



ELSEVIER

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech

Defect tolerance at various strain rates in elastomeric materials: An experimental investigation

Roberto Brighenti*, Andrea Spagnoli, Andrea Carpinteri, Federico Artoni

Department of Engineering and Architecture, University of Parma, Viale delle Scienze 181/A, 43124 Parma, Italy

ARTICLE INFO

Article history:

Received 12 January 2017

Received in revised form 6 April 2017

Accepted 2 May 2017

Available online xxxxx

Keywords:

Highly deformable materials

Strain rate

Polymer

Defect tolerance

Digital image correlation

ABSTRACT

Elastomeric polymers usually show a very low elastic modulus entailing a soft behaviour and a very high deformation capability. This macroscopic behaviour is determined by their microstructure which is characterized by a complex and entangled network of very long linear chains jointed together in some points called cross-links. Because of such a peculiar microstructure, the mechanical response (often time-dependent) of elastomeric polymers to external loads or deformations cannot be described by the classical theories developed for standard materials – such as the ones whose response depends on their crystalline structure (e.g. metal, ceramics, etc.) – since such polymers usually neglect entropic-related effects that are fundamental in highly deformable amorphous materials. In the present paper, the response of elastomeric plates containing a central crack under a tensile strain applied at various rates is experimentally analyzed giving particular emphasis on the observations of the full-field strain maps determined by means of some digital image correlation techniques. Some relaxation tests are performed, and the defect sensitivity of the material is discussed in relation to the applied deformation rate.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

A class of materials which are relevant from the point of view of advanced applications is represented by the so-called soft or highly deformable materials. Materials showing a high deformation capability are for example rubbers, liquid crystal elastomers, colloids, polymers, gels, granular materials, foams, several biological materials, etc.

The application of mechanical concepts in new fields, especially in biomechanics (tissues, cells, soft interfaces, etc.), has drawn a huge attention by the scientific world, since it has been observed that many phenomena occurring in nature have relevant mechanical implications and, as such, the mechanics of materials can be usefully exploited in the prediction of natural systems [1–4]. Moreover, applications employing highly deformable artificial materials (rubbers, artificial muscles, active and self-morphing materials) can have a benefit from the use of the mechanics concepts within the finite deformations framework [5–9].

Many kinds of elastomers – such as natural rubbers – exhibit another peculiar behaviour triggered by a sufficiently high stretch value, namely the strain-induced crystallization: their initially amorphous structure is turned into a semicrystalline-like one thanks to the highly oriented arrangement of polymeric chains developing along the tensile direction [10–12].

Very often highly deformable materials experience a time-dependent behaviour according to which the response of the material under mechanical actions depends on the time scale of the load application [13–15]. This time-dependent

* Corresponding author.

E-mail address: brigh@unipr.it (R. Brighenti).

behaviour is very relevant in real applications, since the response of the material can be quite different considering or not the time scale of the problem being examined.

The structure of fully amorphous materials at the nanoscale level consists of a three-dimensional network of polymer chains linked together at several discrete points identified as cross-links. The mechanical response of these materials at the meso- or macro-scale is heavily affected by the amount of entanglement and the number of existing cross-links per unit volume rather than by the bonding strength existing between the atoms, as happens in fully crystalline materials. The deformation mechanism takes place by first an unentanglement of the polymeric chains which start being effectively stretched once they align approximately along the load direction. This observation enables us to clearly understand, different from crystalline materials whose behaviour is mainly governed by enthalpic effects, the entropic-related effect that enters in the mechanical deformation process of very deformable amorphous materials such as elastomers. Upon the application of load, the loss of the initial amorphous molecular structure – made up of polymeric chains connected to each other through covalent bonding in several cross-link junctions – leads to a more regular structure characterized by a noticeable geometric rearrangement and alignment of the molecular chains, that is responsible for the stiffening behaviour of the material at high strain levels [16–18].

The fundamentals of the chemical and physics-based mechanical behaviour of this class of materials have been established by two Nobel prize winners, Flory [19,20] (awarded by the Nobel prize in chemistry in 1974) and de Gennes [21] (awarded by the Nobel prize in physics in 1991), in their seminal theoretical and experimental research works.

Another key issue characterizing highly deformable polymers is their noticeably defect tolerance. The capability to withstand cracks or notches without failure even at very high applied strain levels allows their use in extremely demanding applications (such as in the biomechanics field). Very high local deformation and chains rearrangement induced by loading lead to flaw reshaping and to material strengthening around the highest strained region, so as to smooth out the strain concentration produced by cracks [22–26].

The present research aims at studying experimentally the defect tolerance and the related strain rate effect in pre-cracked specimens made of silicone elastomers. Various flaw severities (i.e. different relative crack lengths) and strain rates are examined in order to quantify their effects on the macroscopic mechanical response. Furthermore, the final resulting crack path at failure is observed and discussed in relation to the applied strain rate. All the mechanical tests are conducted under strain control and all the kinematically-related quantities are measured through a contact-less digital image correlation technique (DIC) applied to very high deformation levels.

2. Experimental tests

The mechanical response of pre-cracked elastomeric sheets under tension is herein examined by considering the effect of both the relative crack size $2a/W$ and the strain rate. More specifically, thin rectangular sheets with a central crack, made of a silicone polymer system, are tested under tension at different strain rates.

Samples were prepared using the commercially available silicon system TSE3478[®] from Momentive. To prepare a single sample, 50 g of component A (matrix) were thoroughly mixed with 5 g of component B (curing agent). The resulting mixture was carefully degassed in vacuo, and subsequently mechanically spread into the custom made aluminum mold. The mixture was degassed a second time in vacuo, in order to avoid the presence of bubbles in the cured material. The samples were

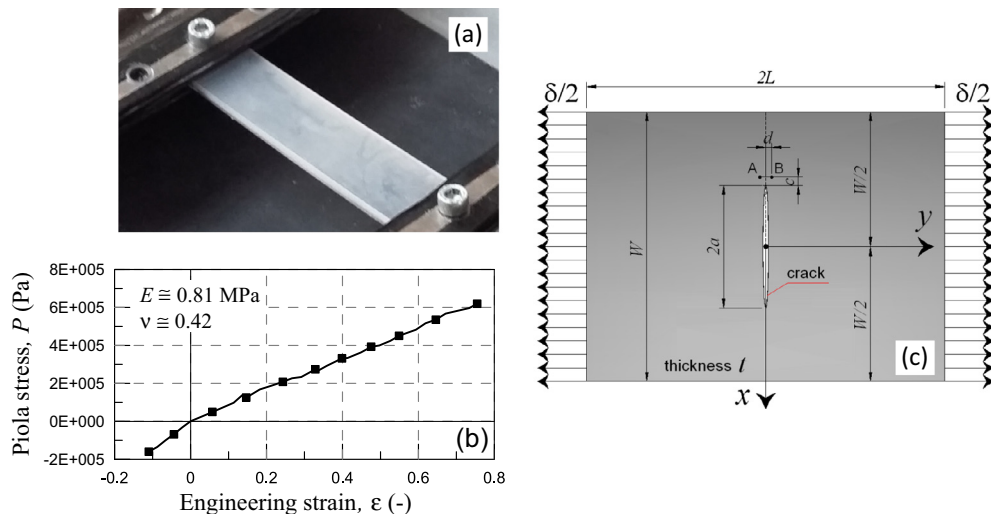


Fig. 1. (a) View of the silicone polymer specimen under tension test; (b) stress-strain curve of the material during a monotonic tension-compression test; (c) geometric characteristics of the tested cracked specimens.

Download English Version:

<https://daneshyari.com/en/article/5013871>

Download Persian Version:

<https://daneshyari.com/article/5013871>

[Daneshyari.com](https://daneshyari.com)