Materials Science and Engineering A 528 (2011) 6998–7004

Contents lists available at ScienceDirect

Materials Science and Engineering A

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

Dynamic tensile behavior of two-dimensional carbon fiber reinforced silicon carbide matrix composites

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ARTICLE INFO

Article history:
Received 27 February 2011
Received in revised form 21 May 2011
Accepted 23 May 2011
Available online 31 May 2011

Keywords:
Electron microscopy
Mechanical characterization
Composites
Failure
Interfaces

ABSTRACT

An investigation has been undertaken to determine the dynamic and quasi-static tensile behavior of two-dimensional carbon fiber reinforced silicon carbide matrix (2D-C/SiC) composites by means of the split Hopkinson tension bar and an electronic universal test machine respectively. The results indicate that the tensile strength of 2D C/SiC composites is increased at high strain rate. Furthermore, coated specimens show not only a 15% improvement in tensile strength but heightened strain rate sensitivity compared with uncoated ones. It is also shown that the tensile failure strain is strain rate insensitive and remains around 0.4%. Optical macrograph of failed specimens under dynamic loading revealed jagged fracture surfaces characterized by delamination and crack deviation, together with obvious fiber pull-out/splitting, in contrast with the smooth fracture surfaces under quasi-static loading. Scanning electron microscopy micrograph of fracture surface under dynamic loading clearly displayed integrated bundle pull-out which implies suppressed in-bundle debonding and enhanced in-bundle interfacial strengthening, in contrast with extensive in-bundle debonding under quasi-static loading. Thus we conclude that, with 2D C/SiC composites, the strain rate sensitivity of in-bundle interface is mainly responsible for the strain rate sensitivity of the tensile strength.

1. Introduction

Two-dimensional carbon fiber reinforced silicon carbide matrix (2D-C/SiC) composites have been considered as one of those promising materials applied in various advanced aerospace structures, due to their high strength, sound stiffness, low density, light weight and high temperature sustainability. A major problem is that they are frequently subjected to severe or harmful circumstances such as the impact of space debris that poses potential collision risk. Therefore, adequate understanding of their dynamic tensile properties has great implications for the appraisal of safety and reliability of C/SiC composite materials and structures.

The present literature on C/SiC and other composites pays a considerate amount of attention to their quasi-static and dynamic compressive behaviors concerning damage mechanism, fracture behavior and strain rate dependency [1–4]. Engesser [5] carried out a monotonic tensile test performed at 550 °C and compared with a room temperature monotonic test. The study showed that elevated temperature had very little effect on the ultimate tensile strength of C/SiC. Gkald et al. [6] investigated the damage mechanisms and associated mechanical response of 2D C/SiC composite subjected to uniaxial tensile and compressive loadings at room temperature from which an extended non-linear stress/strain response was evidenced.

Recently, the split Hopkinson pressure bar (SHPB) has been increasingly used to determine the dynamic behavior and failure properties of composite materials such as ceramics, composites, rocks and concretes. Li et al. [7] studied the compressive mechanical behavior of three-dimensional needle-punched C/SiC composite at strain rates ranging from10^{-4} to $6.5 \times 10^{3}\,s^{-1}$. The experimental results showed that the strain rate had rather slight influence on the mechanical property of the material. Yuan et al. [8] investigated the dynamic compressive fracture behavior of carbon/carbon (C/C) composites at a strain rate of 500/s using a modified split Hopkinson pressure bar. His results showed that the compressive strength and stiffness were increased at high strain rate. Futakawa et al. [9] experimentally investigated loading rate dependency of SiC fiber reinforced SiC composites by measuring the stress–strain response and strength in tension over a strain rate range of 10^{-4} to $200\,s^{-1}$. It was found that the tensile strength increased with volume fraction regardless of the kind of coating and strain rate. Gomez-del et al. [10] studied the dynamic tensile behavior of carbon fiber reinforced composite materials (CFRPs) at low temperature by SHPB. Their results showed little influence of temperature and strain rate on the tensile strength of CFRPs when loaded in the fiber direction while the strength increased appre-

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0921-5093/$ – see front matter
doi:10.1016/j.msea.2011.05.053

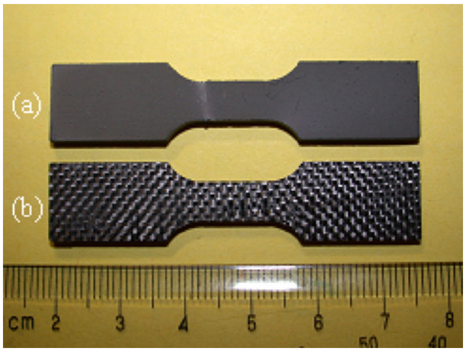

Fig. 1. Geometry of specimens. (a) Coated specimen with a density of 2.05 g/cm^3 (b) uncoated specimen with a density of 1.8 g/cm^3.

ciably in transverse direction at low temperature and high strain rate.

Our present work is basically aimed at an understanding of the dynamic tensile behavior and fracture mechanism of 2D-C/SiC composites by means of SHTB.

2. Experimental procedure

2.1. Material preparation

The 2D-C/SiC composites employed in our work were supplied by the State Key Laboratory of Solidification Processing in Northwestern Polytechnical University, People's Republic of China. The T300-1K carbon fiber was provided by Nippon Toray Corporation. The composites tested in the present investigation were prepared by chemical vapor infiltration of SiC into 2D fabricated performs consisting of stacks of carbon fiber woven fabrics laminated in plane direction, with each layer oriented at 90° with the adjacent cloth. The average thickness of the woven fabrics was 0.16 mm. Before infiltration, the carbon fiber was deposited with pyrolytic carbon interfacial layer with the average thickness of 100–200 nm. In this way, the resultant composite had a fiber volume fraction of approximately 45% and a porosity of 5–8%.

The composite material was machined into flat dog bone shaped specimens, and some were coated with SiC oxidation resistance layer with a thickness of 0.1–0.2 mm. The density of coated and uncoated specimens was 2.05 and 1.8 g/cm^3 respectively. The geometry of the 2D-C/SiC composite specimens prior to quasi-static and dynamic testing are indicated in Fig. 1.

2.2. Quasi-static test

A displacement controlled (CCSS88010) electronic universal test machine with a loading capacity of 10,000 N was used to determine the quasi-static tensile properties of C/SiC composites. Tensile tests were conducted at crosshead speeds of 0.6 mm/min corresponding to a strain rate of 10^{-3} s^{-1}. Two same strain gauges with a resistance of 120.2 ± 0.1 OHMS and a gauge factor of 2.19 ± 1% were mounted on both sides of the specimen to determine its strain.

2.3. Dynamic test

The dynamic tensile properties of the C/SiC composites were determined using the SHTB system as indicated in Fig. 2. The SHTB system consisted of a steel big bar, a steel incident bar, an aluminum alloy transmitted bar, and a steel striker tube. A yoke was connected to one end of the big bar, which was 19.5 mm in diameter, and the incident bar was screwed onto the other end of it. At each end of the incident bar (see Fig. 2) and transmitted bar was located a groove with a width of 3.5 mm and a depth of 18 mm. The flat specimen was sandwiched by epoxy between the incident and the transmitted bar. The diameter and length of both incident and transmitted bar was 12.7 and 1200 mm, respectively. The longitudinal direction of the C/SiC specimen was aligned with the tensile loading direction. The gas released from the gas chamber propelled the striker tube that impinged on the free end of the yoke, thus generating a compressive pulse in the yoke by the impact of the striker tube. The compressive pulse was then converted to a tensile pulse on the free surface of yoke. The tensile pulse propagated along the big bar, and then the incident bar. Some of the incident pulse was reflected back into the incident bar from the input bar-specimen interface and the other part of it was transmitted through the specimen into the transmitted bar. Strain gauges with a resistance of 1000.5 ± 1.0 OHMS and gauge factor of 2.09 ± 1% mounted on the incident (see Fig. 2) and transmitted bar measured the incident, reflected and transmitted pulses. One-dimensional elastic wave equation was

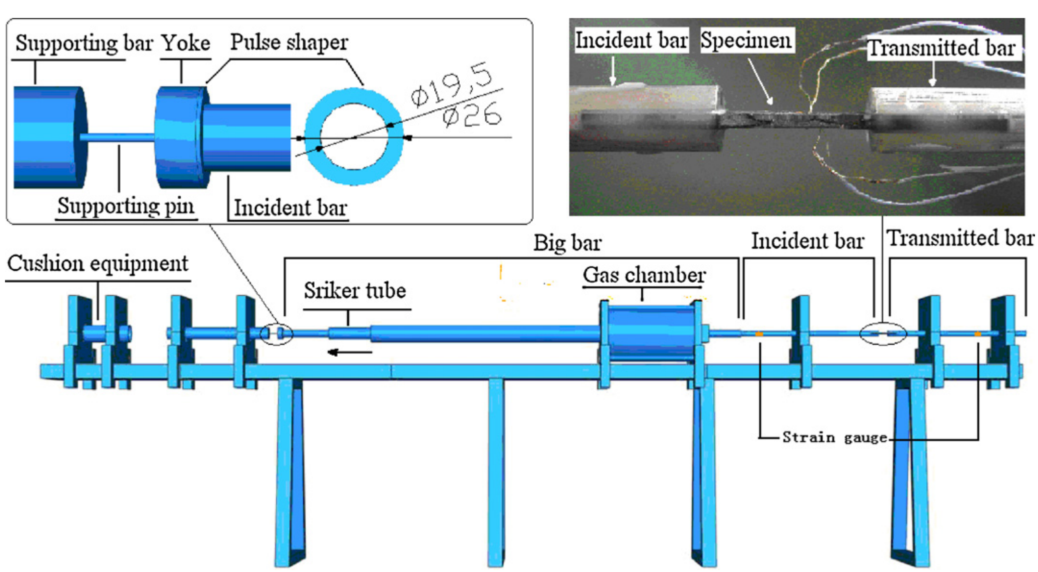

Fig. 2. SHTB setup and the geometry of rubber cushion pulse shaper.