Advanced Composite Materials

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tacm20

Main features of thermostructural composites for space, aeronautic and industrial applications

Pierre Lamicq [a]

[a] SEP, Division de Snecma, Le Haillan, BP 37, 33165 Saint-Medard-en-Jalles, France

Version of record first published: 02 Apr 2012.

To cite this article: Pierre Lamicq (1999): Main features of thermostructural composites for space, aeronautic and industrial applications, Advanced Composite Materials, 8:1, 47-53

To link to this article: http://dx.doi.org/10.1163/156855199X00065

Adv. Composite Mater., Vol. 8, No. 1, pp. 47–53 (1999)

Main features of thermostructural composites for space, aeronautic and industrial applications

PIERRE LAMICQ

SEP, Division de Snecma, Le Haillan, BP 37, 33165 Saint-Medard-en-Jalles, France

Abstract—Thermostructural Composites are made of inorganic fibers, like carbon or ceramic fibers, associated with an inorganic matrix. So, they are able to sustain high temperatures. Many combinations and even more processing routes may be implemented. Fibers and matrix are usually brittle materials, but the composite may present a much higher toughness and a good strain to failure. Mechanical loads on thermostructural composites generate cracks which propagate under monotonous or alternate loadings. The crack pattern governs most of the composite properties. Furthermore, it allows the penetration of oxidative or corrosive agents, thus affecting the long-term properties. Design of parts must take into account the geometrical singularities, where fiber orientations, fiber ratio and matrix content may vary rapidly. Special tests on technological samples are the more efficient way to ascertain the design in these areas. Thermostructural composites are more and more used in high temperature and aggressive atmospheres, because they are light and damage-tolerant.

Keywords: Composites; high temperature; carbon/carbon; ceramic matrix composites.

1. INTRODUCTION

Thermostructural Composites are more and more used in a variety of applications, when the polymer and even the metal matrix composites are not able to sustain the high temperatures involved. Those carbon–carbon and ceramic matrix composites are light, non-brittle and present good or fair creep and fatigue tolerance. Their properties result in some competitive advantages and they are frequently selected in spite of their novelty and some design peculiarities.

Carbon–carbon composites were the first to be developed. They showed the distinctive features of those composites. A wide variety of carbon fibers and reinforcement patterns were used, and many processing routes were implemented, leading to many different products among which only a few gained real industrial and economic success. The basic 2D lay-up has been frequently overtaken by more complex patterns, to achieve better isotropy. But in turn, more fiber orientations led to more intricate mechanical behavior, like in carbon–carbon 4D (Fig. 1) and carbon–carbon 2.5D (Fig. 2). Glass matrix composites opened another field, with the hope of avoiding the main weakness of carbon–carbon, which is very sensitive to high temperature oxidation. The real ceramic matrix composites were then generated with a SiC matrix by the CVI route, inside a reinforcement made of woven SiC(O) fibers obtained by polymer pyrolysis. Since then, many other combinations of carbon and ceramic products have been proposed, and frequently generated and tested, at least at laboratory level. This is due first to the wide variety of ceramics either in oxides and non-oxides, and also to the numerous routes available for processing. In supplement to chemical vapor infiltration, liquid infiltration and powder infiltration used for carbon, sol-gel techniques, chemical vapor reaction, liquid metal oxidation among others have been implemented.

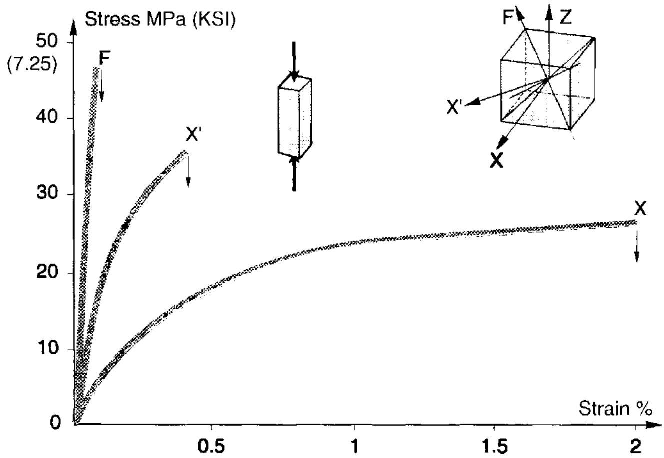

Figure 1. Compression tests of a 4D carbon–carbon.

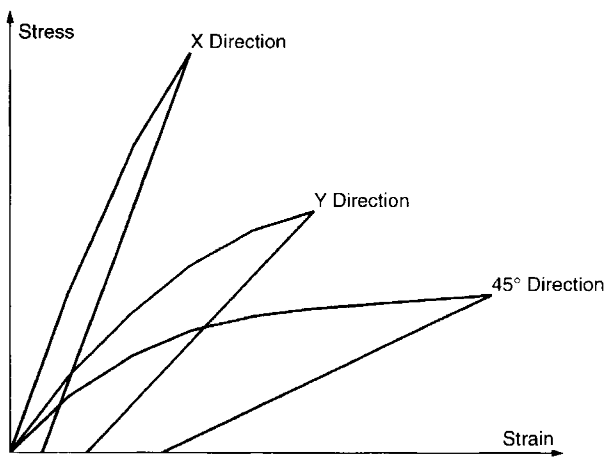

Figure 2. Anisotropy of a 2.5D carbon–carbon composite.

2. PROPERTIES AND ANISOTROPY

Basically, thermostructural composites are complex materials, inhomogeneous, highly anisotropic, non-linear and with brittle constituents. They make it difficult to design a part, but they are likely to survive when other materials would fail. Their competitive advantages vary with respect to the different uses anticipated, but can be generally described as:

- they are light compared to steel and to highly refractory metals and alloys
- they are tough compared to ceramics and also graphite; moreover, the fracture energy necessary to propagate damage rises to 2 or 3 orders of magnitude higher than monolithic ceramics
- they are damage-tolerant, as a localized matrix-cracking may accomodate an overstress or an impact, without resulting in a complete catastrophic part failure
- they have good fatigue properties and, at least for non-oxide composites, some fair creep resistance.

The basic shape of a stress–strain curve on a tension test is well known: after a first linear region, the curve bends towards ther first axis, as the strain is increased faster than the stress. When coming down to zero load, some non-reversible distorsion is usually observed. The tests results may be quite different along various directions inside the same composite (Fig. 2 and Fig. 3). The variations along the fiber orientations are mainly due to different fiber nature or patterns, when the 45° results come from the occurence of shear. The situation is completely different on compression tests, with a quasi-linear relationship, even after a previous tension test creating extended damage in the composite (Fig. 3). This is the situation for the very first loading of a sample or a part.

For cyclic loadings, the stress–strain curve stabilizes after a few cycles, giving a more or less linear relationship with some hysteresis loops. Then, as the number of cycles increases, the modulus slowly decreases (Fig. 4). At the same time, the residual elongation at zero stress remains almost constant. This can be repeated at increasing load levels.

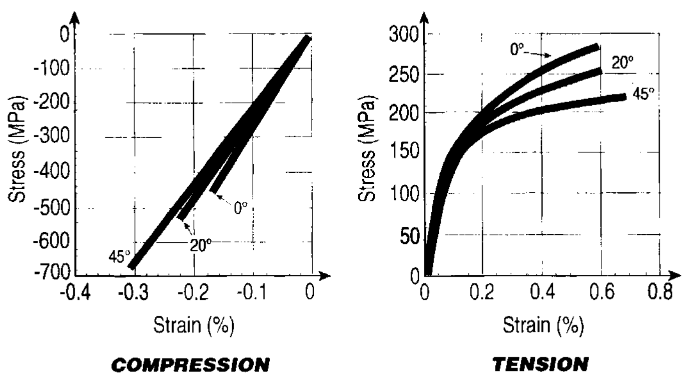

Figure 3. Tension and compression tests on a 2D SiC–SiC *versus* fiber angle.

The phenomena which create such variations in the composite behavior have been identified as crack generation, crack propagation, debonding of the fiber–matrix interface, individual monofilament breaks in the fiber, fiber pull-out in the matrix and at last catastrophic failure of the fiber bundles. This has been for long observed in CT tests. The energy which is necessary to propagate the crack in a sintered monolithic ceramic is multiplied in a ceramic matrix composite where many cracks

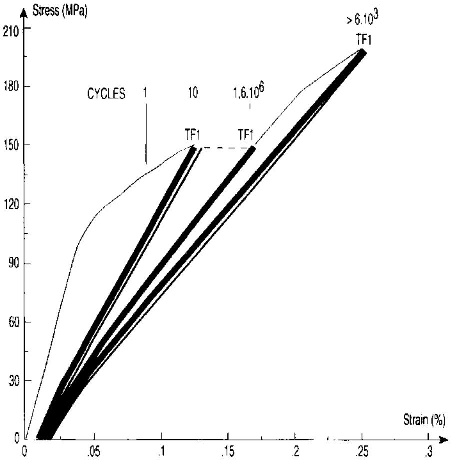

Figure 4. 2D SiC–SiC fatigue at increasing loads.

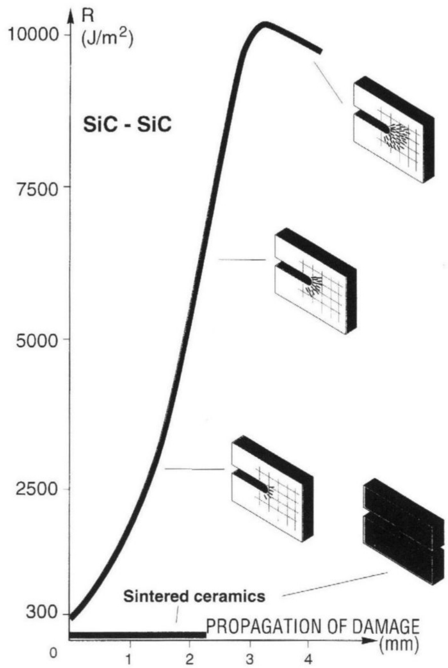

Figure 5. Crack propagation test.

are generated inside a damaged volume. This results in a dramatic increase of the fracture energy (Fig. 5). The rank and amplitude of each mechanism vary from one composite to another, and specific observations have to be made on each material to obtain a good knowledge of the way it is progressively damaged. Of course, most of these effects are temperature sensitive, mainly because the residual stresses change with the temperature. The occurence and propagation of cracks change the response of the material, not only in the direction of applied loads, but also in all others. A convenient way to get a comprehensive view of these effects is to use ultrasonic methods. It is then possible to identify the evolutions of all the coefficients of the stiffness matrix, due to progressive damaging of the composite. Here again, the influence of shear on other parameters has to be noted (Fig. 6).

Thermostructural composites behave like damageable materials. The conditions necessary to obtain non-brittle materials out of brittle fibers and brittle matrix have been long identified: some interfacial properties have to be adjusted to allow matrix crack deviation along the fibers instead of straight propagation across the fibers.

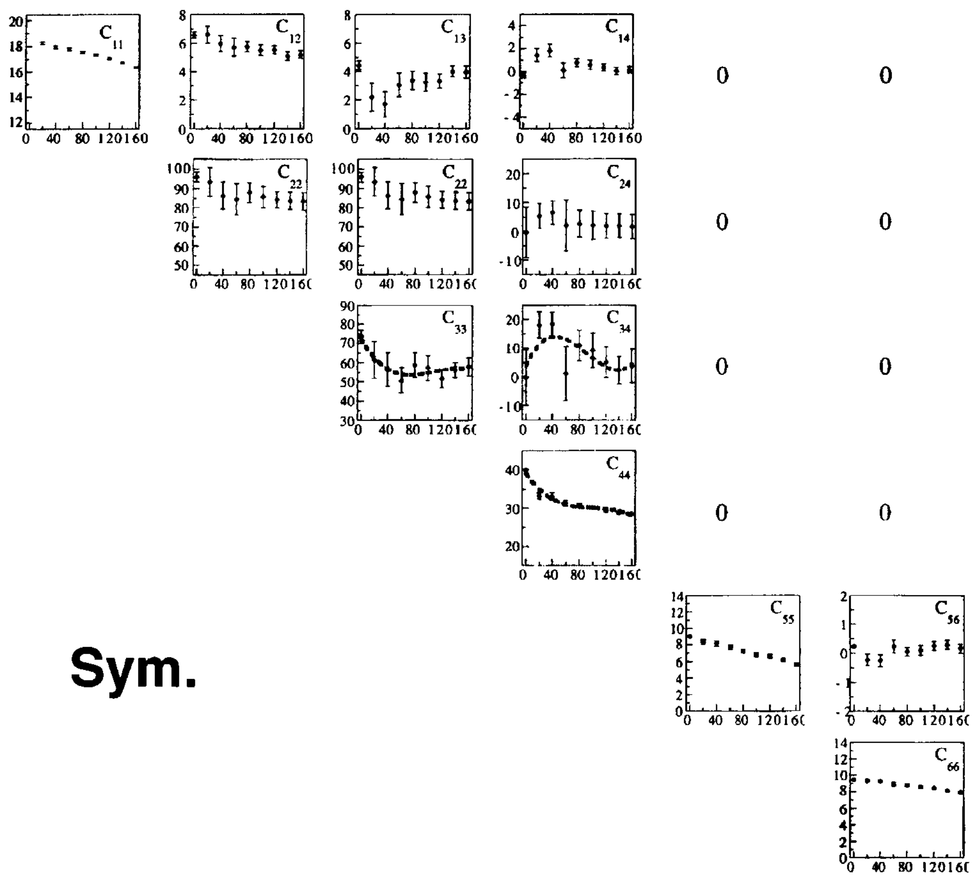

Figure 6. Stiffness matrix of a 2D C/SiC: (horizontal) x-axis: stress applied along axis 1 (MPa); (vertical) y-axis: coefficient of the stiffness matrix (MPa).

Many data have been generated on these issues but no general theory is yet available. In practice, a different material is used as a thin intermediate layer named the interphase. Pyrolytic carbon and boron nitride have been extensively used, but new studies involve more exotic ceramic materials, or multilayered patterns.

3. LONG TERM PROPERTIES

Long term properties of thermostructural composites are related both to mechanical effects, like fatigue and creep, and to chemical reactions. At high temperatures, kinetics are strongly activated and may generate dramatic effects like catalytic oxidation of carbon. Some internal reactions may occur inside some constituents, like SiC(O) fibers, but also interactions between fiber and interphase material, or between interphase and matrix. More generally, thermostructural composites are submitted to both high temperatures and aggressive media, with oxidative or corrosive effects. Here also, the crack network has a strong influence upon the evolution of the composite. The aggressive species are able to penetrate more rapidly in-depth in the material through the cracks opened by the stresses. In turn, the resulting internal chemical attack weakens the composite, generating new cracks. This damage would progress continuously unless the products of the chemical reaction seal the crack, either at its opening or at its tip. Then, the reactants can only be transferred by a solid or liquid diffusion process, much slower than vapour diffusion.

4. DESIGN OF PARTS

The design of thermostructural composites parts has to cope with their basic properties. The manufacturing processes, both for preform lay-up and matrix processing, generate limitations in shape or thickness. Furthermore, the fiber pattern may vary locally near the singularities of the part, either due to the shape, bends or corners, or to reinforcements near the load carrying areas. An analytical approach is difficult and unrealistic in such cases, and has to be substituted by specific tests on technological samples. The geometry of those samples is simplified in order to make easier their manufacturing and testing, but has to remain representative of the composite as it is inside the part in that specific area. In other regions of the part, an analytical approach is sufficient, provided that the more or less complex model representing the composite has been carefully validated against tests measurements on simple samples geometries.

5. CONCLUSION

Thermostructural composites are continuously improved and in turn are entering in new markets. CMC are progressively becoming mature materials as carbon–carbon composites are for long. The basic understanding of the internal mechanisms which govern their non-brittle behavior is progressing. This will lead to better design of parts.

Skilled and interactive people are the key to take the best of thermostructural composites, light, damage-tolerant, high temperature materials.