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Characterization of Glass-Kevlar Hybrid Composite

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Abstract— **Kevlar fibre has unique property of high strength whereas glass fibre plays an important role in designing of many composite applications. In the present study, the hybrid composite material is prepared by combining Glass and Kevlar fibres with different combination. The characterization in terms of tensile stress and shear stress is determined for all combinations. The main aim of the study is to develop the Glass-Kevlar composite which can be used for automobile bumpers and sports applications. The composite laminates were prepared using hand-layup and compression molding process and the dimension of the laminates was 30cmX30cmX3mm. Tensile and shear tests were done according to ASTM D 3039 and ASTM D 5357 standards respectively. It has been observed that H5 combination showed maximum tensile strength and shear strength of 300MPa and 33.5MPa respectively. The result of the study can be used for the development of actual composite and simulation purpose.**

Index Terms— **Hybrid Composite, Glass Fiber, Kevlar Fiber, Mechanical Properties.**

I. Introduction

Metals have been used for decades in various engineering fields due to their good availability and ease of manufacturability. But metals are susceptible to corrosion which results in decrease in strength and ultimately sudden breakdown.[1]

This has led us to search for new type of materials; the solution was obtained in the form of composites. Composites are two or more physical & chemically different constituents combined macroscopically to produce a useful material. The individual components remain separate and distinct within the finished structure. In ancient times mankind made use of various composite like wood and natural fibres.[2,3]

Composite are classified in two categories namely composite made of natural fibres and artificial fibres. Composite made of natural fibres use the fibrous materials like wood, cotton, hemp, Kenaf, banana fibres etc. The artificial fibres include Glass, Carbon, and Kevlar etc. The artificial fibres have high strength, resistance to corrosion, inert to atmospheric effects, electrically nonconductive and do not loose strength at high temperature working conditions.

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Now the trend of use of composite is increasing and led to use for many design criteria required to make components out of these materials. These composites exhibit different properties owing to their orthotropic nature and also when the laminates are made having different volume fraction, fibre orientation and stacking sequence making it mandatory to determine their Mechanical properties before using for any application. Many experiments and analysis are currently being carried out on these materials and what parameters should be used while designing the components.

The composites manufactured using one type of fibre is called as pure composites and when two or more fibres are used for making composites they are called hybrid composite for example Carbon-Glass, Glass-Kevlar Hybrid etc. these type of combination gives an advantage of good strength at lower cost that can be used for applications which was not possible by using the pure composite. So Hybridization of composite fibre material is the key to designing new components having good strength at relatively lower cost. [3,4]

Kevlar has high strength thermal stability and resilience but are poor in moist conditions and are bad with compression loading and are very costly. On the other hand glass fibers have good resistance to the moist environment and do not lose its strength and are cheap, but are brittle and week-abrasive resistant. So to utilize best properties of both the material combination of both these materials is done which is termed as hybrid composite. Due to this combination we can make a composite having best properties of both the parent material and can be used where moderate strength is required and having low budget. So it becomes necessary to determine the mechanical properties of this hybrid composite so they we can know the change in properties with reference to their parent elements which can be used for designing of components.[5,6,7]

When this hybrid composite are going to be used for designing of components then mechanical properties play an important role as design criteria. One such design criteria being the fatigue life of the material, as it happens that in many applications the components undergo various cyclic and fatigue loading, which eventually leads to the slow and progressive failure of the material. So it becomes necessary to determine fatigue life of the composite so any undesirable failure due to fatigue can be avoided during the service life of the component and the design becomes safe for given life of the component.

II. LITERATURE SURVEY

Kretsis [1], used a hybrid made of glass-carbon fibers, used unidirectional material for determining the mechanical properties of the hybrid composite. The tensile modulus of hybrid composites was obtained using the rule of mixtures, while classical laminate theory was used to determine the flexural modulus. Reasonable estimates for the other elastic properties were obtained from the rule of mixtures. In tensile tests of hybrids, the failure stress of the low elongation constituent material was increased. The enhancement of the expected primary failure strain was greater for smaller proportions and concentrations of the low-elongation material. While the compression and flexure failure was undeterminable.

Jones et al.[2], used hybrid micro-composites consisted of around nine single fibers in Epon 828/Versamid 140. E-glass, AS-4 and IM6-G carbon, and Kevlar-49 fibers were used. It was deduced that the AS4/Kevalr-49 hybrid system had least amount of coordinated fracture. A computer model based on hybrid effect, based on local load sharing principle and enhancement in strength of stiffer fibers of the hybrid composite which was similar to those found by other authors experimentation given in that paper.

Qiu et al.[3], single fiber type and hybrid micro-composites were fabricated by using Kevlar-149 as the low elongation fiber and S glass fibers as the high elongation fiber, in a DER 331/DER 732 epoxy mixture. It was found, Kevlar 149 showed higher tensile strength while in micro-composite than which was obtained in single filament, but fibers broke one by one for Kevlar 149 hybrid. Positive hybrid effect for the failure strain but negative hybrid effects for the strength of the hybrid were observed. Experimental as well as simulation results using Monte Carlo model were similar.

Randjbaran et al.[4], specimens were fabricated from Kevlar, carbon, and glass woven fabrics and resin and were experimentally investigated under impact conditions. Ballistic test were performed on the hybrid composite. It was concluded that glass was to be used as 1st layer of hybrid and the use of glass-carbon was best for middle layer which was concluded from the results that were obtained.

Murugan et al.[5], used glass/carbon hybrid composite that had two symmetrical four layered glass/carbon hybrid laminates and two dedicated four layered glass or carbon laminates which were fabricated separately using the hand lay-up and compression moulding techniques. It was found static mechanical properties like tensile strength, flexural strength and impact strength and dynamic mechanical properties such as storage modulus, loss modulus and loss factor. The modulus curves of dedicated and hybrid composite laminates in a Cole-Cole plot which showed an imperfect semi-circular curve indicating the heterogeneity of the laminates and had relatively good fiber/matrix bonding.

Banerjee et al.[6], studied micromechanical analysis of the representative volume element of a unidirectional hybrid composite was performed using finite element method. The fibers were assumed to be circular and packed in a hexagonal array. The effects of volume fractions of the two different fibers were used and also their relative locations within the unit cell were studied. Modified Halpin–Tsai equations were proposed for predicting the transverse and shear moduli of hybrid composites. It was found that the variability in elastic constants and longitudinal strength properties was negligible. However, there was significant variability in the transverse strength properties.

Elanchezhian et al.[7],worked with the fabrication and investigation of fiber composites and compares it with GFRP and CFRP used separately. Mechanical behaviour of the composite were obtained by testing the composite laminates for tensile (at varying strain rates and temperatures), flexural (at varying strain rates) and impact. The composite is manufactured by hand layup process. It was found that the CFRP composite had better properties than the GFRP in tensile and flexural.

Xu et al.[8], performed meso-scale modelling on the textile composites for fatigue life prediction a FE model of unit cell was composite was made and static damage criteria and anistrophic stiffness reduction model are applied. This FE model was validated against the Experimental model given the literature survey in that paper.

Elkhier et al.[9], performed the experimental model analysis was conducted on the work piece that was used for fatigue life determination of the modal parameter like natural frequency, damping ratio and mode shape. An exponential and quadratic equation which gave relative fatigue life ratio was obtained. It was noticed that the value of fatigue damage determined the damping ratio.

Rejab et al.[10], Investigated the effects of fiber volume fraction on GFRP Plate. The volume fraction used for the experimentation was 20-80%, 30-70%, 40-60% Fiber to Matrix volume ratio respectively. The maximum strength in terms of tension and compression was found for the volume fraction having 40-60% Fiber to Matrix Volume ratio.

Dong et al.[11] investigated the effect of different volume fractions of S-2 glass and T700S carbon fiber on the flexure strength of the composite. The optimum hybrid effect was achieved when the hybrid ratio was 0.125 ([0G/07C]) when both Vfc and Vfg were 50% and the increases in strength was 43.46% and 85.57% when compared with those of the full carbon and glass configurations respectively. The optimisation shows that the maximum hybrid effect was 56.1% when Vfc = 47.48% and Vfg = 63.29%.

Fu et al.[12] determined the mechanical properties for different volume fraction of fiber contained in the composite. 30%, 60%, 90% fiber volume was used to determine the properties at different fiber orientation 0^o, 45^o, -45^o, 90^o respectively and it was found that 60% fiber volume and 0, 45, 90, -45, 0, showed the best properties.

Qi et al.[13] Carbon fiber with different orientation angles of 30^o, 45^o, 60^o and 90^o were prepared, and 2D-C_f/Al composites were fabricated by liquid–solid extrusion following the vacuum infiltration technique (LSEVI). The volume fraction of the fiber was kept at 45%. Increase of 112.5% and 63.9% in the tensile strength was observed in the fiber orientation of 45^o and 90^o respectively.

Xiong et al.[14] Joined FRP composite and metal and strengthened with surfi-sculpt and checked mechanical properties for different orientation. +45, -45 orientation was used and the volume fraction was increased from 11.1% to 88.9% all the specimen were joined by surfi-sculpt joined. As the volume fraction increased, the joints damage initiation load was increased by 24.84%, the joints ultimate failure load was increased by 134.5% and the joint energy absorption was increased by 257.39%.

Sarasini et al.[15] studied the effects of basalt fiber hybridization and stacking sequence on low velocity impact response and damage tolerance capability of carbon fabric reinforced epoxy composites. Two different hybrid laminate configurations were prepared; one with a sandwich-like stacking sequence and the other one with an intercalated fabrics lay-up. Carbon laminates failed by multiple matrix cracks localized in the tensile side while in basalt laminates the interface failures was due to relevant energy dissipation mechanisms. Hybrid laminates with sandwich configuration failed by interface failures located in the basalt skins of the compression side which prevented hindering crack propagation in the carbon core.

Yahaya et al.[16] investigated mechanical properties of kenaf-Kevlar hybrid composite having different layering sequence and chemical treatment. The composite was treated with 6% sodium hydroxide (NaOH) solution. The composite having Kevlar as skin layer showed better tensile and flexure properties and the 4 layer hybrid had more tensile and flexure properties when treated Kenaf was used and there was almost no change observed in the impact strength due to chemical treatment.

Ting-Ting et al.[17] used Kevlar fabric and glass fabrics as well as recycled Kevlar/Nylon/low-Tm polyester nonwovens via needle-punching and thermal-bonding processes. Cut resistance of Kevlar fibers and compactness of fiber assembles improved both of static and dynamic puncture resistances.

Gellert et al.[18] glass-fiber reinforced polymer (GRP) materials along with castings of their matrix resins was used to age in sea water in laboratory loaded under set strain. The polyester, phenolic and vinyl-ester GRPs and neat resin castings were used. Flexural strength fell by 15–21% for the water saturated polyester and vinyl-ester GRPs by 25% for the phenolic GRP. The phenolic laminate degraded at 20% of ultimate strain leading to loss in strength by 36%. Inter-laminar shear strengths fell by 12-21% for the GRPs near saturation.

Song [19] used carbon-aramide and carbon-glass hybrid to determine the mechanical properties of the composite and it was 3-4% difference in the mechanical properties was found as the carbon fibers present in the composite dominated the mechanical properties of the hybrid composite.

Zhang et al.[20] used Glass-Carbon hybrid composite having different stacking sequence to determine the mechanical properties like tensile, compression and three point bending and it was found that the hybrid containing 50% carbon fibers showed improvement in the flexure properties when carbon fibers are kept at exterior region, and alternating carbon/glass layup gave good compressive strength and tensile strength was not affected by the stacking sequence.

III. EXPERIMENTAL DETAILS

A. Materials

The laminates prepare for mechanical testing consist of Kevlar fiber 200 GSM and Glass fiber 200GSM having 0^o and 90^o orientation. The Kevlar fibers have density of 1.40 g/cc which was taken from the manufacturer's catalogue. The glass fiber was in form of woven mat was used and the density of Glass fiber mat is 1.90 g/cc. The liquid type 520 Grade epoxy resin having density 1 is used for preparing the laminates.

TABLE I. MATERIAL PROPERTIES

Material	Weight	Density
Glass Fiber	18 gm/mat	1.90 g/cc
Kevlar Fiber	16 gm/mat	1.40 g/cc
520 Grade Epoxy + Hardener	200 gm	1 g/cc

Fig. 1. Glass Fiber Cloth used for making of the Composite Laminate

Fig. 2. Kevlar Fiber used for making the Composite Laminate

B. Composite Laminate Preparation and sample configuration

The Glass fiber and the Kevlar fiber laminates having epoxy resin as the matrix material were prepared using the hand-lay-up method. The Glass and Kevlar fiber mats were hand laid-up using epoxy matrix as a binder which contained the mixture of epoxy resin and hardener in the ratio of 10:1. Total six laminates were prepared with the configuration as given in the

Table II. The laminates were made using the compression molding machine and covering plastic was used on the outer surface of the laminate so the epoxy matrix would not stick to the metal plates of the compression molding machine and it also provided smooth and even outer surface.

Fig. 3. Preparation of Composite Laminate Using Hand Lay-Up Process

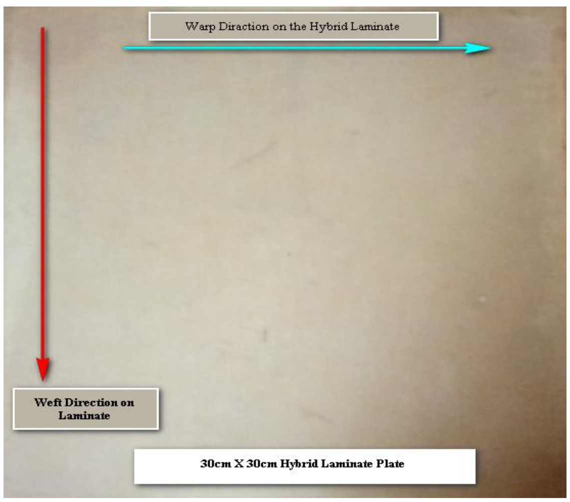

Fig. 4. Final Laminate Having 40% Fiber Volume Fraction

C. Fiber Volume Fraction Calculation

It is defined as the amount of Fiber contained in the composite. For the present research the total fiber volume fraction is take to be 40% fiber to matrix. It was taken because the composite showed best mechanical properties when the fiber volume is kept 40% [10]. During preparing the composite laminate for first trial 50% fiber volume fraction was achieved which was then reduced to 40% by trial and error and calculation using the following formula:

$$V_f = \frac{Wf/\rho_f}{W_m/\rho_m + W_{f1}/\rho_{f1} + W_{f2}/\rho_{f2}} * 100 \qquad (1)$$

Where

- Vf – fiber volume fraction
- W_f – Total mass of fibers.
- ρ_f – Density of Fibers
- W_m – Mass of matrix
- ρ_m – Density of matrix
- W_{f1} – Mass of 1st fiber
- ρ_{f1} – Density of 1st fiber
- W_{f2} – Mass of 2nd fiber
- ρ_{f2} – Density of 2nd fiber

TABLE II. FIBER VOLUME FRACTION AND FIBER SEQUENCE

Laminate Number	Volume Fraction of Fiber to Matrix	Number of Glass Fiber Layers	Number of Kevlar Fiber Layers	Sequence
H1	40%-60%	5	4	G-K-G-K-G-K-G-K-G
H2	40%-60%	6	3	G-K-G-G-K-G-G-K-G
H3	40%-60%	7	2	G-G-G-K-G-K-G-G-G
H4	40%-60%	4	5	G-K-G-K-K-K-G-K-G
H5	40%-60%	3	6	G-K-K-K-G-K-K-K-G
H6	40%-60%	2	7	G-K-K-K-K-K-K-K-G

D. Tensile Test

Tensile test was performed to determine the stress-strain behavior of Glass-Kevlar hybrid composite. The test was done on Universal testing machine model no STS 248 based on ASTM D 3039 standard on the sample having dimension as 210 mm X 20mm X actual thickness. A standard head displacement at a speed of 5 mm/min was applied. For tensile test two specimen were cut, on specimen was cut along the warp direction and another specimen was cut along the weft direction. It was done to determine the stress-strain and elastic limit in both the directions.

Fig. 5. Tensile Test Specimen

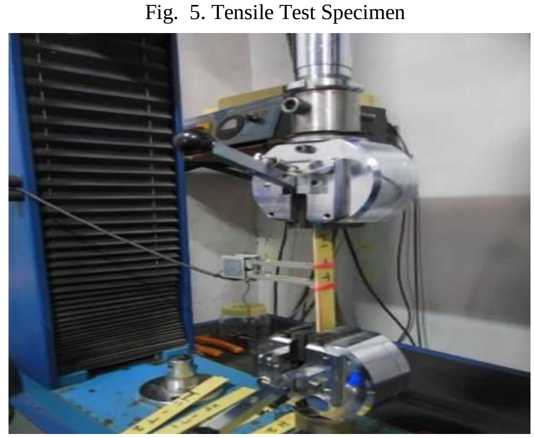

Fig. 6. Tensile Testing On UTM with Strain Gauge

E. Shear Stress

In plane shear test was performed on the specimen having dimensions 76 mm X 20 mm with the notch at the center these dimension were taken according to ASTM D 5357 standard.

FIG. 7. SHEAR TESTING OF THE SPECIMEN

IV. RESULTS AND DISCUSSIONS

A. Tensile Tests

The experimental results obtained for the tensile tests are summarized in the Table 2. In the following table T1 denotes the specimen cut along the warp direction and T2 denotes the specimen cut along the weft direction.

TABLE III. SUMMARY OF EXPERIMENTAL RESULTS

Sample	UTS(MPa)	Elastic Modulus(GPa)
H1-T1	256.17	19.159
H1-T2	226.77	18.510
H2-T1	251.66	22.323
H2-T2	294.98	21.574
H3-T1	183.26	12.415
H3-T2	92.12	12.970
H4-T1	242.45	18.041
H4-T2	280.86	17.908
H5-T1	323.98	17.293
H5-T2	295.17	17.187
H6-T1	219.91	14.856
H6-T2	200.50	15.658

Fig. 8. Failed Tensile Specimen

From the above table the Hybrid composite H5 has maximum Ultimate Tensile strength namely 323 MPa and 295 MPa in warp and weft direction. Also the hybrid H2 has maximum Elastic Modulus of all the combination used for testing.

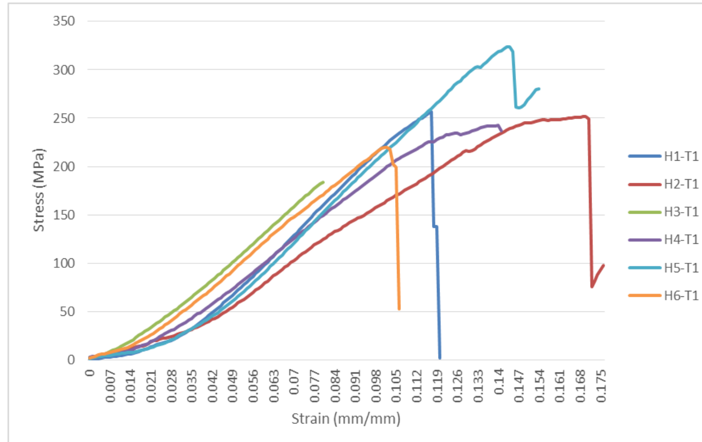

Fig. 9. Tensile Stress-Strain Curve for Warp Direction for H1 to H6 Composite

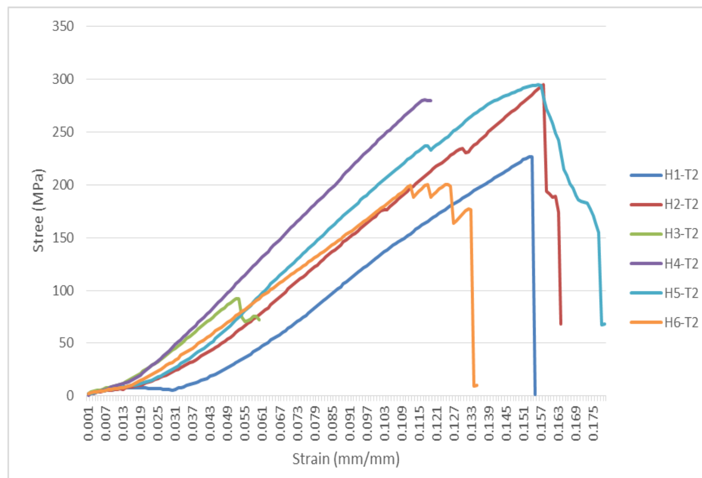

Fig. 10. Tensile Stress-Strain Curve for Weft Direction for H1 to H6 Composite

From the above graphs and table it is evident that the when the number of glass fiber layers are more in the composite the elastic modulus is found to increase up to H2 configuration laminates then again it decreases as the Glass fiber layers are increased further. But for the ultimate strength when the no of Kevlar fiber layers are increased up to H5 configuration it is found to increase. This is happening because of the hybridization effect of fiber in these proportions giving the composite maximum strength when the Kevlar fiber layers are more and maximum elastic modulus when the Glass fiber layers are more.

B. Shear Test

The experimental results obtained for the shear tests are summarized in the Table IV. In the following table S1 denotes the specimen cut along the warp direction and S2 denotes the specimen cut along the weft direction.

Fig. 11. Failed Shear Test Specimen

Table IV- Summary of Shear Test results

Sample ID	Shear Strength(MPa)	Shear Modulus(MPa)
H1-S1	26.13	185.579
H1-S2	23.84	242.408
H2-S1	21.56	393.314
H2-S2	18.94	327.161
H3-S1	27.44	191.579
H3-S2	21.23	132.260
H4-S1	14.37	121.394
H4-S2	32.99	366.332
H5-S1	26.13	114.358
H5-S2	21.23	208.892
H6-S1	33.32	221.452
H6-S2	21.88	350.58

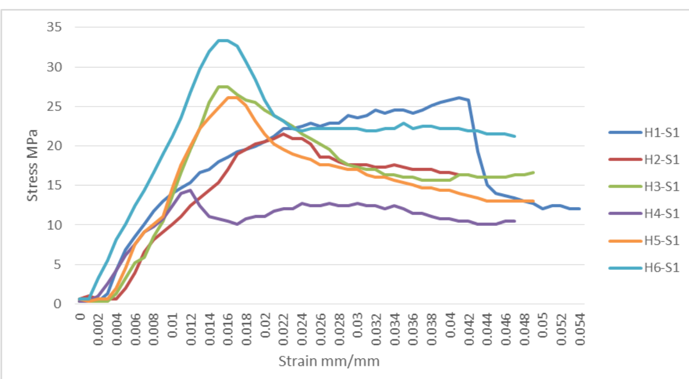

Fig. 12. Shear Stress-Strain Curve for Warp Direction for H1 to H6 Composite

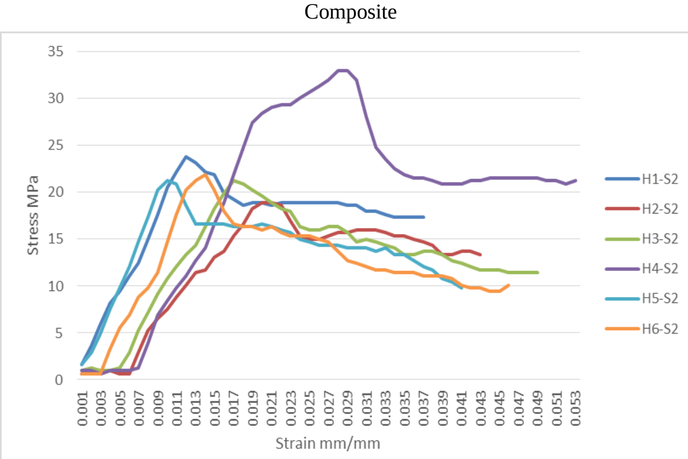

Fig. 13. Shear Stress-Strain Curve for Weft Direction for H1 to H6 Composite

After careful analysis of the data obtained in the table and plotting the graph of that data it is clear that the composite H6 has maximum hear strength for warp direction and the composite H4 has maximum value of the shear strength in weft direction. The maximum shear modulus was obtained for H2 composite sample in warp direction and H4 for the weft direction.

V. CONCLUSION

After conducting various tests on the Glass-Kevlar hybrid composite following can be concluded-

- By using the mixture of Glass and Kevlar to make the composite laminate the tensile strength was found much higher.
- This also lead to increase in the shear strength of the composite laminate which was greater than that of pure Glass fiber composite that which was observed in the literature review.
- The combination of Glass fiber and Kevlar fibers have led to making of composite that has higher tensile and shear strength also lowering of the cost of composite requiring high strength for primary applications.

It can be best summed up that hybridization of Glass fiber and Kevlar fibers have led to new material that has high strength of Kevlar fiber and to lower the cost of the composite as Glass fibers are used in it. This of material provides new ways for using it for the engineering applications that require high strength such as automotive applications, defense application, in sports equipment's and may such applications.

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