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Mechanical Charaterisation of Kevlar/Glass Hybrid Reinforced Polymer composite laminates

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Abstract: In any mechanical and structural systems, the materials used and its properties plays a major role in their behavior to the mechanical and dynamic loadings. 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 vibration and damping characteristics of the hybrid composites laminates along with mechanical properties. The work is also intended to study the tensile behaviour, impact strength, flexural strength and the inter-laminar shear strength of the hybrid and non hybrid Glass fiber and Kevlar fiber reinforced epoxy polymer composites. 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 non hybrid glass fiber reinforced laminate. The tensile strength of the hybrid composite with one-on-one kevlar glass reinforcement is higher than others. In the vibration study, the non hybrid Kevlar reinforced laminate has higher damping properties than the non hybrid glass fiber reinforced composite. The glass fiber reinforced laminate has lowest damping property due to its brittle nature.

Keywords: Kevlar/ Glass-epoxy PVA (Poly Vinyl Alchohol), Hybrid composite, Vibration-damping, Cantilever beam test.

1. INTRODUCTION

A composite is a material consisting of two or more distinct materials bonded together [1], which results in the potential for a limitless number of new material systems having unique properties that cannot be obtained with any single monolithic material. Composites are strongly heterogeneous materials. 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. There are mainly three different types of reinforcements in a composite material like fibrous and particulate reinforced composite materials. Particulate reinforced materials will be stiffer, but less fracture resistance when compared to fiber reinforced materials.

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.

To put things in perspective, it is important to consider that modern composites technology is only several decades old. This is an extremely short period of time compared with other materials such as metals, which go back millennia. In the future, more and more improved and entirely new materials and processes can be expected. It is also likely that new concepts will emerge such as hybridization, greater functionality, including integration of electronics, sensors, and actuators.

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]. For example, woven fabrics and unidirectional tapes are often used together in structural components. In addition, carbon fibers are combined with Glass fibers or Aramid (Kevlar) fibers to improve impact resistance. Laminates combining composites and metals such as “Glare”, which consists of layers of aluminum and glass fiber-reinforced epoxy, are being used in aircraft structures to improve fatigue resistance.

2. MATERIALS AND METHODOLOGY

Epoxy as matrix, BD plain woven glass and kevlar fabric as reinforcements materials are employed for this work.

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2.1 Apparatus and instruments

Materials listed below are used in the preparation of the composite laminates.

- Epoxy resin with its hardener.
- Kevlar fiber pain woven fabric cloth.
- Bi-directional (BD) glass fiber plain woven fabric cloth.
- PVA mold releasing agent.

Computerized Universal Testing Machine (UTM), Impact testing machines are used to study the mechanical behavior of composite laminates. Vibration measuring instrument (Kistler 8774A50), accelometer (SN2081635), data acquisition system (NI9234, national instruments .com), vibration damping analysis of the composites prepared.

2.2 Fabrication of laminates

Laminates are prepared in the form of square plates of 250x250x4 cubic mm. The plain woven fabric cloth is cut into 250 x250 sq.mm. Then it is weighed to find the mass of one layer. By the rule of mixture, volume fraction of 60%-40% on fiber to resin is calculated and then the total mass of resin and fibre required is calculated. Hand lay-up technique followed by hydraulic pressing is the method used to prepare test laminates. The procedure complies of placing the thin layers of reinforcement layers and weighed quantities of resin and hardener and allowed for room temperature curing with hydraulic pressure. The whole layup is covered with a mylar sheets on each sides which is placed in molds before laying up and hydraulically pressing. The excess resin is allowed to squeeze out through the blow holes. The laminate is cured at ambient conditions for a period of about 24 hours. The thickness of the laminate achieved is about 4mm, obtained by using spacers.

2.2 Preperation of test specimen

The cured laminate is cut by using a reciprocating knife type contour cutting machine for the required shapes and dimensions as per the ASTM standards for the respective testings. The specimen samples of five from each type of the specimen are taken for samplings. Below table 2.1 shows the types of specimens prepared with different compositions.

Table 2.1: Types of specimens prepared

Type	A	B	C	D	E
Stacking	16G	(1K/1G)×8	(2K/2G)×8	4K/8G/4K	16K
Total layers	16	16	16	16	16
Reinforcement Material	BD Glass fiber	(Kevlar/Glass)Hybrid			Kevlar fiber
Matrix material	Epoxy resin with its hardener				

2.3Test for mechanical characterization

Mechanical characterization of glass/kevlar - epoxy laminates is done by conducting impact (Izode), flexural (3 point bending) test, inter laminar shear strength test (ILSS) and tensile test as per respective ASTM standards.

2.4Vibration Analysis

In this test method (ASTM E756), measurement of the vibration-damping properties of materials: the loss factor, h, and Young's modulus, E are found. The configuration of the cantilever beam test specimen is selected based on the type of damping material to be tested and the damping properties that are desired. The material loss factor and modulus of damping materials are useful in designing measures to control vibration in structures and the sound that is radiated by those structures, especially at resonance. This test method determines the properties of a damping material by indirect measurement using damped cantilever beam theory. By applying beam theory, the resultant damping material properties are made independent of the geometry of the test specimen used to obtain them. These damping material properties can then be used with mathematical models to design damping systems and predict their performance prior to hardware fabrication.

The schematic diagram of the vibration measuring set up and the actual measurement carried out is represented as shown in Fig 2.1 and Fig 2.2 respectively.

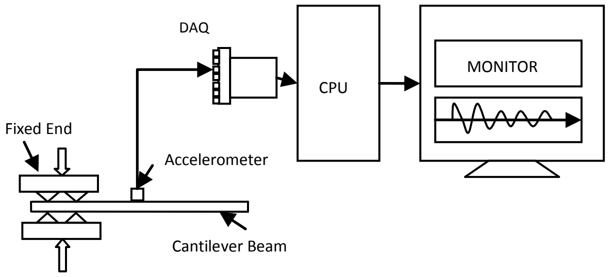

Fig. 2.1 Schematic diagram of vibration measuring apparatus

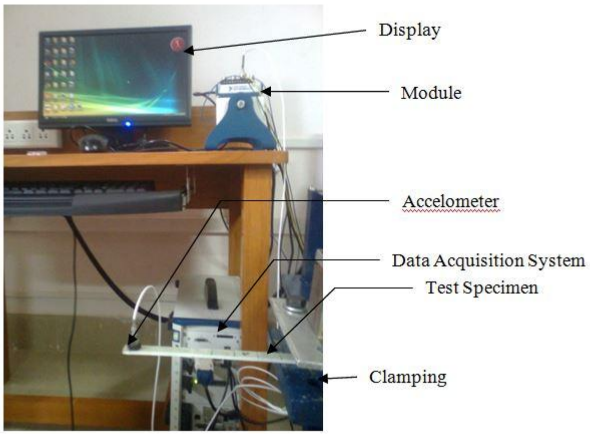

Fig. 2.2 Vibration measuring apparatus

2.5Vibration damping analysis by logarithmic decrement method

This method is based on the time response and is the most popular method used to measure damping. The response of 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).

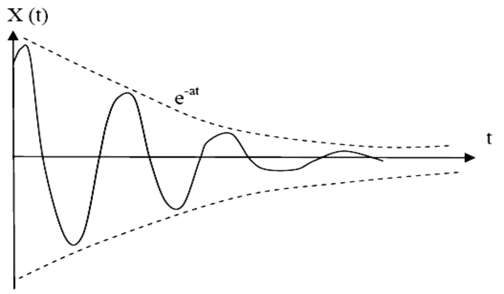

Fig. 5.15 Vibration decay due to damping

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, $\delta=\mathrm{In}\left(\frac{x_1}{x_2}\right)=\frac{1}{n}\left(\frac{x_1}{x_{n+1}}\right)$

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.

3. RESULTS AND DISCUSSION

3.1 Mechanical characterization

Impact Test

Table 3.1: The impact test results

Specimen type	**A**	**B**	**C**	**D**	**E**
Impact Strength (J/mm^2)	0.2611	0.2756	0.1947	0.1994	0.0919

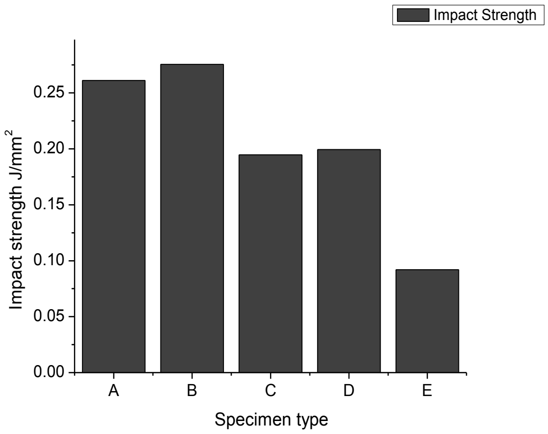

Fig. 3.1 Comparison of impact strengths of Composites

It can be observed that impact strength of specimen A is 0.2611 J/mm^2, which is 64.81% higher when compared to specimen E with value 0.0919 J/mm^2. It is because the glass fibers are brittle in nature.

When impact loading is done, the energy absorbed by the glass fiber reinforced composite is more, inturn the impact strength is more when compare to Kevlar composite.

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 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.

Flexural Test (3 point bending)

The maximum bending load taken by the composite laminate are tabulated as shown in Table 3.2.

Table 3.2

Specimen Type	**A**	**B**	**C**	**D**	**E**
Ultimate load (N)	220.09	152.62	168.30	126.33	111.415
Flexural strength (N/mm^2)	121.40	78.25	96.59	61.44	58.57

The Fig. 3.2 shows the comparison of flexural strengths of different composite specimens

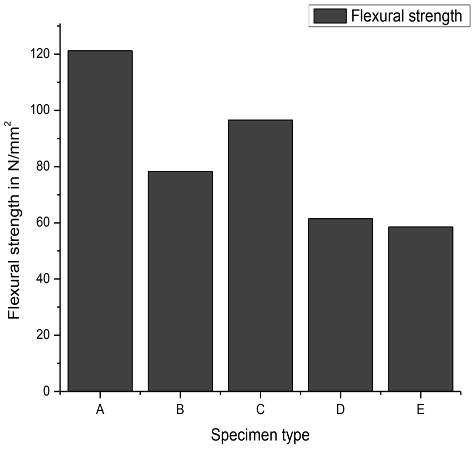

Fig. 3.2 Comparison of flexural strengths of Composites

It is seen from the above Fig.3.2, the flexural strength for specimen A is 51.75% more than the specimen E. It is because of the interlaminar adhesion property. The adhesion between the reinforcement layers in glass fibers are more than Kevlar fiber layers. Also, the stiffness is obviously more for glass fibre reinforced composites than the Kevlar reinforced composites. So, the interlaminar shear strength will be more to glass fiber reinforced composites than the Kevlar reinforced composites.

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 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.

Inter Laminar Shear Stress (ILSS)

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	**A**	**B**	**C**	**D**	**E**
ILSS (N/mm^2)	3.645	2.464	2.897	1.935	1.840

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

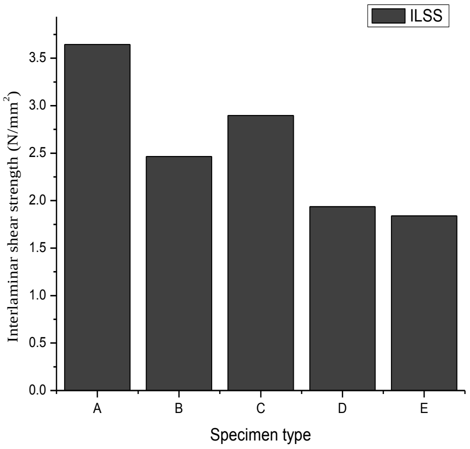

Fig. 3.3 Comparison of Interlaminar shear strengths of Composites

It is seen that, the ILSS for specimen A is 49.5% more than specimen E. Since the wetability of the glass fabric is more than that of the kevlar fabric, the resin has infused properly in between the glass reinforcement layers.

So, the interlaminar adhesion is good in glass fabric than the kevlar, inturn resulting in good interlaminar shear strength. 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.

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	**A**	**B**	**C**	**D**	**E**
Young's Modulus E (N/mm^2)	210	156	284	486	310
Ultimate tensile strength (N/mm^2)	134.03	255.07	235.85	209.66	216.42
% Strain	6.7	8.9	8.6	8.1	9.1

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

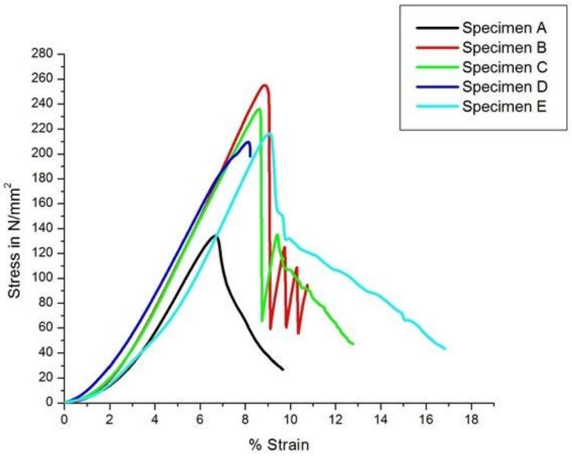

Fig. 3.4 Stress v/s strain curve for all the specimens

The Figure 3.4 depicts that, the failure mechanisms for tensile loading is same for all the specimens.

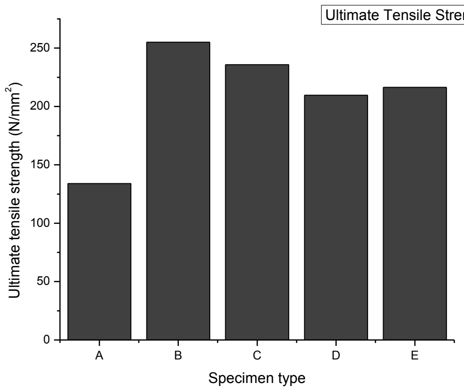

Fig. 3.5 Comparison of Ultimate tensile strength

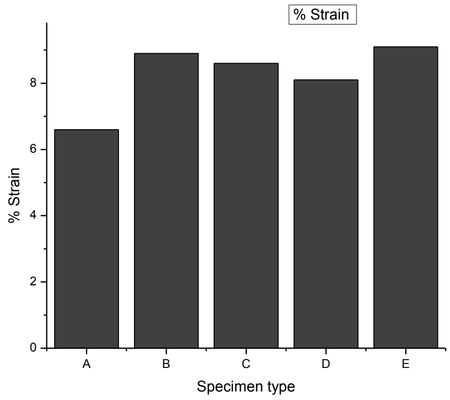

Fig. 3.6 Comparison of % Strain

A comparison on the ultimate tensile strengths and the percentage strains for the composite specimens A, B, C, D and E are shown in the Fig.3.5and Fig.3.6 respectively. It shows that, the specimen E has 38.06% more tensile strength than the glass fiber reinforced composite. So, it is obvious that, the kevlar has more tensile strength than the glass fiber. When the percentage strain of specimens A and E are compared, the specimen E has 9.1% ultimate tensile strain and specimen A has 6.7 % ultimate tensile strain. This is because the glass fibers are brittle hence the lesser tensile strength and the lesser deformation for unit load.

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 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.

3.2Vibration 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.3.7.

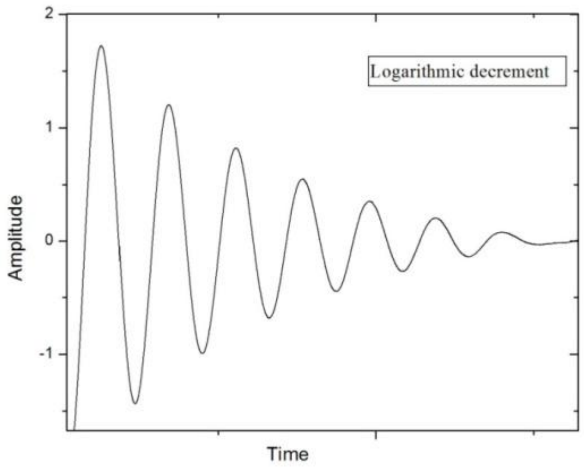

Fig. 3.7 Logarithmic decrement graph

The values of logarithmic decrement and damping ratio are shown in Table 6.5.

The logarithmic decrement comparison is done between the specimens A, B, C, D and E. 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.

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Table 3.5 Vibration analysis results

Position		1 100mm	2 125mm	3 150mm	4 175mm	5 200mm
Specimen A	Logarithmic decrement	0.219	0.1566	0.1479	0.1332	0.0804
	Damping ratio	0.0348	0.0249	0.0235	0.0211	0.0128
Specimen B	Logarithmic decrement	0.5087	0.477	0.3599	0.267	0.2349
	Damping ratio	0.0806	0.0756	0.0571	0.0424	0.0373
Specimen C	Logarithmic decrement	0.2215	0.1872	0.1551	0.1447	0.1307
	Damping ratio	0.0352	0.0297	0.0246	0.023	0.0207
Specimen D	Logarithmic decrement	0.3462	0.2792	0.2687	0.2612	0.1885
	Damping ratio	0.055	0.0443	0.0427	0.0415	0.0299
Specimen E	Logarithmic decrement	0.6332	0.5789	0.5163	0.4961	0.3673
	Damping ratio	0.1002	0.0917	0.0819	0.0787	0.0583

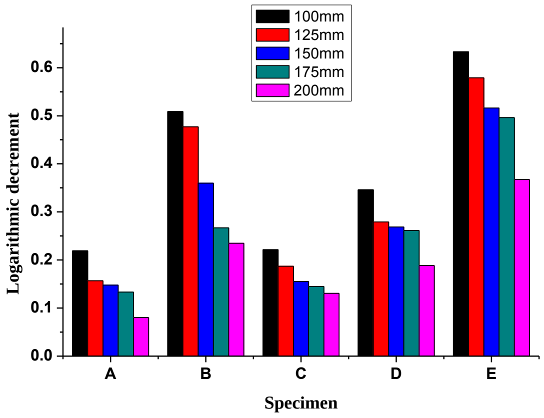

Fig. 3.8 Comparison of logarithmic decrement w.r.t specimen for different length

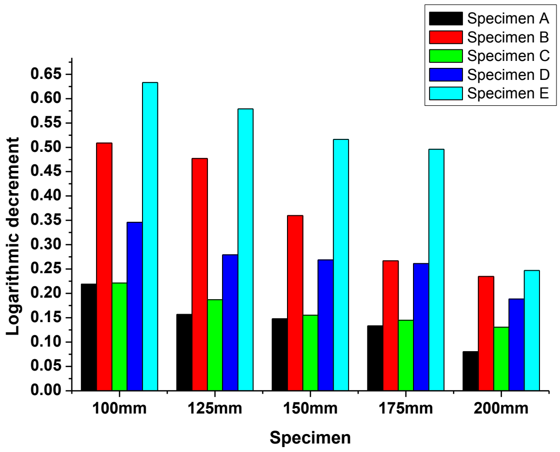

Fig. 3.9 Comparison of logarithmic decrement w.r.t. the length for different specimens

It can be seen from the Fig. 3.8 and Fig.3.9, the logarithmic decrement is decreased for the increase in length due to the decrease in stiffness and decrease in the vibration absorbing capacity. When specimens A and E are compared, the specimen E has more logarithmic decrement. This means that more in the decaying of the vibration. When hybrid composite specimens B, C and D are compared, the specimen B has more logarithmic decrement among the other two hybrid composites. This means that the more decaying of vibration in specimen B.

The damping ratio comparison is done between the specimens A, B, C, D and E. 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.3.10 and Fig 3.11 respectively.

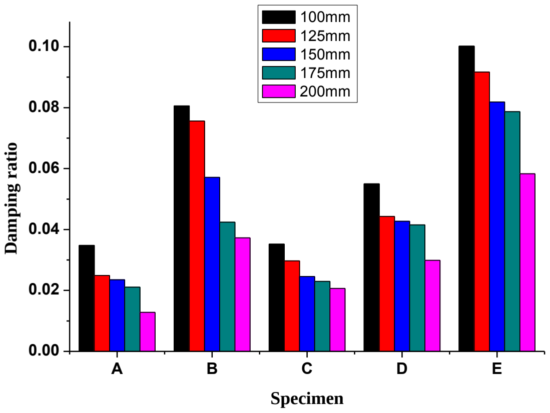

Fig. 3.10 Comparison of damping ratio w.r.t. the specimen for different lengths

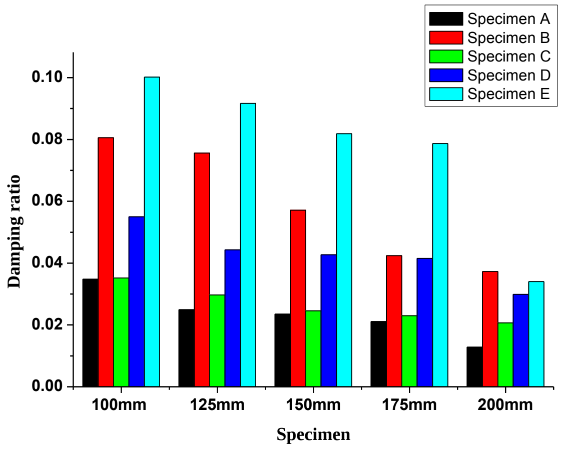

Fig. 3.11 Comparison of damping ratio w.r.t. length for different specimens

It is evident from the above Fig3.10and Fig.3.11, the damping ratio is maximum at the length 100mm, for all the specimens. This is because, more vibration absorbing capacity and the time taken by the specimen to the rest to its mean position is very less. When the specimens A and E are compared, the specimen E has more damping ratio than specimen A. When the hybrid composite specimens B, C and D are compared, the specimen B has more damping ratio among three.

From the comparisons of logarithmic decrement and the damping ratios of composite specimens A, B, C, D and E, it is seen that, the specimen A has lowest logarithmic decrement and damping ratio. The specimen A is glass fiber reinforced composite which is more stiff, brittle material and less capacity to absorb vibration. So, the vibration damping will be lowest among all the specimens. The specimen E is of kevlar fiber reinforced composite has more damping ratio due to higher vibration absorbing capacity. When the hybrid composite specimens B, C and D are compared, the specimen B has highest logarithmic decrement and damping ratio among the three. This is because, of the uniform distribution of the fiber layers and the properties in the macroscopic level. Since the hybridization is done with Kevlar/Glass reinforcements, the damping ratio is increased in specimen B when compared to the glass reinforced specimen A, due to the blocking of vibration waves passing through the different layers. This is the reason in the hybrid composite specimen; it has higher logarithmic decrement and damping ratio when compared to specimen A. 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. CONCLUSIONS

In the present work the epoxy polymer composite specimens of different compositions have prepared by hand lay-up technique and hydraulic pressing. The hybridization of the reinforcements is also done with woven glass and kevlar fabric and the effect of hybridization is studied. 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 the kevlar reinforced composite.
- The flexural strength is maximum in the glass fiber reinforced composite and minimum in the kevlar reinforced composite. Among the hybrid composites the specimen with two-on-two Glass/Kevlar layers gives the good flexural strength.
- The interlaminar shear strength is good in the glass fiber reinforced composite and found to be lowest in Kevlar reinforced composite. Among the hybrid composites the specimen with two-on-two Glass/Kevlar layers gives the good ILSS.
- The tensile strength is found to be maximum in the hybrid composite with one-on-one layers and minimum in the glass fiber reinforced composite.
- The logarithmic decrement and damping ratio is found to be maximum in the kevlar reinforced composite. The glass fiber reinforced composite has the lowest logarithmic decrement and the lowest damping ratio.
- When the reinforcement is hybridized with kevlar and glass better damping ratio is observed for 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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