Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 3 (2017) 68–76

Structural Integrity Procedia

www.elsevier.com/locate/procedia

XXIV Italian Group of Fracture Conference, 1-3 March 2017, Urbino, Italy

Multiaxial fracture of graphite components: a review of recent results

F. Berto[a,*], S.M.J. Razavi[a], M.R. Ayatollahi[b]

[a] *Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology (NTNU), Richard Birkelands vei 2b, 7491, Trondheim, Norway.*

[b] *Department of Mechanical Engineering, Iran University of Science and Technology, Narmak, 16846, Tehran, Iran.*

Abstract

While a large bulk of experimental results from cracked specimens of polycrystalline graphite under pure modes of loading, in particular under mode I loading, can be found in the literature, only a very limited number of tests have been carried out on notches. At the best of authors' knowledge dealing with the specific case of V-notches under mixed mode loading (tension + torsion) no results can be found in the literature. With the aim to fill this lack, the problem of mixed mode (I+III) brittle fracture of polycrystalline graphite is investigated systematically here for the first time.
The present study considers cylindrical specimens weakened by circumferential notches characterized by different acuities. A new complete set of experimental data is provided considering different geometrical configurations by varying the notch opening angle and the notch tip radius. The multiaxial static tests have been performed considering different values of the mode mixity ratio (i.e. the ratio between the nominal stress due to tension and that due to torsion loading). A criterion based on the local Strain Energy Density previously applied by the same authors only to pure modes of loading is extended here to the case of tension and torsion loadings applied in combination. The proposed criterion allows a sound assessment of the fracture loads.

Keywords: multiaxial loading; isostatic polycrystalline graphite; V-notch, strain energy density; control volume

* Corresponding author. Tel.: +47-735-93831.
E-mail address: filippo.berto@ntnu.no

Copyright © 2017 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the Scientific Committee of IGF Ex-Co.
10.1016/j.prostr.2017.04.010

1. Introduction

Isostatic graphite can be used in many industrial applications due to the good compromise between thermal and mechanical properties. The design of industrial products made of graphite is not focused only to structural applications. However, the large majority of components, although not thought as structural ones, is subjected to loads transferred by the other parts of the structure. For this reason, many studies in the past have been devoted to the investigation of the fracture strength of graphite.

Brittle fracture is a typical behaviour for this material and usually happens after the initiation of micro-cracks in the most stressed parts of the structure, combined in some cases with a very limited amount of plasticity (Sakai et al. 1983; Ayatollahi et al., 2015; Ayatollahi et al., 2016; Rashidi Moghaddam et al., 2017). The majority of the studies focused on structural integrity of graphite components have been devoted to the investigation of cracked components by quantifying the fracture toughness under prevalent mode I loading (Mostafavi and Marrow 2011). Dealing with isotropic graphite, innovative techniques have been proposed with this aim (Bazaj and Cox 1969, Kawakami 1985). Some researchers have also studied the fracture behaviour of composite materials reinforced by graphite fibres at room temperature (Wang and Liu 2008). The problem related to the mechanical behaviour of graphite at elevate temperature and in presence of cracks is also a topic of active research (Sato et al. 1978).

Although the problem of brittle fracture of graphite components has been studied continuously for many years, only few predictive models have been proposed for the fracture assessment of cracked components. Some models are based on the microstructural properties (Knibbs 1967). A stress based criterion (Ayatollahi and Aliha 2008) has been recently proposed as an extension of the maximum tensile stress (MTS) criterion originally proposed in a pioneering study by Erdogan and Sih (Erdogan and Sih 1963).

The papers briefly recalled in the first part of this introduction refer to the behaviour of graphite in the presence of cracks. A review of the recent and past literature shows that only very few papers are focused to the study of the notch sensitivity of graphite components. It is worth of mentioning here the pioneering studies conducted by Bazaj and Cox (1969) and Kawakami (1985). Only in the last years the topic of the fracture behaviour of blunt notches has been faced by other researchers, who have investigated the case of pure mode I loading and in-plane mixed mode loading (Ayatollahi et al. 2011, Berto et al. 2012a, Lazzarin et al. 2013, Berto et al. 2013). Only one recent contribution by the present authors deals with V-notched specimens under pure torsion loading (Berto et al. 2012b) while, at the best of authors' knowledge, the case of static multiaxial loading (I+III) has never been investigated until now and no data are available for isostatic graphite.

Due to this complete lack in the literature, the main aim of this research program is to systematically investigate the static behaviour of isostatic graphite subjected to multiaxial loadings obtained as a combination of tension and torsion with different values of the mode mixity ratio (i.e. the ratio between the nominal stress due to tension and that due to torsion loading): 0.40, 0.50 and 1.00. A new complete set of experimental data from cylindrical specimens subjected to combined tension and torsion loads is provided in the present contribution, considering a large variety of geometrical configurations obtained by varying the notch opening angle, notch radius and notch depth. The notch radius has been varied from 0.3 to 2 mm and the notch opening angle from 30° to 120°. A fracture model based on the strain energy density (SED) averaged over a control volume (Lazzarin and Zambardi 2001, Lazzarin and Berto 2005, Berto and Lazzarin 2009, Berto and Lazzarin 20014, Berto et al. 2015, Berto et al. 2016, Campagnolo et al. 2016) is used for the first time for the fracture assessment of notched samples subjected to the multiaxial static loading case of tension and torsion applied in combination. The SED based approach allows a sound fracture assessment of the critical load for the specific material under investigation and it can be potentially extended to other types of graphite subjected to different combinations of mode I and mode III loading conditions. The paper is divided in two parts: in the first one the experimental activity is presented (sample geometry, test setting, and details of experimental data). While the second part deals with the formulation and application of the averaged strain energy density criterion on the new data.

An extended version of the present manuscript can be found in (Berto et al. 2015).

2. Fracture Experiments

The details of the graphite material, the test specimens and the fracture experiments are presented in this section.