DAMAGE IN A SIC/LAS COMPOSITE UNDER DYNAMIC LOADING.

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Quasi-static and dynamic bending tests have been performed on a SiC/LAS composite. Microstructural observations using SEM and electronic microprobe techniques show some differences between the failure modes, depending on the rate of strain. Some hypotheses are discussed to explain these differences.

INTRODUCTION

An important amount of work has been performed over the last decade on ceramic and glass-ceramic matrix composites which are very attractive for applications where lightweight, high temperature resistant materials are needed. Their properties under quasi-static loadings are now better known (1), but their properties at high strain rate have yet to be investigated. This work tries to give a better knowledge of these properties, which is necessary when considering both structural and armor applications in rockets, engines, aircraft and helicopters.

Material and testing

All the observations and testings have been performed on unidirectionnally SiC reinforced LAS glass-ceramic specimens, provided by St Gobain Recherche or ONERA, France. The reinforcement consists in Nicalon NLM 202 silicon carbide fibers. They are wrapped with SGR 6861

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glass powder and aligned in a mould, then hot pressed at 1350° C and densified up to 98 or 99 percent of the maximum theoretical density. An appropriate heat treatment is then applied to crystallise the glassy matrix. All specimens are provided as thin plates, 1.5 to 3 mm in thickness.

Quasi-static tests have been performed using the three point bending technique, with span over thickness ratios S/B ranging from 12 to 20, thus generating an important shear stress leading mainly to shear failure of the composite. Dynamic testings have been performed using a Hopkinson-bar loaded three-point flexural system. The device used has not so far proved satisfactory, giving no reliable quantitative information on the test. The system should be improved to allow the precise knowledge of the phenomena happening during the test. Thus, so far, the work has focused on microstructural aspects of the differences between quasi-static and dynamic failure of this composite.

Preliminary and quasi-static tests

Preliminary tests and observations on as-received samples have shown a marked non-uniform distribution of the fibers. Measurements of the interface shear stress by micro-indentation techniques, following the assumption of a frictionnal fiber-matrix interaction, are shown on Figure 1.They give values ranging from 1 MPa for thick fibers (Ø≈20 μm) to 3 MPa (Ø≈ 12 μm) (2) (3). The decrease in these values can be related to the mismatch of the thermal expansion coefficients of the fiber ($\approx 3.\ 10^{-6}$) and the matrix ($\approx 1.5\ 10^{-6}$) which leads to fiber-matrix decohesion on part of the interface, larger decohesion occuring for larger fibers.

The values of elastic longitudinal modulus, maximum shear stress and maximum equivalent tensile stress are given in Table 1.

TABLE 1: Results of quasi-static tests.

Fiber volume fraction	Flexural modulus	Max. equiv. tensile stress	Max. equiv. shear stress
36.4 percent	102 GPa	570 MPa	18 MPa

As mentioned above, the tests lead mainly to shear failure along the direction of the reinforcement. Actually, the Nicalon/6861 composite seems to be very susceptible to this failure mode. (4)

Dynamic tests

Identical samples have been used for both quasi-static and dynamic tests.Strain rates of 10^3 are achieved, but the dynamic bending test provides a non-uniform distribution of rates of strain over the sample. The results of the tests are widely identical to those of the quasi-static tests, the dominant failure mode being shear failure. Nevertheless, some differences can be noticed, which are probably related to the high rates of strain.

First, for a given residual bend, dynamically loaded samples exhibit larger damage along the main crack than statically tested samples. Secondly, fibers lying along the crack show a partially peeled surface, as shown in Figure 1, while they look smooth after quasi-static failure test. Fiber-matrix decohesion seems to be quite dependent on the rate of strain. Thirdly, some dust can be observed after the test.

DISCUSSION

In order to clear the way to further analysis, it is important to try to explain the main results obtained to date, highlighting the differences between low and high rate of strain.

The sensitivity to shear failure seems to be a characteristic feature of the material. The fiber-matrix decohesion can explain this feature, as it makes the shear stress concentrate in the matrix rather than being shared between the fiber and the matrix. The shear stress in the matrix may reach much higher values than those predicted using calculated shear elastic constants. This is an especially important feature designers will have to be very careful to.

The large damage along the main crack for high strain rates may be explained using a well known result of brittle material fracture mechanics, which is the tendency of fast-propagating cracks to branch into several secondary cracks. Under dynamic loading, the first crack propagates quickly along the fibers and its branches penetrate inside the matrix on both side of the crack. The network of cracks thus created can be dense enough to isolate parts of the matrix thus producing the observed dust. This feature is important, for it may lead to a significant drop in the pull-out work.

The interpretation of the second characteristic feature of dynamic failure requires further microstructural analysis of the interfacial zone. An electronic microprobe analysis has been performed on both polished cross-sections of the composite and post-test extracted fibers. The latter analysis gives the relative intensities of the Kα rays of carbon, oxygen and silicon of the structure as shown in Figure 3. Different layered structures are examinated until the calculated values they give match with the experimental values. The analysis has revealed the interphase structure given in Table 2, which is consistent with the results of Chaïm and Heuer (7), Bischoff et al. (6) and Ponthieu et al (5). One may notice that the thickness given for the second, oxygen-richer layer is only approximate, since this layer shows a diffusion profile.

TABLE 2: Interphase structure on SiC fibres.

Thickness of the layer (A)	C (Wt %)	O (Wt %)	Si (Wt %)
1100	100	0	0
250	10	48	42
Fiber bulk	28.8	12	59.2

X-ray and electronic microprobe analyses on polished cross-sections of the composite have also shown a non-uniform NbC layer between the C layer and the bulk of the matrix. The NbC seems to be crystalline and strongly bonded to the the matrix, while the results of the micro-indentation tests can be related to a very weak bonding between the C layer and the NbC layer.The micrographic observations and electronic microprobes measurements on fibers extracted from dynamically tested composite are consistent with the assumption that the crack occurs between the C and NbC layers ("high" steps) or between the C layer and the bulk of the fiber, in the oxydized layer ("low" steps) as shown in Figure 4. This is confirmed by the measurements performed in the peeled zones ("low" steps), which show a composition almost identical to the bulk of the fiber. The point is that during static tests, no crack occurs between the C layer and the bulk of the fiber but always between C and NbC layers. During dynamic tests the unstability of fast propagating cracks (8) (9) and the non-uniformity of the NbC layer, which gives a non-uniform fiber-matrix bonding, leads to the peeled fiber surface appearence. It is generally admitted that no chemical bonding occurs between fiber and matrix - i.e. between the NbC layer and the C layer - in these composites, but this assumption may prove false in the zones where NbC is lacking. This could explain how unstable cracks running along the C/NbC interface undergo branching phenomena when reaching tougher bonding zones and penetrate the C layer, as well as it could explain the wide dispersion in the measurement of the interfacial shear stress. A micromechanical modelling is under way to test this statement.

CONCLUSION

Some important results on the dynamic failure SiC/LAS composite material have been shown. First one may notice that shear failure is the dominant failure mode of the material. Nevertheless, SiC/LAS elaborated with thinner fibers should prove less susceptible to this failure mode.

Secondly, some noticeable differences between quasi-static and dynamic failure have been evidenced. The crumbling into dust of the matrix , which is a very important phenomenon since it may lead to a significant decrease in the fracture energy of the composite, and the rather different fiber-matrix decohesion mode are the main specific features exhibited by the dynamically tested composite. These results will constitute the basis of further work on the dynamic fracture of this material.

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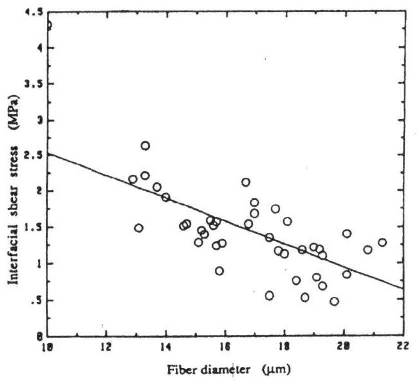

Figure 1 Micro-indentation measurements of the interfacial shear stress.

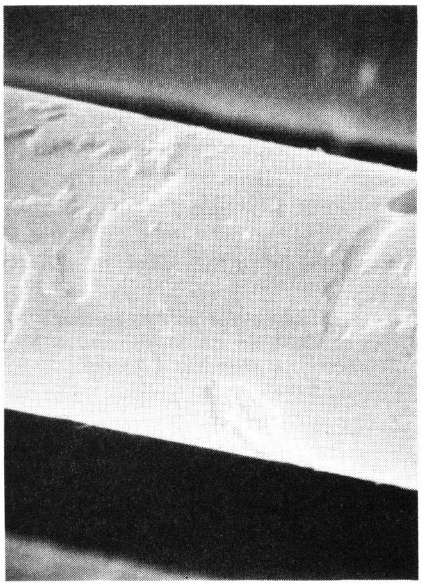

Figure 2 SiC fiber extracted from a dynamically tested composite.

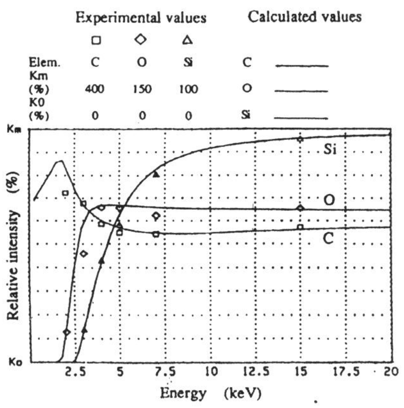

Figure 3 Multi-tensionmicroprobe analysis of the interphase.

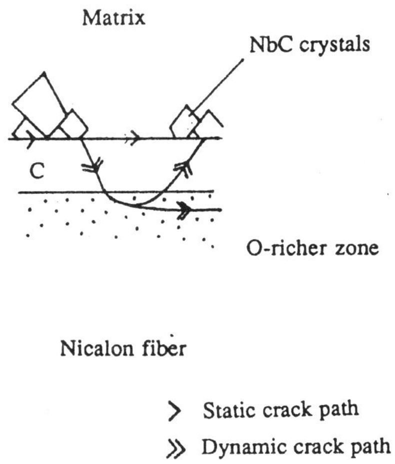

Figure 4 Quasi-static and dynamic crack path through the interphase.