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Damage analysis of thin 3D-woven SiC/SiC composite under low velocity impact loading

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ABSTRACT

Thin 3D-woven SiC_f/SiC samples were subjected to low velocity impact tests at room temperature. For this purpose, hemispherical impactors and circular supports of various diameters were used. The extent of damage was evaluated with the help of optical microscopy. Formation of micro-cracks initiating from the indented site is observed. The predominant internal damages (fiber bundle and matrix cracking) remain localized beneath the impactor. This is confirmed by thermography analysis and post-impact tensile tests. The diameter of the damaged zone can be related to the energy absorbed by the specimen during the impact event.

1. Introduction

Ceramic matrix composites (CMCs) combine high temperature strength with improved oxidation resistance. Those composites are promising candidates to achieve lightweight materials for structural components in gas turbine engines. Significant research efforts have been devoted to the development of various families of CMC including silicon carbide matrices reinforced by silicon carbide or carbon fibers [1] and oxide matrices reinforced by oxide fibers [2]. Tensile properties under static and cyclic loads at room and high temperature have been reported [3–5]. The use of a self healing matrix was demonstrated efficient to increase the life time of SiC_f/SiC composites in oxidative atmosphere at high temperature [6]. Nevertheless, aeronautical applications require to evaluate the influence of impacts by foreign objects. Such events which may occur during maintenance or operating conditions can significantly reduce the strength of the material and the design of a composite structure must take into account the damage tolerance to low velocity impact. An analysis of the damage phenomena involved in the impact event is thus needed.

Although many studies have analysed impact damage on polymer matrix composites [7], it is to be noted that few data can be found in the literature concerning the low velocity impact on CMC. Dropped weight impact tests are reported on laminated glass ceramic matrices reinforced by carbon fibers [8], 2D-C_f/SiC [9] and oxide/oxide [10] materials. SiC_f/SiC [11,12] and oxide/oxide composites [13–17] were tested under ballistic conditions with a velocity ranging from 100 to 400 m/s. Those data mainly show that a low impact energy (less than 10 J) is sufficient to damage a thin CMC sample.

This paper is a part of a study devoted to the damage tolerance analysis of a 3D-SiC_f/SiC composite. A previous paper was dedicated to the damage analysis under a static indentation loading [18]. A similar material is here subjected to low velocity impact loading in order to assess the corresponding damage mechanisms. Instrumented dynamic indentation tests were performed on thin plates with a hemispherical indentor. Damage mechanisms were investigated with the help of micrographic observations. Tensile tests on impacted specimens were used to evaluate the mechanical behavior after impact.

2. Experimental procedure

2.1. Material

The SiC_f fiber reinforced SiC matrix composite was fabricated by SAFRAN-Snecma Propulsion Solide (Le Haillan, France) and belongs to the same material family already described in the first part of this work [18]. The woven fiber architecture is a proprietary 3D geometry (Guipex® preform) based on a twill weave with five layers in the warp direction, five layers in the weft direction and an interlock weaving [6]. Each yarn includes 500 Nicalon® fibers. A pyrocarbon interphase and a self healing matrix have been deposited by chemical vapor infiltration. This elaboration process induces some macroporosities between the fiber bundles and some smaller pores within the fiber bundles with a volume fraction about 7%. The fiber volume fraction is 30%. The nominal density is about 2.2. The typical modu-

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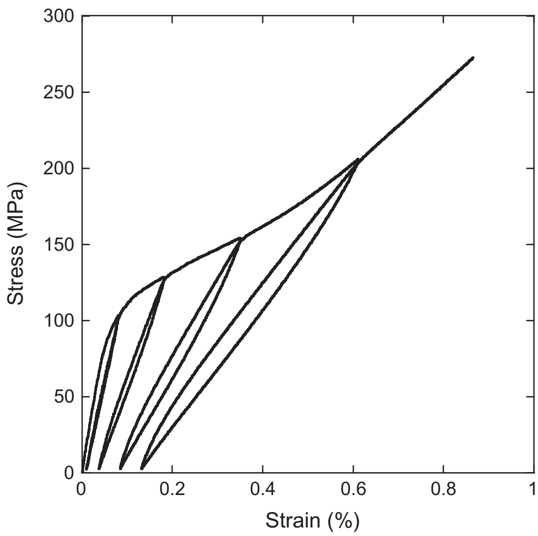

Fig. 1. Tensile response of the 3D-SiC_f/SiC composite (the loading direction is parallel to the fiber direction).

lus in the warp or weft direction is 218 GPa. Fig. 1 depicts the tensile response obtained at 0° to the fiber direction. A non linear behavior is observed which results from the development of various families of micro-cracks as already described elsewhere [19]. The as-fabricated composite panels with a 1.4 mm thickness were machined into square specimens with the respective dimensions 24 × 24 mm^2 (samples 1–5) and rectangular specimens with 150 × 100 mm^2 dimensions (samples 6–9).

2.2. Low velocity impact tests

Low velocity impact tests were conducted using an instrumented drop weight impact tester (Dynatup Minitower, INSTRON). A mass m is attached to the guided impactor equipped with a hemispherical steel indentor (diameter D_p = 9 or 12.7 mm) and a load cell. In the following, the indentor radius will be noted as R_p with $R_p = \frac{D_p}{2}$. The specimen is clamped between a steel support plate and a steel circular cover plate (diameter D_s = 18 or 76.2 mm) using four bolts. An optical sensor evaluates the initial impact velocity v_0 which is adjusted by modifying the highest position of the impact tester. The time history of the impact force $P(t)$ is recorded with a data acquisition system (the sampling frequency is set to 204.8 kHz). An electromechanical device prevents the tup from impacting the specimen a second time if rebound occurs. The initial energy E_i is given by

$$E_i = \frac{1}{2} m v_0^2. \quad (1)$$

The velocity $\dot{\delta}(t)$ and the displacement $\delta(t)$ of the impactor are obtained by integrating the equations of motion with

$$\ddot{\delta}(t) = g - \frac{1}{m}P(t), \dot{\delta}(t) = v_0 + \int_0^t \ddot{\delta}(t)dt, \delta(t) = \int_0^t \dot{\delta}(t)dt. \quad (2)$$

Assuming that the indentor does not deform, the energy $E(t)$ transferred to the specimen is

$$E(t) = \int_0^t P(t)d\delta(t), \quad (3)$$

which is usually partitioned [20–21] with

$$E(t) = E^e(t) + E^{ab}(t), \quad (4)$$

where $E^e(t)$ is the elastic energy and $E^{ab}(t)$ is the absorbed energy. Table 1 summarizes the experimental conditions for each tested specimen.

Table 1
Experimental conditions for the impacted 3D-SiC_f/SiC specimens (thickness 1.4 mm).

Sample	Dimensions (mm^2)	Support diameter D_s (mm)	Indentor diameter D_p (mm)	Initial velocity v_0 (m/s)	Impactor mass m (kg)	Impact energy E_i (J)
1	24 × 24	18	9	1.07	1.13	0.65
2	24 × 24	18	9	1.52	1.13	1.31
3	24 × 24	18	9	1.54	2.13	2.53
4	24 × 24	18	9	2.01	2.13	4.30
5	24 × 24	18	12.7	2.02	1.15	2.35
6	150 × 100	76.2	12.7	2.07	1.15	2.46
7	150 × 100	76.2	12.7	2.08	1.15	2.49
8	150 × 100	76.2	12.7	1.60	1.15	1.47
				1.60	1.15	1.47
9	150 × 100	76.2	12.7	2.44	3.65	10.86

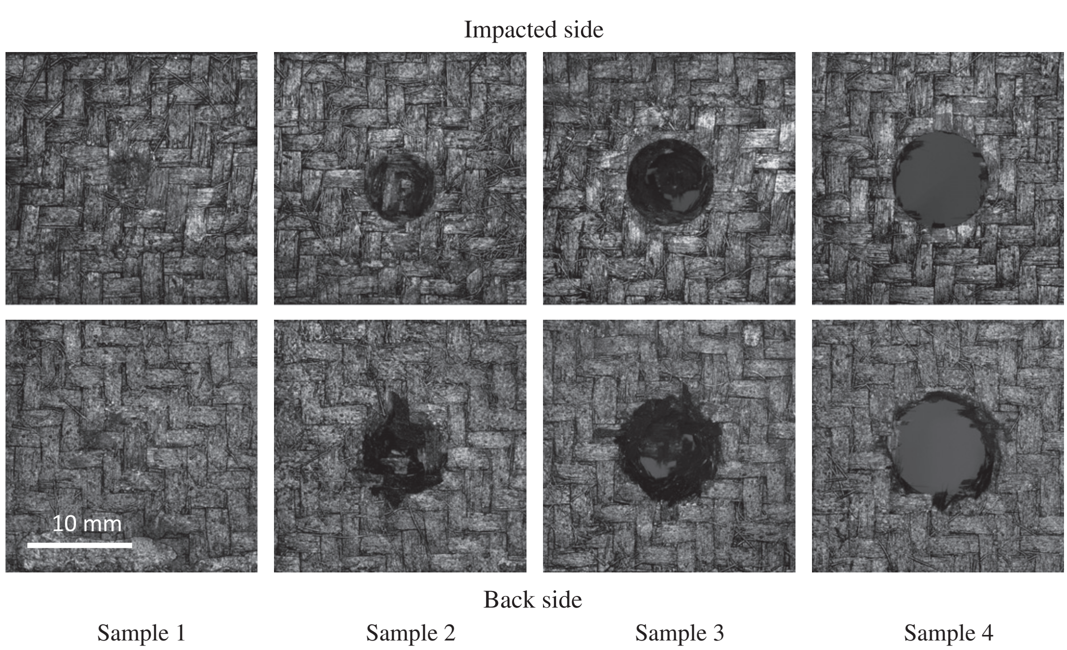

Fig. 2a. Optical photographs of the 3D-SiC_f/SiC impacted samples 1–4 (with D_p = 9 mm and D_s = 18 mm). The dimensions of the specimens are 24 × 24 mm^2.