Absorption of Water at Ambient Temperature and Steam in Wood–Polymer Composites Prepared from Agrowaste and Polystyrene

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ABSTRACT: Hemp, banana, and agave fibers were employed for the preparation of wood–polymer composites using polystyrene in the ratio of 50 : 50 w/w. These fibers were esterified with maleic anhydride (MA) and the effect of MA was studied on the absorption of water at ambient temperature and steam in wood–polymer composites made from said fibers and polystyrene. The absorption of water increases with increase in time from 2 to 30 h in all fiber composites. The maximum absorption of water was found in hemp fiber composites, and the minimum in agave fiber composites. The MA-esterified fiber composites showed less absorption of water than did the untreated fiber composites. Steam absorption in MA-treated and untreated fiber composites is higher than the water absorption in the respective fiber composites. Untreated fiber composites show more absorption of steam in comparison to MA-treated fibers composites.
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Key words: wood–polymer composites; polystyrene; banana; hemp; agave; fiber; maleic anhydride; absorption; steam; water

INTRODUCTION

In our earlier research article,[1] we studied the effect of the absorption of steam and water at ambient temperature on Novolac and banana, hemp, and agave fiber composites. The absorption of steam is more than that of water due to the higher penetration of steam. The organic synthetic materials are less compatible with fibers due to that it becomes a mixture of two components rather than a composite in which component interaction exists. The methyl methacrylate and styrene monomers are polymerized *in situ* by introducing wood with monomers which are effective in filling the lumens of wood but do not usually penetrates the cell wall.[2] Several reports are available in the literature[3–6] where maleic anhydride (MA) was used as an effective compatibilizer for wood fiber–polyolefin composites. In the present study, MA is used as a compatibilizer for polystyrene–fiber (banana, hemp, and agave) composites and the swelling behavior (steam and water absorption) is studied with and without MA in fiber–polystyrene composites.

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EXPERIMENTAL

Polystron 678 SF1 having a specific gravity of 1.05 and an MFI of 15 g/10 min is used for the preparation of fiber–polymer composites. This sample was obtained form Polychem, Mumbai. The fibers

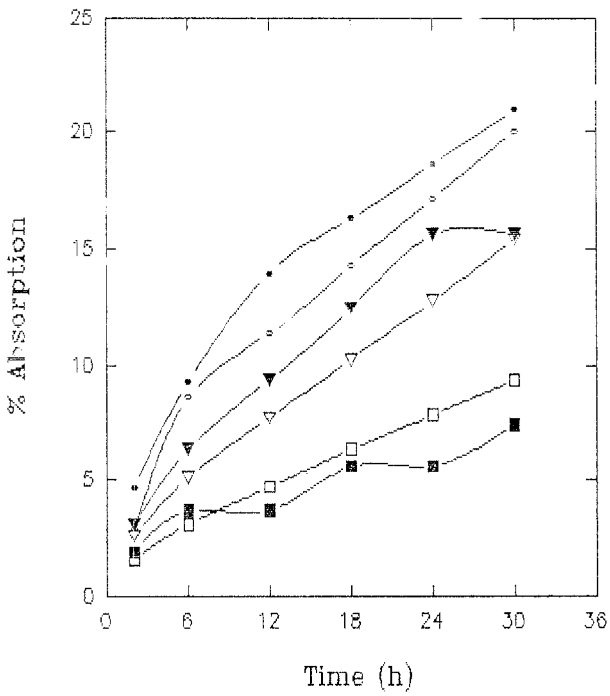

Figure 1 Absorption of water at ambient temperature in hemp, banana, and agave fiber composites with and without treatment of MA: (●) untreated hemp fibers; (○) untreated banana fibers; (□) untreated agave fibers; (▽) MA-untreated hemp fibers; (▼) MA-treated banana fibers; (■) MA-treated agave fibers.

of banana, hemp, and agave are prepared by retting. The details of fiber preparation and composite preparation were given elsewhere.[1]

RESULTS AND DISCUSSION

Absorption of Water at Ambient Temperature With and Without MA-Treated Hemp, Banana, and Agave Fiber–Polystyrene Composite

The polystyrene and banana fiber (50 : 50 w/w) composite are used for the study of absorption of water for 2–30 h at ambient temperature. It is observed from figure 1 that the absorption of water increases with increase in time in banana fiber composites. Figure 2 shows the results of the rate of absorption for water at ambient temperature in a banana, hemp, and agave fiber–polystyrene composite at different times. The minimum of the absorption of water in untreated banana fiber composites is recorded only to be 2.9% at 2 h and a maximum of 20% absorption of water is observed at 30 h. The rate of absorption of water increases to 6 h and thereafter it becomes constant. The rate of absorption is measured, from 6 to 30 h, at the time interval of 6 h.

The MA-treated fiber–polystyrene composites are used for water absorption for the same period of time. About 3.1% absorption of water is observed at 2 h and a maximum of 15.6% absorption of water is recorded at 24 h. Beyond 24 h, the absorption becomes constant. The rate of absorption of water in MA-treated banana fiber composites is constant from the very beginning to 30 h.

Figure 1 illustrates the results of hemp fiber/polystyrene composites with and without treatment of MA. Like banana fiber, the absorption of water at ambient temperature increases with increase in time in MA-treated and untreated hemp fiber composites. On comparison of the absorption of water in MA-treated and untreated fiber composites, it is observed that at 2 h the difference in absorption of water is much less and this difference increases with increase in the absorption of water to 12 h; further, the difference in absorption of water between treated and untreated hemp fiber composites declines from 18 to 30 h, which is due to the lesser absorption of water in the untreated hemp fiber composites.

Like banana and hemp fibers, the agave fibers are also treated with and without MA and, further, composites made from these fibers are employed for water absorption from 2 to 30 h. It is surprising that the polystyrene–agave fiber composites show much less absorption of water in comparison to the MA-treated and untreated banana and hemp fiber composites. The absorption of water is more in the MA-treated fiber composites for 6 h than in the untreated agave fiber composites and, further, it becomes equal at about 8 h duration of absorption, and beyond it, the absorption of water declines in treated fiber composites in comparison to untreated fiber composites.

The results of MA-treated and untreated fiber–polystyrene composites (Fig. 1) are compared to determine the effect of MA on the water absorption at ambient temperature as MA is being used as a compatibilizer. The maximum effect of MA is observed in the hemp fiber composites. However, the untreated hemp fiber composites absorb the maximum amount of water with respect to other fibers, which is due to the maximum number of free —OH groups present in

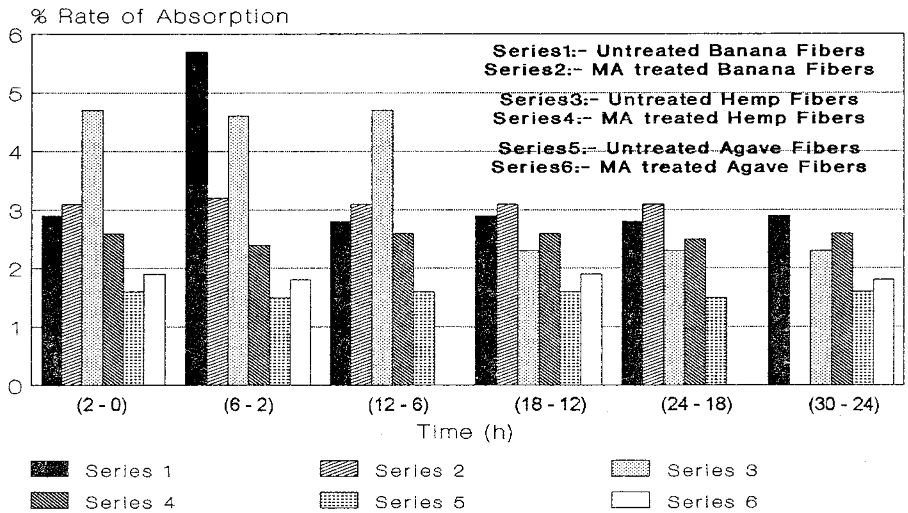

Figure 2 Rate of absorption of water at ambient temperature in banana, hemp, and agave fiber–polystyrene composites at different times.

hemp fibers. The groups become esterified with MA and, thus, the absorption of water declined. In banana fibers, free —OH groups are fewer than in the hemp fibers and, thus, they show less absorption of water. The MA soaking results show that hemp fibers soak the maximum amount of MA, followed by banana fibers. The least amount of MA soaking is observed in agave fibers. Thus, it is very clear that hemp fibers react at the maximum with MA. The absorption of water is the capillary phenomenon but the presence of —OH groups enhance the absorption of water by forming hydrogen bonding; it is therefore possible that the free —OH group present in banana fibers is not fully esterified, which causes more absorption of water than in the MA-treated hemp fiber composite. The more absorption of water and earlier saturation (i.e., at 24 h) in the banana fiber composites in comparison to the hemp fiber composites show that MA penetrates more in hemp fibers, and due to that, the rate of absorption becomes less than in banana fibers. The agave fiber composites are compactly bonded and have fewer free —OH groups; due to that, the penetration of water is much less. Further, the free —OH groups available in agave fibers become esterified with MA and, thus, the absorption of water decreases. The difference in MA-treated and untreated agave fiber composites is also much less and thus it strengthens the above-said phenomenon.

Absorption of Steam in With and Without MA-Treated Banana, Hemp, and Agave Fiber–Polystyrene Composites

Figure 3 shows the results of the absorption of steam in MA-treated and untreated banana, hemp, and agave fiber composites. The maximum absorption of steam was obtained in untreated hemp fiber composites, and the least absorption, in MA-treated agave fiber composites. The absorption of steam increases with increase in time up to 18 h in untreated hemp and banana fiber composites, while agave fiber composites show an increase in the absorption of steam only up to 12 h and absorption becomes constant after the respective periods of time.

Banana, hemp, and agave fibers treated with MA were employed for steam absorption. The absorption of steam increases with increase in time up to 12 h in banana and agave fiber composites, but in hemp fiber composites, increase of the absorption in of steam increases up to 24 h. The absorption of steam becomes constant beyond the respective periods of time. The MA-treated fiber composites show much less absorption of steam with respect to untreated fiber composites.

On comparison with untreated and MA-treated hemp fibers, the absorption of steam at 2 h in untreated fibers is 30% more than in the MA-treated fiber composites. Further, the difference in the absorption of steam increases with increase

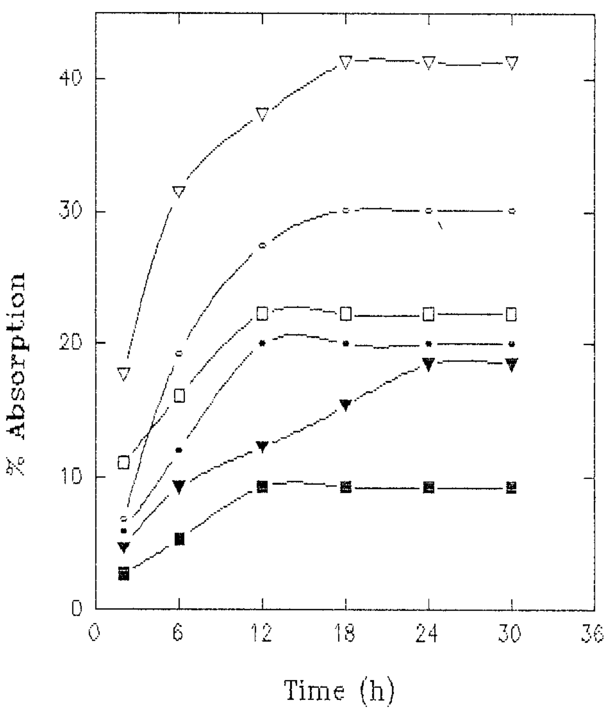

Figure 3 Absorption of steam in hemp, banana, and agave fiber composites with and without treatment of MA: (▽) untreated hemp fibers; (○) untreated banana fibers; (□) untreated agave fibers; (▼) MA-treated hemp fibers; (●) MA-treated banana fibers; (■) MA-treated agave fibers.

in time and the maximum difference is obtained at 18 h, since at this period, the absorption in untreated hemp fibers increases, and beyond it, absorption becomes constant. However, in MA-treated hemp fibers, the absorption of steam increases up to 24 h and, further, it becomes constant. The difference, therefore, decreases marginally after 18 h of steam absorption. In the same way, the absorption of steam increases with increase in time for MA-treated and untreated banana fiber composites. However, there is little difference at 2 h and, further, this difference increases (i.e., 10%) and becomes constant after 18 h. Like the hemp fibers, the untreated and MA-treated agave fiber composites shows a wide difference in the absorption of steam at 2 h and, further, the difference in the absorption of steam increases up to 13% and becomes constant.

Figure 4 shows the difference of the absorption of steam at various time intervals. The maximum absorption of steam is observed at 2 h in untreated hemp fiber composites. The rate of the absorption of steam decreases with increase in time up to 18 h, and beyond this period, no absorption of steam is recorded up to 30 h. However, the rate of the absorption of steam up to 6 h in MA-treated hemp fiber composites is 4.6%, and beyond this period, it decreases up to 3.1% at 6 h for the period of 12–24 h. There no change in the rate of absorption observed at 30 h.

Unlike the hemp fiber composites, banana fiber composites show an increase in the rate of the absorption of steam with an increase in time intervals from 2 to 6 h, which is highest at 6 h, and, further, the rate of absorption decreases up to 18 h. The rate of steam absorption becomes constant at 24 h and, further, no absorption is recorded up to 30 h. MA-treated banana fiber composites show a rate of absorption of steam of 6% at the periods of 2 and 6 h and, further, it increases up to 8% at 12 h. There zero-percent steam absorption is observed beyond 12 h.

The untreated agave fiber composites absorb steam very sharply for the first 2 h, and for a further 4 h, the absorption rate increases, but it also increases in the next 6 h, that is, at 12 h. However, MA-treated agave fiber composites show a constant rate for 2 and 6 h. The rate of steam absorption increases for a further 6 h, that is, at 12 h. There is no absorption in MA-treated and untreated fiber composites after 12 h. If we compare the rate of absorption of steam in MA-treated and untreated fiber composites for the respective fibers, it is observed that there is a drastic reduction in the rate of absorption in MA-treated fiber composites except for banana fiber composites at 12 h.

As we have earlier discussed that the hemp fiber composites absorb more water, in same way, steam is also being absorbed more by hemp fibers. The overall absorption of steam is quite higher than that of the water because steam penetrates more into the cell wall and forms a hydrogen bond with cellulose. When these fibers are soaked in MA, the fibers become esterified [Fig. 5(a)]. It has been observed from the results that the total —COOH groups do not esterify as the acid value is recorded in all MA-treated fibers, while no acid value is observed in the untreated respective fibers. By the virtue of this reaction, the fibers become nonpolar in nature and form a bond with polystyrene [Fig. 5(b)] and the result is the reduction in the penetration of steam into the cell wall. These results are also supported by the Shore-D hardness of

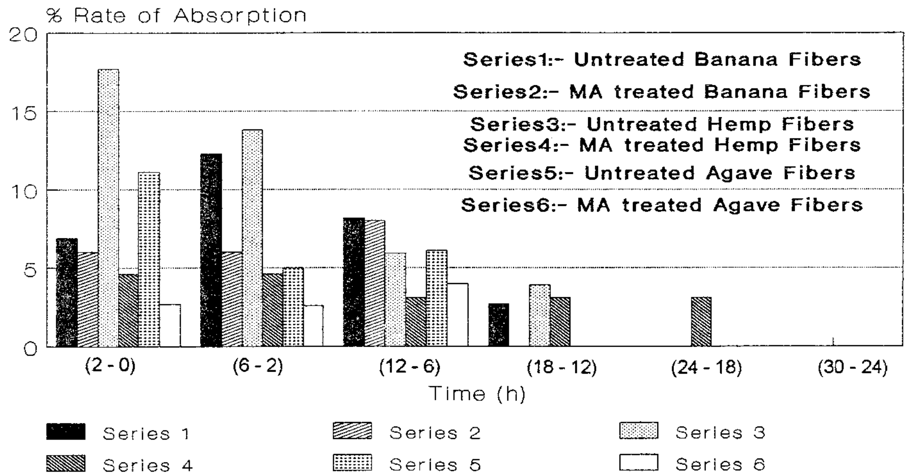

Figure 4 Rate of absorption of steam in banana, hemp, and agave fiber–polystyrene composites at different times.

MA-treated and untreated fiber composites (Table I). Here, treated fiber composites show a higher hardness than that of the untreated fiber composites.

CONCLUSIONS

The following conclusions can be drawn from this study:

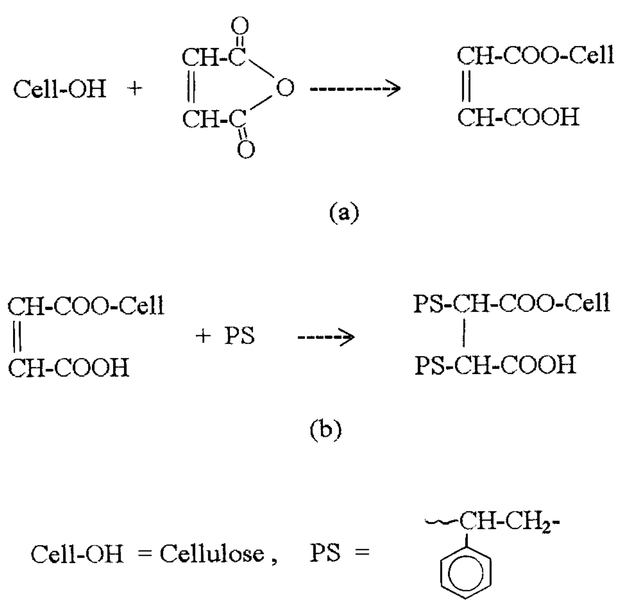

Figure 5 Mechanism of esterification of fibers and crosslinking with polystyrene.

1. The absorption of water at ambient temperature in hemp fiber–polystyrene composites is maximum, followed by banana fiber composites. The minimum absorption of water is obtained in agave fiber composites.
2. The absorption of water increases with increase in time in all fiber composites.
3. The MA-esterified fiber composites shows less absorption of water and steam than do the respective fiber composites.
4. The maximum absorption of water is obtained in MA-treated banana fiber composites followed by MA-treated hemp fiber composites, and the least absorption is obtained in MA-treated agave fiber composites.
5. The absorption of steam in MA-treated and untreated agave fiber composites and MA-treated banana fiber composites becomes constant at 12 h.
6. The difference in absorption of steam is very high (30%) as observed in MA-treated and untreated hemp fiber composites at an 18 h

Table I Shore-D Hardness of Composites Based on MA-Treated and Untreated Fibers

Sample No.	Samples	Hardness	
		Untreated	MA-Treated
1	Banana fibers	63.00	69.00
2	Hemp fibers	62.00	67.00
3	Agave fibers	65.00	73.00

absorption period of time. These differences are due to the maximum esterification of hemp fibers, which acts as a compatibilizer for the bond formation between the fibers and polystyrene.

7. The maximum (41%) absorption of steam is observed in hemp fiber–polystyrene composites and the minimum (9%) absorption of steam is observed in MA-treated agave fiber composites.
8. The Shore-D hardness of MA-treated fiber composites is more than that of the untreated respective fiber composites.

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