MECHANICAL CHARACTERISATION OF CFRC COMPOSITES EXTRACTED FROM AN AIRCRAFT BRAKE DISK

Damião, A.A., alexdamiao23@hotmail.com
Barbosa Filho, A.J.T., albertojorgefilho@yahoo.com.br
Silva, F.F., ffs.felipe@gmail.com
Marques, J.G.O.O., zaca_jg@yahoo.com.br
Levy Neto, F., flaminio@unb.br
Souza, D.H.C., diego.unb@hotmail.com
Universidade de Brasilia, UnB/FT/ENM, 70910-900 Brasilia - DF

Abstract. *Carbon Fiber Reinforced Carbon (CFRC) composites have been recently adopted as structural materials for use in aircraft brake disks, nozzle throats for rocket motors, heat shields for aerospace vehicles, orthopedic implants, and special optic instruments. This kind of advanced composite consists of a carbonized matrix reinforced with carbon fibers. The main purpose of this work was to measure the hardness, as well as the absorbed energy in Charpy impact tests, of CFRC specimens extracted from the brake disks of an aircraft. Two kinds of hardness tests were adopted Rockwell L and M and, for the measurement of the absorbed energy, both at 25 °C and –190 °C, rectangular samples endowed with V notches were used. The repeatability of the results was quite good and, in particula, the absorbed energy of the test samples did not vary significantly when the temperature was changed from –190 °C to 25 °C.*

Keywords*: composite brakes, mechanical properties, CFRC composites, Charpy impact test*

1. INTRODUCTION

The purpose of this work is to evaluate a Carbon Fiber Reinforced Carbon (CFRC) used in aircraft brake disks, as well as to discuss its advantages over other materials applied for the same purpose. This work also shows CFRC mechanical properties and the main reasons for using it in aircraft brake disks. For being a carbon/carbon composite, CFRC presents the combined advantages of the carbon fiber, which are high stiffness and strength, and the excellent ablative and refractory properties of the graphitic matrix (Callister Jr, 2005; Thomas, 1993; Levy Neto et al., 1995).

The aircraft landing gear is compound with two groups of intercalated concentric disks: one stator set which remains fixed on the landing gear structure, as well as one rotor set which rotates fixed to the aircraft wheel. During the braking process, hydraulic pistons press both sets one against each other. Vast amount of heat is produced once rotational kinetic energy of the rotor set is transformed in thermal energy. In this context, C/C composites have many advantages over other metallic materials, for the reason that their mechanical properties are preserved in high temperatures or even in low temperatures (when the aircraft is cruising at high altitude). The braking process requires materials with resistance and specific properties such as: high capacity and thermal conductivity, low coefficient of thermal expansion, high thermal-shock strength, adequate mechanical strength, impact strength, high elongation in high temperature, high melting point, and low density among others. These materials can be applied to many other areas, for example, raw materials for nozzle throats for rocket motors, although their main applications are in aircraft brakes (Fisher, 1990).

The major problem about C/C composites is their oxidation process, which occurs at high temperature (from about 450°C). For being a porous material, their faying surface in air are larger than other materials used for the same purpose, and consequently, oxidation is 10 to 100 times larger than it would be with their geometric surface. Usually, one solution to solve the oxidation problem is to coat the composites external surface with silicon carbide or boron nitride, which act as a prime barrier against the oxygen that enters through disks edges (Levy Neto and Pardini, 2006; Savage, 1993). The main objective of the present paper is to report, analyze, and discuss the obtained experimental results for the hardness, the density, as well as the dynamical Charpy impact tests of indented rectangular specimens of C/C extracted from an aircraft brake (Sims, 1988). Some of the experimental tests that can be conducted with C/C composites are (Savage, 1993; Levy Neto, et al., 1994):

-Optical Microscopy;
-Hardness Tests;
-Three-point-flexion Tests;
-Density and Porosity;
-The Modulus of Flexural Elasticity by the Method of Sonic Resonance;
-Electrical Resistivity; and
-Ablation Tests;

All the tests carried out in this work, for reasons of time and equipment restriction, were: (i) Rockwell hardness, and (ii) Charpy impact tests.

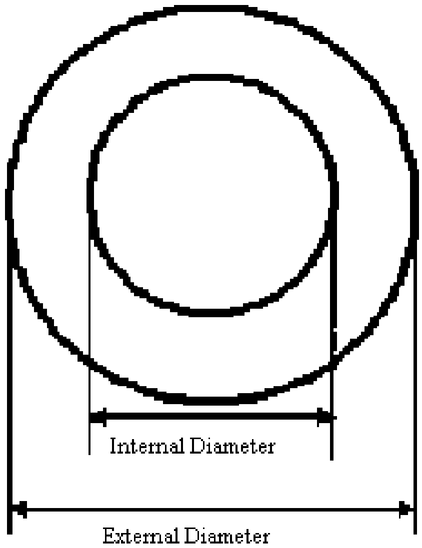
2. MATERIALS AND EXPERIMENTAL PROCEDURE.

2.1 Tested Materials

The solid C/C specimens tested in this investigation, reinforced with high strength carbon fabrics, were extracted from an aircraft brake disk of a commercial aircraft, which present a thickness of 16.60 mm. The other main dimensions are presented in Figure 1. When the aircraft brake disk was examined carefully, it was verified that the disk consisted of two identical disks, of thickness 8.80 mm each, bonded together. These disks were designated as disk 1 and disk 2, as shown in Tables 1 and 2.

2.2 Mechanical and Physical Tests

In order to carry out the mechanical and physical tests, samples of rectangular cross sections were cut from the disks, using diamond tools. The main dimensions for the disk that was taken samples from are shown in Figure 1.



Internal Diameter: 281 mm; External Diameter: 371 mm; Disk thickness: 16,60 mm

Figure 1: Brake disk dimensions

Since the C/C composites investigated are not conventional materials, although an extensive survey on the literature was carried out, only test standards adopted to characterize similar materials such as reinforced polymers (i.e. green composites) and synthetic graphites were found (Freitas, 1994). Based on this fact, it was decided to use the Rockwell L and M (ASTM C748-83, for graphite materials) tests to measure the hardness of the C/C samples. To make the testing for superficial hardness a PANTEC hardness machine was used. The parameters used for the Rockwell L tests were a 10 kgf (98.1 N), pre-load, combined with a 60 kgf (588.6 N) load using a ¼''sphere. For the Rockwell M a 10 kgf pre-load with 100 kgf (981 N) load, using the same ¼'' sphere, were adopted.

The repeatability of the Rockwell hardness measurements was very good. The hardness tests were easy to perform, and, the results based on 7 indentations for the C/C of Disk 1 and 7 for those of Disk 2, are presented in Table 1 and Table 2.

Table 1- Rockwell **M** Hardness results

Specimen	Disk 1	Disk 2
1	82	63
2	87	57
3	77	70
4	72	73
5	69	67
6	83	62
7	77	57
Average	78.1	64.1
STD	6.33	6.18

Table 2. Rockwell **L** Hardness data

Specimen	Disk 1	Disk 2
1	90	80
2	96	80
3	105	86
4	96	87
5	90	95
6	96	82
7	92	80
Average	95.0	84.3
STD	5.20	5.55

A comparison with the results of the Rockwell L hardness, using previous literature for Rockwell L Hardness testing on C/C samples, was carried out. For a C/C material of a fighter aircraft, the average Rockwell L Hardness was 112±3 (Levy Neto, et al., 1997), and the measurements obtained in the present investigation were 96, for disk 1, and 84, for disk 2 (average 90), which gives percentage differences from the literature values varying from 17,4% to 21,7%. In addition, it was also found in the literature, the Rockwell L Hardness of CFRC specimens extracted from a F1 racing car, which average result is presented in Table 3.

Table 3. Results from the literature for the Rockwell L tests (Levy Neto, et al. 1997)

C/C MATERIAL	AVERAGE HARDNESS AND STANDARD DEVIATIONS	SPECIFIC MASS (g/cm^3)
	Rockwell L	-
F1 Car	75±10	1.78
Fighter Aircraft	112±3	1.74

The Charpy impact test is a useful and simple experiment, normally adopted for metallic materials, in which the principal objective consists in measuring the amount of energy absorbed by the sample, when a known force impacts it. Impact test using standard samples for Charpy impact test for CFRC samples were carried out in the present investigation. The machine in which the test was performed is a VEB WERKSTOFFPRUFMASCHINEN LEIPZIG whose precision is 0,1 kgm. The gap in which the Charpy sample was put on the machine is 39,10 mm and the diameter of the tip of the hammer is about 3,60 mm. The following data are collected from Charpy impact test realized in both room and very low temperature. For the tests that were carried out in a very low temperature, liquid nitrogen was used. The Figure 2 shows the sample that was used on the test and Table 4 has the data collected from the experiment.

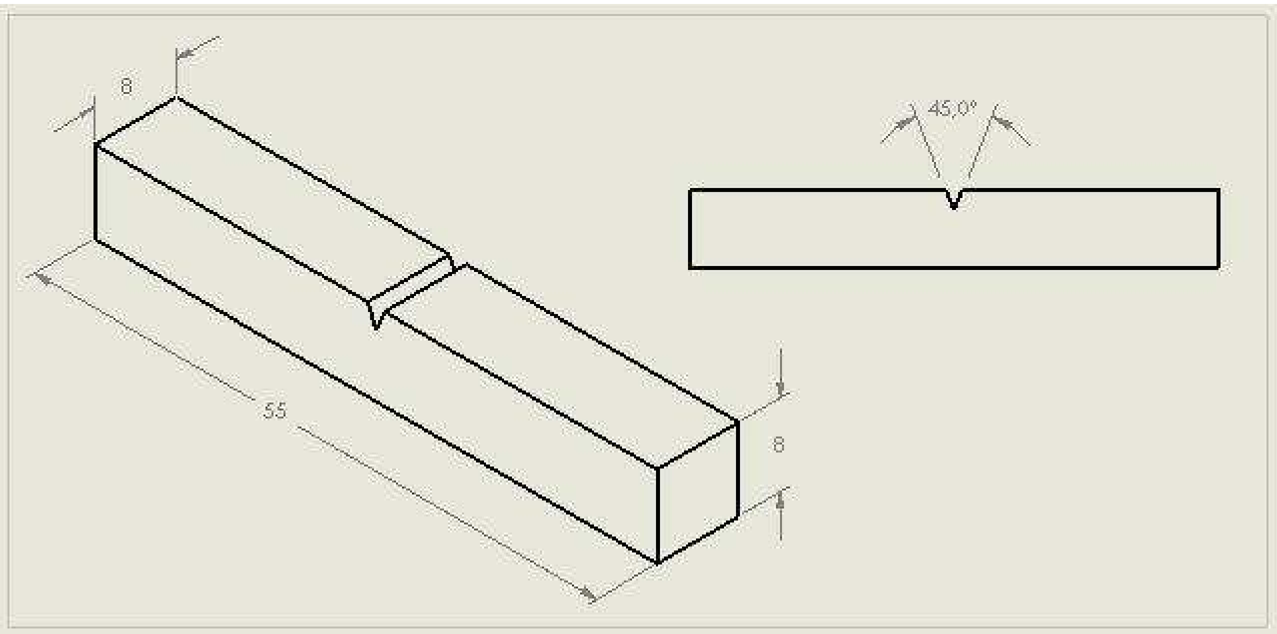


Figure 2. Charpy impact test sample dimensions in mm

Table 4: Charpy impact test results in Joules [J].

Energy Absorbed [J]		
Temperature	Disk 1	Disk 2
25 °C	0.981	0.785
25 °C	0.981	0.883
-190 °C	0.785	0.981
-190 °C	0.883	0.883

Besides Rockwell hardness tests and impact tests carried out in C/C brakes, another parameter, the density, was needed. So measurements were carried out in order to find C/C composites specific mass. A caliper was used to obtain the dimensions A, B and H, presented in Figure 3; while a digital scale, with precision of 0.01 g, was used to measure the mass of the samples. The collected data are shown in Tables 5 and 6.

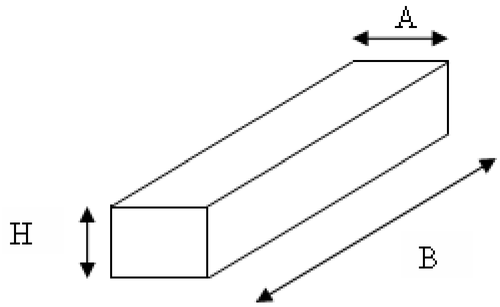


Figure 3. Dimensions of the rectangular specimens for specific mass

Table 5. Dimensions of the sample 1 form disk 1 for specific mass

Measurements	H (cm)	A (cm)	B (cm)
1	0.830	1.440	7.145
2	0.825	1.440	7.150
3	0.815	1.430	7.155

Table 6. Dimensions of the sample 2 form disk 2 for specific mass

Measurements	H (cm)	A (cm)	B (cm)
1	0.815	1.190	5.385
2	0.815	1.210	5.395
3	0.810	1.195	5.375

As specific mass is the ratio between mass and volume the data presented in Table 7 was obtained.

Table 7. Average specific mass obtained from the specimens 1 and 2.

Specimen	Mass (g)	Average Volume (cm^3)	Specific Mass (g/cm^3)
Disk 1	13.68	8.458	1.62
Disk 2	8.84	5.249	1.68

3. DISCUSSION OF THE TEST RESULTS AND CONCLUSIONS

The repeatability of the Rockwell L and M hardness of the disks 1 and 2 obtained in the present investigation, presented in Tables 1 and 2, was quite good. In particular, similar results concerned with the Rockwell L hardness, for a fighter aircraft brake disk, were found in the literature (Levy Neto, et al. 1997), as presented in Table 3. On the main, the hardness of the disks tested in this work was lower, with differences from the literature values varying from 17,4%

to 21,7%. However, the specific masses of the CFRC specimens tested in this work (disks 1 and 2) were also lower, in comparison with the results found in the literature. So, since the hardness of a CFRC material increases with its density (Savage, 1994), the fact that the values of the experimental hardness obtained in this work were below than those found in the literature was quite expected.

All the specimens subjected to impact in the Charpy test machine failed exactly at the cross section, localized in the V notches and the fractures were typically brittle. In addition, the energies involved were much lower if compared to materials like steel, at 25 °C, using specimens with the same dimensions. However the main advantage of the CFRC (or C/C) material tested in the present work were found by observing the tests performed at two quite different temperatures, –190°C and 25°C. The Charpy tests presented in Table 4 showed that the absorbed energy of the C/C is still practically the same, even when the temperature is varied for about 215 °C (i.e. from–190°C to 25°C). That indicates a unique behavior of a CFRC material, which is used in both aircraft and F1 racing cars. In these situations, the brake disks can be subjected to very high or cold temperatures. So, it is extremely important the maintenance of their mechanical properties. But those characteristics are maintained if the brake is on a non-oxidizing environment, which means a utilization of an external surface to protect the brake from the presence of oxygen. Finally, the determination of the density shows another quality of this C/C material. In aircrafts and in F1 racing, the weight is very important problem to be solved, and becomes more crucial when the performance is optimized. The density of the C/C composite is very low comparing with that of steel and, for this reason, the CFRC brakes are considerably lighter. The critical problem found with a C/C composite is that its fabrication is normally very expensive, compared with other materials, with prices of about US$ 200/Kg, only for the raw material (Callister, 2005). That is why CFRC are used only in aircrafts, F1 racing and fast trains.

4. ACKNOWLEDGEMENTS

The group is grateful to the support they received from CNPq.

5. REFERENCES

Callister, W. D. Jr., 2005, “Ciência e Engenharia de Materiais: Introdução”, Ed. LTC, Rio de Janeiro, Brazil 375 p.

Fisher, R., 1990, “Carbon – Carbon Brakes for Aircraft”, in Composite Materials in Aircraft Structures. Edited by D.H. Middleton, Longman Scientific & Technical, London.

Freitas, A.C., 1994, “Anteprojeto de um Freio de Carbono-carbono para uso em Aeronave”, Trabalho de Graduação, ITA, Divisão de Engenharia Aeronáutica, São José dos Campos.

Levy Neto, F. Rezende, M. C. and Barbosa, S. C., 1994, “Flexure and Transverse Shear Tests on Unidirectional CFRC Composite Rods”. IV Simpósio Latino Americano de Polímeros (IV SLAP), Gramado, pp. 692 - 694, Setembro, 1994.

Levy Neto, F., Pardini, L. C., and Da Silva, J. L. G., 1995, “Development of a Tri-Directional Carbon Fibre Reinforced Carbon Composite for Aerospace Applications”. Revista Brasileira de Ciências Mecânicas da ABCN, Vol. XVIII, Nr 2, pp. 171 - 180.

Levy Neto, F., Freitas, A.C. and Cairo, C.A.A., 1997, “Characterization of Carbon/carbon Composite Materials for Brake Disks”, Proceedings of COBEM 1997, Bauru.

F. Levy Neto; L. C. Pardini, Compósitos Estruturais, Edgard Blucher, São Paulo, 2006.

Savage, G., 1993, “Carbon - Carbon Composites”. Chapman & Hall, London.

Sims, G.D., 1988, “Understating Charpy Impact Testing of Composite Materials”, Sixth International Conference on Composite Materials, Imperial College, London.

Thomas, C. R., 1993, “Essentials of Carbon - Carbon Composites”. Royal Society of Chemistry, 1993.

6. RESPONSIBILITY NOTICE