Available online at www.sciencedirect.com
ScienceDirect
Polymer Testing 25 (2006) 994–1005
POLYMER TESTING
www.elsevier.com/locate/polytest

Data Prediction

A fracture criterion of rubber-like materials under plane stress conditions

A. Hamdi[a], M. Naït Abdelaziz[a,*], N. Aït Hocine[b], P. Heuillet[c], N. Benseddiq[a]

[a] *Université des Sciences et Technologie de Lille, LML (UMR CNRS 8107), Polytech'Lille Avenue P. Langevin, 59655 Villeneuve d'Ascq Cedex, France*
[b] *Laboratoire de Rhéologie. 6, Avenue V. Le Gorgeu, C.S. 93837, 29238 Brest Cedex 3, France*
[c] *LRCCP, Vitry Sur Seine 94400, France*

Received 21 April 2006; accepted 17 June 2006

Abstract

In this work, we attempt to derive a fracture criterion for filled and unfilled elastomer vulcanizates and thermoplastics from a set of experimental data. Firstly, fracture criteria reported in the literature have been applied to experimental data obtained from tests including various loading modes (simple tension, equal biaxial tension and biaxial tension) and performed on four materials: a natural rubber (NR), a styrene butadiene rubber (SBR), a polyurethane (PU) and a thermoplastic elastomer (TPE).

Then, a new failure criterion based on an equivalent elongation concept is proposed. This equivalent elongation seems to be linearly dependent on a given biaxiality ratio $n = (\ln(\lambda_{2b})/\ln(\lambda_{1b}))$, which leads to expressing the principal elongations at break as functions of both the biaxiality n and two experimental parameters. Quite good agreement is highlighted when comparing the failure experimental data with the proposed criterion for the tested elastomers.

Keywords: Rubber; Finite deformation; Principal logarithmic elongation; Biaxiality ratio; Fracture criterion

1. Introduction

Elastomers are highly deformable materials and their uses are very widespread in industry. Therefore, a failure criterion, under monotonic loadings, in order to predict and prevent the failure of the rubbery parts in a structure is required for engineers designing such structure components.

The fracture criteria of rubber like materials can be classified into two categories. The first one is based upon fracture mechanics concepts and investigates the complete fracture of a material containing a crack [1–5], whereas, the second one, assumes a perfect material with no defect and thus focuses on the mechanical quantities governing the fracture and/or the crack nucleation.

Indeed, in the absence of cracks or defects, several authors have developed fracture criteria for unfilled rubbers, based upon the stresses or elongations at break. Smith et al. [6–11], Bueche and Halpin [12–14] have earlier examined the ultimate

*Corresponding author.
E-mail address: Moussa.Nait-Abdelaziz@polytech-lille.fr (M. Naït Abdelaziz).

0142-9418/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.polymertesting.2006.06.005

properties of elastomers. They defined the concept of "failure envelope" in a stress–strain plan, which is built by using the time-temperature equivalence principle. Then, Smith and Rinde [9] have designed an experimental equipment to obtain a constrained biaxial strain field (pure shear) in a sample. The specimen consists of a long thin-walled cylinder made of an unfilled vulcanizate elastomer (SBR). It is stretched in the longitudinal direction while the outside diameter is simultaneously maintained at its initial value by regulating the internal gas pressure. For more details concerning this experimental set up, see Smith and Frederick [15]. They noticed that the ultimate elongations in simple tension are similar to those in pure shear, whereas the corresponding axial stresses are slightly higher in shear tests [9]. As theoretically established by Adkins and Rivlin [16], an equal biaxial strain field in the region near the pole can be generated by inflating a rubber membrane. Using such an experimental setup with a pure SBR, Dickie and Smith [10,11], found that both the failure elongations and the corresponding stresses were more important in equal biaxial tension than in uniaxial tension. These values were also higher than that obtained by Smith and Rinde [9] under a constrained biaxial loading. Dickie and Smith explained this result by the fact that, in a state of equal biaxial deformations, there are no privileged directions for the nucleation and growth of a crack. This divergence may rather be attributed to the lower accuracy in strain measurements. Later, Kawabata [17] developed experimental techniques to generate various biaxial stretching ratios. The first one consists of pulling thin plates in two perpendicular directions, while the second one is based upon the inflated membrane set up. He found the elongations at break are constant whatever the loading path for the two investigated unfilled vulcanized elastomers (NR and SBR). However, the stresses at break depend on the loading path, the maximum value being reached under equal biaxial loading.

Another interesting elongation criterion is the one proposed by Neviere et al. [18] to characterize the failure of solid propellants. Some other authors have focused their investigations on criteria based on failure stresses and originally developed for metallic alloys (i.e. Rankine, Tresca and Von Mises criteria). These criteria were reviewed by Thorkildsen [19] who tried to extend them to rigid polymers. They were also applied by Smith and Rinde [9] to unfilled SBR elastomers.

In this paper, we shall only focus our investigation on the fracture of smooth (non-cracked) specimens, fracture meaning here the complete breaking of the considered specimen. A generalized failure criterion under multiaxial quasi-static loadings using unfilled and carbon black filled elastomer vulcanizates and thermoplastics is the main goal which is pursued. More precisely, in the first part of this paper, some of the fracture criteria reported in the literature will be examined. In the second part, a criterion based upon an equivalent elongation is proposed and experimentally validated for various loading paths. The most important result is that this criterion requires only two parameters to be identified from two loading modes (for example uniaxial tension and equal biaxial tension tests).

2. Experimental study

2.1. Materials

Four kinds of materials have been investigated:

- a filled natural rubber (NR) vulcanizate (which is crystallizable),
- a filled styrene-butadiene rubber (SBR) vulcanizate,
- a thermoplastic elastomer (TPE) (Sarlink 4165: an elastomer EPDM blended with a thermoplastic PP),
- an unfilled crosslinked polyurethane (PU).

The mechanical behaviour of the two vulcanizates, NR and SBR, is hyperelastic while for PU and TPE materials it is rather viscoplastic. The composition of the two vulcanizates is summarized in Table 1.

2.2. Specimens and fracture tests

To obtain a wide range of loading conditions, sets of experiments including uniaxial tension, equal

Table 1
Formulations of the NR and SBR elastomers

Compounds	NR	SBR
SMR 10 CV 60	100	—
SBR 1502	—	100
Carbon black N650	25	—
Carbon black N330	—	60