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Experimental Determination of Mechanical Properties of Chopped Fiber Composite Materials

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***Abstract*- Mechanical properties of chopped composites are one of the most important parameter for determining the application of the use of these materials. An experimental identification for mechanical properties of different composite material was conducted. Tensile test at different temperatures, -40°c, 25°c (normal), 100 °c and 200 °c were done. Three different chopped composites which are Carbon fiber, Basalt and Fiber glass with a phenol resin as a matrix were selected to determine their mechanical properties. For comparison with the previous type of composite materials, a carbon fiber with epoxy resin as a matrix was selected. Carbon fiber with the epoxy was the highest mechanical properties among these materials, but when the temperature raised, its tensile property deteriorated whereas the carbon fiber with the phenol withstand the elevated temperatures. Three point bending and compression tests were done for these materials; Carbon fiber with Epoxy was the highest properties. Hardness test as another important factor was done for those composite materials. The four materials are in the rigid zone but also carbon fiber with epoxy was the hardest material among the selected materials.**

Keywords: Composite, Chopped Fiber, Mechanical Properties, Tensile Test, Compression Test, Hardness.

1. INTRODUCTION

A composite is made up of different components and combining their essential or typical characteristics while preserving their separate identities. Composite materials became an important factor in modern technological society, especially for applications requiring great strength and light weight such as in the aerospace industry. Because these materials are hybrid heterogeneous materials, they can be difficult to characterize with any one single methodology [1]. Woven fabrics composites give an assortment of alluring properties, since they have high ability to adjust to complicated shapes. This is suitable for manufacturing parts with complicated shapes and more adaptability in processing operation compared to metals and even their chopped counterparts [2]. Knowing the mechanical behavior of these fabrics is important in many applications in particular for the simulation of textile composite forming. Shearing behavior of woven performs is the most considered mechanical property, since this mechanism of deformation is important for shaping on double curvature surfaces. [3-7].

Characterization of such materials has a great deal of consideration. The objectives are usually have two phases: to know the non-linear mechanical reaction of the materials during shear and to describe the cutoff of distortion. Many researches have been done on the mechanical properties of composite materials behavior. [8–13].

Improvement of new materials is turning out to be progressively difficult because of increased environmental concerns and because the number of useful materials made from simple components is limited. Composite materials can be narrowly defined to be fiber-reinforced polymers, such as carbon fiber-reinforced epoxy/phenol resin, fiber glass reinforced phenol and basalt. However, as composite technology has advanced, the definition of composite materials has become broader, to include materials such as molecular composites and Nano-composites which are also similar to immiscible blends. From a characterization perspective, these materials can be treated as heterogeneous materials.

In this work three different composite materials “carbon fiber, basalt and fiber glass with phenol as a matrix” were selected to determine its tensile strength and hardness. Carbon fiber was selected again with epoxy as a matrix to compare the results with the previous one.

2. EXPERIMENTAL WORK

For identifying material mechanical properties, four composite materials were studied experimentally. The steps conducted to achieve the tensile (at different temperatures), bending, compression and hardness of these materials, are illustrated in the following

2.1 Preparing the Tested Samples

Four composite materials were selected to obtain their characteristics which are Basalt with phenol as a resin, Fiber glass with phenol as a resin, Carbon fiber with phenol as a resin and Carbon fiber with epoxy as a resin [14].For the Carbone with Epoxy resin a mixture of fiber and resin was prepared and mixed together then cured under pressure only at normal temperature. For the three materials mixed with the Phenol, a mixture of chopped fiber Figure 1 and resin was prepared and mixed together and then cured under pressure and temperature to obtain composite materials in the sheets shape of dimensions 300 *300* ≈3 mm in the cured stage as shown in Figure 2.

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Fig. 1 Chopped Carbon fiber, Chopped Fiber glass and Chopped Basalt

To obtain the mechanical properties of these materials some tests might be done which are tensile test, three point bending, the compression test and the hardness test. According to the DIN 3039[15], the specimens were cut to make strips with dimensions 250x25x3.5mm. Tapping material was used at the both ends of the specimens as shown in Fig 3

Fig. 2 Carbon fiber, Basalt, Fiber glass and Carbon/epoxy sheets

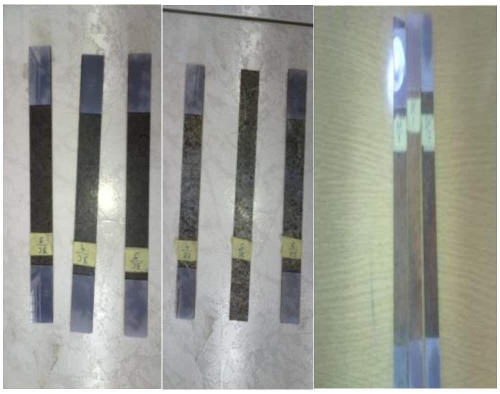

Fig. 3 Carbon fiber, Basalt and Fiber glass specimens

The tensile test has been done to the strip specimens shown in the figure 3 for three materials which are carbon fiber, basalt and fiber glass. Two problems occurred which are the slipping of the specimens from the tapping material and sliding was occurred between the tapping material and the jaws.

The JANNAF (Joint Army-Navy-NASA-Air Force Propulsion Committee) specimens [16-18] with dimensions as shown in Figure 4 were used instead of the strip specimens to avoid these problems. Sample specimens were cut according to the JANNAF standard as shown in Figure 5.

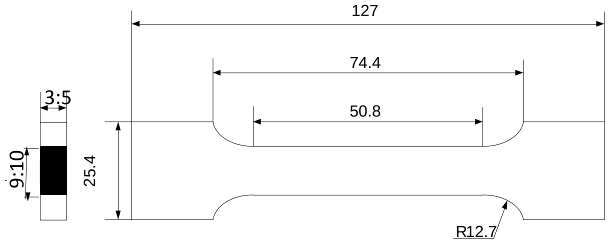

Fig. 4 Standard sample dimension with JANNAF

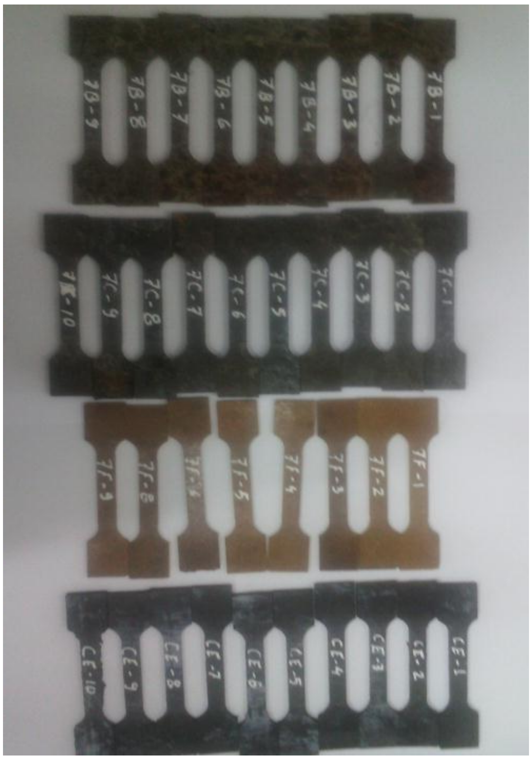

Fig. 5 JANNAF samples for Basalt, Carbon fiber, Fiber Glass and Carbon / Epoxy

2.2 Test machine

The ZWICK Z050 universal test machine has been used for carrying out all the mechanical tests. This machine has remote control software which could acquire record, analyze, store and print test data with minimum manual effort. The maximum permissible test load is 10KN, and the range of crosshead speed varies from 0.0005 to 1000 mm/min with accuracy 0.004 % of the set speed. The machine is provided with temperature chamber having a range varies from -70 to +250 ^{o}c.

2.3 Test plane

The specimens were prepared to satisfy the mechanical tests requirements as shown in table 1 for the tensile tests, it was done at deferent temperatures which were (-40°c, 25°c,

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100°c and 200°c). At the normal temperature 3 specimens were prepared for each material, at -40 °c 2 specimens were prepared for each material and one specimen for both 100 °c and 200°c. In total, 28 specimens were prepared for the tensile test.

For the compression and three points bending tests three specimens for each material were prepared with a total number of twelve specimens for each test and the both tests were done at normal temperature as shown in table 1.

Table 1 Test specimens' plane

Test	-40 °c	25 °c	100 °c	200 °c	No. of Materials	total
Tensile	2	3	1	1	4	28
Compression		3			4	12
3 point bending		3			4	12

3. Measured Data

3.1 For the Basalt

3.1.1 The tensile test

The values of the maximum stresses at different temperatures were as shown in figure 6:

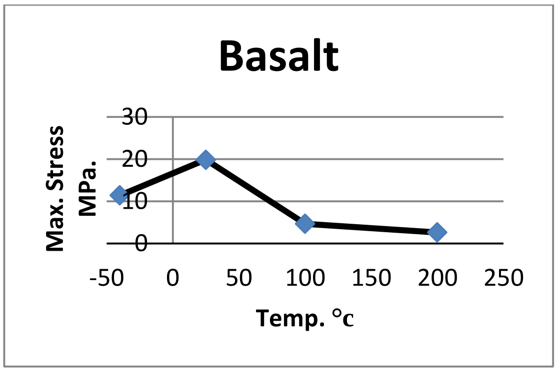

FIG. 6 Tensile strength of Basalt

At normal temperature, the maximum stress for the Basalt reaches 19.8 Mpa and at -40°c it reaches 15.6 Mpa with a decreasing percentage of 20%. When the temperature rises to 100 °c, the stress decreases to 4.66 Mpa with a decreasing percentage of 76% and at 200°c the stress decreases again to 3.2 Mpa with a decreasing percentage of 83.8%.

3.1.2 Three point bending test

For the three points bending the results for the three specimens were as shown in table 2:

The maximum stress for the three samples varies from 20.2 Mpa to 21.6 Mpa where the strain varies from 0.79% to 0.85%.

Table 2 Bending test results of the Basalt

Spec. No.	Max. Stress Mpa	Max. strain %	Break Stress Mpa	Strain at break%	$Q = \frac{\mu}{\rho}$
1	20.8	0.79	19.5	0.91	
2	21.62	0.85	20.5	1.02	
3	20.2	0.82	19.5	0.97	
The mean	20.87	0.82	20	0.9667	$Q_b =$ 13.125

3.1.3 The compression test

For the compression test the results were as shown in table 3

Table 3 Compression test results of the Basalt

Spec. No.	Max. Stress *Mpa*	Max. strain	Break Stress*Mpa*	Strain at break	$Q = \frac{\mu}{\rho}$
1	343.23	4.4	326.56	4.6	
2	318.7	4.9	300	5.7	
3	346.2	3.1	345.19	3.2	
The mean	336.04	4.13	323.94	4.5	Q_c= 211.35

Here the maximum stress for the compression test for the Basalt varies from 318.7 Mpa to 346.2 Mpa where the strain varies from 3% to 4.9%.

3.1.4 The Hardness test:

The value of hardness of the Basalt is 82 Shore D which means that it is in the hard zone.

3.2 For the Fiber glass

3.2.1 The tensile test

The values of the maximum stresses at different temperatures were as shown in figure 7:

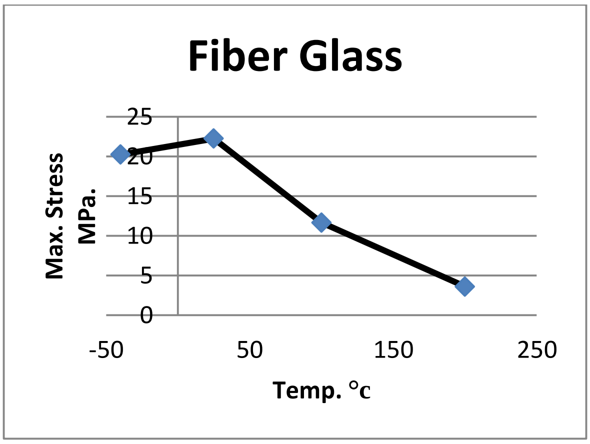

FIG. 7 Tensile strength of Fiber Glass

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At normal temperature, the maximum stress for the Fiber glass reaches 22.26 Mpa and at -40 °c it was 20.2 Mpa with a decreasing percentage of 9.25%. When raising the temperature to 100 °c the stress decreases to 11.66 Mpa with a decreasing percentage of 47.5% and at 200 °c the stress decreases again to 3.56 Mpa with a decreasing percentage of 83.9 %.

3.2.2 Three point bending test

For the three points bending the results were as shown in table 4

Table 4 Bending test results of the Fiber glass

Spec. No.	Max. Stress Mpa	Max. strain	Break Stress Mpa	Strain at break	$Q = \frac{\mu}{\rho}$
1	43.4	0.42	30.8	0.43	
2	45	0.59	32.1	0.65	
3	47.9	0.71	34.4	0.77	
The mean	45.433	0.57	32.4	0.62	Q_c= 211.35

For the bending test of the Fiber glass, the results of the maximum stress varies from 43.4 Mpa to 47.9 Mpa where the strain varies from 0.42% to 0.71%

3.2.3 The compression test

For the compression test the results were as shown in table 5:

Table 5 Compression test results of the Basalt

Spec. No.	Max. Stress Mpa	Max. strain	Break Stress Mpa	Strain at break	$Q = \frac{\mu}{\rho}$
1	309.89	1.5	308.9	1.5	
2	298.22	1.4	297.23	1.4	
3	322.6	1.6	321.65	1.6	
The mean	310.18	1.5	309.2	1.5	Q_c= 179.29

For the compression test of Fiber Glass, the maximum stress varies from 298.22 Mpa to 322.6 Mpa where the strain varies from 1.4% to 1.6%.

3.2.4 The Hardness test

The value of hardness of the Fiber glass is 78 Shore D which means that it is in the hard zone.

3.3 For the Carbon with phenol:

3.3.1 The tensile test

The values of the maximum stresses at different temperatures were as shown in figure 8:

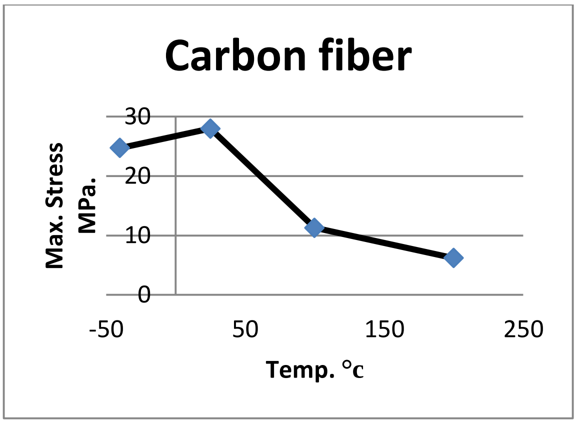

FIG. 8 Tensile strength of Carbon/phenol

At normal temperature, the maximum stress for the Carbon/phenol reaches 28 Mpa and at -40 °c it was 24.7 Mpa with a decreasing percentage of 11.5 %. When temperature rises to 100 °c the stress decreases to 11.27 Mpa with a decreasing percentage of 60 % and at 200 °c the stress decreases again to 6.14 Mpa with a decreasing percentage of 78%.

3.3.2 Three point bending test

For the three points bending the results were as shown in table 6:

Table 6 Bending test results of the Carbon/phenol

Spec. No.	Max. Stress *Mpa*	Max. strain	Break Stress *Mpa*	Strain at break	$Q_b = \frac{\mu}{\rho}$
1	35.2	0.8	24.6	1.2	
2	37.5	0.5	26.3	0.87	
3	35.4	0.45	22.8	0.53	
The mean	36	0.58	24.5	0.86	Q_b= 24.65

For the bending test of the carbon with phenol the Maximum stress varies from 35.2 Mpa to 37.5 Mpa where the strain varies from 0.45% to 0.8%.

.3.3 The compression test

For the compression test the results were as shown in table 7:

Table 7 Compression test results of the Carbon/phenol

Spec. No.	Max. Stress Mpa	Max. strain	Break tress Mpa	Strain at break	$Q = \frac{\mu}{\rho}$
1	743.3	2.8	743.3	2.8	
2	728.6	2.5	727.7	2.6	
3	753.2	3.1	752.2	3.3	
The mean	741.7	2.8	741	3	Q_c= 508

For the compression test of Carbon/phenol, the maximum stress varies from 728.6 Mpa to 753.2 Mpa where the strain varies from 2.5% to 3.1%.

3.3.4 The Hardness test

The value of hardness of the Carbon/phenol is 80 Shore D which means that it is in the hard zone.

3.4 For the Carbon with Epoxy:

3.4.1 The tensile test

The values of the maximum stresses at different temperatures were as shown in figure 9:

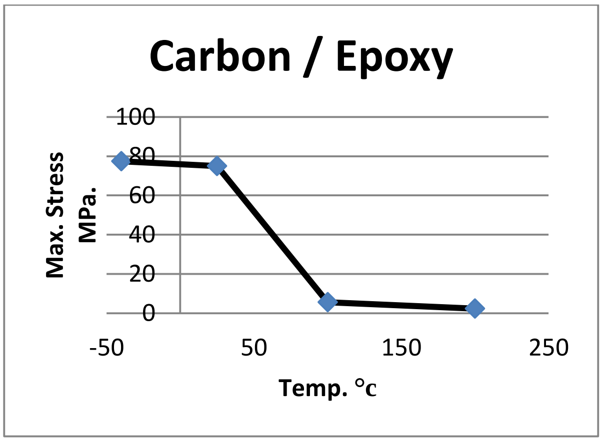

FIG. 9 Tensile strength of Carbon/Epoxy

At normal temperature, the maximum stress for the Carbon/Epoxy reaches 64.82 Mpa and at -40°c it was 77.5 Mpa with an increasing percentage of 19.5%. When the temperature rises to 100°c the stress decreases to 5.6 Mpa with a decreasing percentage of 91.4 % and at 200 °c the stress decreases again to 2.38 Mpa with a decreasing percentage of 96.3%.

3.4.2 Three point bending test

For the three points bending the results were as shown in table 8:

Table 8 Bending test results of the Carbon/Epoxy

Spec. No.	Max. Stress Mpa	Max. strain	Break Stress Mpa	Strain at break	$Q = \frac{\mu}{\rho}$
1	55.5	0.99	39.6	1.1	
2	51	0.92	34.3	0.97	
3	56.5	1	38.7	1.1	
The mean	54.3	0.92	37.5	1.1	Q_b= 42.75

For the bending test of the carbon with epoxy the Maximum stress varies from 51 Mpa to 56.5 Mpa where the strain varies from 0.92% to 1%.

3.4.3 The compression test

For the compression test the results were as shown in table 9:

Table 9 Compression test results of the Carbon/Epoxy

Spec. No.	Max. Stress Mpa	Max. strain	Break Stress Mpa	Strain at break	$Q = \frac{\mu}{\rho}$
1	831.6	5.6	830..6	5.6	
2	866	3.6	854.5	4.4	
3	848.3	4 .6	838.2	4.6	
The mean	848.6	4.6	841.1	4.86	Q_c= 668.2

For the compression test of carbon/ epoxy the maximum stress varies from 831.6 Mpa to 866 Mpa where the strain varies from 3.6% to 5.6%.

3.4.4 The Hardness test

The value of hardness of the Carbon/Epoxy was 90 Shore D which means that it is in the hard zone.

3.5 Comparison of Measured Data in the Tensile Strength

3.5.1 Comparison of materials with the same resin

As mentioned before, three materials with the same resin were selected so when making a comparison between these materials figure 10, the comparison here is between the fibers itself.

It is noticed that the max stress of the three materials takes the same behavior at the different temperature. It has a low value at freezing temperature compared by its value at room temperature. When the temperature rises, the stress decreases to lower values.

From the previous chart it is noticed that the Carbone fiber was the highest stress values among the selected materials at different temperatures and the Basalt was the lowest stress at the same temperatures.

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If we assume a ratio factor between the ultimate tensile strength and the density of the materials we will have the following results: 12.48 for the basalt, 12.87 for the fiber glass, 19.16 for the carbon/phenol and 59.05 for the carbon/epoxy.

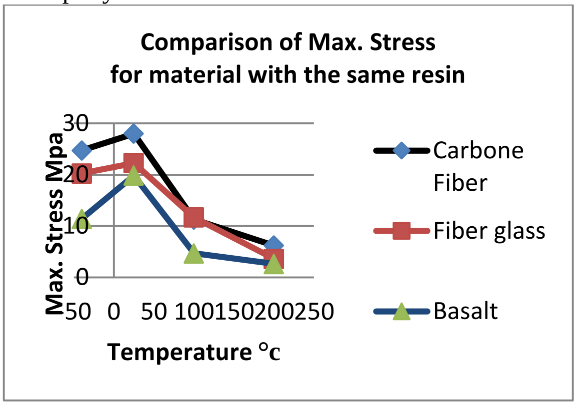

FIG. 10 Comparison of stress for materials with the same resin

3.5.2 Comparison of materials with the same Fiber

Here is a comparison between the same fibers with using two different resins as shown in figure 11:

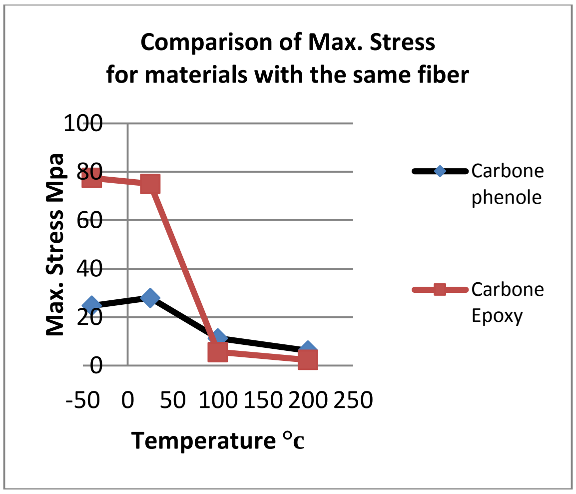

FIG. 11 Comparison of stress for materials with different resin

Here it is noticed that the Carbone / Epoxy stress is more higher than Carbone/ Phenol but at elevated temperatures, the stress of the Carbone / Epoxy deteriorate with percentage of 96.8% and reaches 2.38 Mpa while the stress of the Carbone/Phenol decreased with a percentage of 77.84% and reaches 6.14 Mpa.

3.6 Comparison of Measured Data in the Bending Test

The Carbon with Epoxy has the highest value in bending test which reaches 54.3 Mpa where the Basalt has the lowest value of the bending by the value of 21Mpa.

When assuming a ratio factor between the flexure and the density of the materials we get the following data: 13.125 for basalt, 26.26 for the fiber glass, 24.65 for the carbon/phenol and 42.75 for the carbon/epoxy. It is obvious the carbon/epoxy has the highest ratio among the selected materials.

3.7 Comparison of Measured Data in the compression test

The Carbon /Epoxy has also the highest value of the compression test by the value of 848.6 Mpa where the Fiberglass has the lowest value of 310.2 Mpa.

When assuming a ratio factor between the compression and the density of the materials we get the following data: 211.35 for basalt, 179.29 for the fiber glass, 508 for the carbon/phenol and 668.2 for the carbon/epoxy. it is obvious the carbon/epoxy has the highest ratio among the selected materials.

3.8 Hardness test results

The values of the Hardness of the composite material are as shown in figure 12:

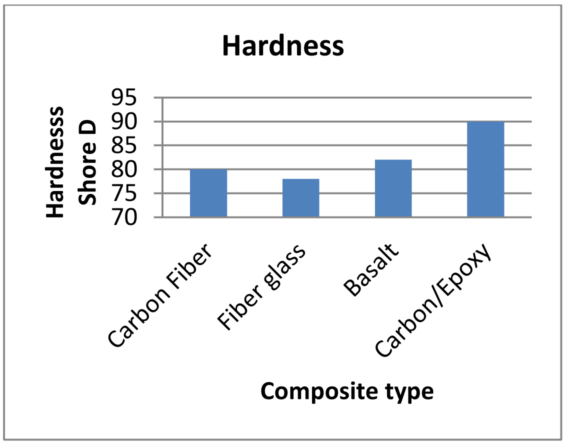

FIG. 12 Measured Data of Hardness test

4. CONCLUTION

The results show that for carbon/phenol, it reaches its maximum strength at the normal temperature which was 28 Mpa and it can withstand the high temperature (200 °c) and its strength reaches 0.22% of its strength at normal temperature. For the carbon / epoxy it also reaches its maximum strength at the normal temperature which was 64.8 MPa but at high temperature its strength decrease to 0.03% from its strength at normal temperature. For the fiber glass it also reaches its maximum strength at the normal temperature which was 22.26 Mpa and at high temperature its strength reaches 0.18% of its strength at normal temperature. For basalt it reaches its maximum strength at the normal temperature which was 19.8 Mpa and at high temperature its strength reaches 0.23% of its strength at normal temperature.

For Hardness, the four materials are almost in the same range but also the carbon fiber with epoxy is the most rigid one.

The results show that at normal temperature, the carbon with epoxy is the highest tensile properties and the highest hardness among the selected materials. But when the temperature rose, the carbon fiber with phenol is the highest one.

The mechanical properties for the selected composite materials are now known. The JANNAF standard is more efficient for getting accurate results for the chopped composite materials.
The Carbone fiber with the epoxy resin is the highest mechanical properties among the selected composite materials at room temperature.
At higher temperatures, Carbon fiber with phenol resin can withstand this temperature better than carbon fiber with epoxy resin.
For the hardness, the four selected composite materials are in the hard zone which is greater than 50 but the carbon fiber with epoxy is the hardest one.

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