1 Introduction

Carbon-Carbon (C/C) composite materials are often used for tribological applications in aerospace industry due to their low density. In working conditions, the main mechanical loads are applied in the through-thickness direction of the material. This paper investigates the through-thickness mechanical behavior of a 2,5 C/C composite subjected to monotonic and cyclic compression aiming to characterize the elastic, inelastic and damageable domains.

2 Material and samples

The fiber preform is obtained by staking of unidirectional carbon fiber yarns using 0°/±60°/−60° directions. After deposit of each layer a needling operation gives the 2,5D fiber structure. The matrix is obtained by Chemical Vapor Infiltration and final porosity is close to 10%. A through the thickness optical micrograph is shown in Fig. 1, where the in-plane and vertical (thickness) fiber yarns, the pyrocarbon matrix and the porosities are visible; layer thickness is typically close to 500 µm.

3 Experimental results

3.1 Monotonic through-thickness behavior

Testing samples have cylindrical shape with 22 mm in high and a diameter of 10,5 mm. They have been machined from a brake disc.

Testing was performed on an electromechanical testing machine (Instron 5800R) at constant crosshead displacement rate and strain was recorded with an 10 mm gage length contact extensometer (Instron 2620-602). Two types of testing procedures were applied: a monotonic compression test until sample’s rupture, whereas the second is a cyclic one in which the sample is submitted to successive loading/unloading cycles each 20MPa.

Elastic and inelastic properties are derived from the two procedures and damage parameters where determined form the cyclic test.

Through-thickness compressive material behavior is elasto-plastic as shown in Fig 2 where the compressive stress is plotted against the compressive strain. It can be fitted with two straight lines, the first one corresponding to the elastic domain with a Young’s modulus close to 11,5 GPa. It ends at a strain close to 1% corresponding to a stress ranging
form 100 to 120 MPa. When comparing to the elastic properties of the constituents (fiber transversal 19 GPa, fiber longitudinal 110 GPa and pyrocarbon 10-12 GPa [1,2]), it can be concluded that material elastic properties are mainly related to the fiber transversal and pyrocarbon properties, and that fibers pulled down by needling give low contribution. The second linear domain corresponds to the hardening with a modulus close to 1.5 GPa. Physically it corresponds to a microcraking of the matrix. Rupture of the samples occurs in shearing at 45° of the loading direction for a rupture stress ranging from 180 to 200 MPa and a strain between 5 and 5.5%.

In monotonic loading conditions, the compressive behavior can be easily described with an elastoplastic isotropic hardening model.

### 3.2 Inelastic and Damageable properties

![Fig. 3: 2,5D C/C typical behavior under cyclic through-thickness compression](image)

Fig. 3 shows the typical experimental behavior of the 2,5D C/C subjected to successive loading and unloading during the compression test. Each unloading shows a progressive decrease of the apparent elasticity modulus that is related to an increased microcracking of the matrix. It is used to derive a damage parameter [3,4] as defined in (Eq.1)

\[
d_i = \frac{(E_{i+1} - E_0)}{E_0}
\]

where \(E_{i+1}\) the elastic modulus of the cycle \(i + 1\) and \(E_0\) the elasticity modulus of the virgin material.

It can be seen also in Fig. 3 that after unloading a residual strain remains that is related to the matrix debris after microcracking. Several tests prove that the relation between applied load and residual strain is closely linear and that its evolution an be modeled as follow:

\[
\varepsilon = a \sigma \quad \text{with} \quad \sigma \geq 100 \text{MPa}
\] (2)

Unloading-reloading curves show an increased hysteresis loop that is related to internal friction between fiber and matrix but also between pyrocarbon matrix blocs. The macroscopic behavior of the material in the inelastic domain can be modeled as a damageable behavior with increasing residual strain.

### 4 Conclusion

A characterization of the 2,5D C/C composite mechanical behavior in compression was performed. Mechanical properties, material damage and rupture mechanisms were analyzed to explain the macroscopic behavior.

Two modeling approaches were performed to model this behavior: an elasto-plastic isotropic hardening for monotonic compression description and an elasto-plastic damageable kinematic hardening for cyclic compression tests. Parameter identification and comparison with experiment will be reported in full paper.

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### References


