



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

# IJIRSET

International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**

# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 10, Issue 12, December 2021

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

Impact Factor: 7.569

9940 572 462

6381 907 438

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# Comparative and Experimental Investigation on Mechanical Properties of Kevlar and Kevlar/Carbon Composites

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**ABSTRACT:** Fiber reinforced Composites (FRC) play a vital role in engineering applications due to its light weight and high strength character. FRCs offer the excellent mechanical properties compared to its constituent materials. The objective of the current study is to investigate and characterize the hybrid composites of Kevlar49 and carbon fibers as reinforcement material in epoxy matrix and compare the properties with composites of pure Kevlar49. Hand lay-up moulding method is used for the preparation of the composites, so as to have good compaction and to achieve uniform thickness. Some mechanical tests are carried out which includes tensile, flexural, shear and impact test under ASTM standards. The results thus obtained from the above tests have been analysed and compared with composites prepared with pure kevlar49.

**KEYWORDS:** Kevlar49 fiber, Epoxy Resin, Hybrid composite, hand lay-up, Mechanical testing.

## I. INTRODUCTION

A composite material consists of two or more distinct materials in macroscopic level with different properties that are combined together in order to get desired enhanced properties. The material that is used in the form of fibers to strengthen the composite is called reinforcement material. The other material used for holding the reinforcement materials intact in position is termed as matrix material. The composites with reinforcement material as fibers are generally known as Fiber Reinforced Composite (FRC). The FRCs are finding its usage as engineering materials in various areas like automobiles and aerospace owing to its light weight and enhanced structural properties.

The FRCs has drawn the interest of many researchers in recent times as it exhibits altogether different properties of its constituent elements. Further, the FRCs are fabricated to required shape and size by various manufacturing methods such as hand layup moulding, injection molding, extrusion and vacuum forming methods. In FRCs, the commonly used synthetic fibers are glass, carbon, Kevlar and graphite. However, the natural fibers such as hemp, wood and sisal fibers have also been used and characterized by various researchers. The commonly used matrix materials are epoxy, polyester, vinyl ester and polyimide resins. The FRCs has the desirable properties such as corrosion resistant, durability, toughness and light weight [1]. The FRCs has been investigated in different dental and implant structural applications [2].

The FRCs consists of Carbon Fibers as reinforcement material is termed as Carbon Fiber Composites (CFC). The CFC claims the advantages such as light weight, ease of fabrication, high stiffness and lower thermal conductivity. Hence, it is best suited for the applications in the area of aerospace, electronics and infrastructure industry [3]. Some new applications of CFCs have been found in building and construction industry.

In General, the hybridization of composites is carried out in three different ways such as interlayer, intralayer and intrayarn configurations. In interlayer composites, two different layers of different fibers are stacked one over another and binders such as resins are used in between layers so as to form a composites and it is the simplest form of hybrid composites. In intra layer composites, two fibers are combined together within a layer and such layers are

stacked one over another and bonded using resins. It is illustrated in the figure 1, where the Kevlar 49 and carbon fibers are co-woven in a single layer and stacked one over another. In case of Intra-yarn, two different fibers are combined in the fiber level and used in composites [4]. Further, the new configurations by incorporating any of the above configurations are also possible. For example, the intra-yarn layers are formed by combining two different fibers in different directions as a mat that makes more complex configuration.

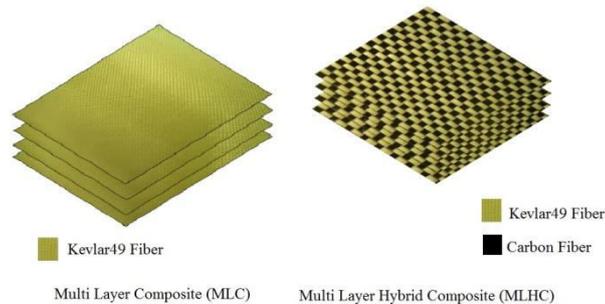


Figure 1 Image of MLC &amp; MLHC

Kevlar49 is one type of aramid fiber widely used in various engineering applications due to its improved tensile and impact properties. However, its flexural properties are not significant [5]. Hence, in the present study, the hybridization of Kevlar49 and carbon fibers are used to enhance the flexural properties of the composites. The properties of the hybrid composite are compared with the composites of pure Kevlar 49 fibers. The fibers are used in the woven form for the preparation of composite specimen. In order to get good compaction and to eliminate voids between the layers hand lay-up method is employed. Further, other mechanical properties such as tensile, impact, shear and impact tests are also performed for both hybrid and pure Kevlar49 composites.

## II. EXPERIMENTAL RESULTS

The multi-layered composites (MLC) of pure kevlar49 and multi-layered hybrid composites (MLHC) using reinforcement materials as Kevlar49 and carbon with epoxy resin matrix material are prepared for analysing its characteristics. In hybrid composites, the Kevlar49 and carbon fibers are used as intra layer in woven form. Multiple layers have been prepared with successive addition of resin using hand lay-up moulding technique so as to produce less thickness with high compaction between layers. The properties of MLHC are compared with MLC to study the effect of incorporation of carbon fibers. The procedure of preparation of MLC and MLHC using hand lay-up method, preparation of test specimen and testing methods are described in the following sub sections.

### FABRICATION OF MLC AND MLHC

The MLC and MLHC are prepared using the reinforcing materials in woven form with epoxy resin (LY556) and araldite hardener (HY951) is used during the fabrication. In MLC, the Kevlar49 fiber in the woven form is used in multiple layers and the fibers are oriented perpendicular to each other. In MLHC, the kevlar49 and carbon fibers are woven in a mat form with the orientation of fibers as  $90^{\circ}$  as intralayer form. The care is taken such that the intra layers are in same orientation. In other words, the direction of kevlar49 and carbon fibers in different layers are in same position. In a similar way, 8 layers are stacked and hand lay-up is used to squeeze the excessive resins and for better compaction between the layers. The hand lay-up technique is effective in fabrication of composites without air bubbles and voids. The laminates are then placed in hot air oven for two hours at  $100^{\circ}\text{C}$  and allowed to cool at room temperature. The hot air oven used for curing process has two separate heating zones of each 1.5KW power and the size  $700 \times 610 \times 700$  mm. The temperature range of the oven is between 0 to  $300^{\circ}\text{C}$ .

### Specimen Preparation

In order to predict and compare the mechanical characteristics of MLC and MLHC, tensile, flexural, shear and impact test are performed as per ASTM standards. With respect to tensile test, flexural, shear and impact test the ASTM standards of ASTM D 638-03, ASTM D790, ASTM D7617M-11 and ASTM D 256 are used respectively. The test specimens are prepared from the large size mate of size  $350\text{mm} \times 350\text{mm}$  of thickness 2.6 mm. During the



preparation of specimen the orientation of the kevlar49 and carbon fibers are taken to consideration. With respect to tensile test, in case of MLC, as the kevlar49 fibers are kept at 90° to each other, in both longitudinal and transverse directions only kevlar49 fibers will be present. However, in case of MLHC, the specimen with kevlar49 fibers in longitudinal direction and carbon fibers in transverse direction is termed as LKTC. The specimen with carbon fibers in longitudinal direction and kevlar49 in transverse direction is termed as LCTK.

**Testing Procedures**

The digital flexural testing system is used for testing the specimens of both MLC and MLHC for tensile, flexural and shear strength. The machine has a capacity of applying load up to 5 tons. Using the specially designed fixtures, the machine is used to conduct flexural and shear test on specimen. The load vs. displacement curve is obtained through the software connected to the machine. There is a provision to change strain rate in the machine. The photographic view is shown in the figure 2.



Figure 2 Photographic image of tensile testing machine.

**III. RESULTS AND DISCUSSIONS**

The results of mechanical tests carried out on the epoxy resin reinforced with hybrid kevlar49/carbon fibers and kevlar49 composites are discussed in this section. In order to characterize the composites, the tensile strength, young’s modulus, flexural strength, impact strength and shear strength etc. have been performed and the outcome of the results with discussion have been presented in appropriate places.

**TENSILE TEST:**

In view of predicting tensile strength of the specimen of MLC and MLHC is carried out. The ASTM D 638-03 standard is employed for the test. The tensile test is performed in Digital Universal testing machine of with appropriate testing fixtures. The machine is capable of giving Ultimate load ( $F_u$ ) in KN, Ultimate stress ( $\sigma_u$ ) in  $KN/mm^2$ , yield stress ( $\sigma_y$ ) in  $KN/mm^2$ , Elongation at the maximum load ( $\delta_u$ ) in mm and maximum elongation ( $\delta_{max}$ ) in mm for each specimen. The stress vs. strain curve is generated till the specimen breaks. In the present work, the specimen of size 150mm×13mm×3mm is used for the tensile test for both MLC and MLHC are shown in the figure 3.

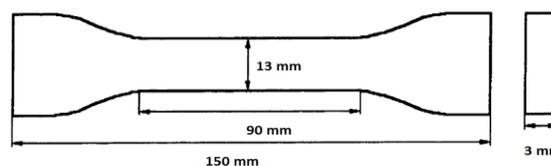


Figure 3 Image of dimensions of the specimen (MLC & MLHC)



The effective length for tensile test is kept as 90mm apart from end portions that are used for gripping. The photographic view of the specimen before and after tensile test is shown in the Figure 4.



Figure 4 Photographic image of specimen (MLC)

In each category three specimens are considered and the corresponding results are presented in Table 1. The specimen that yields higher values of Ultimate load is highlighted in the Table 1 and corresponding the stress Vs. strain plot is presented in the Figure 5.

Table 1 Tensile test results of MLC and MLHC

Specimen Code	FU(KN)	$\delta_u$ (mm)	$\delta_{max}$ (mm)	$\sigma_u$ (KN/mm <sup>2</sup> )	ELONGATION (%)	$\sigma_y$ (KN/mm <sup>2</sup> )	E (N/mm <sup>2</sup> )
MLC1	12.350	04.8	05.1	0.316	08.100	0.297	6000
MLC2	11.400	05.3	06.3	0.292	07.875	0.284	7500
MLC3	15.565	03.6	07.4	0.399	09.250	0.375	10000
LKTC1	09.835	10.6	10.7	0.182	17.830	0.063	6700
LKTC2	10.500	05.5	06.0	0.269	07.500	0.240	7000
LKTC3	14.305	02.9	03.7	0.305	06.160	0.301	8000
LCTK1	08.845	03.8	04.7	0.227	05.875	0.078	6000
LCTK2	08.085	07.8	07.8	0.200	13.000	0.037	6444
LCTK3	08.450	03.5	04.2	0.216	05.700	0.021	6200

In MLC, the Kevlar 49 fiber has the good resistance in withstand load, higher rigidity and stiffness compared to MLHC. Whereas in MLHC, the entire three LKTC specimen has the capability to withstand higher load compared to LCTK specimen because the kevlar49 fiber is oriented in the longitudinal direction and the carbon fiber in the transverse direction. The stress vs. strain curve obtained for the sample specimens of MLC3, LKTC3 and LCTK1 are shown in the Figure 5 (a, b & c).

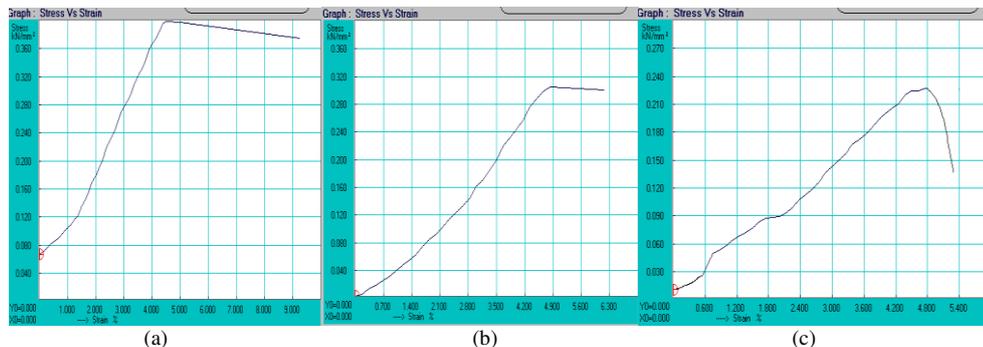


Figure 5 (a, b & c) Typical diagram of stress versus strain curves (a) MLC3 specimen, (b) LKTC3 specimen, and (c) LCTK1 specimen.



**FLEXURAL TEST:**

Flexural test indicates the load required to deflect a beam when it is subjected to three points loading. It is often used to design and select the materials that support loads without deflection. Flexural modulus is the indication of a material’s stiffness when deflection occurs. The flexural test is carried out on a specimen that is supported between two supports and the load is applied at the centre of the span at a specified rate. The parameters for the test are span length, rate of loading and maximum deflection. As per the standard, the variety of shapes of the specimen can be used. However, commonly used shape is a beam of rectangular cross section with dimension is shown in the figure 6.

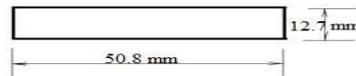


Figure 6 Image of dimensions of the specimen (MLC & MLHC).

In the present work, the specimen of size 50.8mm×12.7mm×3mm is used for the flexural test of both MLC and MLHC. The load is applied till the rupture of the specimen and the load versus displacement curve is obtained for each specimen. The ultimate load, ultimate stress, maximum displacement and displacement at maximum load are obtained as output from the machine. The MLC specimen (Pure Kevlar49) is tested and the test results are compared with the test results of two types of specimens of MLHC (LKTC and LCTK). In each case three specimens are tested and the average value is taken for the corresponding type of specimen so as to eliminate the experimental error. The test results of MLC of kevlar49, LKTC and LCTK have been predicted and presented in the Table 2. The number of specimen is provided at the end of each specimen code. The ultimate load ( $F_u$ ) in KN, ultimate stress ( $\sigma_u$ ) in KN/mm<sup>2</sup>, displacement at ultimate load ( $\delta_u$ ) in mm and maximum displacement ( $\delta_{max}$ ) in mm for all the specimens are presented in the Table 2.

Table 2 Experimental results of Flexural test

Specimen Code	$F_u$ (KN)	Avg. $F_u$ (KN)	$\sigma_u$ (KN/mm <sup>2</sup> )	Avg. $\sigma_u$ (KN/mm <sup>2</sup> )	$\delta_u$ (mm)	Avg. $\delta$ (mm)	$\delta_{max}$ (mm)	Avg. $\delta_{max}$ (mm)
MLC1	0.290	0.315	0.008	0.008	10.000	11.800	14.600	14.633
MLC2	0.305		0.008		13.600		14.500	
MLC3	0.350		0.009		11.800		14.800	
LKTC1	0.690	0.660	0.018	0.017	02.500	02.333	04.500	04.900
LKTC2	0.640		0.017		02.200		05.200	
LKTC3	0.650		0.017		02.300		05.000	
LCTK1	0.410	0.418	0.011	0.011	01.600	01.933	02.900	05.100
LCTK2	0.425		0.011		02.200		06.400	
LCTK3	0.420		0.011		02.000		06.000	

The specimen that yields higher values of Ultimate load is highlighted in the Table 2 and the corresponding Load versus Displacement plot is presented in the Figure 7(a, b & c).

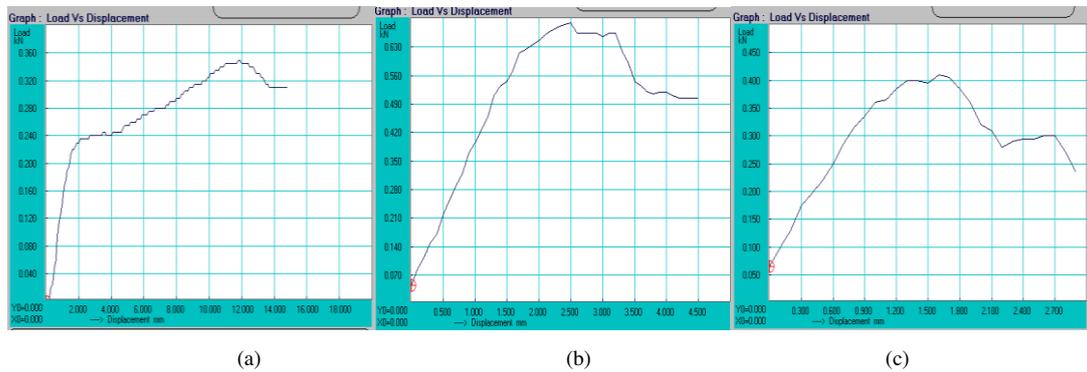


Figure 7 Typical diagram of Load versus Displacement curve for flexural test on Specimen MLC3 (a), Specimen LKTC1 (b), and Specimen LCTK2 (c).

**SHEAR TEST:**

The shear strength of the prepared composites of both MLC and MLHC type are predicted as per ASTM D7617M-11. The size of the specimen used for the shear test is 50×9.2×3mm and the shear load is applied for the cross section of 9.2 X 3mm in digital UTM with appropriate fixture are shown in the figure 8.

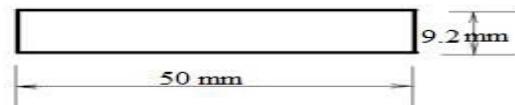


Fig 8 Image of dimensions of the specimen (MLC & MLHC)

Three specimen in each category of MLC (Kevlar 49) and two types of MLHC (LKTC and LCTK) type are used. The test results such as applied load ( $F_U$ ) in KN and shear stress ( $\tau_u$ ) in  $KN/mm^2$  is presented for each category of the specimen in the Table 3. The photographic view of the specimen after shear test is shown in the Figure 9



Figure 9 Photographic image of specimen (MLHC) after shear test.

The test results of MLC of kevlar49, LKTC and LCTK have been predicted and presented in the Table 3.

Table 3 Experimental results of Shear test.

Specimen Code	$F_U$ (KN)	Avg. $F_U$ (KN)	$\tau_u$ (KN/mm <sup>2</sup> )	Avg. $\sigma_u$ (KN/mm <sup>2</sup> )	$\delta_u$ (mm)	Avg. $\delta$ (mm)	$\delta_{max}$ (mm)	Avg. $\delta_{max}$ (mm)
MLC1	10.370	10.440	0.375	0.377	7.500	7.533	8.100	8.100
MLC2	10.605		0.383		7.500		8.300	
MLC3	10.345		0.374		7.600		7.900	
LKTC1	06.735	07.387	0.244	0.268	7.600	7.272	9.300	7.600
LKTC2	08.205		0.297		7.000		8.500	
LKTC3	07.222		0.262		7.215		5.000	
LCTK1	07.255	07.202	0.263	0.261	5.100	5.149	6.800	6.400
LCTK2	07.231		0.262		5.215		6.400	
LCTK3	07.025		0.255		5.132		6.000	

The specimen that yields highest shear stress in each category is also highlighted and the corresponding load vs. displacement curve obtained for the sample specimens of MLC2, LKTC2 and LCTK1 are shown in the Figure 10.

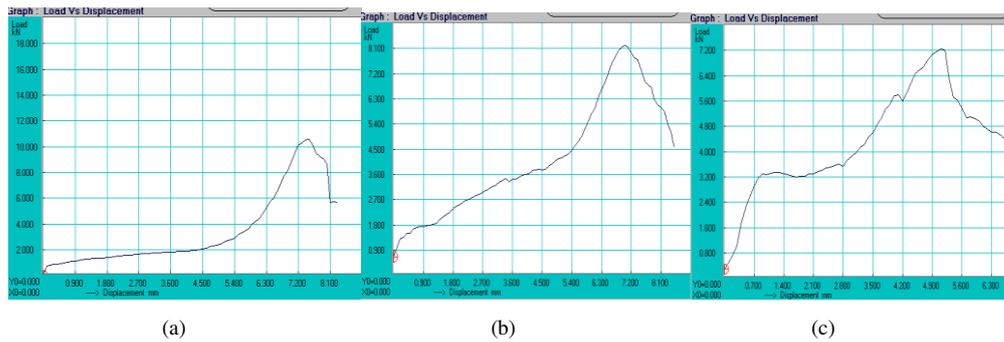


Figure 10 Typical diagram of Load versus Displacement curve for shear test on Specimen MLC2 (a), Specimen LKTC2 (b), and Specimen LCTK1 (c).

**IMPACT TEST:**

The impact test is used to measure directly the total energy absorbed by the specimen for complete failure under impact loading condition. The ASTM D 256 standard is employed for the test. The impact strength (I.S) of the MLC and MLHC specimens has been predicted using IZOD test. The specimen is supported at both of its ends and the load is applied at the middle using a hammer that falls with velocity of 3.5m/sec. The energy absorbed by the specimen is recorded from the dial provided in the machine directly. The IS is calculated for a particular specimen by dividing the total energy absorbed by the cross sectional area of the fracture location. The specimen of size 64mm×12.7mm×3mm is used for the impact test of both MLC and MLHC and the line sketch of the specimen is shown in the figure 13. The test results of MLC of kevlar49, LKTC and LCTK have been predicted and the highest impact energy is highlighted in the Table 5.

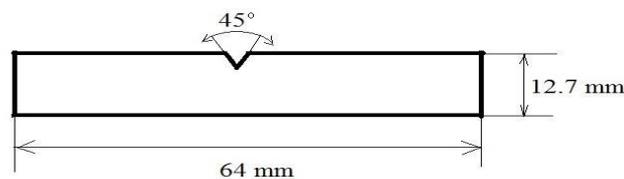


Figure 13 Image of dimensions of the specimen (MLC & MLHC).

Table 5 Experimental results of Impact test.

Specimen Code	UC (joules)	Avg.	(I.S) J/mm <sup>2</sup>	Avg.
MLC1	8.600	7.530	0.225	0.197
MLC2	7.000		0.183	
MLC3	7.000		0.183	
LKTC1	5.800	5.900	0.152	0.154
LKTC2	6.000		0.157	
LKTC3	5.900		0.154	
LCTK1	4.500	4.030	0.118	0.106
LCTK2	3.600		0.094	
LCTK3	4.000		0.105	

#### IV. CONCLUSION

The two types of composites one with hybridization of kevlar49 and carbon fibers and the other one with pure Kevlar49 fibers are prepared and tested for its characterization. Based on the experimental results, the following conclusions are arrived and presented below.

The Tensile test results indicated that the cracked specimens are tougher along the fiber orientations as compared with across the fiber orientations. The tensile strength and yield strength values of the MLC are higher than that of MLHC. The MLC specimens have the capability to withstand higher load compared to MLHC specimens. It reflects, the high stiffness and rigidity of MLC compared to MLHC. The percentage elongation indicates that the MLC and MLHC specimen has ductility and toughness. In this present work, it is clearly stated that MLC is recommended for tensile application.

Flexural test reveals that the flexural strength of the MLHC is higher than that of MLC. The MLHC specimens have the capability to withstand higher load compared to MLC's specimens. Hybridization resulted in increased flexural strength. Minimum displacement takes place only in MLHC's specimen compared to all specimens of MLC. Kevlar49 in combination with the carbon fiber has the good flexural strength and hence MLHC is highly recommended for flexural application. The MLC specimen has the good shear strength and capability to withstand higher load compared to MLHC's specimen. In the Impact Test, the total impact energy required to fracture the specimen is measured and can be used as a basis for comparison of MLC and MLHC specimen tested under the same conditions. The results indicate that the impact strength is higher for MLC compared to MLHC. The MLC has the good toughness and impact resistance.

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