.
- Uniaxial tension, planar tension and equi-biaxial tension test data are needed to characterise Hyperelastic behaviour. Test methods for these properties have been established.
- A fixture for performing equi-biaxial tension tests has been developed. Validation studies confirm the equi-biaxial nature of the stress and strain states in the centre of the specimen.
- FEA software can calculate model coefficients from least squares fits to this data for use modelling the joint performance. Checks should be made on the quality of the agreement between the derived material models and the input data.

Materials such as flexible adhesives are likely to have strain rate and temperature dependent properties. Tests for characterising the properties for the Hyperelastic models must be carried out at the same temperature and at comparable strain rates.

Acknowledgements

This measurement note was prepared as part of a project on the *Performance of Adhesive Joints*, a programme of underpinning research financed by the Engineering, Automotive and Metals Division of the DTI. The assistance of Roger Hughes, Tony Maxwell, Louise Crocker, Jeannie Urquhart, Fangzong Hu and Abayomi Olusanya (all NPL) is greatly appreciated.

References

1. Crocker, L.E., Duncan, B.C., Hughes, R.G. and Urquhart, J.M., Hyperelastic Modelling of Flexible Adhesives, NPL Report No. CMMT(A)183, May 1999.
2. ABAQUS/Standard User and Theory Manuals, Version 5.8, HKS Inc, USA, 1998.
3. Duncan, B.C., Maxwell, A.S., Crocker, L.E. and Hunt, R.A., Verification of Hyperelastic Test Methods, NPL Report No. CMMT(A)226, October 1999.

For further information contact:

Bruce Duncan
Centre for Materials Measurement and Technology
Tel: 020 8943 6795
Fax: 020 8943 6098
Email: Bruce.Duncan@npl.co.uk

Experts [Link to Expert](#)

National Physical Laboratory
Queens Road
Teddington
Middlesex
United Kingdom
TW11 0LW

Tel: 020 8977 3222
Fax: 020 8943 6458
Email: materials@npl.co.uk

CMMT(MN)054
Test Methods for Determining Hyperelastic Properties of Flexible Adhesives
October 1999