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Effect of Stacking Sequence on Mechanical/ Vibration Characteristics of Kevlar/Glass Hybrid Reinforced Polymer Composites

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Abstract: The advanced structural materials are designed and manufactured in the purview of enhanced properties like high strength to low weight ratio, vibration and its damping characteristics etc. One of the important purposes of vibration study is to reduce vibration through proper design of machine components or structural materials. In this context, the present study is focused on the hybrid composite laminates with the Epoxy as polymer matrix and Glass fibers/Kevlar fibers as reinforcements, which is finding applications widely for its high strength to low weight ratio. Present work is intended to study the tensile behaviour, impact strength, flexural strength, the inter-laminar shear strength, vibration and damping characteristics of the hybrid composites laminates along with mechanical properties. It is observed that, impact strength is higher in hybrid composite of one on one kevlar/glass reinforced laminate. The flexural and the interlaminar shear strength are higher in the two on two kevlar/glass reinforced hybrid laminate. The tensile strength of the hybrid composite with one on one kevlar/glass reinforcement is higher than others. In the vibration study, one on one kevlar/glass reinforced hybrid laminate has higher damping properties than the others.

Keywords: Stacking Sequence, Glass fibers, Kevlar fibers, glass reinforced laminate.

1. INTRODUCTION

Composite materials are the important materials that are now used widely in the aerospace industry and also in a large and increasing number of commercial applications including machine components, thermal control and electronic packaging, automobiles, pressure vessels, dimensionally stable components, marine structures, sports equipments, biomedical devices, civil engineering structures and most importantly in the army and defense applications. This results in increased development and production volumes of composite materials. The development of composite materials and the related design and manufacturing technologies is one of the most important advances in the history of materials. Composite materials technology also makes possible the use of an entire class of solid materials and ceramics in applications for which monolithic versions are unsuited because of their great strength scatter and poor resistance to mechanical and thermal shocks.

Composites are strongly heterogeneous materials[1]. The properties of heterogeneous material vary considerably from point to point in the material, depending on the material phase in which the point is located. The heterogeneous nature of composites results in complex failure mechanisms that impart toughness. Fiber-reinforced materials have been found to produce durable, reliable structural components in wide applications [2]. The excellent mechanical properties of composites were the main reason for their wide use and applications [3].

However, there are an increasing number of applications for which the unique and tailorable physical properties of composites are key considerations. For example, the moderately high stiffness, near-zero co-efficient of thermal expansion (CTE) Glass fibers, and low density of Aramid (Kevlar) fiber-reinforced polymers have made the composites materials of choice in a variety of applications, including spacecraft structures, antennas, and optomechanical system components such as telescope metering structures etc. Designers prefer the usage of hybrid composites that combines different types of matrix or reinforcement forms to achieve greater efficiency and reduce cost [4], [5].

2.MATERIALS AND METHODS

Epoxy as matrix phase, Bi-directional plain woven kevlar and glass fabric as reinforcement phasefor hybridization of reinforcements in this work.

2.1 Apparatusand instruments

A hydraulic press for composite preparation, computerized universal testing machine, computerized impact testing equipment for the testing and characterization of the composite materials prepared.

2.2 Composite preparation

Specimens are prepared in the form of square plates of 250x250x40 cubic mm. The BD woven fabric cloth is cut

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into 250x250 sq.mm. Then it is weighed to find the mass of one layer. By the rule of mixture, a volume fraction of 60% to 40% on fiber to resin followed and the total mass of resin and fiber cloth required is calculated. Once we get the total mass of fiber required, we can calculate the number of layers required. For hybrid laminate, only the difference in density plays a role in the mass of reinforcement required and the number of layers required.The plate is of 25×25 sq.cmThe thickness of plate required is 0.4 cm. Therefore the volume of the plate is 25×25×4 cm^3.

Table 2.1 Types of composites

Type	B	C	D
Stacking	(1K/1G)×8	(2K/2G)×8	4K/8G/4K
Total layers	16	16	16
Reinforcement Material	(Kevlar/Glass)Hybrid		
Matrix material	Epoxy		

2.3Tests for mechanical characterization
Mechanical tests have been done on the composite laminate specimens of different compositions of stacking sequence for its characterization.

2.3.1 Impact Test (IZODE)
Impact strength is the ability of a material to resist breaking under a shock or impact loading or the ability to resist fracture under stress applied at high speed. The impact resistance of fiber-reinforced composite depends on fiber rigidity, interfacial stress resistance and fiber aspect ratio. According to ASTM D256-56, impact test has been carried out. Cantilever beam or Izod type test in which specimen is held as a cantilever beam (usually vertical) and is broken by a blow delivered at a fixed distance from the edge of the specimen clamp. The test requires a notched specimen as shown in Fig.1.

Fig2.1 Impact test specimen

2.3.2Flexural Test (3-Point Bending)
According to ASTM D790-91,the specimens were prepared for static bending. Each test specimen of 13mm width, length 191mm and thickness 10mm was used for the present investigation.

Fig2.2 Flexural test specimen

The span (centre to centre distance between roller supports) for each specimen is 150mm. The flexural test specimen is shown in Fig.2.

2.3.3Tensile Test
According to ASTM D3039/D3039M – 08, tensile testing has been carried out. The test method covers the determination of the tensile behaviour of reinforced polymers in the form of beam shaped test specimens when tested under defined conditions of pre-treatment, temperature, humidity, and testing machine speed. As per the above standards the composites specimens were prepared for test as shown in Fig.3

Fig2.3 Tensile test specimen

2.4Vibration Analysis
The method (ASTM E756) measures the vibration-damping properties of materials: the loss factor, h, and Young's modulus, E. Accurate over a frequency range of 50 to 5000 Hz and over the useful temperature range of the material, this method is useful in testing materials that have application in structural vibration, building acoustics, and the control of audible noise. Such materials include metals, enamels, ceramics, rubbers, plastics, reinforced epoxy matrices, and woods that can be formed to cantilever beam test specimen configurations.
The schematic diagram of the vibration measuring set up is shown in Fig.4

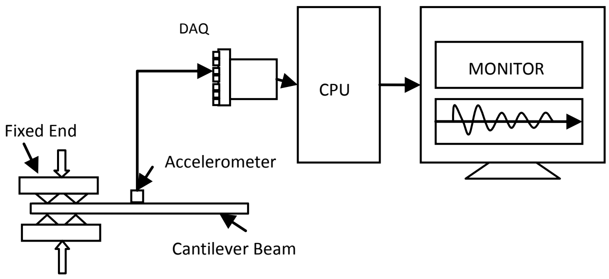

Fig2.4 Schematic diagram of vibration measuring apparatus

The flexural test specimen is shown in Fig.5

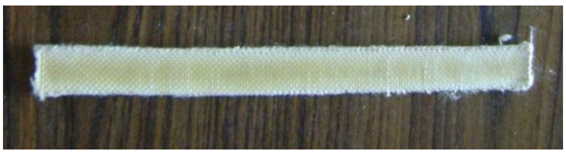

Fig2.5 Vibration analysis test specimen

2.5Logarithmic Decrement Method for Vibration damping analysis
This method is based on the time response and is the most popular method used to measure damping. The response of

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a single degree of freedom oscillatory system with viscous damping on initiating an excitation is as shown in Fig.5.15. The amplitude of vibration x(t) decays exponentially w.r.t. time (t).

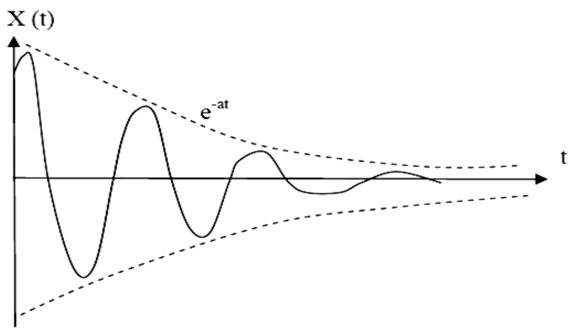

Fig2.6 Vibration decay due to damping

With a spring-mass system, the logarithmic decrement is the natural log of the two successive amplitudes of the oscillation. The logarithmic decrement (δ) is calculated from tile plot of position versus time using below equation.

Logarithmic decrement, $\delta = \ln\left(\frac{x_1}{x_2}\right) = \frac{1}{n}\left(\frac{x_1}{x_{n+1}}\right)$

Where δ= logarithmic decrement
x_1 = the amplitude of the first peak
x_2= the amplitude of the second peak
x_n= the amplitude of the n^{th} peak
n = peak no

The damping ratio ξ in terms of the logarithmic decrement is represented in below equation.

Damping ratio, $\xi = \frac{\delta}{\sqrt{4\pi^2+\delta^2}}$

All the values for the vibration analysis tests are calculated as discussed above according to the ASTM standards for the testings.

3. RESULTS AND DISCUSSION

3.1 Impact test

The impact test is conducted on the specimens B, C and D. The impact strengths of the composites are tabulated in Table 3.1 and the comparison of the results are shown in Fig 6.1.

Table 3.1 The impact test results

Specimen type	B	C	D
Impact Strength (J/mm^2)	0.2756	0.1947	0.1994

Considering the impact strengths of hybrid composites B, C and D, the specimen B shows the highest impact strength of 0.2756 J/mm^2 and the specimen C shows the lowest impact strength of 0.1947 J/mm^2. This is because, the impact energy absorption is more uniform in B and

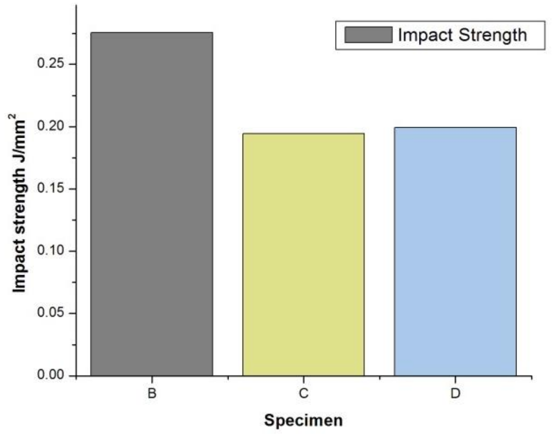

Fig. 3.1 Comparison of impact strengths of Composites

number of absorbing layers also higher compared to C and D. The impact strength of specimen B is 5.26% more than the specimen A, due to the presence of kevlar layers. When it is introduced with stronger Kevlar fibers, the Kevlar absorbs more energy than the glass fibers.

3.2Flexural strength test

The flexural strength test has been conducted by three point bending mechanism for all the specimens. The maximum bending load and the flexural strength are shown in Table 6.2.

Table 3.2 Flexural test results

Specimen Type	B	C	D
Ultimate load(N)	152.62	168.30	126.33
Flexural strength (MPa)	78.25	96.59	61.44

The Load v/s Deflection curves for the specimens B, C and D has been plotted and shown in Figures 3.2.

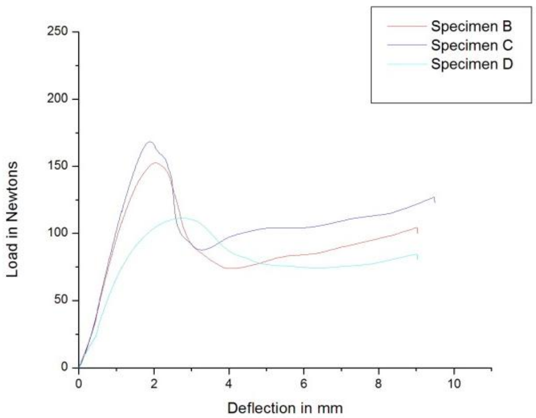

Fig. 3.2 Load v/s Deflection curve for composite laminates

When the hybrid composites B, C and D are compared, the specimen C has 36.18% more flexural strength than the specimen D. This is because, in the flexural loading for specimen, the top surface subjected to compressive force and bottom to tensile forces. When the specimen C is placed in such a way the top surface will be with glass

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fibers and bottom with kevlar, the flexural strength will be more because the kevlar has more tensile strength than glass in turn resulting in more flexural strength.

3.3Interlaminar shear strength test

The values of ILSS for the different composite laminate are calculated in relation to the flexural strength and are tabulated in Table 3.3.

Table 3.3 ILSS test results

Specimen	B	C	D
ILSS (N/mm^2)	2.464	2.897	1.935

The Fig. 3.3 shows the comparison of ILSS of different composite specimens.

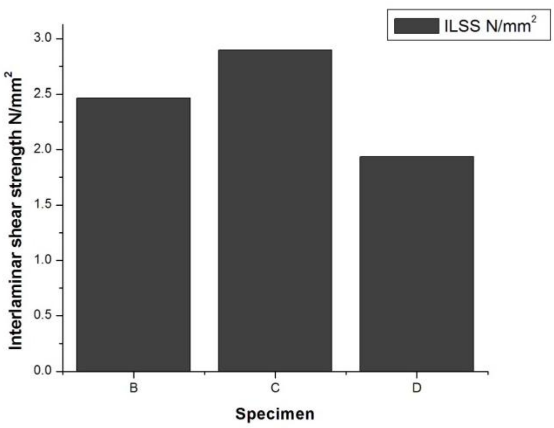

Fig. 3.3 Comparison of Interlaminar shear strengths of Composites

When the hybrid composites B, C and D are compared, the specimen C has 14.9% more strength than the specimen B and 21.46% more than specimen D. The specimen C has two-on-two type of stacking sequence exhibits better adhesion between the glass fiber layers due to its better wetability property leads to higher value of ILSS.

3.4 Tensile test

The tensile tests for the different composite laminate have been conducted. The Young's modulus (E), Ultimate Tensile strength and the percentage strain are calculated and shown in Table 3.4.

Table 3.4 Tensile test Results

Specimen	B	C	D
Young's Modulus E (N/mm^2)	156	284	486
Ultimate tensile strength (N/mm^2)	255.07	235.85	209.66
% Strain	8.9	8.6	8.1

The stress v/s strain curves for the specimens B, C and D has been plotted and shown in below Fig 3.4.

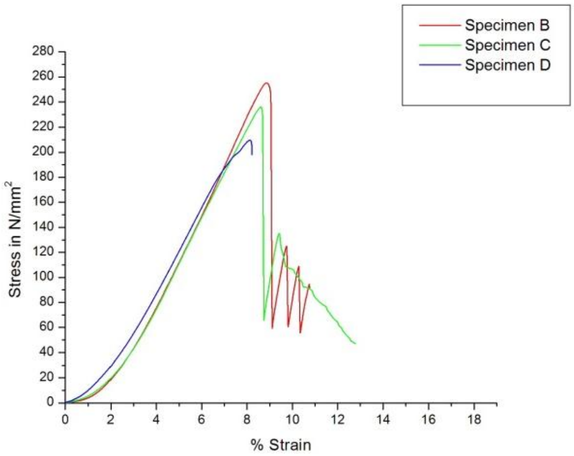

Fig. 3.4 Stress v/s strain curve

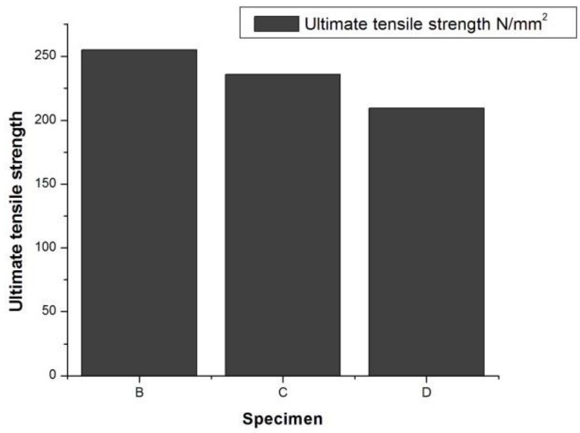

Fig. 3.5 Comparison of Ultimate tensile strength

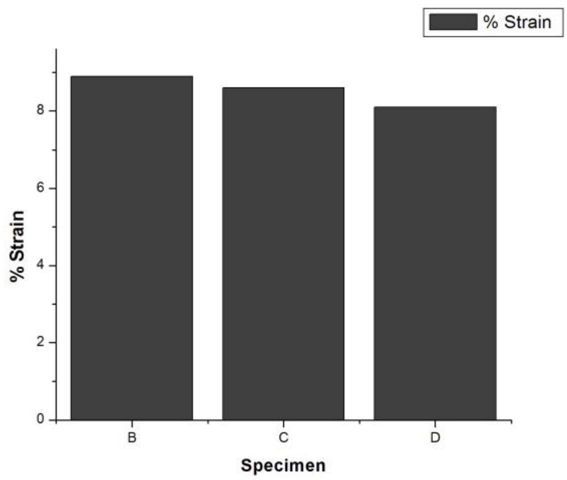

Fig. 3.6 Comparison of % Strain

When the hybrid composite specimen B, C and D are compared, the specimen B has the highest tensile strength, which is 17.8% more than the specimen D. Also the percentage strain of specimen B is 8.9% and specimen D is 8.1%, which means the deformation of specimen B will be more for unit load. This is because the kevlar has more tensile strength and less stiffness, when it is hybridized with the brittle and stiffer glass fiber, the total tensile

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strength of the hybrid composite is increased. At the same time as the number of alternate layers increases, the interlaminar adhesion helps in increasing the tensile strength.

3.5Vibration damping analysis

The test is conducted for the all the specimens. The specimens are treated as cantilever beam. The vibration datas are collected through the data acquisition system (DAQ) using free vibration method and it is analysed for damping properties. The acceleration sensor is used to collect the acceleration signal.

The damping ratio calculation is done on the basis of decaying of the vibration or logarithmic decrement method. The logarithmic decrement graph is shown in Fig.6.16.

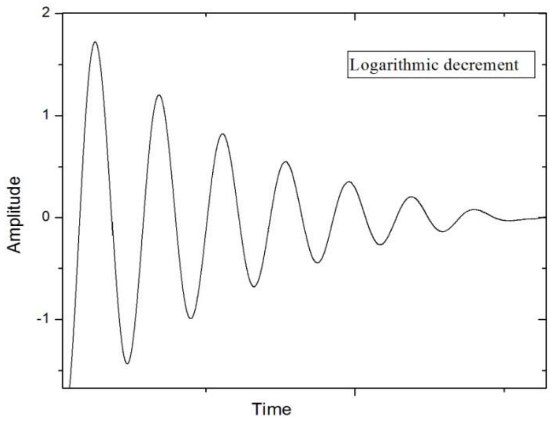

Fig. 3.7 Logarithmic decrement graph

The values of logarithmic decrement and damping ratio are shown in Table 3.5.

Table 3.5 Vibration analysis results

Position	Specimen B		Specimen C		Specimen D	
	Log decrement	Damping ratio	Log decrement	Damping ratio	Log decrement	Damping ratio
1 100mm	0.5087	0.0806	0.2215	0.0352	0.3462	0.055
2 125mm	0.477	0.0756	0.1872	0.0297	0.2792	0.0443
3 150mm	0.3599	0.0571	0.1551	0.0246	0.2687	0.0427
4 175mm	0.267	0.0424	0.1447	0.023	0.2612	0.0415
5 200mm	0.2349	0.0373	0.0373	0.0207	0.1885	0.0299

The logarithmic decrement comparison is done between the specimens B, C and D. The bar charts are drawn with respect to type of specimen and with respect to the length of the specimen and are as shown in Fig.3.8 and Fig 3.9 respectively.

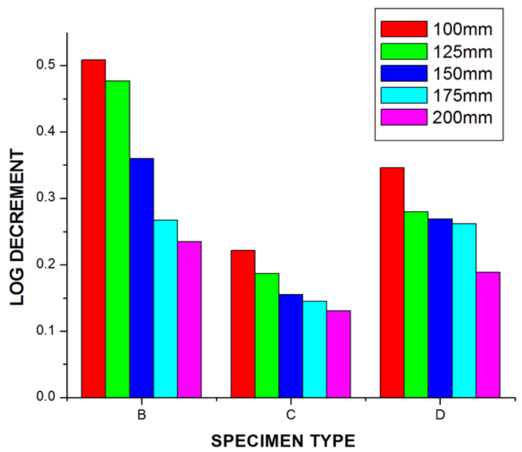

Fig. 3.8 Comparison of logarithmic decrement w.r.t specimen for different length

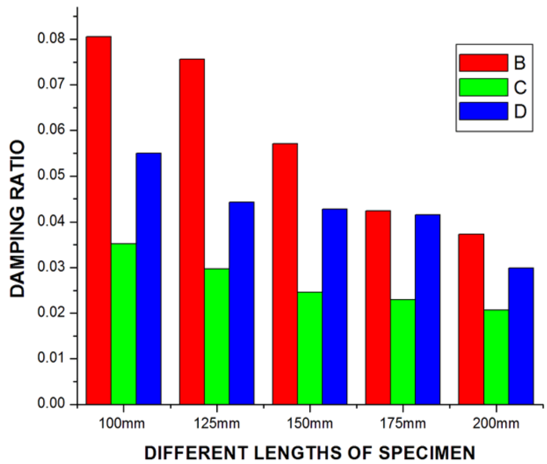

Fig. 3.9 Comparison of damping ratio w.r.t. length for different specimens

When the hybrid composite specimens B, C and D are compared, the specimen B has highest logarithmic decrement and more damping ratio among three. This is because, of the uniform distribution of the fiber layers and the properties in the macroscopic level. The logarithmic decrement and the damping ratio in hybrid composites C and D are lesser than the hybrid composite B because, in hybrid composite specimen B, the blocking of the vibration waves takes place in each different layers, but in specimen C with two-on-two type of layers and in specimen D with 4Kevlar/8Glass/4Kevlar type layers, place for the blocking of vibration waves are lesser. Lower the vibration decaying leads to decrease in the damping ratio.

So, hybridized composite specimen with one-on-one Glass/Kevlar layer reinforced Epoxy composite can be rated as better composite specimen with higher vibration absorbing characteristics and mechanical properties.

4. CONCLUSION

In the present work the epoxy polymer composite specimens of different compositions have prepared by hand lay-up technique and hydraulic pressing. The three types of hybrid composites with different stacking sequence have prepared and tested for mechanical characterization and vibration analysis.

- The impact strength is found to be maximum in hybrid composite with one-on-one Glass/Kevlar layers and minimum in specimen with two-on-two layered composite
- The hybrid composite specimen with two-on-two Glass/Kevlar layers gives the good flexural strength than others.
- The hybrid composite with specimen with two-on-two Glass/Kevlar layers gives the good ILSS among three.
- The tensile strength is found to be maximum in the hybrid composite with one-on-one layers.
- The hybrid composite with stacking sequence one-on-one Glass/Kevlar layers can be rated as the best hybrid composite specimen produced in this work

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