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Effect of impact energy on damage resistance and mechanical property of C/SiC composites under low velocity impact

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ABSTRACT

The present study investigated the damage resistance of two dimensional carbon fiber reinforced silicon carbide (C/SiCs) composites subjected to low velocity impact (LVI). Damage microstructures of specimens under different impact energies (E_i) were characterized by infrared thermography, X-ray computed tomography and scanning electron microscopy. The real damage radii of specimens were found to change slightly with E_i, whereas apparent damage radii where much larger. Overall, the fabricated 2D C/SiC composites exhibited good damage resistance to LVI with nominal post-impact tensile strengths remaining at 89.4%, 83.35%, 76.97%, and 74.84% of their pre-impacted counterpart of 158 MPa, for impact energies of 3, 4, 5, and 6 J, respectively. Compared with the as-received one, after LVI real tensile strengths of the C/SiC composite specimens increased by 5.84% for the E_i of 3 J, 9.27% for 4 J, −1.83% for 5 J, −3.16% for 6 J.

1. Introduction

Carbon fiber reinforced silicon carbide composites (C/SiCs) have been widely used in aeronautic and astronautic fields due to their excellent high temperature strength, low density, good oxidation resistance and wear resistance [1,2]. The loss of space shuttle Columbia due to foreign object damage (FOD) under impact of a SiC-C/C panel highlighted previously unprecedented concerns relating to fabrication-induced defects and environmental/mechanical damage of ceramic matrix composite parts [3]. Even through C/SiC composites offer numerous advantages over traditional metallic materials, their underperformance under FOD limits their applicability as primary load-bearing structures; studying this performance has been a challenging research topic during the last years. Evans et al. were one of the first to investigate the FOD imparted to a thermal barrier system in a turbine engine in [4]. In [5], the FOD response of three-dimensional woven SiC/SiC composites at room temperature and at 800 °C were investigated along with embrittlement damage characteristics in thermally exposed specimens.

In the process of understanding the damage mechanism behind composite materials failure from FOD, one approach suggests the simulation of FOD on composite laminates by impact testing wherein quasi-static indentation (QSI) [6] and low velocity impact (LVI) [7–12] are the two main testing protocols. Previous studies initially and mainly focused on carbon fiber reinforced polymers with the objectives of studying the complex nature of the damage phenomenon in these composites and evaluating the influence of fiber type, fabric weave pattern, and resin system on the impact behavior as for example in the work on thin CFRP panels of Found et al. [6]. The LVI behavior of E-glass/epoxy laminated composite plates was studied experimentally and numerically by Aslan et al. [7]. It was found that the mechanical behavior of composite under LVI was dependent on the in-plane dimensions of the composite. Similar researches have also been conducted on ceramic matrix composites. Thin three dimension woven SiC_f/SiC specimens were subjected to LVI testing at room temperature and results indicated that the internal damage remained predominantly localized beneath the impactor [8,9] while the diameter of the damaged zone related to the impact energy absorbed by the specimens. The effect of stitched density on low-velocity impact damage of cross-woven C/SiCs were also investigated and delamination as well as residual tensile strength were found to both decrease with the increase of stitched density [10]. The LVI response and damage of composite laminates under in-plane loads were analytically and experimentally investigated in [11,12]. These studies verified that stacking sequence and impact energy (E_i) level affected the dynamic response of composite plates.

In general, critical parameters of LVI testing involve impact velocity, specimen stacking sequence, impactor mass, specimen geometry, impactor size and impact energy E_i. Damage thresholds for woven and unidirectional glass fiber reinforced polymer laminates with varying thicknesses were established through LVI testing at variable E_i in [13]. Results revealed that unidirectional laminates possessed lower

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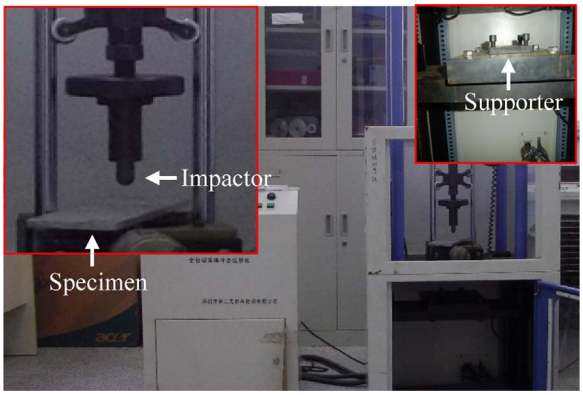

Fig. 1. Photograph of drop-weight impact testing machine with the configuration of the specimen, impactor and supporter.

impact damage resistance than their woven counterparts. The effects of stacking sequence and laminate thickness on the energy absorption capability of woven carbon–epoxy composite laminates under LVI with variable E_i were investigated in [14]. The experimental results confirmed that the absorbed energy increased almost linearly with E_i while the absorption capability of a laminate was found dependent on laminate thickness and stacking sequence. The above findings converge to the conclusion that impact energy is the most important factor affecting the damage behavior of composites. Yet extremely limited information is available on the relation between LVI damage level and impact energy.

This study aims to fill this lack of knowledge by investigation of the damage resistance of 2D C/SiC composites under different impact energies. The effect of E_i on the mechanical properties and microstructure of 2D C/SiCs was also investigated. Three independent non-destructive testing (NDT) methods, namely acoustic emission (AE), infrared (IR) thermograph and X-ray computed tomography (CT), were used to examine the real-time and post-LVI damage aspects of the composites [15,16].

2. Experiment and methods

2.1. Materials

T300™ carbon fiber fabrics (Toray industries Inc., Tokyo, Japan) of 0°/90° orientation were used to prepare the two-dimensional (2D) preforms through layer-by-layer lamination. In this process, 1 K plain weave carbon fiber cloths were laminated to 2D preforms which were

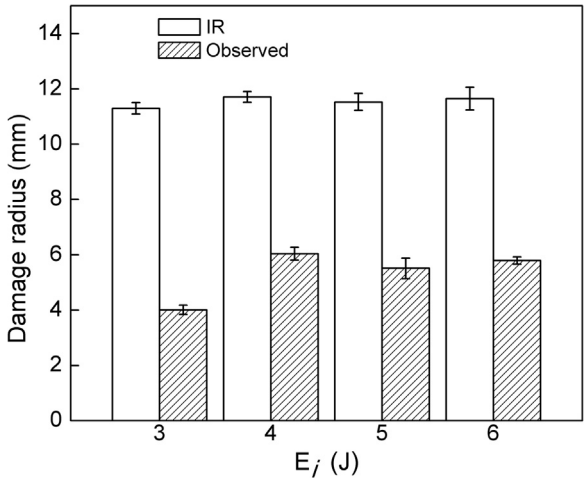

Fig. 3. The effect of impact energy on the observed and IR damage radius of 2D C/SiC composites at the different impact energy of E_i=3, 4, 5, and 6 J.

stitched with 3 K carbon fiber. Pyrolytic carbon (PyC) interface was initially deposited on the fibers inside the 2D preform by chemical vapor deposition (CVD) at a temperature of approximately 900 °C. Subsequently, silicon carbide (SiC) matrix was infiltrated into the preform at around 1000 °C by chemical vapor infiltration (CVI). The detailed CVD and CVI conditions and parameters can be found in our previous works [17,18]. The average density of obtained composite specimens was 2.0 g/cm^3 while the carbon fiber volume fraction was ca. 40%. In order to investigate the effect of E_i on tensile strength, C/SiC specimens were initially machined from the as-fabricated composite plates into dimensions of 200 mm (length)×50 mm (width)×3 mm (thickness) and further subjected to LVI at impact energies of 3, 4, 5 and 6 J. Specimens were named according to the imposed impact energy as S0 (0 J), S1 (3 J), S2 (4 J), S3 (5 J) and S4 (6 J).

2.2. Low velocity impact test

LVI tests were conducted on an automatic drop-weight impact testing machine (Sans Materials Co., Shenzhen, China) consisting of an impactor ball and supporter as depicted in Fig. 1. The impactor constructed of AISI 1045 steel had a weight of 30 kg and a diameter of 16 mm diameter as per ASTM D7136-05 specifications [19]. The machine controlling landing height was capable of automatic lifting and holding the hammer system for preventing secondary impact,

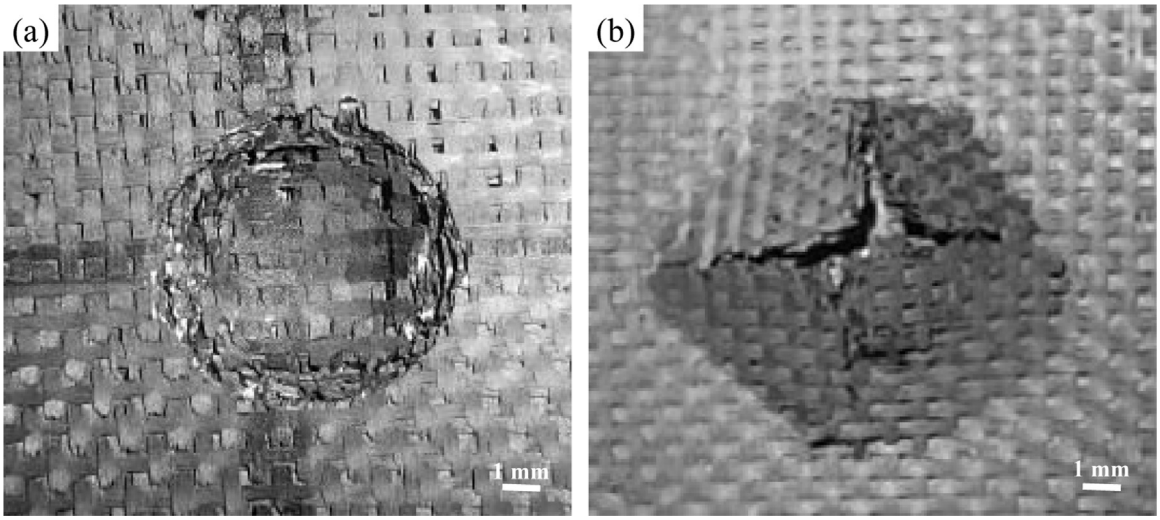

Fig. 2. Photographs of impact damage to the C/SiCs specimens under E_i=6 J showing (a) front side and (b) back side.