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EXPERIMENTAL RESEARCH ON THE MECHANICAL PROPERTIES OF THE CARBON AND KEVLAR BASED COMPOSITES

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Abstract: *Composite materials, increasingly used in high-end fields such as aerospace and automotive, offer major advantages due to their high strength-to-weight ratio. This paper investigates the mechanical properties of carbon fiber and kevlar reinforced composites through flexural testing. Experimental tests were performed using standardized methods, and the results highlighted the differences in performance between the two materials. Carbon fiber composites have higher stiffness, while Kevlar ones are more elastic and impact resistant. The findings highlight the importance of applying these materials in industries where light weight and mechanical performance are critical.*

Keywords: *Composite materials, Carbon fibers, Kevlar, Mechanical properties, Bending*

1. INTRODUCTION

Composite materials have evolved significantly over time, being used in various technological applications due to their ability to combine two or more components with superior properties. Carbon fibers and Kevlar are two of the most used types of reinforcements, offering advantages such as low weight, high mechanical strength and thermal stability [1].

Carbon fibers, originally introduced in the aerospace industry, became popular due to their outstanding tensile strength and low density. Kevlar, a polymer of the aramid class, is known for its impact resistance and ballistic properties [2], being widely used in protective equipment and structures that require reduced weight and increased durability [3].

This work focuses on investigating the mechanical behavior of these two types of composites through experimental bending tests, with the aim of evaluating their performance in industrial applications.

2. CURRENT STATE OF RESEARCH

Composite materials reinforced with carbon fibers and kevlar have experienced accelerated development due to their outstanding properties. They are used in areas such as the aerospace, automotive, construction and sports equipment industries. A worldwide use of Kevlar fiber is in the military community, where it is recognized as a high-performance material for protecting life (body armor and bulletproof vests are light, comfortable, offering superior protection against fragmentation and ballistic threats).

To obtain carbon fiber, the predominant material is polyacrylonitrile (PAN) fiber, which is obtained by polymerization, spinning and then the designation of the polymer [1,5].

The chemical composition of Kevlar fiber is poly-paraphenylene terephthamide, known as para-aramid [2,6]. Kevlar filaments are manufactured by extrusion through a die [3,7].

Modern composites consist of a matrix (polymers, metals, or ceramics) and a reinforcing agent (usually fibers). Their main characteristic is that the component materials retain their individual properties but, when combined, generate new superior mechanical characteristics [4, 8, 9].

3. EXPERIMENTAL METHODOLOGY

To test the mechanical properties of the composites reinforced with carbon fibers and Kevlar, standardized specimens were made [10, 11, 12], according to SR EN ISO 14125. The bending tests were performed on a Lloyd's type mechanical test stand Instruments [13], model LR5K Plus (Figure 1).

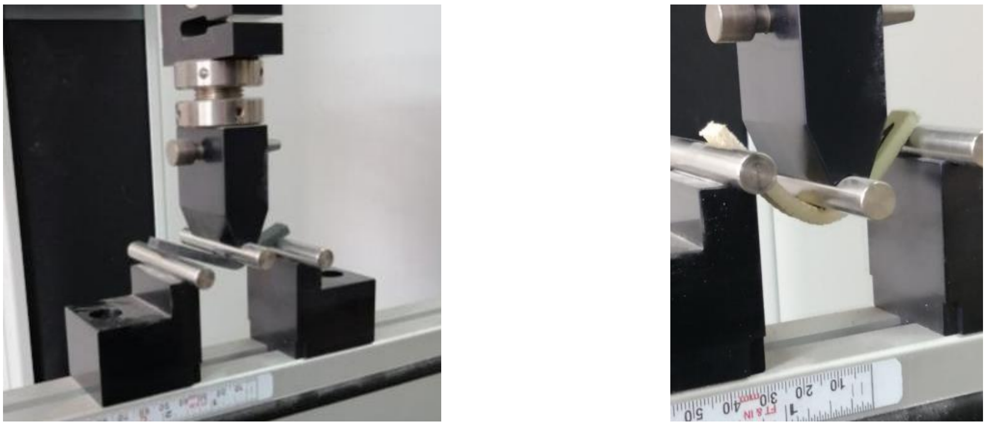

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Figure 1: Lloyd's Instruments LR5K Plus Test Machine [13]. a. Carbon fiber specimen during bending stress; b. Kevlar fiber specimen during bending stress

The specimens were subjected to a load applied perpendicular to the longitudinal axis, according to the three-point test method. They were made of composite reinforced with carbon fibers and Kevlar, and the results were recorded electronically by means of NEXYGEN Plus software [13].

The tests were carried out to determine the bending behavior of the samples, but also to determine the bending resistance, the bending modulus and other aspects related to the stress/deformation relationship under the given conditions of the composites reinforced with carbon fibers and Kevlar.

The specimens were subjected to loads applied perpendicular to the longitudinal axis using the standard three-point test scheme, according to SR EN ISO 14125. The Lloyd's Instruments LR5K Plus [13] testing machine was used to perform the tests with a maximum force of 5 kN. The specimens were placed end-to-end on two supports and a central load was applied until the material failed (Figure 2).

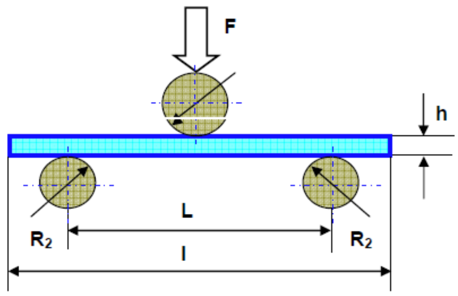

Figure 2: Scheme of the 3-point bending test

Tests were performed at different speeds to determine elasticity and breaking behavior. The exact dimensions of each specimen were also measured prior to testing to obtain accurate cross-sectional and length data. NEXYGEN Plus software [11] was used for experimental data recording and processing.

4. RESULTS AND DISCUSSION

Bending tests performed revealed significant differences between carbon fiber reinforced and kevlar reinforced composites.

determined following bending tests, for the carbon fiber and Kevlar samples: Carbon fibers were characterized by higher stiffness, with an average modulus of elasticity of approximately 14000 MPa, compared to Kevlar, which demonstrated higher elasticity but lower stiffness.

Test results showed that Kevlar-reinforced materials exhibit superior resistance to impact and dynamic stresses, while carbon fiber composites perform better in static stresses such as bending.

Table 1 below summarizes the main mechanical properties

Table 1. Mechanical properties of carbon fiber and Kevlar specimens, in bending

Material	Max. force [kN]	Max. tension [MPa]	Stiffness [N/mm]	Young's Modulus [MPa]
Carbon	0.68	267.77	1.423	14179
Kevlar	0.18	109.00	0.084	1281

The force-deformation graphs for both types of composites highlight the fact that carbon fiber reinforced materials exhibit a "brittle" behavior, while those with kevlar have a larger deformation before failure.

a. Composite materials reinforced with carbon fibers:

The results of the bending tests for the carbon fiber reinforced composite material are shown in Figure 3 and the representative data are shown in Table 2, from which it can be seen that the stiffness is directly related to the structure of the material

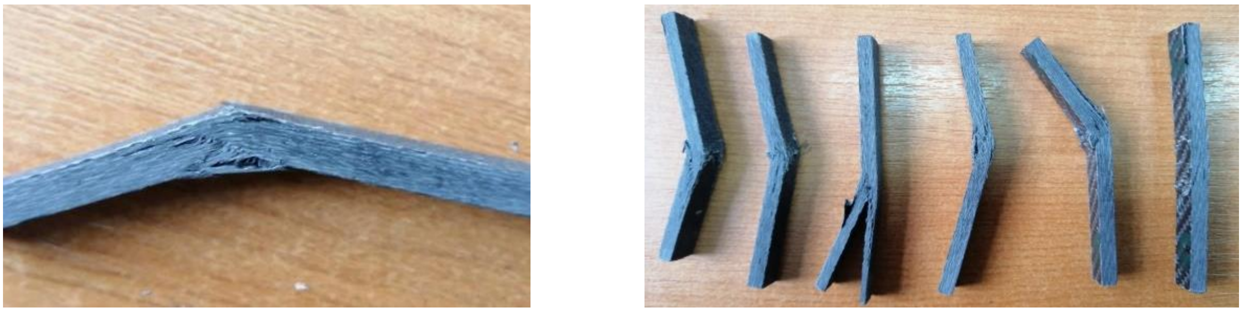

Figure 3: Carbon-based composite material specimen after bending stress

Table 2: Results of the carbon fiber specimens obtained from the stress in the bending tests

Sample No.	Force under max load.	Max. voltage on charg.	Bending stiffness	Young's Modulus
	[kN]	[MPa]	[Nm^2]	[MPa]
Sample 1	0,692731762	292,28289	1,288574414	14459,72227
Sample 2	0,602559878	241,0239511	1,267932452	1267,32452
Sample 3	0,67189371	274,4663849	1,361270153	14481,1044
Sample 4	0,750618108	282,5856408	1,454433116	13688,78227
Sample 5	0,69167873	250,5779724	1,530433504	13327,83489
Sample 6	0,59376362	242,5504984	1,440203032	15320,78729

During the test, the load borne by the specimen as well as its elongation are measured. At the same time, the dimensions of each sample were precisely measured: the cross section and the width of the sample. These dimensions were entered as input data in the computer connected to the test machine, having the NEXYGEN software [11], which takes the experimental data from the test machine and processes them statistically.

Thus, based on the results obtained from the bending tests for the carbon fiber samples, we represented the force-displacement characteristic curves (Figure 4), respectively the Stress-deformation characteristic curves (Figure 5).

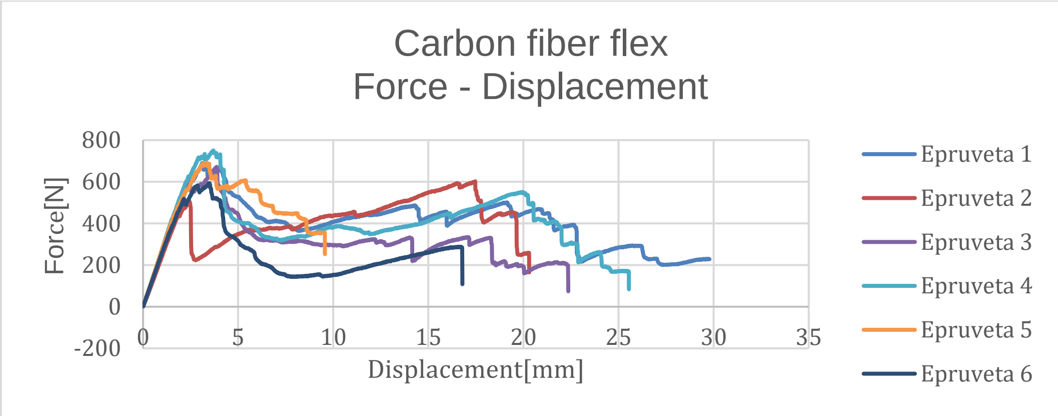

Figura 4: Force-Displacement Characteristics for Carbon Fiber Composite Specimens after Bending

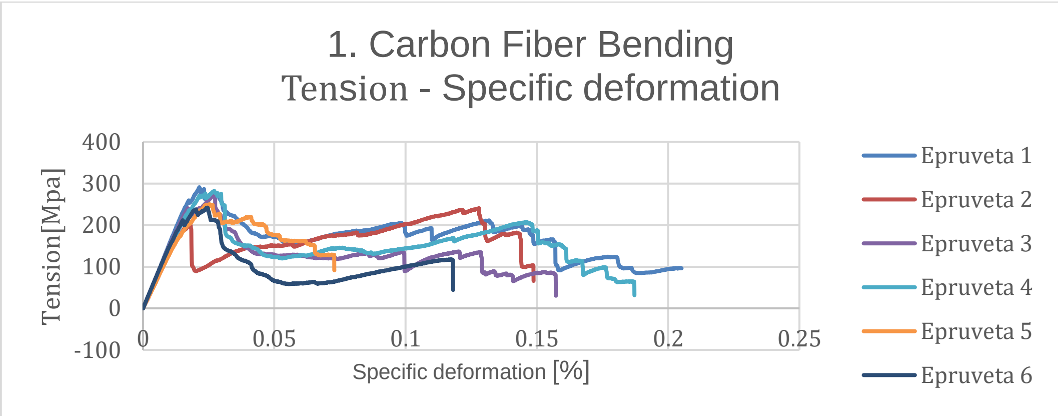

Figure 5: Carbon Fiber Samples - Characteristic Curves Tension – Displacement after bending stress

b. Composite materials reinforced with kevlar fibers:

Kevlar fiber composites were made at S.C COMPOZITE S.R.L., and following bending tests, they showed superior elasticity, but with a lower stiffness compared to carbon fibers (see table 1). The average modulus of elasticity recorded was approximately 1250 MPa.

During the test, both the load borne by the specimens and their elongation were measured. It can also be seen that the material deformed considerably before failure, confirming its ability to withstand impact and absorb energy. (Figure 1b).

The bending test results for the five-layer Kevlar fiber-reinforced composite material are shown in Table 3.

Table 3: The results of the Kevlar fiber specimens obtained from the bending test request

Sample No.	Force under load. max.	Max. voltage on charge.	Bending stiffness	Young's Modulus
	[kN]	[MPa]	[Nm^2]	[MPa]
Sample 1	0,245589261	133,6267489	0,060201585	1049,874429
Sample 2	0,177125721	108,0336808	0,13880174	2784,831147

Sample 3	0,245617169	130,4161958	0,068463755	1136,013639
Sample 4	0,162779264	101,9177442	0,00300626	63,47020754
Sample 5	0,141966655	79,29575244	0,098083933	1755,928612
Sample 6	0,150300272	84,7006861	0,049589631	895,6952663

Based on the results obtained from the bending tests for the Kevlar fiber samples, we represented the force-displacement characteristic curves (Figure 6), respectively the Stress-Strain characteristic curves (Figure 7)

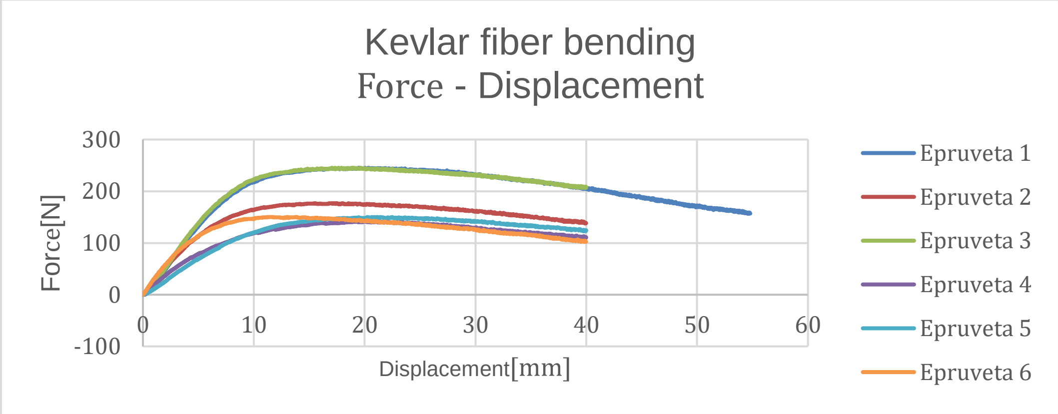

Figure 6: The Kevlar fiber samples - Characteristic curves Force – Displacement after bending stress

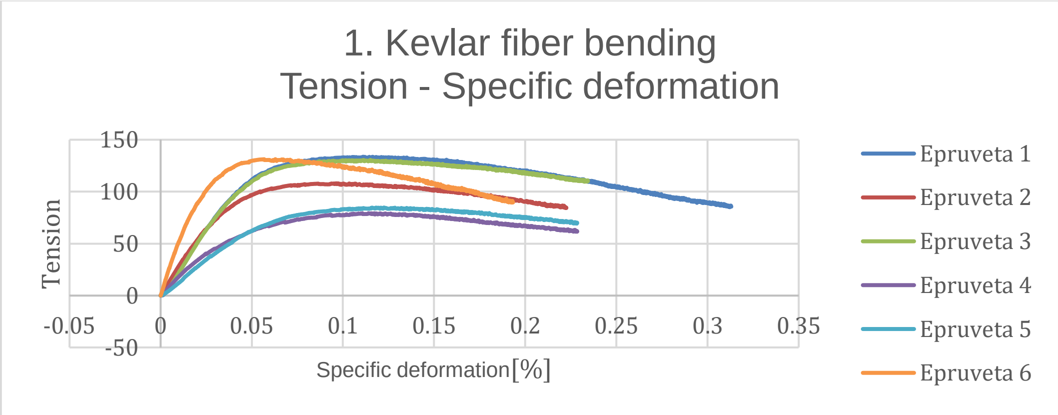

Figure 7: Kevlar fiber specimens - Characteristic curves Stress - Specific deformation after bending stress

These data highlight that Kevlar-reinforced composite materials are more suitable for applications that require resistance to dynamic stresses and large deformations, such as ballistic protection or energy-absorbing structures.

c. Comparative analysis:

From the comparison of the two types of materials, it can be seen that carbon fibers offer superior rigidity, but with a brittle behavior, while Kevlar has a much higher elasticity and better resists impact forces (see Figures 8 and 9)

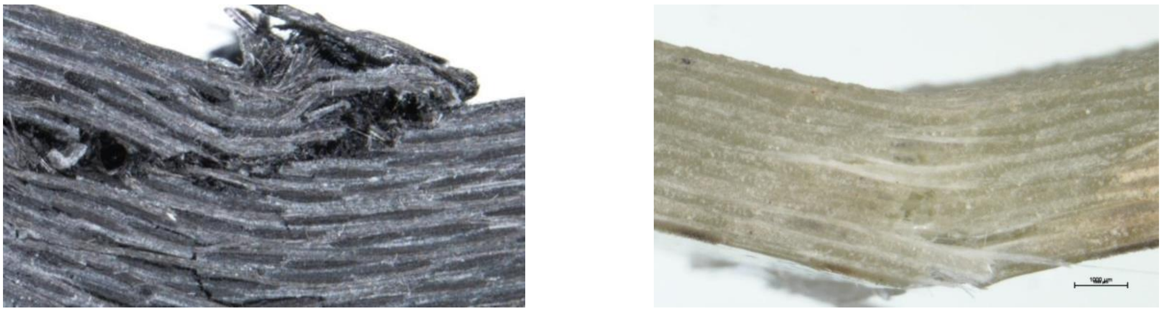

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Figure 8: Visualization of cracks under the microscope, after bending stress: a. carbon fibers, b. kevlar fibers

The choice of material depends on the specific requirements of the application: carbon is ideal for static or structural applications, while Kevlar is preferred in areas where energy absorption and protection are priorities.

5. DESIGN AND SIMULATION OF MECHANICAL TESTS

Using HyperMesh 2021, we performed a bending stress simulation where we designed a carbon fiber reinforced specimen and simulated the bending stress, see Figure 9. Using arbitrary data and the material in the programming menu, I gradually acted with a bending strength, force that increases proportionally with time, to see the behavior of the composite material. The data being counted automatically by the program.

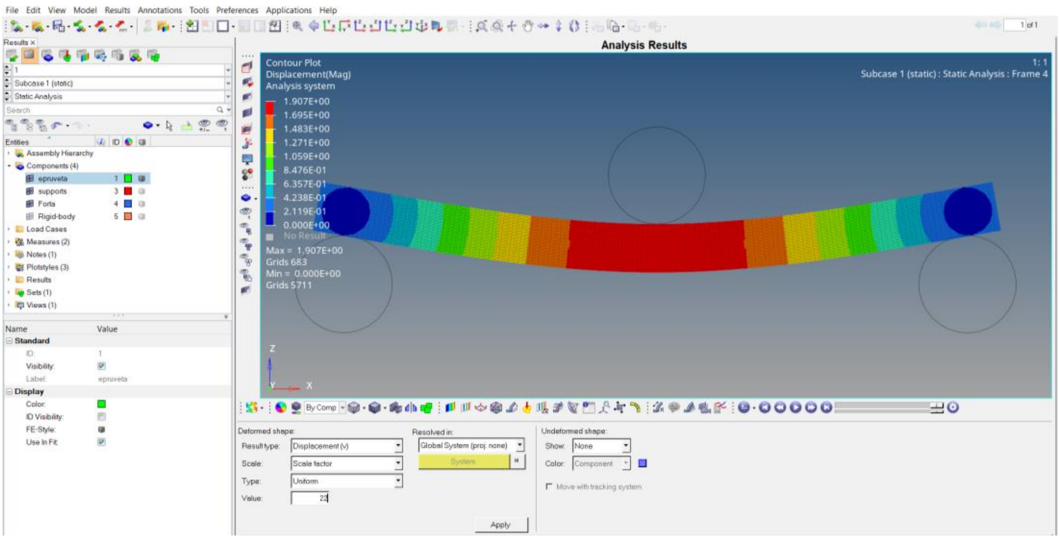

Figure 9: HyperMesh design Structural analysis - deformation of the carbon fiber specimen

Verification calculation for the carbon fiber composite material sample

F=500 N

L_0=64 mm

b=10 mm

h=5 mm

A= b* h= 50mm^2

E= 14 MP_a

$$I_Z = \frac{b * h^3}{12}$$

$$I_Z = \frac{10*5^3}{12} = 104.166$$

The maximum arrow in the middle of the sample:

$$F = \frac{F*{L_0}^3}{48*E*I_Z}$$

$$F = \frac{500*(64)^3}{48*14000*104.16} = 1.872$$

Also, for the design of the bending stress of the composite material reinforced with Kevlar fiber, the same steps were followed as in the case of the composite material reinforced with carbon fiber (Figure 10).

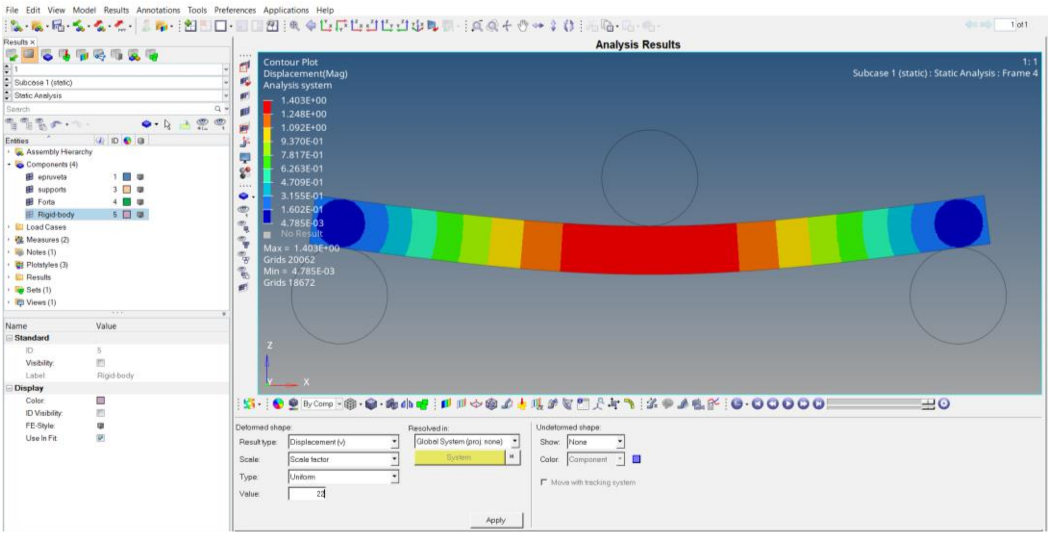

Figure 10: HyperMesh design Structural analysis - deformation of the Kevlar fiber specimen

The verification calculation for the modeling of the sample made of composite material reinforced with Kevlar fiber

F=500 N

L_0=64 mm

b=11 mm

h=5 mm

A= b* h= 51 mm^2

E= 19 MP_a

$$I_Z = \frac{b * h^3}{12}$$

$I_Z = \frac{11*5^3}{12}$=114.583

The maximum arrow in the middle of the sample:

$$F = \frac{F*L_0{}^3}{48*E*I_Z}$$

$$F = \frac{500*(64)^3}{48*14000*104.16} = 1.254$$

6. CONCLUSIONS

Based on the experimental tests, the following conclusions were drawn:

• Composites reinforced with carbon fibers offer superior rigidity and strength, but have a less elastic behavior, "brittle" under bending stress

• the composite material reinforced with Kevlar fibers presents better resistance properties, but lower permissible deformations than those of the composite material reinforced with carbon fibers.

• Kevlar fibers are more elastic and show better resistance to dynamic stress and impact. They offer a balance between elasticity and tear strength, making them ideal for applications such as ballistic protection and safety equipment.

• Increasing the number of layers in both composites improved the overall mechanical performance, increasing the allowable forces and increasing the specific stress (see Figures 4 and 6).

• Despite different mechanical properties, both carbon fiber and Kevlar are essential for high-end industrial applications, depending on the specifications of each project.

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