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On the fracture behavior of polyurethane notched components

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Abstract

Local Strain Energy Density represents an engineering approach for assessing the brittle fracture of cracked and notched components. Experimental determination of fracture parameters (critical value of deformation energy W_c in a local finite volume around the notch tip and the radius of the control volume R_c) represents a key issue. The paper presents a methodology to determine these parameters using a notched tensile specimen. The obtained values will be used to predict the fracture load in different types of notches and cracked specimens under mode I; for cracked specimens under mixed mode and mode II has defined a personal approach that confirms PUR foams can be treated as brittle materials. The considered specimens are made of polyurethane materials of different densities from 100 to 651 kg/m^3.

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1. Introduction

Polyurethane (PUR) materials represent a class of organic units joined by urethane links. They can be manufactured in a wide range of densities:

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- at low densities (30 - 200 kg/m^3) they are rigid foams having a close cell cellular structure. The main applications of PUR foams are: high-resilience seating, rigid foam insulation panels, microcellular foam seals and gaskets, high durable elastomeric wheels and tires, automotive suspension bushings (necumer).
- at higher densities (> 200 kg/m^3) they show a porous solid structure, and are used for fixtures and gauges, master and copy models, draw die moulds, hard parts for electronic instruments (necumer).

Mechanical properties of these materials are directly related to the mechanical property of solid materials used for manufacturing, by the geometry of cellular structure and the relative density, (Gilbson and Ashby, (1997); Ashby, (2005)). Cellular and porous materials have a crushable behaviour in compression, being able to absorb considerable amount of energy due to plateau and densification regions. However, in tensile they have a linear elastic behaviour up to fracture and a brittle failure (Marsavina, (2010)). So they can be treated as brittle materials. For this reason it's very important to define which methods can be used to predict the failure for notched components. Numerous method have been proposed in the literature for fracture assessment of cracked and notched components (Ayatollahi et al., (2015, 2016, 2017); Razavi et al., (2017); Rashidi Moghaddam et al., (in press)). Dealing with the fracture of notched components, the concept of strain energy density (SED) has been already reported in literature (Sih, (1973, 1974); Kipp and Sih, (1975), Sih and Ho, (1991)). Sih's criterion postulates that the failure is controlled by a critical value of strain energy density factor S, whilst the crack propagation direction is determined by imposing a minimum condition on factor S. Different from aforementioned S factor criterion, which is a point-related criterion, Lazzarin and Zambardi (2001) predicted the static and fatigue behaviour of sharp V-notched components using the average SED in a defined control volume around the notch tip. Concerning the case of static brittle fracture, the control volume radius R_C depends on two material parameters: the ultimate tensile strength σ_u and the fracture toughness K_{IC}. The "local strain energy approach" was analytically developed to blunt V- and U-notches under mode I loading by Lazzarin and Berto (2005) and extended to mixed mode I-II conditions based on a numerical procedure by Gómez et al. (2007) and Berto et al. (2007). Validation of these developments of local SED was carried out on both static and fatigue multiaxial conditions (Lazzarin et al., (2008a, 2008b, 2009), Berto and Lazzarin, (2009)).

In the present paper the major purpose is to understand if is it possible to define the parameters (R_c and W_c) that validates the SED method on PUR foams and see an experimental way to determine these ones.

2. Materials

Polyurethane materials of five different densities (100, 145, 300 and 708 kg/m^3) manufactured by Necumer GmbH – Germany, under commercial designation Necuron 100, 160, 301 and 651, were experimentally investigated. At low densities 100 and 145 kg/m^3 the materials have a rigid closed cellular structure, while the PUR materials of higher densities show a porous solid structure (300 and 708 kg/m^3). A QUANTA™ FEG 250 SEM was used to investigate the microstructures of the materials at different magnifications. The cell diameter and wall thickness were determined by statistical analysis, together with the density of PUR materials obtained experimentally according with ASTM D1622-08. The elastic properties Young modulus and Poisson ratio were determined by Impulse Excitation Technique (ASTM E-1876-01). Tensile strength was determined on dog bone specimens according with a gage length of 50 mm and a cross section in the calibrated zone with 10 mm width and 4 mm thickness, according to EN ISO 527, and described in the research published by Marsavina et al., (2014a).

Table 1. Elastic, mechanical and fracture properties of PUR materials, by varying the density.

PUR Density	100	145	300	708
Young's modulus [MPa]	30.18±1.75	66.89±1.07	281.39±2.92	1250±15.00
Poisson's ratio [-]	0.285	0.285	0.302	0.302
Tensile strength [MPa]	1.16±0.024	1.87±0.036	3.86±0.092	17.40±0.32
Mode I fracture toughness [MPa m$^{0.5}$]	0.087±0.003	0.131±0.003	0.372±0.014	1.253±0.027
Mode II fracture toughness [MPa m$^{0.5}$]	0.050±0.002	0.079±0.004	0.374±0.013	1.376±0.047