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The effects of stitched density on low-velocity impact damage of cross-woven carbon fiber reinforced silicon carbide composites

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Abstract

Two dimensional carbon fiber reinforced silicon carbide composites (2D C/SiCs) subjected to low-velocity impact (LVI) damage were investigated, in order to evaluate the efficiency of stitching as a reinforcing mechanism able to improve the delamination resistance of 2D C/SiCs. The damage microstructures of the specimens at different stitched density (SD) were observed by infrared thermography and industrial computed tomography scanners. While the damage depth of specimens with the SD of 10 mm/needle was greater than that of specimens with SD of 5 or 15 mm/needle, the residual tensile strength of the specimens with the SD of 10 mm/needle was the highest. With the decreasing of SD, the real damage radius of 2D C/SiCs measured by thermography increased whereas the residual tensile strength did not appear the same phenomenon. The 2D C/SiCs with the SD of 5, 10, and 15 mm/needle had good damage resistance after the LVI, with the tensile strength still retaining 72.43%, 95.20%, and 91.49%, respectively.

Keywords: Ceramic matrix composites; Stitched density; Impact behavior; Low velocity impact; Nondestructive tests

1. Introduction

The carbon fiber reinforced silicon carbide composites (C/SiCs) for its superior properties (such as excellent high temperature resistance, low density, and high wear resistance) have an increasingly important application prospect in rotary ultrasonic machining and high temperature structural applications especially in the aerospace field [1–3]. The ratios of stiffness to mass and strength to mass and high temperature properties of structural material are of great interest in the aerospace field. The aeroplane composed of C/SiCs, however, may be damaged by hail impact, accidental impacts from dropped tools during maintenance and servicing, or impacts from stones on the tarmac during take-offs and landings. These damages may seriously destroy the structural integrity of the aircraft, so it is necessary to use impact test to simulate the effect of the foreign object damage (FOD) on the composites. The FOD imparted to a thermal barrier system in a turbine engine has been researched [4]. The FOD behaviors of three-dimensionally woven silicon carbide SiC/SiC composites at room temperature and 800 °C were investigated and the embrittled damage characteristics in thermally exposed specimens were observed [5].

In order to simulate the FOD process veritably, the impact test has been widely reported [6–11]. The static indentation and impact tests were undertook on four carbon fiber reinforced polymer materials and then evaluated the influence of fiber type, fabric weave pattern, and resin system [6]. The ceramic matrix composites were received relatively limited attention, mainly focusing on the high velocity impact (> 100 m/s) behavior of SiC/SiC composites [7]. First the term 'low-velocity impact' (LVI) was defined and the major impact-induced damage modes were described. The LVI is considered potentially dangerous mainly because the damage may be left undetected. Whereafter, thin three dimensions-woven SiC/SiC specimens subjected to LVI tests at room temperature were investigated [8,9]. The damage behavior of 2D C/SiCs after the LVI was experimentally investigated [10,11]. The residual mechanical and thermo-mechanical properties of C/SiC, which was exposed to the LVI, were studied. The

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changes in microstructure and thermo-mechanical properties of C/SiC through exposure to multiple experimentally simulated re-entries were investigated.

To evaluate the resistant ability of C/SiCs to FOD, not only was the impact process to 2D C/SiCs considered, but also the preparation and structures of 2D C/SiCs were investigated. The in-plane dimensions showed a great influence on the mechanical behavior of composite structures under the LVI [12]. Certainly, it was investigated that the carbon fiber's stacking sequence made a difference to low-velocity impact characteristics and residual tensile strength of carbon fiber composite laminates [13,14]. Stitching did not increase the load at which delamination begins to propagate, but greatly reduced the extent of delamination growth at the end of the impact event [15]. A comprehensive study [16] demonstrated that the stitching was particularly effective in improving the compression-after-impact strength and Mode I fracture toughness of carbon/epoxy laminates, and moderately effective in improving the Mode II fracture toughness.

However, so far few LVI damage date with the effects of different stitched densities (SDs) on 2D C/SiCs was reported. In this paper, the effects of SD on the mechanical property and microstructure of 2D C/SiCs were discussed. Three non-destructive testing (NDT) methods (such as infrared (IR) thermograph, X-ray computed tomography, and microscopy) were used to detect the 2D C/SiC specimens after the LVI. It was suggested that thermography should be used to evaluate the LVI damage of C/SiC [17,18].

2. Experiments and methods

2.1. Materials

T300™ carbon fiber [0°/45°] fabric (Toray industries Inc., Tokyo, Japan) was used to prepare two-dimensional (2-D) preform by laminating layer by layer. The planar laminates were stitched by T300™ carbon fiber to 5, 10, and 15 mm/needle of specimens, manually. Pyrolytic carbon (PyC) interface was deposited on the fibers inside the 2D preform by a chemical vapor deposition (CVD) method at around 900 °C, and through a chemical vapor infiltration (CVI) method then silicon carbide (SiC) matrix was infiltrated into the preform at around 1000 °C. The detailed CVD and CVI conditions and parameters were described elsewhere [19,20]. In order to investigate the effect of the SD on tensile strength, the C/SiC specimens after the LVI were cut from the as-fabricated composite plates into dimensions of 200 mm (length) × 50 mm (width) × 3 mm (thickness) for tension. The specimens with three stitched densities were denoted as S_1 (5 mm/needle), S_2 (10 mm/needle), and S_3 (15 mm/needle). The densities of composite specimens were 2.0 g/cm^3 in average and the volume fraction of carbon fiber approximated to 40%.

2.2. Low velocity impact test

LVI tests were conducted on an automatic drop-weight impact testing machine (Sans Materials Co., Shenzhen, China).

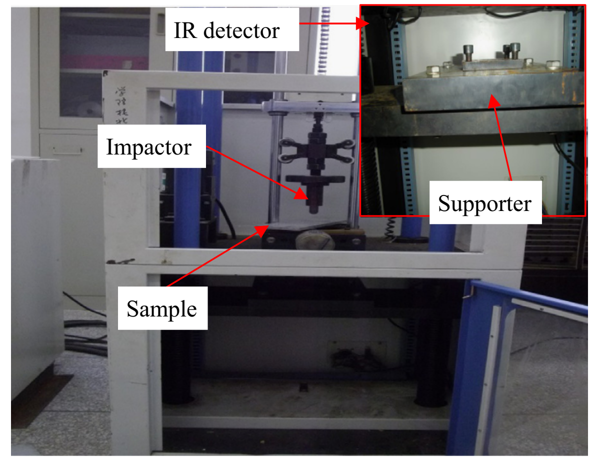

Fig. 1. Photograph of weight drop impact testing machine with the configuration of the sample, impactor, IR detector, and supporter. The inset showing the supporter and sample.

The machine controlling landing height which is able to control the low-velocity process, as visible in the graph of Fig. 1, has the ability of automatic lifting and holding the hammer system of preventing secondary impact. The impact experimental machine is made up of sample, impactor, IR detector, and supporter. The impactor weighted 30 kg is made from 45 steel in 16 mm diameter according to ASTM D7136-05 standard [21]. The deformation of impactor material was not considered. The damage depths of the specimens were measured by a Digital Indicator (Guanglu Number Measuring Instrument Co., Shenzhen, China) and then the observed damage radii were calculated by,

$$R_{OB} = \sqrt{R^2 - (R-H)^2} \quad (1)$$

where R_{OB} is the observed damage radius, R is the impactor radius and H is the damage depth.

The monolithic tensile tests of the damaged C/SiC specimens were conducted on an electronic universal testing machine (Mechanical Engineering Research Institute Co. Ltd., Changchun, China) according to ASTM C1275-00 standard [22]. The mechanical tests were implemented in a displacement controlled mode with a loading rate of 0.5 mm/min, and both ends of the specimens were bonded with Aluminum tab in order to prevent the specimen end from grip crush. The plate specimen number of each condition was five to guarantee data efficiency. Microstructures and morphologies of the C/SiC specimens were observed by scanning electron microscopy (SEM, Hitach S-2700, Tokyo, Japan).

2.3. Nondestructive tests

The damages of the specimens after the LVI were examined by using an infrared (IR) thermograph (EchoThem, TWI Co. Ltd., USA). The instrument consists of the infrared cameras, thermal excitation systems and computer with special software, image acquisition and processing system. The heat application