FEA of Adhesive Joints

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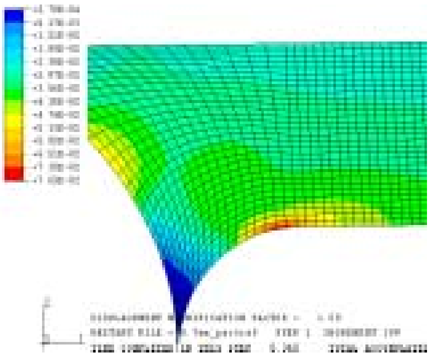
Photograph of lapjoint showing the adhesive yielding and cracking around adherend end radius



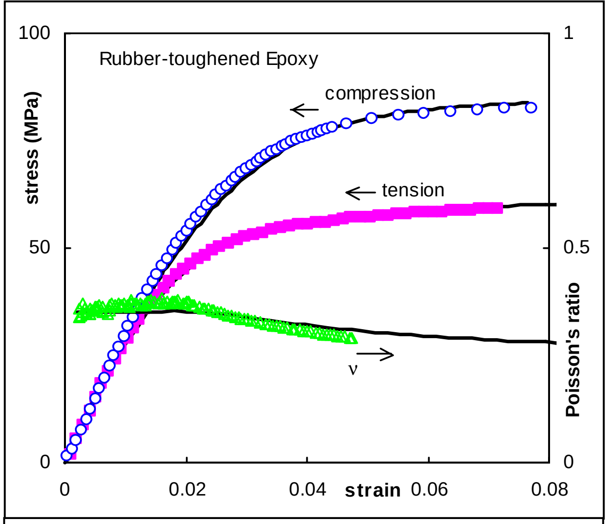
Contour plot of lapjoint adhesive layer showing a peak in maximum principal strain around the radius at the end of the adherend

The NPL Materials Centre, through the DTI 'Performance of Adhesive Joints' research programme has extensive experience of finite element analysis (FEA) for predicting the performance of adhesive joints. Commercial FEA software packages (such as ABAQUS) and accurate materials properties data enable the prediction of stress and strain distributions within adhesive joints. Analyses locate regions of stress and strain concentration in the adhesive that are sites for failure initiation. For instance the photograph (top right) shows a crack growing around the adherend radius in the region where the maximum principle strain is highest in the FE contour plot (right).

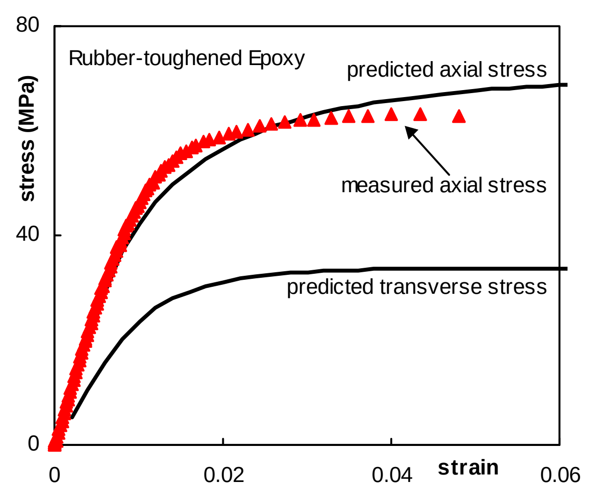
With a suitable failure criterion for failure of the adhesive, the point where a joint will fail under loading conditions such as impact or fatigue can be predicted. High accuracy is needed in the calculated stress and strain levels in the regions where failure initiates, requiring a valid material model and reliable test data.

Toughened adhesives sustain large strains before failure and their behaviour is highly non-linear, involving plastic deformation and flow. The large strain properties of rubber-toughened adhesives can be modelled using elastic-plastic material models. At NPL, various elastic-plastic material models have been evaluated through FEA and experimental tests on different adhesive joint types.

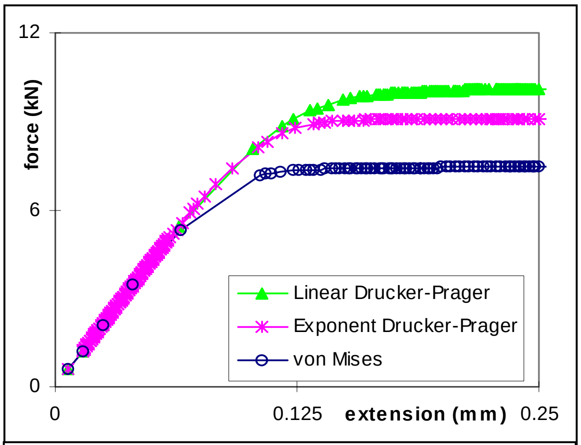
The most commonly used model is based on the von Mises yield criterion. However, our tests on specimens under tension, shear and compression show that the von Mises criterion does not accurately describe adhesives where plasticity is sensitive to the hydrostatic component of stress as well as the shear component. Hence, yield criteria that allow for hydrostatic stress sensitivity, such as the linear and exponent forms of the Drucker-Prager materials model need to be used for rubber-toughened adhesives. In both these models calculations of stress and strain distributions at low strains are based on the theory of linear elasticity. The onset of non-linearity in a stress-strain curve is due to plastic deformation and occurs at the first yield stress. The subsequent increase in stress with strain is associated with the effects of strain hardening. The two Drucker-Prager models differ in the form of yield criterion employed. In analyses of a lap joint (right) the three material models predict different plateau stress values. The plateau stress of the von Mises model is far below both the Drucker-Prager model predictions. The model parameters were determined from samples prepared and tested at NPL.



Comparison of experimental and predicted data for tension and compression tests



Comparison of experimental and predicted data for a butt tension test



FE analyses of a lap joint using three different materials models

Even materials models that include a dependence of yield behaviour on the hydrostatic stress component (e.g. linear Drucker-Prager) are not able to describe the non-linear behaviour of adhesives in certain joint configurations (e.g. butt joint). Where there is a significant component of hydrostatic stress, yielding is associated with the formation of microvoids by cavitation in the rubber toughening agent.

NPL is developing a modified yield criterion to describe the non-linear behaviour of rubber-toughened adhesives, allowing for the effects of cavitation. Preliminary analyses have been encouraging. Predictions using the new model compare well with experimental results under different states of stress (left). Other applications where NPL has developed greater understanding of measurement and modelling requirements for predicting non-linear behaviour of polymeric materials include the performance of flexible adhesives and impact simulation of plastic parts. NPL has test procedures for determining the material properties of adhesives needed for FEA.

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