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Analysis of damage mechanisms and associated acoustic emission in two SiC/[Si–B–C] composites exhibiting different tensile behaviours. Part I: Damage patterns and acoustic emission activity

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Abstract

The present work deals with two SiC/[Si–B–C] composites exhibiting different mechanical behaviours under tensile testing: low strain to failure for the one, high strain to failure for the other with similar ultimate strength. In the present Part I, mechanical hysteresis loops of stress–strain curves are analysed, and detailed cracking patterns are presented and quantified for both materials. The difference between both composites is explained by different values of the interfacial shear stress. Acoustic emission activities are compared as regards to the damage accumulation scenarios. In a companion paper [Moevus M, Godin N, Rouby D, R'Mili M, Reynaud P, Fantozzi G, et al. Analyse of damage mechanisms and associated acoustic emission in two SiC/[Si–B–C] [23] composites exhibiting different tensile curves. Part II: Unsupervised acoustic emission data clustering. Comp Sci Technol, in press], the AE data will be submitted to an unsupervised clustering procedure in order to distinguish the different damage mechanisms.

Keywords: A. Ceramic matrix composites; B. Stress–strain curves; B. Matrix cracking; C. Damage mechanics; D. Acoustic emission

1. Introduction

Non-oxide ceramic matrix composites (CMCs), and more particularly SiC/SiC composites have been widely studied during the last decades [1–15]. Such fibre reinforced ceramic composites are very attractive candidates for many high-temperature structural applications, because of their excellent creep resistance, high-temperature strength and light weight. Damage tolerance is achieved through the use of low shear-strength fibre coating that deflects cracks along the interfaces [6]. Future engine applications in civil aircrafts are foreseen for such composites [7–9]. These applications require very long lifetimes under in-service conditions. The concept of functional multilayered matrix was therefore recently introduced in the new generations of SiC_f/[Si–B–C] composites in order to improve the lifetime under medium and high temperatures thanks to the formation of sealant glasses [10,11]. Various authors have studied the mechanical behavior of the SiC_f/[Si–B–C] composite and the degradation mechanisms occurring at high temperatures [12–15]. Now more information is needed at intermediate temperatures: the oxidation kinetics of the different constituents are complex, and the effect of matrix sealing on the lifetime of the composite has to be examined. The current problematic is a better comprehension of the degradation mechanisms and kinetics in order to perform reliable predictions of very long lifetimes.

The acoustic emission (AE) technique seems to be a very appropriate tool to detect in situ information about the damage occurring during mechanical testing [16]. Acoustic emission is a transient wave resulting from the sudden release of stored energy during a damage process. In composite materials, matrix cracking, fibre failure, interfacial debonding and sliding are possible sources of AE. Several studies have shown that it is possible to identify the acoustic signatures of some damage mechanisms [17–22]. The

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issue of the present work (described in two companion papers) is to assess if the different damage mechanisms occurring in SiC_f/[Si–B–C] composites can be detected by the AE technique and distinguished by a statistical clustering procedure. The methodology may further be applied to static fatigue tests at intermediate temperature in order to perform lifetime predictions.

The study will focus on two SiC_f/[Si–B–C] composites exhibiting substantially different stress–strain behaviours at room temperature. The comparison between them represents an interesting opportunity to assess the AE analysis methodology. In this paper an experimental study of these two composites leads to the identification of two distinct scenarios of damage accumulation. It is shown that different mechanical behaviours lead to distinct AE activities in each composite. So it seems possible to find some link between AE and damage mechanisms. In the companion paper [23], a pattern recognition-based analysis of the AE data will be presented in order to identify the AE signatures of the main damage mechanisms.

2. Materials

The present study deals with two materials of the same family: both have a multilayered [Si–B–C] matrix reinforced with Hi–Nicalon fibres and a carbon interphase layer. The fibre preform is composed of a stacking of woven cloths in the *X*–*Y* plane. The multilayered matrix was processed by several chemical vapour infiltration steps with different compositions from the ternary [Si–B–C] system: SiC, B_4C and Si–B–C. Some macroporosity (nearly 12% volume fraction) still exists between adjacent and crossed yarns. Once the specimens are machined from the initial plate of material, an external seal-coat is processed by several chemical vapour deposition steps, which results in closing the open porosity of the tensile specimens and increasing the matrix volume fraction. The seal-coat has the same mechanical role as the matrix in the composite, it is submitted to cracking at small applied strain, whereas the fibres will fail at higher applied strain.

By this elaboration process, two composites exhibiting significant differences in the mechanical behaviour were obtained. They are noted M-E (elongation) and M-S (stiffness) (Fig. 1). The origin of such difference was not clearly identified. The cycled tensile tests presented in Fig. 1 were performed at room temperature, with a displacement rate equal to 0.2 mm/min, except during the unload–reload cycles where the rate was 2 mm/min. Both materials exhibit nearly the same initial Young's modulus (205 GPa for M-E and 225 GPa for M-S) but M-E fails after a twice larger elongation than M-S. The ultimate strength of M-S (321 MPa) is a bit higher than that of M-E (293 MPa).

Our own experimental study is based on special tensile tests described in the next section. Results of post-mortem microscopic investigation are presented to specify the differences in the damage accumulation of both materials.

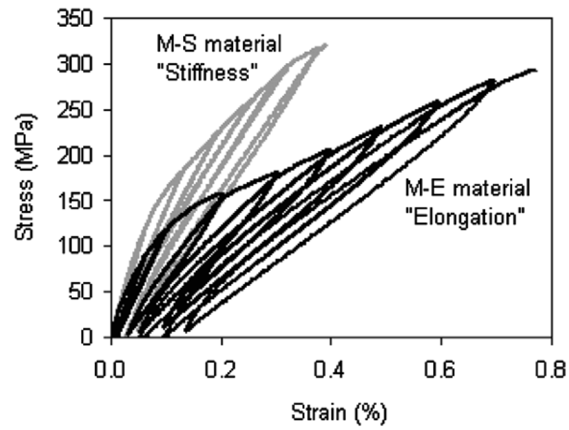

Fig. 1. Stress–strain curves by cycled tensile test. Black: M-E material; grey: M-S material.

Then the global AE activity is discussed in relation with the observations made after the tests.

3. Experimental procedure

3.1. Mechanical testing

The tests were conducted on a servohydraulic INSTRON 8502 machine at room temperature. Dog bone-shaped tensile specimens were used. Their dimensions are specified in Fig. 2a. The specimen M-E is 3.5 mm thick, whereas the M-S one is 4.5 mm thick. The fibre and matrix volume fractions before the seal-coat deposition are the same in both composites. It was decided to perform special tensile tests including a constant load-hold step which is representative of in-service conditions, followed by unload–reload cycles to characterize the influence of the preceding step on the mechanical behaviour. The applied loadings are schematised in Fig. 3. The specimens were first loaded in tension at a constant rate of 600 N/min up to the test load (O → S), which corresponds to a strain equal to 0.3%: 184 MPa for M-E and 280 MPa for M-S. The load

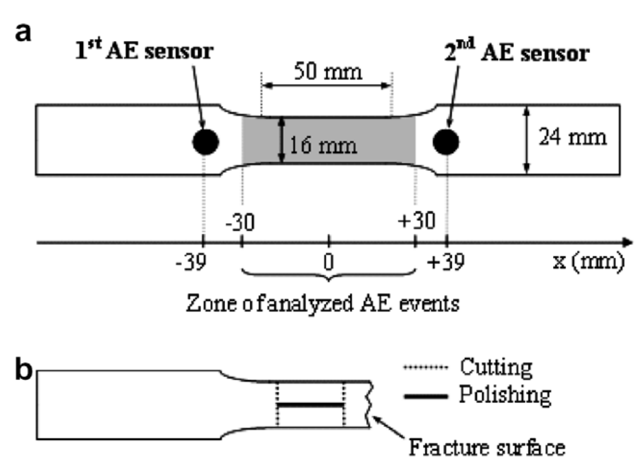

Fig. 2. Dimensions of the specimens and position of the AE sensors (a), and description of sample preparation after fracture for microscopic observations (b).