DEVELOPMENT AND CHARACTERIZATION OF POLYESTER BASED HYBRID COMPOSITES WITH E-GLASS AND S-GLASS REINFORCEMENTS

By

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Abstract Hybrid Composites are amongst the newest class of engineered materials which combine the advantages of two different reinforcements in a single matrix. Present research work focuses on polyester resin based composites which were developed with E-glass and S-glass plain weave fiber reinforcements.

The objective of this research work is to investigate the hybrid effect of the two reinforcements. For this purpose, nine different laminates were developed with varying percentages of the two reinforcements and by changing the sequence of their plain weaves. Hand-lay-up method was used to develop theses laminates. The composites developed, characterized and compared in the light of information available in the literature reviewed on the subject. It has been reviewed and concluded that the laminates with higher percentages of relatively stronger and stiffer S-glass fibers had better strength than those having more volume of E-glass reinforcement.

Introduction

A new class of engineered materials that combine two or more different reinforcements in a single matrix is named as Hybrid Composites. The presence of multiple reinforcing materials helps to achieve very precise and unique combination of properties as it combines the advantages of the structural constituents whilst overcoming their disadvantages. Moreover, the principle of *Hybridization* may also be utilized to develop cost-effective materials, without compromising the overall performance, as one of the reinforcing materials being cheaper than the others [1-4].

Hybrid composites can be made with metallic or ceramic or polymeric matrices. The information about possible materials combinations and expected properties of such materials are too numerous to discuss here. As far as polymer matrix composites are concerned the most common examples include carbon/aramid reinforced epoxy [5-7] and glass/carbon reinforced epoxy [5,8-9]. The earlier exhibits excellent combination of strength and impact resistance and the later is a strong material at a reasonable price.

There are different types of Hybrid Composites depending upon the way in which reinforcing fibers are mixed, these include: (i) Interplay or Laminated Hybrids obtained by layer by layer stacking of two or more reinforcements, (ii) Intimately Mixed Hybrids obtained by random mixing of reinforcing fibers avoiding the localized concentration of either fibers, (iii) Intraply Hybrids obtained by using tows of two or more reinforcements in the same layer, (iv) Sandwich Hybrids, also known as core-shell, in which one material is sandwiched between two layers of another, and (iv) Super Hybrid Composites obtained by stacking plies of metal composites or metal foils in preferred sequence and orientations [4,10-12].

In the present study interply hybrid composites were developed by using E-glass and S-glass fibers (plain weave form) as two reinforcements and unsaturated polyester resin as matrix. The objective was to develop a hybrid composite system with locally available raw materials and mechanical characterization to confirm the effect of *Hybridization*. For this purpose, three

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different combinations of composites were developed in such a way that one of them contained layers of only E-glass fibers, in second type of developed composite, there was a layer of S-glass fibers after every two layers of E-glass fibers, and in third combination there were alternate layers of the two reinforcing fibers. Additionally, the effect of ply thickness on mechanical properties of the developed laminates was also investigated for 3-ply, 6-ply and 9-ply thickness.

Development of Laminates

The reinforcements used were the E-glass & S-glass fibers (woven plain weaves) and unsaturated polyester was the matrix. Three different laminates were developed by using different combinations of E-glass & S-glass fibers. And theses combinations are as under:

(**X**---E-glass, **Y**----S-glass)

Laminate-1**: XXXXXXXXX......**

Laminate-2**: XXYXXYXXY…..**

Laminate-3**: XYXYXYXYX…..**

Each of three laminates was developed in 3-ply, 6-ply & 9-ply thickness. So there were total nine combinations. Each combination was developed four times making total number of sheets equal to thirty six.

The materials used were:

(i) Unsaturated polyester(Matrix)
(ii) MEKP (initiator)
(iii) Cobalt-Naphthalate (accelerator)
(iv) E-glass(plain weave fabric)
(v) S-glass (plain weave fabric)
(vi) Wax (mold release agent).

And the tooling used was:

(i) Mixing Pot
(ii) Coating Brush
(iii) Paddle / Washer Rollers
(iv) Gloves
(v) Molding Plate (glass sheet)
(vi) Scissors.

Hand lay up method was used as fabrication technique. Which was carried out in following steps:

<u>*Step-1*</u>: Pre determined amount of polyester resin was taken in the mixing pot. Then additions of MEKP and Co-Naphthalate were made into this resin. Each of the two is 1% by wt of the resin. These were mixed by very slow & gentle stirring to avoid the entrapment of air bubbles.

<u>*Step-2:*</u> Preparation of Mold: A glass sheet was used as mold. A uniform layer of wax (mold releasing agent) was applied onto it.

<u>*Step-3*</u>: Application of Layers of Fibers and Reinforcements: A little volume of resin was dropped on the mold and spread over it with the help of brush. Then a layer of woven fiber cloth (10” x 10”) was placed. And some more resin was dropped and was rolled to impregnate

both the constituents and also to squeeze out extra resin. The same procedure was followed for every next layer until the required thickness of the laminate was achieved.

<u>*Step-4:*</u> Curing: Then, the laminates were left in the open atmosphere for 24 hours for curing.

<u>*Step-5*</u>: The cured laminates were peered off the mold.

Characterization

Tensile testing was used for mechanical characterization of the developed laminates. It was carried out in two stages;

(i) specimen preparation and *(ii). tensile testing*.

(i). Tensile specimens were prepared by following ASTM D638. Samples of specified dimensions were cut by using scroll saw. And finishing of specimens was done by using surface grinder and simple files.

(ii): Tensile tests were carried out using universal tensile testing machine *TIRA test2810 E6 (German made)* having maximum capacity of 10 kN with varying strain rates ranges between 5mm/min to 50mm/min. However the testing variables were maximum load of *10 kN* and strain rate was set at *5mm/sec.*

Figure 1: Photograph of universal testing machine-TIRA test2810 E6 (Germany) (Department of Polymer Engineering UET Lahore).

Results

Since there were total nine different laminates. And each of this laminates were tested for its tensile strength and elongations. And these results are presented in Table 1 to Table 6.

Composite type	Strength [MPa]	%Elongations
Laminate-1 (XXX)	64.6 ± 0.4	2.72 ± 0.02
Laminate-2 (XXY)	67.1 ± 0.3	2.58 ± 0.05
Laminate-3(YXY)	84.2 ± 0.6	3.53 ± 0.04

Table 1*: Strength values and elongations of laminate-1, laminte-2 and laminate-3 with 3-ply arrangements*

Composite type	Strength [MPa]	%Elongations
Laminate-1(XXXXXX)	124.6 ± 0.5	3.24 ± 0.04
Laminate-2(XXYXXY)	151.6 ± 0.3	5.56 ± 0.05
Laminate-3(YXYXYX)	185.4 ± 0.6	5.93 ± 0.02

Table 2*: Strength values and elongations of laminate-1, laminte-2 and laminate-3 with 6-ply arrangements*

Composite type	Strength[MPa]	%Elongations
Laminate-1 (XXXXXXXXX)	172.6 ± 0.3	3.94 ± 0.05
Laminate-2 (XXYXXYXXY)	201.2 ± 0.6	6.95 ± 0.03
Laminate-3 (YXYXYXYXY)	223.4 ± 0.4	7.07 ± 0.04

Table 3*: Strength values and elongations of laminate-1, laminte-2 and laminate-3 with 9-ply arrangements*

Composite type	Strength [MPa]	%Elongations
3-ply	64.6 ± 0.4	2.72 ± 0.02
6-ply	124.6 ± 0.5	3.24 ± 0.04
9-ply	172.6 ± 0.3	3.94 ± 0.05

Table 4*: Strength values and elongations of laminate-1 with 3-ply, 6-ply and 9-ply arrangements*

Composite type	Strength [MPa]	%Elongations
3-ply	67.1 ± 0.3	2.58 ± 0.05
6-ply	151.6 ± 0.3	5.56 ± 0.05
9-ply	201.2 ± 0.6	6.95 ± 0.03

Table 5*: Strength values and elongations of laminate-2 with 3-ply, 6-ply and 9-ply arrangements*

Composite type	Strength MPa]	%Elongations
3-ply	84.2 ± 0.6	3.53 ± 0.04
6-ply	185.4 ± 0.6	5.93 ± 0.02
9-ply	223.4 ± 0.4	7.07 ± 0.04

Table 6*: Strength values and elongations of laminate-3 with 3-ply, 6-ply and 9-ply arrangements*

Discussion

The strength & elongation values of the three constituents are given below in Table 7.

Constituent Material	Strength [MPa]	% Elongation
Polyester resin(cured)	55-65	2.1-2.3
E-glass	3100-3800	4.5-4.9
S-glass	4380-4590	5.4-5.8

Table 7: *Strength values and elongations of cured polyester resin, E-glass and S-glass fibers [14,15].*

! Table 1 indicates that the strength values of the laminate-1 are the lowest amongst the three, whereas laminate-3 has the highest value of strength, whilst all three composites have the same 3-ply thickness.

! The reason for this variation in strength values is that laminate-1 has only E-glass fibers as compared to laminte-2 & laminate-3 which has layers of relatively stronger & stiffer S-glass reinforcement in addition to E-glass fibers. So the presence of S-glass fibers along with E-glass fibers is the reason for this variation.

! Also, since laminate-3 has two layers of S-glass fibers & one layer of E-glass as compared to two layers of E-glass reinforcements & one layer S-glass fibers of laminate-2. This more volume fraction of S-glass fibers in laminate-3 plays its role towards more strength of the laminate-3.than laminate-2.

- To verify this fact of hybridization, the same three combinations (sequence) of composites were developed in 6-ply & 9-ply thickness. The results of tensile tests of theses laminates are summarized in Table 2 & Table 3. Tensile strengths of laminate-3 are once again the highest whereas laminate-1 has the lowest values.
- So this authenticates the fact that replacement of E-glass fibers with S-glass results in the better strengths of laminte-2 & laminte-3 as compared to laminate-1 which has only E-glass fibers.
- Table 4, Table 5 & Table 6 show the strength values for laminate-1, laminate-2 & laminate-3 respectively with varying thickness i.e. in 3-ply, 6-ply & 9-ply combination. From these tables it can be concluded that by increasing number of plies, higher strengths can be achieved.

This relationship is plotted in Figure-2.

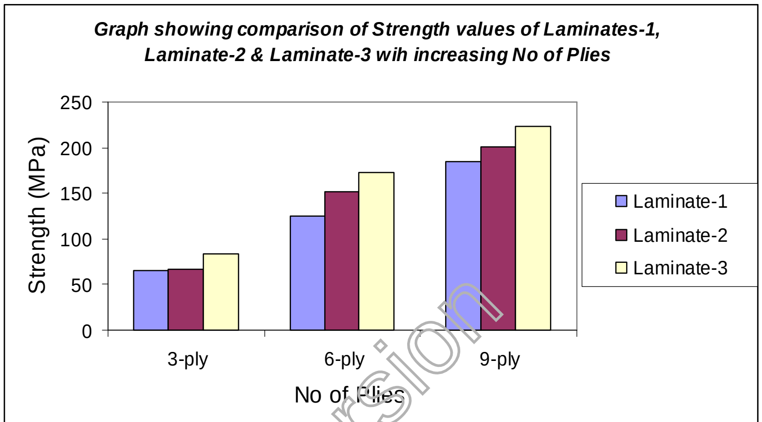

Figure-2*: Graph showing comparison of strength values of Laminate-1, Laminate-2 and Laminate-3 with increasing no of plies.*

- However, it is also observed that weight and strengths do not increased in the same fashion. This is due to the fact that the compaction of the resulting laminates with higher thickness is not as good as the plies added up.
- During cutting of the samples a lot of stress raisers are produced because of the brittle nature of the matrix which ultimately became the cause of failure at lower stresses.
- When the reinforcements were cut for their use in the laminates, the fibers were misplaced in the woven fabrics creating the probability of low strength areas with lower reinforcement volume fraction and vice versa.
- The glass fibers are not preferably oriented with respect to the tensile axis due to the improper rolling in the matrix system during composite sample fabrication.
- One of the causes of lower observed strengths of the laminates is the presence of voids due to entrapment of air, moisture, excessive resin, improper cure cycle and improper handling. Also inclusions in the form of dirt and loose fibers also results in reduction of tensile properties.

Conclusion

The objective of this research work was to develop and mechanically evaluate a Hybrid composite system that combine the advantages of two reinforcements i.e. E-glass and S-glass fibers in a single matrix i.e. unsaturated polyester resin.

The comparison of the strength values of the developed laminates, having only E-glass reinforcement with the laminates that had both E-glass and S-glass fibers, show that by replacing E-glass with S-glass reinforcement, the strength is improved. e.g. Laminte-3 and Laminate-2 are stronger than Laminate1 in all 3-ply, 6-ply and 9-ply thickness. Experimental results also show that by increasing the volume fraction of the reinforcement the tensile strengths also increases.

The abovementioned facts may also be utilized to develop such a composite system in which cost of the materials system may be minimized by reducing the content of relatively expensive reinforcement while maximizing the performance by optimal addition of a relatively cheaper reinforcement with comparable properties.

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