FRACTURE CHARACTERISTICS OF TWO CARBON FIBRE REINFORCED CERAMICS

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ABSRACT

The fracture characteristics of two carbon fibre reinforced silicon carbide composites have been investigated. Strength tests have been performed using notched and un-notched specimens. Fractography has been used for the identification of damage evolution during the tensile load of the double notched specimens. The materials were found notch insensitive in the form of specimens with width from 8 mm to 14.5 mm, loaded in tension at room temperature.

1. INTRODUCTION

Fibre reinforced composites based on C/C, C/SiC, and SiC/SiC are attractive materials for many high-temperature structural applications thanks to their excellent mechanical and thermophysical properties as high-temperature strength, low thermal expansion coefficient, good heat conductivity, thermal shock resistance, abrasion resistance, low density, etc. Their potential applications include; disk brakes, rocket nozzles, parts of automotive gas turbines, jet engines, etc., [1,2]. For development of improved materials and to design parts with these materials, designers need a reliable approach to assess structural integrity when notches and/or holes are present in the material [3,4]. Two approaches for characterizing notch size effects in brittle matrix composites with intermediate behaviour have been proposed. The first, the large-scale bridging mechanics approach (LSBM), is applying when fracture from the notch involves a single matrix crack with bridging traction provided by fiber reinforcement. The second, the continuum damage mechanism, is more applicable in the case when multiple cracks emanate from the notch [5,6].
During the last decade a number of contributions have been devoted to the notch effects in ceramic matrix composites (CMC). He et al [7] modeled the tensile fracture process by a traction-deformation law, assuming that the notched sample loaded in tension is damaged with a tensile band ahead of, and two shear bands perpendicular to the notch. They found that the shear bands can substantially increase the work of fracture which in turn reduces the notch-sensitivity. Keith and Kedward [8] used two approaches for the notched strength prediction of two aluminium phosphate based CMC reinforced with satin-weave SiC cloth; the net-section criterion combined with the Griffith criterion and the Waddoups-Sou (WS) criterion. Both materials (with weak and strong interface) in the case of specimens with a 12.7 mm width were notch insensitive, however the material with strong interface, tested using a specimens with a 50.8 mm width, was found notch sensitive. Evans et al [5,9]

investigated the notch effect in different CMC´s reinforced with carbon and silicon carbide fibers. They found the 0/90 laminated silicon carbide/calcium aluminosilicate composite notch insensitive in tension at room temperature. This behaviour can be explained by inelastic strains, arising from matrix cracking, which leads to the stress redistribution around notches. In a systematic study, they investigated the stress redistribution mechanisms that operate in various carbon matrix composites subjected to strain concentrations, such as holes and notches. In the SiC/C material, where no shear bands formation and relatively small fiber pullout lengths was detected, the LSBM approach was found to provide consistent predictions of the influence of notches and holes. For C/C materials, where shear bands constitute a major mode of stress redistribution, LEFM was found to be a reliable strength prediction method, despite of the relatively large-scale nonlinear zones around the notch.

The aim of the present contribution is to study the notch sensitivity and damage evolution of two carbon fibre reinforced SiC composites at room temperature

2. EXPERIMENTAL MATERIALS AND METHODS

Two different commercially available carbon/carbon composite (material A and B from Schunk Kohlenstofftechnik GmbH) have been used as experimental material. Both materials were silicon treated via a combined capillary pack cementation procedure developed at Schunk.

The materials are based on phenolic prepregs with a carbon cloth reinforcement using standard HT-C-fibers. The textile structures are 5 H satin weave with 3K-C-fibers for grade “A” and a 2/2 twill weave with 6K-C-fibers for grade “B”.

Both carbon/carbon grades were fully densified to find open porosities below 8 % including 3 redensification / recarbonization cycles. The final heat treatment was 2100 °C.

The silification (P75) was performed as a post treatment resulting in Si-uptakes between 10 - 20 %, which were fully converted into SiC. The amount of free silicon was below 0.3 %. The final density of both grades was approximately 1.70 up to 1.75 $g \cdot cm^{-3}$ with an open porosity between 5 % and 7 %.

The notch width was ~300 µm. The ratio of notch length to specimen´s width is varied from 0.24 to 0.5. The specimens were machined in such a way that the cross section area was approximatelly the same (~24 mm^2) in all specimen. All the tensile tests were carried out using a Shimadzu AGC-10 TC universal testing machine under a constant crosshead speed of 0.5 mm/min at room temperature in air. After the test the fracture surfaces were studied by scanning electron microscope [11].

The net fracture stresses (σ_c^{net}) of the notched specimens is defined as:

$$\sigma_c^{net} = \sigma_c^{gross} / (1-a/b)$$
$$\sigma_c^{gross} = F_c/2bt$$

were calculated at different relative notch sizes,

where σ_c^{gross} is the gross fracture stress, F_c is the fracture load, 2b is the specimen width and t is the thickness of the specimen.

3. RESULTS AND DISCUSSIONS

In Fig. 1 characteristic microstructure of studied materials are illustrated. No significant difference was found in the microstructure of these composites. In Fig. 2 the influence of the relative notch size on the net fracture stress is illustrated. The net fracture stress of the

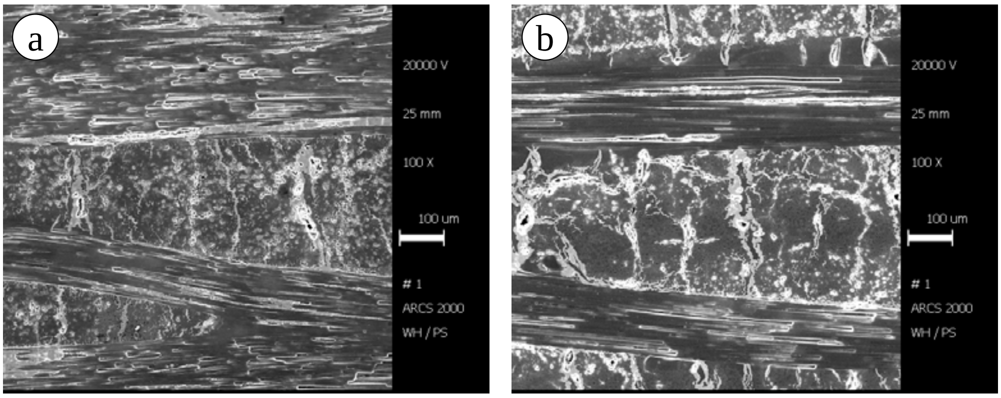

Fig. 1 Characteristic microstructure of the investigated materials; material A(a) and B(b)

notched specimens is independent of the relative notch size and is very similar to the fracture stress of the unnotched specimen (or is even higher). This is an evidence, that the investigated materials with the given geometry are notch-insensitive at room temperature. The higher net fracture stress compared to the fracture stress of the un-notched specimens in the case of the specimens with high relative notch sizes can be explaned by two facts;

- in all tested un-notched specimens the failure takes place in the vicinity of the gripping area, even using specimens with aluminium end, which show that the gripping can damage the specimens and lowerestimate the fracture stress,
- in the case of the specimens geometry used in this investigation, with net-section area approximatelly 24mm^2, the number of the loaded longitudinal fibre bundles can differ in individual specimens, leading to the relativly high scatter in the measured net fracture stress values.

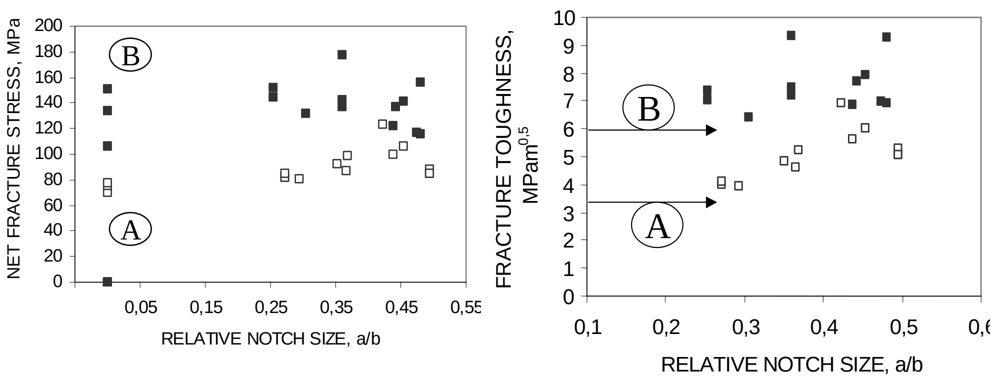

Fig. 2 Influence of the relative notch size on the net fracture stress

According to the Griffith criterion [7] notch insensivity means, that the κ value ($\kappa = K_C/(\sigma_0 b^{1/2}$, where σ_0 is the unnothed strength) is higher than the value approximately 0.7. If it is true, from the measured un-notched strength of the specimens, 75.2 MPa and 129.1 MPa for the material A and B, respectively, the lower-bound of the fracture toughness can be estimated for specimens with different width. According to the results, the lower

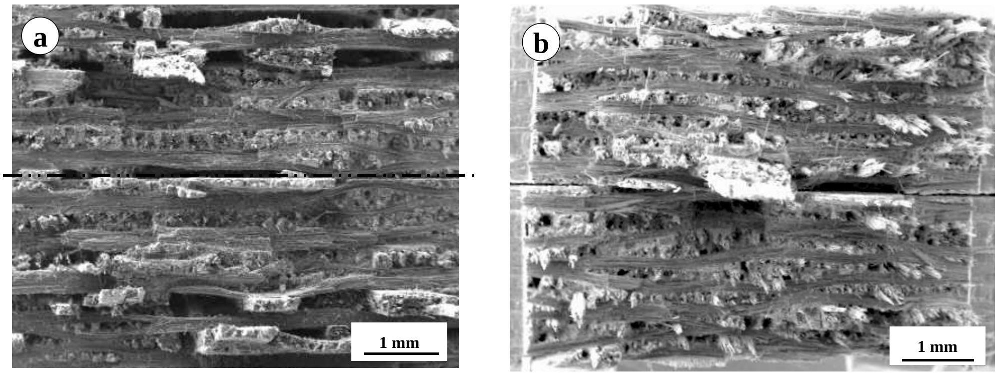

Fig. 3 Fracture surfaces of the investigated materials; material A(a) and B(b)

bound fracture toughness values, resulting from the net-section criteria are 3.8 MPam^{0,5} and 6.4 MPam^{0,5} for the material A and B respectivelly. The real fracture toughness values of these materials corresponds with a higher κ value, resulting approximatelly 6 MPam^{0,5} and 10 MPam^{0,5} for material A and B, respectivelly.

The WS criterion, according to which the presence of a notch always reduces the net-section strength, is not aplicable for the notched-strength prediction of the investigated materials.

Observation of fracture specimens conducted in scanning electron microscope is in agreement with the results of [5] obtained for C/C composites, Fig. 3. Sometimes the all bundles are pulling out (more frequent in the material A), sometimes individual fibres or groups of fibres are pulling out and make the fracture path very rough (characteristic for material B).

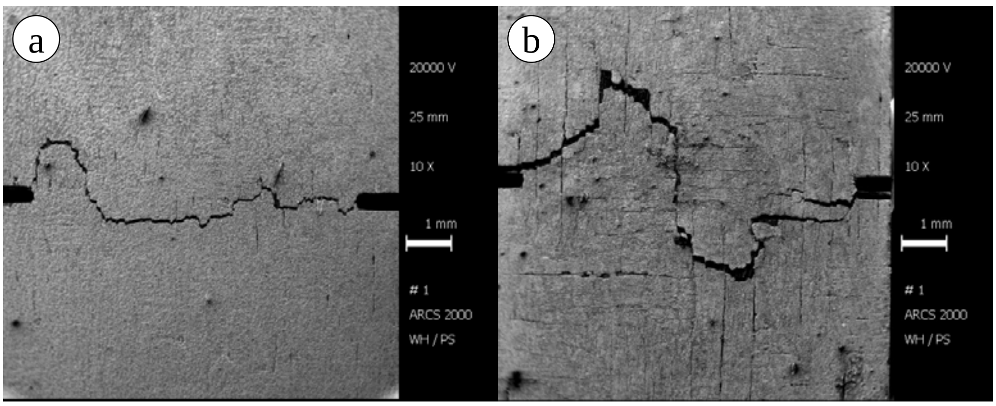

Fig. 4 Damage mechanisms and fracture propagation in the material A (a) and B(b).

Longitudinal (0°) fibre bundles close to the notch have been found typically failed at some distance from the notch plane, leading to the bundles pulled out of the composite, Fig. 6. This phenomenon was more pronounced in the materials B, however even in this material was not as evident as it was reported in [7]. In both systems cracks were found in the 90° bundles at the notch root, but it was again more frequent in the system B.
Observation of fracture path supports the results obtained by the study of the fracture surfaces, Fig. 4a-b. Differences have been revealed in the damge zone formation at the notch and in the crack propagation in the individual materials. The crack propagates easyly through the 90° bundles, but is bridged by the 0° bundles.
Intensive crack/void formation was found between the 90° bundles, sometimes relatively far from the plane of the notches, mainly in the material B. According to the results the pull-out length of the fibre bundles and individual fibres is limited with the architecture of the composite. Very long pullouts where found only at the edge of the specimens.

3. CONCLUSIONS

The notch sensitivity of two batches of carbon fibre reinforced silicon carbide composite was investigated at room temperature. The materials were found notch insensitive. The inelastic strains, originated from shear damage, matrix cracks and pullout tractions redistribute stress around the notches.

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