Chapter

4

HYBRID EFFECT IN TENSILE AND FLEXURAL PROPERTIES OF SHORT SISAL/GLASS HYBRID FIBRE REINFORCED LOW DENSITY POLYETHYLENE SANDWICH COMPOSITES

Part of the results presented in this chapter has been communicated to Journal of Sandwich Structures and Materials (1999)
4.1. Introduction

Hybrid composites possess unique features that can be used to meet different design requirements with respect to strength, stiffness and flexural behaviour. A key parameter in hybrid composite structures is the arrangement of fibres within the hybrid. It was reported that the hybrid design strongly affects a variety of properties such as flexural strength, modulus fatigue behaviour, and impact performance of hybrid composites based on high performance polyethylene and carbon fibres.\(^1\)-\(^3\)

Hybrid effect in composites was reported by several researchers.\(^4\)-\(^10\) Hayashi et al.\(^4\) and Hayashi\(^5\) examined the effect of tensile curves on sandwich type of hybrid composites of carbon fibre reinforced plastic (CFRP) core and glass reinforced plastic (GRP) shell. They found that the initial and final moduli and final breaking stress and strain were in agreement with the theory predicted by rule of mixtures. Bunsell and Harris\(^6\) reported an efficient load transfer between phases from the observed multiple cracking in the CFRP of the hybrid composites composed of alternate layers of bonded CFRP and GRP. Based on their investigation on aramid reinforced plastics (ARP)/CFRP composites, Zweben\(^7\) reported that high elongation fibres in low elongation fibre composites could act as crack arrestors on micromechanical level, by increasing the failure strain of low elongation component. Aveston and Sillwood\(^8\) suggested that a low elongation fibre (carbon) cannot be broken until sufficient energy is available to form fracture surfaces in intimately mixed carbon/glass hybrid composites. Kirk et al.\(^9\) indicated that a negative synergistic effect was observed at low and high volume fractions of CFRP in the carbon/glass hybrid composites. They found that the decrease in fracture energy was due to the effect of the carbon fibres on the post debond sliding
mechanism at the glass fibre/epoxy resin interface. Marom et al.\textsuperscript{10} reported the hybrid effect in carbon/carbon and glass/carbon hybrid composites based on epoxy resin matrix. They found that all the mechanical properties of carbon/carbon hybrid composites did not show any signs of synergism or hybrid effect except in the case of fracture energy results. Peijs et al.\textsuperscript{11} presented a detailed study by analysing the mechanical properties such as tensile, fatigue, and impact properties of sandwich and intermingled PE/carbon fibre composites. They reported that hybrid effect was observed under tension only in the case of intermingled type composites.

Studies on natural fibre reinforced composites revealed that their properties can be more effectively utilised by hybridising them with other fibres. Several research works\textsuperscript{12}-\textsuperscript{14} reported in these area confirmed the fact that natural fibres are good substitute for synthetic fibres in terms of unaged mechanical properties.

The present chapter mainly describes the hybrid effect in tensile and flexural properties of LDPE laminates (sandwich) reinforced with longitudinally oriented short sisal and glass fibres. It is important to note that very limited amount of research work was devoted so far to short fibre reinforced thermoplastic hybrid composites, especially to hybrid laminates. The purpose of this study is to explore the conditions at which the physical characteristics and mechanical properties of the laminates change, as a function of the varying degree of hybridisation or hybrid design.

4.2. Results and discussion

The terms SRP, GRP, GSRP, SGS and GSG used in this study correspond to sisal/LDPE, glass/LDPE, intimately mixed sisal-glass/LDPE, sisal shell-glass core/LDPE laminate and glass shell-sisal core/LDPE laminate respectively. Schematic representations of these composites are shown in Figure 4.1.
Figure 4.1. Schematic representation of the cross-sectional view of the composites prepared (○ - sisal, ● - glass).

Figure 4.2 shows the stress-strain curves of SRP, GRP and SGS at different relative volume fractions of SRP and GRP (90/10, 70/30, 50/50, 30/70, 10/90 compositions of SRP/GRP). From the figure it can be seen that, all the composites undergo necking and yielding and the value of peak stress increases as the volume fraction of glass (GRP) increases. Necking and yielding are characteristic features of almost all thermoplastics and the stress corresponding to yield point is called yield stress. The peak stress value goes on increases when polyethylene is filled with increasing quantity of fibres. As modulus of the fibre increases, the yield stress also increases. The increase in yield stress with increase in volume fraction of glass
fibre (GRP) is attributed to the high modulus of glass compared to sisal fibre. From Figure 4.2 it can also be seen that a fluctuation in stress-strain behaviour is exhibited by curves of SGS, after yield point. This behaviour can be visible at all compositions.

Figure 4.2. Stress-strain curves of SRP (20% sisal), GRP (20% glass) and SGS (90/10, 70/30, 50/50, 30/70, 10/90 compositions of SRP and GRP)

This fluctuation in stress-strain behaviour may be due to the interlayer slippage or due to the difference in crack propagation mechanisms in individual sisal and glass layers in SGS. For example, at low volume fractions of SRP and GRP, an initial crack may originate either at sisal/LDPE or glass/LDPE interface. But it can also be seen from the figure, that SRP and GRP alone shows no fluctuation in stress-strain behaviour after yield point.

Figure 4.3 shows the stress-strain behaviour of GSG as a function of volume fraction of glass in them. It follows a similar trend as in the case of SGS.
But it is observed that these composites exhibit lower value of yield strength than SGS. The reason may be attributed to the fact that the overall contributions to the strength of sandwich type composite is more from its core region. In SGS the central core region is made up of GRP and its maximum yield strength is higher than outer SRP layer.

![Stress-strain curves of SRP (20% sisal), GRP (20% glass) and GSG [90/10, 70/30, 50/50, 30/70, 10/90 compositions of SRP and GRP]](image)

**Figure 4.3.** Stress-strain curves of SRP (20% sisal), GRP (20% glass) and GSG [90/10, 70/30, 50/50, 30/70, 10/90 compositions of SRP and GRP]

It can be confirmed from Figure 4.4 that the stress-strain behaviour of GSRP is not similar to sandwich type composites. It shows the stress-strain behaviour of SGS, GSG and GSRP having 70/30 and 30/70 SRP/GRP compositions. From the figure it is seen that the peak stress is maximum for GSRP and minimum for GSG. It is due to the higher dispersion of sisal and glass fibres in GSRP. It has been observed from the figure that after yield point GSRP does not show any fluctuation in stress-strain behaviour as in the case of SGS and GSG. The reason may be attributed to the uneven distribution of applied stress in sisal and glass layers and their interlayer slippage in SGS and GSG. But in GSRP, the
applied stress initiate a crack, which will propagate more or less evenly across the material, till its final fracture.

![Stress-strain curves of GSRP, SGS and GSG at 70/30 and 30/70 compositions of SRP and GRP](image)

**Figure 4.4.** Stress-strain curves of GSRP, SGS and GSG at 70/30 and 30/70 compositions of SRP and GRP

Figures 4.5 and 4.6 show the variation in maximum tensile strength and Young’s modulus of SGS, GSG and GSRP composites as a function of volume fraction of GRP. The figures clearly indicate that these properties, in general, change in the same manner as in the case of GSRP. But it is seen that the properties of SGS and GSG are lower than that of GSRP. In SGS and GSG, sisal and glass fibres form discrete layers of SRP and GRP in which these fibres are more or less agglomerated and this reduces the dispersion. But in GSRP, the dispersion of sisal fibre is highly enhanced by the presence glass fibres. It is clearly explained in Chapter 3. A schematic model, in Figures 4.7a, b and c represents the fibre dispersion in GSRP, SGS and GSG composites. Scanning electron micrographs of fracture surfaces SGS and GSG at 50/50 composition of SRP/GRP are shown in Figures 4.8a and b.
Figure 4.5. Variation in tensile strength of SGS, GSG and GSRP as a function of volume fraction of GRP

Figure 4.6. Variation in Young's modulus of SGS, GSG and GSRP as a function of volume fraction of GRP
Figure 4.7. A schematic modelling of fibre dispersion in (a) GSRP, (b) SGS and (c) GSG

Figure 4.8. Scanning electron micrographs of tensile fracture surfaces of (a) GSG and (b) SGS at 50/50 composition of SRP and GRP

The photographs clearly reveal that the agglomerated discrete layers of sisal and glass fibres are formed in both composites. Higher degree of fibre pull out seen in these photographs gives a clear support to shear failure in these composites. Also, the decrease in tensile properties of SGS and GSG compared to GSRP may
be attributed to the stress concentration at the interface between the layers of sisal and glass. The scanning electron micrograph of the cross section of SGS shown in Figure 4.9 which reveals the presence of interface between sisal (SRP) and glass (GRP) layers.

![Scanning electron micrograph of the cross section of SGS sandwich composite containing 50/50 composition of SRP/GRP](image)

**Figure 4.9.** Scanning electron micrograph of the cross section of SGS sandwich composite containing 50/50 composition of SRP/GRP

It is obviously understood from the Figures 4.5 and 4.6 that the tensile properties of SGS are higher than that of GSG. It may be noted that the tensile properties of sandwich type composites is mainly decided by the nature of the material which constitutes the core. When tensile force is applied to a composite material, the force acting at the centre of the material normal to the direction of applied force is higher than the force acting at the periphery. This is clearly shown in the schematic representation described in Figure 4.10. In SGS, the core material is made up of glass reinforced polyethylene (GRP). Therefore it is clearly understood that the tensile properties of GRP is greater than that of SRP. The reduction in tensile properties of GSG compared to SGS may be attributed to the low strength and stiffness of core material (SRP). Hybrid effects in all these composites were theoretically calculated using the additive rule of hybrid mixtures. According to this law, hybrid properties are calculated using the equation;

\[ X_H = X_1 V_1 + X_2 V_2 \]  \hspace{1cm} (4.1)
where $X_H$ is the characteristic property of hybrid composite, $X_1$ and $X_2$ are the characteristic properties of individual composites and $V_1$ and $V_2$ are their volume fractions. Figures 4.5 and 4.6 show that at every composition, the tensile properties of SGS and GSG are compared with those of GSRP. It has been observed that, GSRP composites exhibit a positive hybrid effect whereas SGS and GSG show a negative hybrid effect in tensile strength and Young's modulus. It has also been observed that as volume fraction of GRP increases, the degree of negative hybrid effect also increases to some extent. The reason for negative hybrid effect is attributed to the low degree of dispersion of sisal and glass fibres in SGS and GSG. It has been reported that for hybrids with constant fibre volume ratios, the largest hybrid effects have been observed for composites with the highest degree of dispersion. Another reason for the negative hybrid effect is the difference in elastic moduli of sisal and glass fibres. The highest hybrid effect in GSRP compared to GSG and SGS can be attributed to the good sharing of load between low modulus sisal fibre and high modulus glass fibre.

Figure 4.10. A schematic representation of tensile forces acting on the specimen
The variation in elongation at break values as a function of volume fraction of GRP is shown in Figure 4.11. It clearly indicates that the elongation at break values of SGS composites is lower than GSG which in turn is lower than GSRP at every composition of fibres. The GSRP composites exhibit high value of percentage strain compared to SGS and GSG composites. It is due to the highest degree of dispersion of sisal and glass fibres in GSRP. It has been reported that maximum value of elongation at break is observed in intermingled hybrid composites than laminates.\textsuperscript{11} Stress concentration effect between the interlayer of sisal and glass may be another reason for the low value of elongation at break in GSG and SGS. Among SGS and GSG, SGS exhibits low value of elongation at break compared to GSG. This is due to the low elongation component (GRP) in the core of SGS composites.
Flexural stress-strain curves of GSRP, SGS and GSG specimens are shown in the Figures 4.12-4.14. The flexural stress and corresponding strain values are calculated using the following equations:

\[
\text{Flexural stress} = \frac{3PL}{2bd^2} \quad (4.2)
\]

where \( P \) = applied load

\( L \) = span length

\( b \) = width of the specimen

\( d \) = thickness of the specimen.

\[
\text{Flexural strain} = \frac{6Dd}{L^2} \quad (4.3)
\]

where \( D \) = maximum deflection from the centre.

![Flexural stress-strain curves of an SRP, GRP and GSRP (70/30, 50/50, 30/70 compositions of SRP and GRP)](image)
Figure 4.13. Flexural stress-strain curves of SRP, GRP and SGS (70/30, 50/50, 30/70 compositions of SRP and GRP)

Figure 4.14. Flexural stress-strain curves of SRP, GRP and GSG (70/30, 50/50, 30/70 compositions of SRP and GRP)
It is observed from the figures that in all the cases, there is an initial abrupt increase in flexural stress with marginal increase in strain. But after reaching the maximum stress, the degree of strain enhancement is higher than the initial portion. From Figure 4.12, it can be seen that the yield stress goes on increasing with volume fraction of glass in GSRP. It has been observed that SRP shows minimum and GRP shows maximum yield stress. It can be noted that the trend in stress-strain behaviour of GSRP is similar to SRP and GRP. The system (GSRP) shows uniform load distribution among sisal and glass fibres under flexure. SGS and GSG show different trends in stress-strain behaviour (Figure 4.13) as compared to that of GSRP. In SGS, beyond yield point, a small increase after a decrease in stress is observed as a function of strain. A small initial decrease after yield point denotes the failure of SRP shell and increase in stress is due to the reinforcing effect of GRP core. In the case of GSG (Figure 4.14) small stress decay after yield stress is due to the failure of strong GRP shell. At high volume fractions of sisal, a small fluctuation was observed after yield point in GSG. But this fluctuation is found to be vanishing at low volume fractions of sisal. This indicates that the influence of SRP core is negligible especially at high volume fractions of glass.

Figure 4.15 shows that the stress-strain behaviour of GSRP, GSG, SGS at 50/50 composition of SRP and GRP under flexure. The figure obviously reveals the difference in stress-strain behaviour of these samples, as discussed above.
Figure 4.15. **Flexural stress-strain curves of SRP, GRP, GSRP, GSG and SGS at 50/50 composition of SRP and GRP**

Variation in flexural properties of GSRP, SGS, and GSG as a function of volume fraction of GRP is depicted in Figures 4.16 and 4.17. It has been found that flexural properties increase as the volume fraction of GRP increases. But the flexural strength and modulus of GSG is higher than SGS which in turn is higher than that of GSRP. When a flexural force is applied on a sandwich specimen, the force will mainly act on the outer layer of the material (shell) than its inner layer (core). A schematic representation showed in Figure 4.18 clearly reveals the nature of force acting on the sandwich type composite. In GSG the resistance offered by the GRP shell is more sufficient than SRP shell in SGS against the flexural force. Figures 4.19a, b and c show the photomicrographs of tensile sides of the flexural fracture surfaces of GSG, SGS and GSRP at 50/50 SRP/GRP composition. From Figure 19a it has been observed that small whitening (crazing) formed on the GSG sample after flexural testing. This clearly indicates the high resistance of GRP shell
against the flexural force. But in the case of SGS (Figure 19b) it is seen that some fibre pull out occurs on its surface after flexural failure. This fibre pull out is a clear indication of the premature failure in SGS as result of insufficient resistance offered by SRP shell. That is, the low flexural strength of SGS compared to GSG is due to the premature failure of SGS composite. The failed surface of GSRP (Figure 4.19c) in flexure shows that these composites exhibit low flexural strength than GSG and SGS. A small degree of whitening appeared on the tensile side of the fracture surfaces reveal that these composites were failed by shear. This might have been caused by the fact that failure in GSRP mostly initiate and propagate through weak sisal-LDPE interface. Hybrid effect in flexural properties was calculated using the additive rule of hybrid mixtures. From Figures 4.16 and 4.17 it can be observed that GSG shows positive hybrid effect in both flexural strength and modulus, while SGS and GSRP show negative hybrid effect.

![Graph showing variation in flexural strength of GSRP, SGS and GSG as a function of volume fraction of GRP](image)

**Figure 4.16.** Variation in flexural strength of GSRP, SGS and GSG as a function of volume fraction of GRP

In the Figures 4.5, 4.6, 4.11, 4.16 and 4.17 the points on x-axis at zero and one volume fraction of GRP represents 100% SRP (20% sisal in LDPE) and 100% GRP (20% glass in LDPE) respectively.
Figure 4.17. Variation in Flexural modulus of GSRP, SGS and GSG as a function of volume fraction of GRP

Figure 4.18. A schematic representation of flexural force acting on the specimen
The water absorption tendency of GSRP, SGS and GSG were studied by immersing these composites in boiling water for three hours. Circularly shaped samples having diameter 1.96 cm and thickness 4 mm were used for water absorption studies. It is found that in all the composites, water absorption tendency decreases as the volume fraction of glass increases. The gravimetric data of these composites before and after immersing in boiling water are shown in Table 4.1. The decrease in water absorption tendency is due to the water impermeable nature of glass fibres compared to sisal fibres. As hybrid design varies, water absorption tendency also varies.
### Table 4.1. Water uptake values of composites

<table>
<thead>
<tr>
<th>Composition (SRP/GRP)</th>
<th>Initial weight of the sample (g)</th>
<th>Weight after 3 h (g)</th>
<th>Water uptake (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SRP</td>
<td>GRP</td>
<td>GSRP</td>
</tr>
<tr>
<td>0</td>
<td>0.7438</td>
<td>0.8366</td>
<td>-</td>
</tr>
<tr>
<td>90/10</td>
<td>-</td>
<td>-</td>
<td>0.7459</td>
</tr>
<tr>
<td>50/50</td>
<td>-</td>
<td>-</td>
<td>0.7613</td>
</tr>
<tr>
<td>10/90</td>
<td>-</td>
<td>-</td>
<td>0.7939</td>
</tr>
</tbody>
</table>
It has been found that GSG shows the lowest water uptake compared to GSG and GSRP. The water uptake increases in the following order GSG < GSRP < SGS. In GSG, outer water impermeable GRP layers act as barriers to prevent the diffusion of water through it and thereby reducing the water uptake values. But in SGS the outer SRP layers are interactive with water, which allows water to be sorbed through it. Therefore the water uptake values increase in this case. The medium water uptake of GSRP is due to the fact that the water impermeable glass fibres surround the sisal fibres. This factor reduces the water uptake of sisal fibres.

4.3. References