Chapter 10

Environmental Durability of Composites

Abstract
The aging behavior of banana fibre reinforced phenol formaldehyde composites has been discussed in this chapter. The composites were subjected to water aging, thermal aging, oven aging, soil burial and outdoor weathering. Effects of chemical modification and hybridization using glass fibres on the degradability of the composites at different environments have been analyzed. The extent of degradation was monitored by weight change and change in tensile properties after aging. The tensile strength and modulus of the banana/PF composites were increased by water aging, while those of glass/PF composites decreased by water aging. The tensile properties of the composites were increased by oven aging. The weight loss was found to be higher for soil aged samples than for outdoor-weathered samples. The weight loss and decrease in tensile strength of glass/PF composites and banana/glass/hybrid /PF composites were found to be much lower than that of banana/PF composites. Silane treatment, NaOH treatment and acetylation improved the resistance of the banana/PF composites to the degradation by outdoor exposure and soil burial.

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During the last few decades the ecological concern has resulted in renewed interest on natural fibre composites [1-6]. The natural fibres are environment friendly alternatives for synthetic glass fibres. A major restriction to the successful use of natural fibres in composite applications is their poor ageing and weathering resistance and high moisture absorption. Several attempts were carried out to reduce the degradation and improve mechanical properties of composites by chemical modifications. Hill and Khalil [7] studied the effect of environmental exposure upon the mechanical properties of coir and oil palm fibre reinforced polyester composites. They found that the mechanical properties of the composites were deteriorated by such exposure and acetylation and treatment with silane coupling agent could afford a significant degree of protection.

The principal types of damage that occur to composites are interlaminar cracking, interlayer delamination, fibre breakage, fibre/matrix interface failure and fibre pull out. All these kinds of damages arise as a result of pre-existing technological defects, design features and events that occur during usage. They propagate and interact as a consequence of environmental aging, leading to progressive degradation of the properties of the material. Ishak et al. [8] found that immersion of the RH-PP composites in water resulted in the reduction of tensile properties, the extent of which depends on the water immersion temperature. This was attributed to the interfacial degradation and also to microstructural changes in RH, which reduced its efficiency in acting as reinforcement. Siddaramiah et al. [9] exposed glass fibre reinforced epoxy and unsaturated polyester composites to different aggressive environments such as heat, water ageing, lubricating oil, fuel, and seawater and noticed a marginal increase in properties for heat aging but a reduction in properties in all other aging processes.
Singh et al. [10] reported that in order to minimize the effect of external agents causing degradation of composites a hydrophobic morphology should be developed at the fibre/matrix interface and resin rich layer on the outer face of composites are necessary prior to use under wet/dry environments. Lin et al. [11] found that the tensile strength of wood flour filled polypropylene composites with wood floors of different contents, mesh sizes and surface treatment increased after immersion in water baths of various temperatures. The contrary was true for flexural strength and modulus when immersed in 60 and 100°C. Pavlidou and Papaspyrides [12] studied the effect of hygrothermal history on water absorption and interlaminar shear strength of glass/polyester composites characterized by different interfacial strengths to indicate interfacial degradation and hence interfacial contributions during absorption experiments. It was found that strong interface leads to matrix dominated absorption behavior and weak interface offer an easy path for water penetration and is interface dominated water absorption. In the case of silane treated composites once water reaches the interface, the siloxane bonds between the silane coupling agent and glass surface are easily hydrolyzed. However even a small amount of remaining covalent bonds prevents liquids from deteriorating the joint under wet conditions. It is reported that long term water exposure of composites fabricated from silane treated fibers can cause significant decrease of mechanical properties.

The effect of water on the physico-mechanical properties of composites based on low density polyethylene and linen yarn production waste (LW) with and without coupling agent were investigated by Kajaks et al. [13]. They found that the introduction of interfacial modifiers SA(stearic acid) and DIC (diphenyl metane diisocyanate) in to the system reduces the
amount of absorbed water and drop in tensile properties is also not much significant.

Hybridization using a stronger and corrosion resistant synthetic fibre like glass also improves the aging resistance of the natural fibre composites. Effect of environmental aging on the mechanical properties of bamboo-glass fibre reinforced polypropylene hybrid composites were done by Twe and Liao[14]. They [15] also found that the property retention in both bamboo fibre composites and bamboo/glass hybrid composites with malieic anhydride modified PP (MAPP) matrix is better than those with PP. They observed that hybridizing more durable glass fibres with bamboo fibre is an effective way to improve the durability of natural fibre composites under environmental aging.

Only a few reports are available about the effect of different aggressive environments on the properties of natural fibre composites. In this chapter the effects of fibre modification and hybridization on the aging resistance viz. cold water, boiling water and thermal aging of the composites are analyzed. Effects of outdoor weathering and soil immersion on the mechanical properties of composites are also studied.

**10.1. Banana/glass/hybrid composites**

**10.1.1. Percentage weight change**

The percentage weight change of banana fibre reinforced PF composites, glass/PF composites and banana/glass/hybrid composites after water aging are given in Figure 10.1.
Boiling water and cold water ageing result in an increase of the composite weight due to the absorption of water. The percentage weight gain is found to be the maximum in banana fibre composites than that of glass fibre composites, after both boiling water and cold-water ageing. In the case of banana/PF composites, the hydrophilic lignocellulosic fibre absorbs water. Penetration of water through fibre/matrix interface is less in this case due to the strong fibre/matrix interface through the chemical interaction. But in glass/PF composites, such a chemical interaction is not possible at the interface and so water enters into the composite through the interface. The absorption of water by glass fibre is not considerable and a very low weight gain is obtained in this case. The weight change of two types of hybrid composites, one having glass fibre at periphery and banana fibre at core and other having both the fibre as intimate mix were calculated. It was found that both the hybrid composites show weight change intermediate between banana fibres and glass fibres. The
effects of hybrid ratio on the weight change of banana/glass/hybrid composites are given in Figure 10.2.

![Graph showing weight change of banana/glass/hybrid composites (30%) after water aging]

*Figure 10.2. The effect of hybrid ratio on the percentage weight change of banana/glass/hybrid composites (30%) after water aging*

It is clear from the figure that composite containing 0 % glass fibre shows maximum weight change and as the glass fibre loading increase, the weight change also decreases with minimum value for glass/PF composite.

Figure 10.3 shows the effect of air oven aging on the weight loss of banana/PF, glass/PF and banana/glass/ hybrid fibre reinforced composites having GBG and intimate mix layering patterns. The weight loss is maximum for banana/PF composites while it is minimum for glass/PF composites. About 15% weight loss occurs in banana/PF composites while it is only 3.5% for glass/PF composites. The loss of weight in banana/PF composites is associated with removal of moisture and less stable (volatile) components in the fibre and the moisture entrapped in the micro voids in the composites. In the case of glass/PF composites, as there is no degradation of glass fibre below 1000 °C, so the weight loss is associated with removal of moisture from micro voids and microcracks present in the composite. Similarly the development of crosslinks
at the uncrosslinked sites if present will also result in the removal of water molecules evolved by the condensation reaction of PF resin at this temperature. Hybrid composites with both the layering patterns have lower weight loss compared to banana/PF composites. It is lower for intimate mix compared to GBG arrangement. The effect of hybrid ratio on the weight loss of banana/glass hybrid composites are given in Figure 10.4.

![Figure 10.3](image)

**Figure 10.3.** The effect of air oven aging on the weight loss percentage of banana/PF, glass /PF and banana/glass/ hybrid fibre reinforced composites (30%).

![Figure 10.4](image)

**Figure 10.4.** The effect of hybrid ratio on the weight loss percentage of hot air oven aged composites (30%)
It is clear from the figure that the weight loss is maximum in banana fibre composites which decreased with increase in glass fibre addition. The minimum value of weight loss in the glass/PF composites is due to the higher thermal stability and lesser moisture content in glass/PF composites compared to banana/PF composites.

10.1.2. Tensile properties

The percentage retention of tensile strength, Young’s modulus and elongation values of banana/PF, glass/PF and hybrid fibre reinforced PF composites after cold water and boiling water aging are given in Figures 10.5, 10.6 and 10.7. The tensile strength and Young’s modulus of the banana fibre reinforced composites are found to be increased by both the boiling water and cold water aging. Though the increase in modulus for the aged composites is low there is about 25% increase in tensile strength after water immersion. This is because the absorption of water will result in the swelling of fibres in the composite by which the stress transfer at the fibre/matrix interface is enhanced. The change in tensile strength for glass/PF composites and hybrid composites with GBG and intimate mix are lower when compared to banana/PF composites. About 5% increase in tensile strength is obtained for boiling water aged glass/PF composite and hybrid composite with intimate mix of the fibres.
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Figure 10.5. The percentage retention of tensile strength of banana/PF, glass/PF and hybrid fibre reinforced PF composites (30%) after cold water and boiling water aging.

Figure 10.6. The percentage retention of Young’s modulus of banana/PF, glass/PF and hybrid fibre reinforced PF composites (30%) after cold water and boiling water aging.
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1 Cold water aging

1. BananalPF, 2. GlassIPF, 3. GBG arrangement, 4. Intimate mix of B and G

Figure 10.7. The percentage retention of elongation values of bananfl, glass/IPF and hybrid fibre reinforced PF composites (30%) after cold water and boiling water aging

The tensile strength of hybrid composite with GBG arrangement shows about 9% decrease in tensile strength. The modulus values of glass/PF composites and hybrid composites are found to be decreased by the water ageing. The elongation at break value is also found to decrease by water ageing except cold water aged hybrid composite with GBG arrangement.

Effect of glass fibre content on the change in tensile strength, modulus and elongation at break values of banana/glass/hybrid composites are given in Figures 10.8, 10.9 and 10.10 respectively. Only banana fibre/PF composites shows considerable enhancement in tensile strength value.
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Figure 10.8. Effect of glass fibre content on the percentage retention of tensile strength of banana/glass/hybrid composites (total fibre content 30%).

Figure 10.9. Effect of glass fibre content on the percentage retention of Young's modulus of banana/glass/hybrid composites (total fibre content 30%).
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Glass fibre content (%)

Figure 10.10. Effect of glass fibre content on the percentage retention of elongation at break values of banana/glass/hybrid composites (total fibre content 30%)

As the glass fibre loading increases in the hybrid composites, the change in strength is reduced and at higher glass fibre loading, a slight decrease in strength is obtained. In glass/PF composites also the effect is less and a slight decrease in tensile strength for cold water aged and a slight increase in tensile strength for hot water aged composites is observed. The modulus of the water aged composites decreases with the incorporation of glass fibre. A slight increase in modulus is obtained for banana/PF composites after ageing. The glass fibre composites show a decrease in modulus and for banana/glass/hybrid composites also the water ageing results in decrease in modulus. But cold water aged hybrid composite with 0.5 glass fibre volume ratio and hot water aged hybrid composite with 0.75 glass fibre volume ratios show a slight increase in modulus value. The elongation value of most of the hybrid composites is also decreased by water aging.
The effect of hot air oven aging on the tensile properties of the composites is given in Figure 10.11. It is clear from the figure that tensile strength and modulus of the composites increases with oven ageing. This can be explained due to the possible crosslinking of the uncrosslinked sites present in the composite.

**Figure 10.11.** The effect of hot air oven aging on the tensile properties of the banana/glass/hybrid composites (total fibre content 30%)

### 10.2. Effect of banana fibre modification

#### 10.2.1. Percentage weight change

The effect of boiling water and cold-water aging on the weight gain of banana fibre composites after different chemical modifications is given in Figure 10.12. All the surface modifications except latex treatment decrease the amount of
absorbed water. The cyanoethylation and silane treatment impart hydrophobicity to the fibre surface thus decreasing the amount of absorbed water.

Figure 10.12. Effect of boiling water and cold-water aging on the percentage weight gain of banana fibre composites (30%) after different chemical modifications

Figure 10.13 shows the weight loss of hot air oven aged composites. The latex treated fibre/PF composites shows maximum weight loss (about 10 %), whereas the other treatments decrease the weight loss percentage compared to the untreated one. This is due to the high thermal stability of treated fibre/composites over the untreated one. Latex treatment decreases the fibre/matrix adhesion and hence the composite stability.
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10.2.2. Tensile properties

The change in tensile properties of treated fibre/PF composites after water aging is given in Figures 10.14, 10.15 and 10.16. The tensile strength of the composites is found to be increased by water aging. The increase in tensile strength of the composites is found to be decreased by surface modifications and the boiling water aged silane treated fibre/composite show decrease in tensile strength. The moduli of the cyanoethylated and silane treated fibre/PF composites are found to be decreased after both water aging. The increase in modulus is also decreased by the surface modifications. The elongation of the composites is found to be decreased by the water aging.

Figure 10.13. Effect of hot air oven aging on the weight loss of chemically treated composites (30%)
Figure 10.14. The percentage retention of tensile strength of treated fibre/PF composites (30%) after water aging.

Figure 10.15. The percentage retention of tensile modulus of treated fibre/PF composites (30%) after water aging.
The effect of oven aging on the tensile properties of modified banana/PF composites is given in Figure 10.17. The tensile strength of the composites is found to be decreased by oven ageing, but the modulus value shows slight increase after oven aging. This may be due to the additional crosslinks formed in the composites. The elongation and flexibility of the composites is decreased with aging. That is, oven aging makes the composite more brittle.
Figure 10.17. The effect of oven aging on the tensile properties of modified banana/PF composites (30%)

10.3. Soil burial and outdoor weathering studies

Figure 10.18 shows the weight loss of banana/PF, glass/PF and banana/glass/hybrid fibre/PF composites after 12 months soil immersion and exposure to natural weathering. It is clear from the figure that the weight loss is higher for soil buried samples compared to weathering conditions. Of the soil buried samples, maximum weight loss is obtained for banana/PF composites. It is associated with the biodegradation of banana fibre in the composite. The weight loss of glass fibre composite is found to be much lower compared to banana fibre/PF composites.
Hybridization is found to decrease the weight loss of the composites. The hybrid composites with GBG arrangement is having slightly higher weight loss compared to intimate mix of the fibres. This is because in layered composite interlayer delamination is possible. The microorganisms present can enter into the composite through the interlayer and degradation of banana fibre occurs, while in intimate mix, the weight loss is very low, comparable to that of glass fibre. A similar trend in weight loss is obtained for weathered composites also, where the percentage weight loss is in the order banana/PF > GBG > Glass/PF > Intimate mix. Here the intimate mix is found to have the lowest degradation even lower than that of glass/PF composite.
Effect of chemical modification of the fibre on the weight loss of banana/PF composites after soil ageing and out door weathering is given in Figure 10.19. From the figure it is clear that the percentage weight loss is lower in treated fibre/PF composites compared to that of untreated one. Maximum weight loss is obtained for soil buried untreated fibre/PF composites where the possibility for microbial attack is higher. The latex treated composite also showed high weight loss after soil immersion.

![Figure 10.19](image_url)

**Figure 10.19. Effect of chemical modification of the fibre on the percentage weight loss of banana/PF composites (30%) after soil ageing and outdoor weathering**

This is assumed to be due to biodegradation of natural rubber, where microbial attack is possible. Similarly, a poor fibre/matrix interface in latex treated fibre makes the penetration of microorganisms through interface by which the degradation of fibre will be easy. The treatments with NaOH, silane and acetylation are found to decrease the percentage weight loss of composites compared to untreated fibre. This is due to strong fibre/matrix
interface and hydrophobicity induced by the treatments, which will make the composite more stable against microbial attack.

The percentage retention of tensile strength in banana/PF, glass/PF and hybrid composites after soil burial and outdoor weathering exposure is given in Figure 10.20.

![Figure 10.20](image)

*Figure 10.20. The percentage retention of tensile strength in banana/PF, glass/PF and hybrid composites (30%) after soil burial and outdoor weathering*

As in the case of weight loss percentage, the decrease in tensile strength after outdoor weathering is maximum in banana/PF composites and low in hybrid composites. The property of glass/PF composite is not against our expectation as neither glass fibre nor banana fibre is biodegradable. But the poor fibre/matrix interaction in glass/PF composite is the reason for decrease in tensile strength after ageing. The hybrid composite with GBG arrangement is found to have higher decrease of tensile strength compared to intimate mix. In GBG arrangement interlayer delamination may be the reason for this behavior, but this effect is found to be maximum.
in weathered samples. The intimately mixed fibre/PF composite is found to be the most stable one.

The change in Young's modulus of the banana/PF, glass/PF and hybrid composites after soil burial and outdoor weathering exposure are given in Figure 10.21. The outdoor weathering considerably affects the modulus of composites, especially the banana/PF composites, while the modulus is not having considerable decrease after soil immersion. About 40% decrease in modulus is observed in banana/PF composites after outdoor weathering, while a slight increase in modulus is obtained after soil immersion. In glass/PF and hybrid composites also the effect of soil immersion is low compared to outdoor weathering. Both the hybrid composites are found to be better than glass/PF and banana/PF composites in its ability to resist modulus loss by soil burial and outdoor weathering.

![Figure 10.21](image_url)

*Figure 10.21. The percentage loss of young modulus in banana/PF, glass/PF and hybrid composites (30%) after soil burial and outdoor weathering exposure.*
The decrease in tensile properties of treated fibre/PF composites after soil burial and outdoor weathering exposure is given in Figure 10.22. From the figure maximum decrease in tensile strength is obtained for untreated fibre/PF composites. NaOH treatment and acetylation decreases the loss in tensile strength by both soil burial and outdoor weathering. The latex treated composite shows a similar decrease in tensile strength like that of untreated fibre/PF. But no considerable change occurs by soil burial. Silane treatment also decreases the degradation of the composite.

![Graph showing percentage retention of tensile strength](image)

(U) Untreated, (VS) silane treated, (L) Latex treated, (M) alkali treated, (A) Acetylated

**Figure 10.22.** Percentage retention of tensile strength of treated composites (30%) after soil burial and outdoor weathering
The decrease in modulus of the treated composites after soil burial and outdoor weathering exposure is given in Figure 10.23. All the treatments except the latex treatment decrease the modulus loss of the composites after outdoor weathering. In the case of untreated, acetylated and latex treated composites an increase in modulus occurs after soil burial. No considerable change in modulus is observed for other composites after soil burial. The elongation at break values of banana/PF, glass/PF, hybrid composites and the treated composites after soil burial and outdoor weathering exposure are given in Figure 10.24. The elongation of most of the composites is decreased by soil immersion and outdoor weathering. Out door-weathered latex treated, NaOH treated and soil buried silane treated composite shows a slight increase in elongation at break value.

Figure 10.23. The percentage retention of modulus of the treated composites (30%) after soil burial and outdoor weathering exposure.
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Figure 10.24. The percentage decreases in elongation at break values of banana/PF, glass/PF, hybrid composites and the treated composites (30%) after soil burial and outdoor weathering exposure.

References

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