Development of Hemp Fibre – PP Nonwoven Composites

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Summary: *Nonwoven mats* from hemp and polypropylene fibres in various proportions were produced and hot pressed to make composite material. The effect of hemp fibre content and anisotropy in nonwoven mats resulting from the carding technology were examined on the basis of the three-point bending, tensile and impact properties of the resultant composite materials. Because of the hydrophilic nature and poor dimensional stability of cellulosic fibres due to swelling, the *effect of water sorption* on mechanical performances was also investigated. Optimal mechanical properties were achieved in composites made from 40–50% of hemp fibre by weight. As it was expected, better mechanical properties were found in the specimens cut from the composite sheets parallel to the direction of carding. A strong decrease in three point bending properties was noticed after immersing the composite samples in distilled water for 19 days, while the impact strength increased. *Double carding* of raw materials resulted in a decreased anisotropy in composite material.

Keywords: composites; polypropylene; renewable resources; structure-property relations; swelling

Introduction

Natural fibres, such as flax, hemp, jute, and kenaf, have received considerable attention as an environmentally friendly alternative to the use of glass fibres in engineering composites.[1,2] These plant fibres have a number of techno-ecological advantages over traditional glass fibres since they are renewable, can be incinerated leading to energy recovery, are less harmful in terms of safety and health (e.g. skin irritation) and cause less abrasive wear to processing equipment such as extruders and moulds. In addition, they exhibit excellent mechanical properties, especially when considering their low density (1.4 g/cm^3 versus 2.5 g/cm^3 of glass).[3–5] Although natural fibres have a number of ecological advantages over glass fibres they also possess a number of disadvantages, such as lower impact strength, higher moisture absorption which brings about dimensional changes thus leading to micro-cracking, as well as poor thermal stability, which may also lead to thermal degradation during processing.[6–8]

Up to now most of the studies in the area of natural fibre composites have been focused on the use of polypropylene as a matrix. Polypropylene offers a number of favourable characteristics for high volume applications because of its low price, high toughness and low density. Moreover, polypropylene can easily be processed, recycled and upgraded via the use of glass fillers, which has successfully bridged the gap between the commodity polypropylene composites and the engineering thermoplastics.[1,9,10] Using hybrid-nonwovens as semi-finished products, made from a blend of natural and thermoplastic fibres, provides a good basis for high product quality. By mixing the two composite components before the consolidation a proportionate

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distribution and a good wetting of the reinforcing fibres are ensured.[11,12]

In our earlier studies, short fibre reinforced flax-PP composites were prepared, and the best properties occurred at a fibre content of 20–30%.[6] A slight effect of water uptake on the mechanical properties was observed.[13] Experiments were also carried out on flax-PP nonwoven composites. A strong effect of water was found on the dimensional and mechanical properties, and the best parameters were observed at 30–50% of reinforcement by weight.[14]

In this study, the effects of hemp fibre content and anisotropy of the nonwoven mat, resulting from the carding technology, on the properties of polypropylene composites were studied. The effect of water uptake on mechanical performance was also investigated.

Experimental

Materials, Preparation

Nonwoven fleeces of polypropylene fibres (75 mm long, 11 dtex) and hemp fibres (from Nagylak, Hungary) were prepared in different blend ratios.

The fibres were blended manually in the desired ratios of 30, 40, 50 and 70% hemp by weight. After carding the thin layers were bonded on a needle-punching machine. The technological parameters were maintained constant for all samples. Blended mats, containing 40% hemp by weight, were also produced by double carding the reinforced polypropylene before needle punching. Composite sheets were then prepared by hot pressing the hybrid mats at a temperature of 190 °C. The test specimens were cut by means of a TRUMPF CO_2 laser cutting equipment in the machine and cross-machine directions of the carding machine.

Testing Methods

The test specimens were stored in distilled water at room temperature (23 ± 2 °C) for about 450 hours (19 days). Each day the samples were dried by means of a paper towel and the increase in weight was measured.

Tensile tests were performed on a ZWICK tensile tester according to the MSZ ISO 527 standard, 5 repetitions being done on each sample.

The three point bending test was carried out on a ZWICK bending tester according to the MSZ ISO 892-78 standard. The specimens were tested in both dry and wet states (after immersion in distilled water for 19 days). 5 repetitions being done on each sample.

The impact strength was tested on ZWICK equipment according to the MSZ ISO 180 standard. The test was carried out in both dry and wet states, 5 repetitions being done on each sample.

All the above tests were carried out at 23 ± 2 °C.

Results and discussion

Water Sorption, Swelling

The characteristics of the water sorption curves were actually not affected by the fibre content of the composites. The well-separated water sorption curves indicate the strong effect of the fibre content on sorption characteristics. In contrast with the short fibre reinforced structures of earlier studies,[9] the water uptake of the nonwoven composites is not a linear function of the square root of time, as shown in Figure 1.

The water uptake is due to the hydrophilic nature of cellulose, and also due to the capillary effect when fibre-ends exposed to water. In our case, when the composite samples cut from sheets, the capillary effect of free fibre-ends has a leading role in the water uptake. That is the explanation of the higher **water uptake** at higher fibre content. Differences being found even after the first day of immersion in water, for example, the weight of the composites increased by 2.4%, 6%, 13% and 42%, for hemp fibre contents of 30%, 40%, 50% and 70%, respectively.

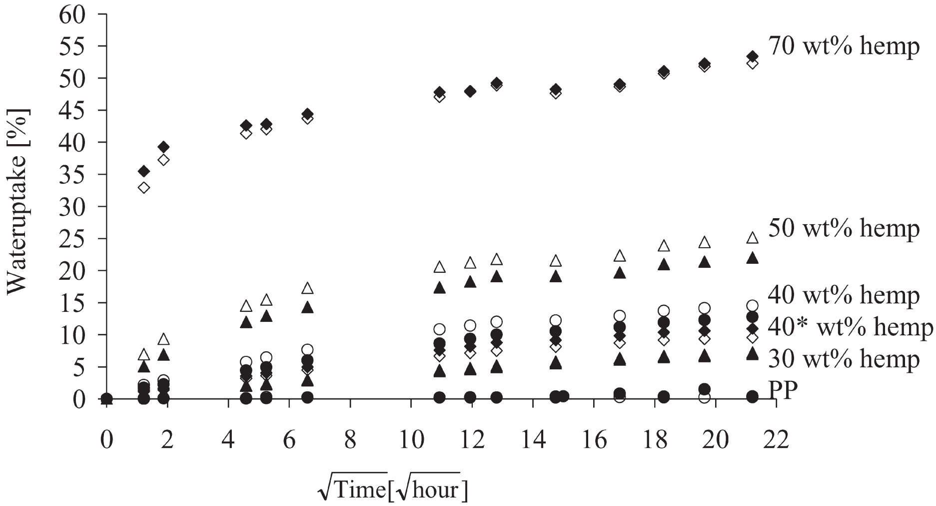


Figure 1.
The correlation between water uptake and square root of time; ▲ = parallel to the direction of carding, △ = perpendicular to the direction of carding, * = double carded samples.

The rate of water absorption decreased significantly after the fifth day, saturation being achieved from 17 to 19 days in the case of composites containing the lower fibre content, where as saturation did not occur in the case of the composites containing 50% and 70% of hemp.

For assessing the influence of anisotropy resulting from carding, specimens from the composite sheets were cut both parallel and perpendicular to the direction of carding. The real effect of anisotropy on water uptake was found for the 50% hemp fibre in reinforced composites, samples cut perpendicular to the direction of carding show higher water uptake because of the larger number of free fibre-ends than those cut in parallel. Almost 53% **water uptake** was measured at the highest fibre content whereas only 7% water uptake was observed in composites containing 30% hemp fibre as shown in Figure 2.

Composites prepared by double carding showed about 1 to 5% lower water uptake than those made by single carding.

As it was expected the **thickness** of the composites increased by increasing the hemp content (by 18% for the composites containing 70% hemp fibre). The effect of double carding was minimal, reducing the thickness only about 1 to 2%.

Mechanical Properties

The degree of effectiveness of reinforcement can be characterized by the Young's modulus of the composites (Figure 3.a). In general, the Young's modulus increased with an increase in fibre content – reaching a maximum value - two and a half times higher than at pure PP - at 50% fibre content and then decreasing slightly for a 70% fibre content, presumably by the poor wetting of fibres by the PP. Some 20–40% lower values were found in perpendicular than in parallel to the direction of carding. By double carding the modulus decreased by about 5% in the parallel direction and increased by about 20% in the perpendicular direction related to single carding.

Figure 3.b shows the anisotropic behaviour in the tensile parameters of the composite materials. The value of the ratio of the tensile parameters in the parallel direction to that in the perpendicular direction indicates the extent of anisotropy, a value of 1 means isotropicity. The lower this value, the lower the anisotropy.

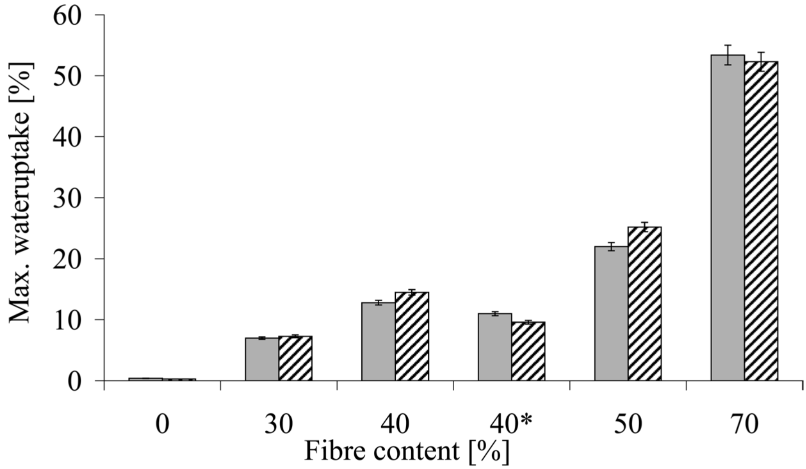


Figure 2.
The maximum water uptake as a function of fibre content; ▢ = parallel to the direction of carding, ▨ = perpendicular to the direction of carding, ∗ = double carded samples.

Double carding resulted in less anisotropic composite material, which is indicated by the lower difference between the properties measured in parallel and perpendicular directions as shown in Figure 3.b.

Tensile strength in the parallel direction tended to decrease with increasing hemp fibre content in the composite (a maximum decrease of 34% at 70% of hemp) as can be seen in Figure 3.c. This suggests that there is little stress transfer from the matrix to the fibres due to the incompatibility between the different surface properties of the polar fibres and non-polar PP. The un-wetted or poorly wetted fibre bundles can be easily pulled out of the composite matrix due to a lack of cohesiveness.

The tensile strength is about 20–40% lower in perpendicular than those in the parallel direction. Since the fibres lay perpendicular to the direction of load, they cannot act as load bearing elements in the composite matrix structure that is a potential defect, which could cause failure. Double carding produced similar effects in strength and modulus producing higher strength in the perpendicular direction but a lower strength in the parallel direction than that of the single carding as shown in Figure 3.b.

To qualify the composite materials, bending properties were also investigated. In the parallel direction, the **modulus** (Figure 4.a) calculated from the three point **bending** test increased continuously as a function of fibre content, and was two and half times higher for the highest fibre content (70%) than that of the pure PP, where as in the case of perpendicular direction no significant increase was found above 30% fibre content. In these samples the fibres laying parallel with the loading, and can not act as load bearing elements, in this case mostly the matrix ''works''. Double carding had a positive effect in both directions.

The bending modulus decreased dramatically after 19 days immersion in water, for example, by 10–40% at 30–50% fibre content, and by 77% at the highest fibre content related to the values of ''dry'' modulus, thus being lower than that for the PP. In perpendicular direction a similar tendency occurred, for example, the values in the wet state being 30–60% lower than those in the dry state.

The **ultimate bending stress** (calculated from the stress-strain curve at 10% deflection) showed a maximum at a 50% fibre content as shown in Figure 4.b. At the highest fibre content the lowest values were

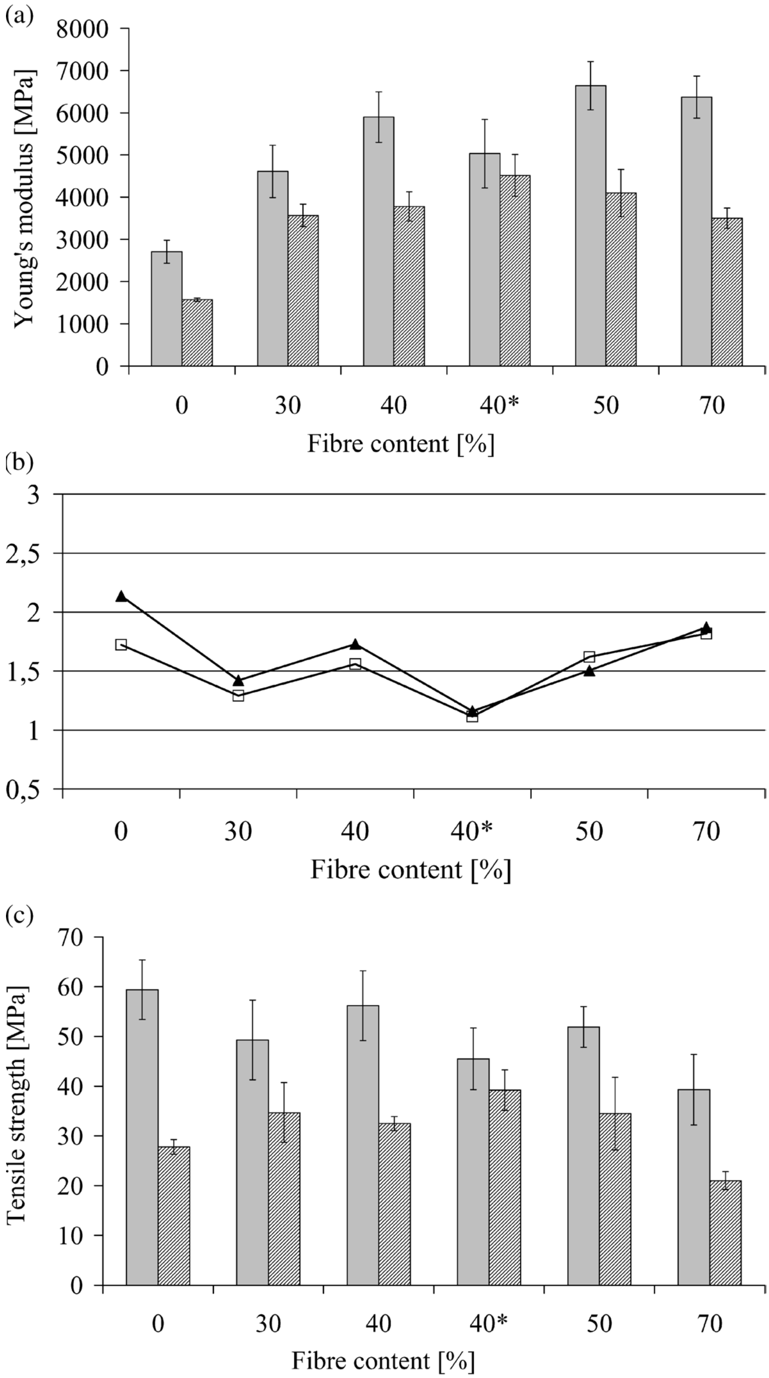
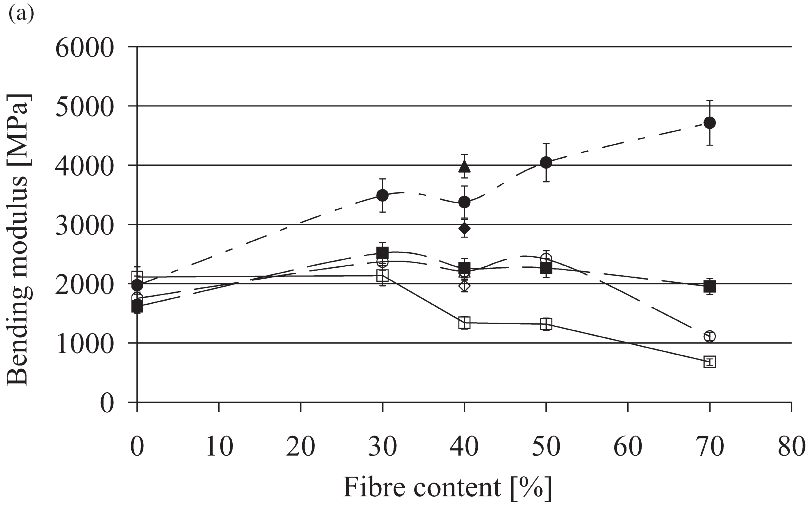


Figure 3.
a. Young's modulus as a function of fibre content; ▒ = parallel to the direction of carding, ▨ = perpendicular to the direction of carding, ✱ = double carded sample. b. The ratio of tensile parameters (parallel to perpendicular); □ = Young's modulus, ▲ = Tensile strength, ✱ = double carded sample. c. Tensile strength as a function of fibre content; ▒ = parallel to the direction of carding, ▨ = perpendicular to the direction of carding, ✱ = double carded sample.



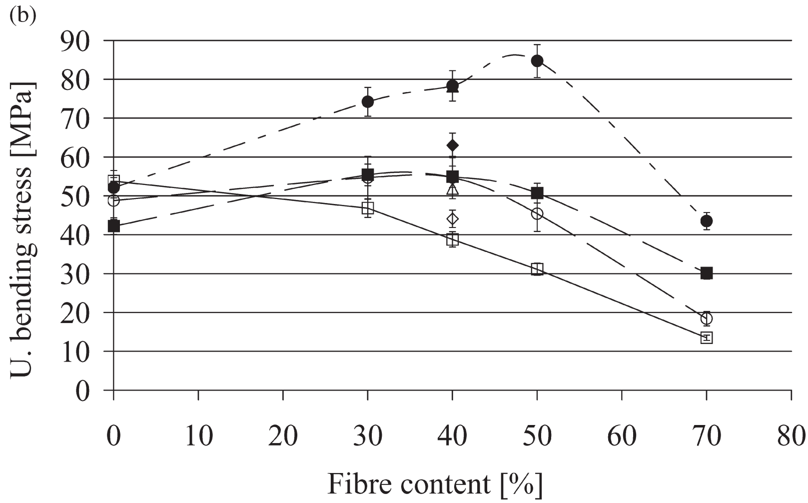


Figure 4.

a. Bending modulus as a function of fibre content,● = parallel to the direction of carding and tested in dry state (○ = tested in wet state), ■ = perpendicular to the direction of carding and tested in dry state (□ = tested in wet state), ▲ = double carded samples parallel in dry state (△ = tested in wet state),◆ = double carded samples perpendicular to the direction of carding and tested in dry state (◇ = tested in wet state).b. Ultimate (U.) bending stress as a function of fibre content,● = parallel to the direction of carding and tested in dry state (○ = tested in wet state), ■ = perpendicular to the direction of carding and tested in dry state (□ = tested in wet state), ▲ = double carded samples parallel in dry state (△ = tested in wet state), ◆ = double carded samples perpendicular to the direction of carding and tested in dry state (◇ = tested in wet state).

observed, lower than that of pure PP. The reduction in the strength is attributed to poor adhesion of fibers to the polymer matrix resulting from poor wetting of fibres by the polymer. As in the case of the other properties, lower values were found in the perpendicular direction. The ultimate bending stress of the double-carded composites was higher than for single carding. Similarly to the bending modulus, a higher decrease (28–60%) in bending strength can be seen in the wet state.

The **Izod impact strength** (Figure 5) of the dry composites increased by increasing

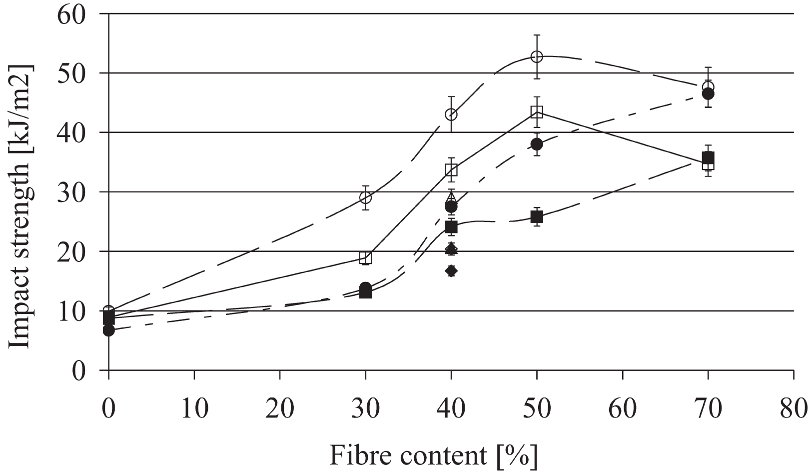


Figure 5.
Impact strength as a function of fibre content, ● = parallel to the direction of carding and tested in dry state (○ = tested in wet state), ■ = perpendicular to the direction of carding and tested in dry state (□ = tested in wet state), ▲ = double carded samples parallel in dry state (△ = tested in wet state), ◆ = double carded samples perpendicular to the direction of carding and tested in dry state (◇ = tested in wet state).

fibre content, being 4 and 5 times higher at 50% and 70% fibre content than that for PP alone.

Similarly to the other properties, higher impact strength was found in the machine direction than in the cross-machine direction. The impact strength decreased by about 25–30% in both directions due to double carding.

In contrast with the other characteristics, 110, 56, 40% higher impact strength was showed by the composite samples after immersion in water for 19 days as the fibre content increased from 30 to 50%. Test specimens containing 70% hemp showed the same result also in the parallel and perpendicular directions than those in the dry state.

Conclusion

The effect of hemp fibre content on the properties of hemp-PP nonwoven mats was investigated. Tensile, three point bending and impact tests were carried out in both the dry and wet states in order to study the effect of fibre content and structural anisotropy resulting from carding. The sorption characteristics and swelling of the composites were also investigated. The results of this study are as follows:

- The water uptake increased significantly with time of immersion, up to 19 days the maximum water uptake was lower at all hemp fibre content levels than was in the case for flax-PP composites previously reported.[14] The strongest anisotropic effect was observed at a 50% hemp fibre content, similar to the flax reinforced systems.
- On the basis of the mechanical tests, 40–50% fibre content appeared to be optimal.
- Bending properties of the wet composite samples was much lower than those of the dry samples, being the same or lower than that of PP, while the impact strength was significantly higher.
- Lower values for the mechanical properties were found in the direction perpendicular to carding compared to that in the direction parallel to carding, the water uptake was nearly the same in both directions.

– Composites from double-carded mats showed higher water resistance, and better bending properties than those made from single carded mats. In the case of the tensile properties, double carding produced higher values in the perpendicular direction but lower values in the parallel direction compared to single carding, which indicate the less anisotropic nature of the composites. A 25–30% decrease of impact strength was produced by double carding.

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