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Modelling of damage initiation mechanism in rubber sheet composites under the static loading

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Analysis and modelling

ABSTRACT

Purpose: Modelling – Finite Element Analysis (FEA) of the damage initiation mechanisms in thin rubber sheet composites were carried out under static solicitation at room temperature. Natural rubber vulcanised and reinforced by carbon, NR is used in this study.

Design/methodology/approach: Experimental results were compared with that of the Finite Element Analysis (FEA). Damage mechanism has been described with a threshold criterion to identify the tearing resistance, characteristic energy for tearing (T) and damage in the specimens was evaluated just at the beginning of the tearing by assuming large strain. Typical specimen geometry of thin sheet rubber composite materials was considered under static tensile tests conducted on the smooth and notched specimens with variable depths.

Findings: This stage of this research, a finite element analysis (FEA) has been applied under the same conditions of this part in order to obtain the agreement between experimental and FEA results. The numerical modelling is a representation of a previous experimental study. The specimen is stretched more than once its initial size, so that large strains occur. A hyper elastic Mooney-Rivlin law and a Griffith criterion are chosen.

Practical implications: A tearing criterion was suggested in the case of simple tension conditions by assuming large strain. In the next step of this study, a finite element analysis (FEA) will be applied under the same conditions of this part in order to obtain the agreement between experimental and FEA results.

Originality/value: This study proposes a threshold criterion for the damage just at the beginning of the tearing for thin sheet rubber composites and gives a detail discussion for explaining the damage mechanisms. Comparison of FEA results with those of experimental studies gives many facilities for the sake of simplicity in industrial application.

Keywords: Finite element analysis; Rubber composites; Damage mechanism; Static solicitation

1. Introduction

Considering a natural rubber (NR) in static tensile loading, the applied stress is increased sufficiently high and evidently a tearing will begin to develop from a stress-raising defect, frequently in one edge, and eventually it reaches the other side, breaking the specimen in two pieces [1-5]. Griffith's theory of fracture of an elastic solid indicates that a crack, once started, will grow forward rapidly, because the strain energy released by growth increases continuously as the crack grows. But, in practice, the crack often takes a surprising deviation path, especially in the initial stages. It turns sharply into a direction parallel to the applied stress (sideways), instead of going forward, and grows for some distance in this unexpected direction before coming to a halt. When the applied stress is increased further, a new crack tip appears, pointing in the forward direction, but again it quickly turns sideways, parallel to the applied stress, grows for some distance in this direction, and then stops. This process may be repeated several times before a crack forms that grows across the specimen and breaks it in two pieces [6-15].

Design and chose of an elastomeric material for a specific usage requires determining precisely the mechanical behaviour of this material. This determination includes four-step processes. First one has to find the models that are able to fit with the ranking of materials. This step is based on a bibliographic study and a good knowledge of the mechanics of elastomeric materials. The second step requires an experimental study of the materials according to a specific usage. This stage is well adapted to select the most suitable behaviour model among those selected in the first stage. It also allows determining the numerical values of the mechanical parameters of the selected model. The third step consists in a numerical modelling of the experimental study, so as to validate the choice of the mechanical model and the determination of its constants. The last step, it is satisfactory to model numerically the final usage of the material, so as to produce a accurate dimensioning.

This paper is related to the third stage of the formerly exposed process in the study of damage initiation mechanism of Natural Rubber (NR) composite strips [6-8].

The numerical modelling consists in a quasi-static uniaxial tension on a thin rectangular notched rubber specimen. This modelling aims at validate the mechanical behaviour model of NR and evaluate the associated strain energy, so as to determine the limit load for a given thickness. In fact, the numerical modelling is a representation of a preceding experimental study. The specimen is stretched very heavily from its initial size, so that large strains occur. A hyper elastic Mooney-Rivlin law is chosen. The finite elements analysis (FEA) was performed with ABAQUS code (V.6.4.4). The strain energy is evaluated integrating the force-displacement curve (post-treatment of the finite elements analysis).

2. Finite elements model

The geometry of the smooth specimen is presented in Fig. 1.

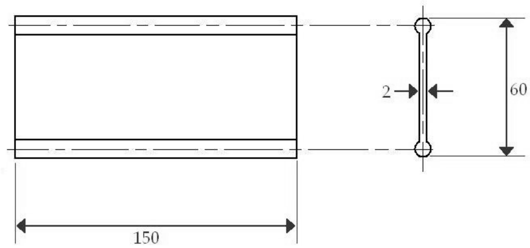
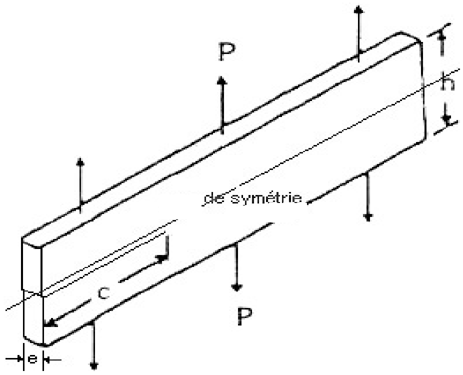


Fig. 1. Geometry of the smooth specimen

The notch is then made at one end, through the symmetry plane of the specimen with an initial length, c, and is submitted to a uniaxial tension, as presented in Figure 2.

According to the symmetry of the model, only half of the geometry is modelled. In addition, due to the thinness of the specimen, a plane stress situation is assumed. The half model is then partitioned into geometrical sets according to the notch length. This partition, adapted to each notch length, allows a specific meshing for each problem, specifically around the notch front. Calculations were performed for notch length ranging from 0 to 50 mm, corresponding to length ratios (notch length divided by specimen length) ranging from 0% to 50%.

a)



b)

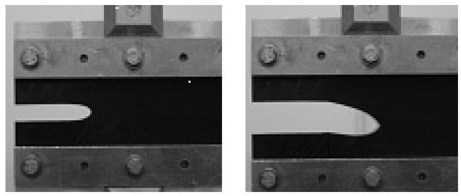


Fig. 2. Notched specimen loading path a) and crack deviation phenomenon under uniaxial tension b)

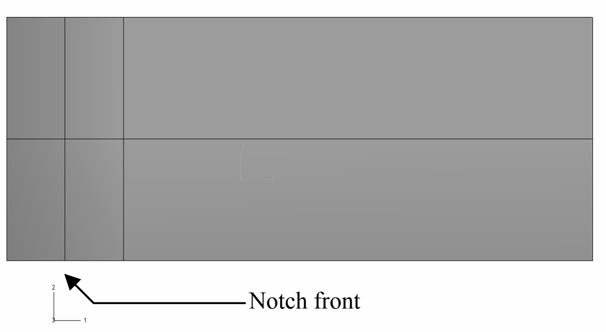


Fig. 3. Partition of the geometry of half of the specimen with a notch size of 15mm

2.1. Material

The Natural rubber experiences the second order hyper elastic Mooney-Rivlin law, whose coefficients have been identified from the former experimental studies [6-7]. The coefficients of the law are summarized in Table 1.

2.2. Boundary conditions and load

Since only half of the geometry is modelled, one has to introduce the symmetry boundary conditions. These have to be applied to the lower face of the specimen excepting the specimen has been notched, so that the notch lips remain free.

On the upper side of the specimen, a 23mm vertical displacement is imposed.

Table 1.
Coefficients of the Mooney-Rivlin law

Coefficient	Value
C10	0.295788
C01	-0.018755
C20	0.014761
C11	0.
C02	0.
D1	0.000967
D2	0.

2.3. Mesh analysis

A mesh seed was imposed on the geometrical boundaries and on the partition lines. The element size was 1mm and a more refined length of 0.5 mm element size was assigned to the region around the notch front, to ensure a reasonable description of the deformation of the lips of the notch. The meshing was then performed using the linear quadrangular elements (fig.4).

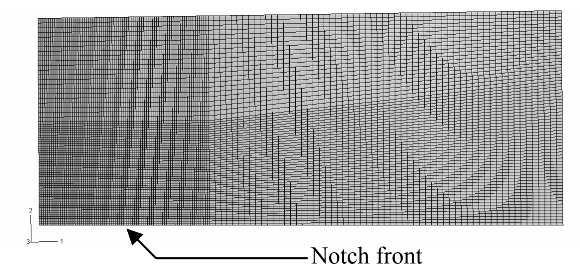


Fig. 4. Meshing of the specimen with a 25mm length notch

3. Finite elements results and analysis

Calculations were made on a PC (Pentium 4, 3 GHz, 1 GB RAM) and required 13.3 s CPU time and 8.30 GB disk space. After calculation the results are examined using ABAQUS post-treatment tools and then data concerning the nine contours are extracted to be post-processed using Matlab.

3.1. Energy calculations

The strain energy is defined as the area under the force-displacement curve. For each length of the notch, a 30mm ramp displacement was applied along the 1s step time. This means that the step time parameter (ranging from 0 to 1) allows determining for each increment the applied displacement. Therefore, with one single load case, and using the results for each increment, the

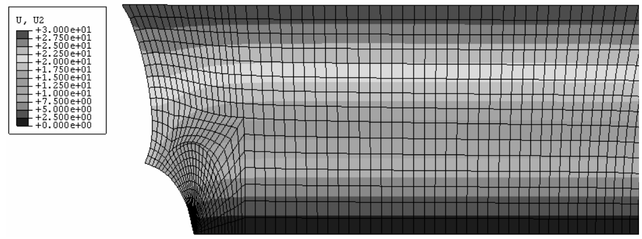


Fig. 5. Displacement in the tension direction (scale factor: 1.0)

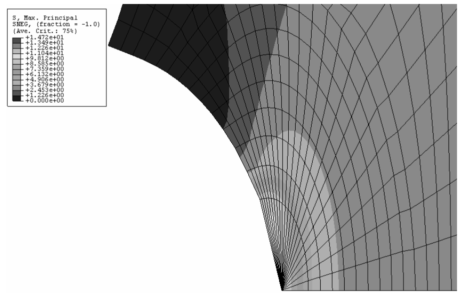


Fig. 6. Maximum principal stress (detail around the notch front)

whole force-displacement curve was deduced (discredited using the step-time parameter). The post-processing of the FEA gave for each displacement level the associated total reaction force. An integration of the force-displacement curve (fig. 7) was performed, giving a strain energy–displacement curve (Fig. 8).

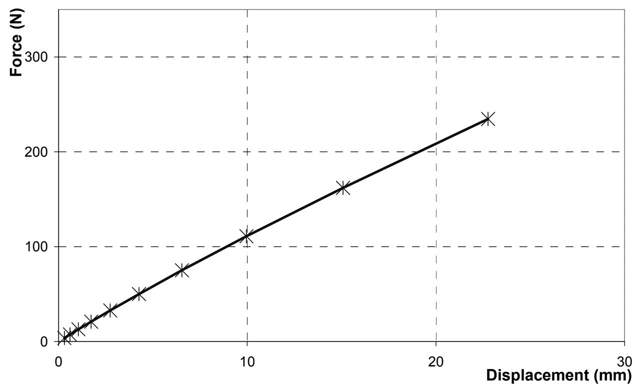


Fig. 7. Example of Force-displacement curve for a 50 mm notched specimen deduced from FEA post-treatment

From the analysis of Fig. 8, it is shown that the smaller values of the notch size give the higher strain energy levels, which is also an experimental result. In addition, the displacement-energy curves exhibit a second order polynomial shape.

These numerical results were then compared to the experimental data. Fig. 9 indicates a comparison of strain energy between numerical and experimental results for notch lengths ranging from 0 to 50 mm and for given tension displacements ranging from 5 to 18 mm. The whole numerical results are shown to be in accord with experimental observations of elastic stored energy depending on the length of the edge crack for the given displacements.

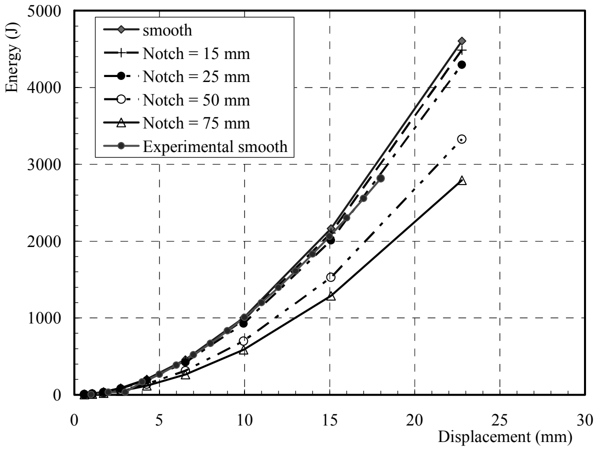


Fig. 8. Evolution of the tearing energy depending on the displacement for NR specimen

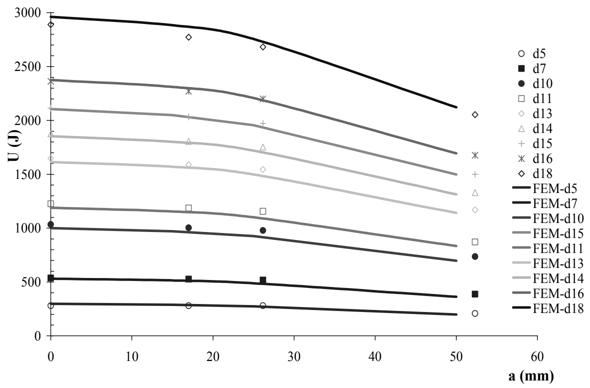


Fig. 9. Elastic stored energy depending on the length of the edge crack for a given displacement for NR specimens

Additionally, the J-integrals can be evaluated as indicated in Figure 10 shows the evolution of the J-integral through the contours. The main contribution to J is provided by the J_1 term.

4. Conclusions

For dimensioning study purpose of future NR composite applications, a detailed work has been carried out in a preceding work. The second order Moonley-Rivlin law coefficients was chosen to describe the mechanical behaviour. In the present work, this law was implemented for Finite Elements Analysis and the tearing of a notched NR thin strip has been carried out.

The strain energy was analyzed in particular, since it is a relevant parameter for failure criteria. The comparison of experimental and numerical results has shown a very good truthfulness of the chosen mechanical law.

Next step of such a dimensioning process will be based on the modelling of real future applications for NR composites.

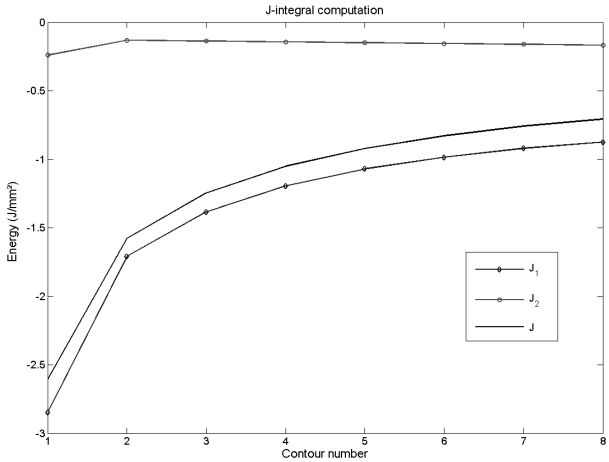


Fig. 10. J-integral computation from the data extracted from the finite elements analysis

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