Development of hemp fibre-PP nonwoven composites

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1. Introduction

Natural fibres, such as flax, hemp, jute, and kenaf have received considerable attention as an environmentally friendly alternative for the use of glass fibres in engineering composites [1]. These plant fibres have a number of techno-ecological advantages over traditional glass fibres since they are renewable, can be incinerated with energy recovery, show less concern with safety and health (e.g. skin irritation) and give less abrasive wear to processing equipment such as extruders and moulds. In addition, they exhibit excellent mechanical properties, especially when their low density (1.4 g/cm^3 versus 2.5 g/cm^3 of glass) and price are taken into account [2-3]. 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 [4-5].

Using hybrid nonwovens as semi-finished products, made from a blend of natural and thermoplastic fibres, provide a good basis for high product quality. By mixing the two composite components before the consolidation a proportionate distribution and a good wetting of the reinforcing fibres is ensured [6-7].

In our earlier studies, short fibre reinforced and nonwoven flax-PP composites were prepared, and the effect of water uptake on their mechanical properties was also investigated [8-9]. A strong effect of water was found on the dimensional and mechanical properties, and the best parameters of nonwoven composites were observed by 30-50 % of reinforcement by weight [10].

In this study the effect of hemp fibre content and anisotropy of 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.

2. Materials and Methods

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

The fibres were blended manually in desired ratios of 30, 40, 50 and 70 % hemp by weight, after carding the thin layers were bonded by needle punching machine.

The technological parameters were maintained the same 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 of mats at a temperature of 190ºC. The test specimens were cut in machine and cross-machine directions of the carding machine used for making the mat.

The test samples were stored in distilled water at a room temperature for about 450 hours. Every day the samples were dried by paper towel and the increase in weight was measured. The tensile and three point bending test was performed on ZWICK equipment. The impact strength was also investigated. The specimens were tested in dry and also in wet states (after immersion for 19 days in distilled water).

3. Results and Discussion

3.1. Water sorption, swelling

The water sorption characteristics were not affected by the fibre content of composites (see Fig.1).

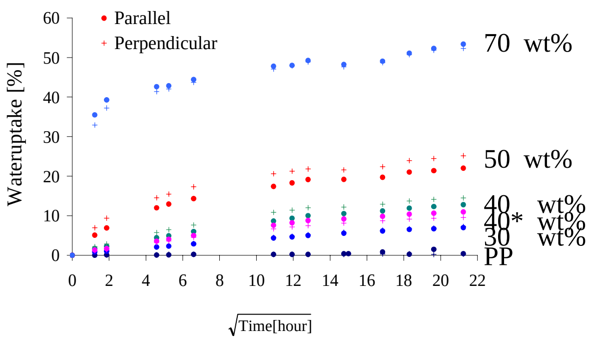


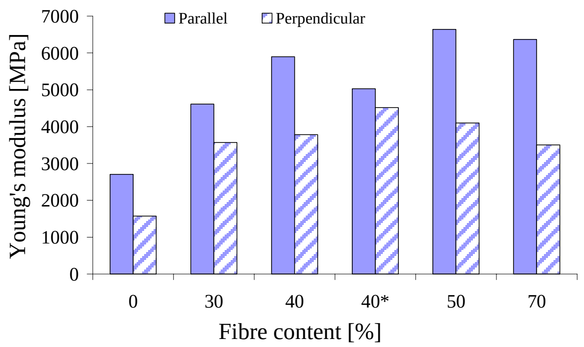
Fig.1: The correlation between water uptake and square root of time in parallel and in perpendicular to the direction of carding

The well-separated water sorption curves indicate the strong effect of the fibre content on sorption characteristics. At higher fibre content higher **water uptake** is noticed, and differences were found even after the first day of immersion in water. The **rate of water absorption** decreased significantly after the fifth day, the saturation was achieved on 17 to 19 days in the case of composites containing lower fibre content, however, no saturation was found in composites containing 50% and 70% hemp fibre.

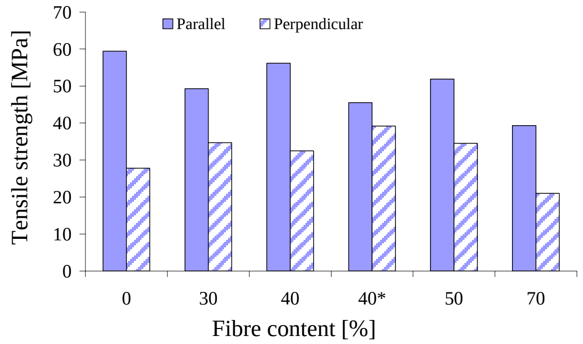
Almost 53% **water uptake** was measured at the highest fibre content of 70% by weight whereas only 7% water uptake was noticed in composites made by using 30% hemp fibre by weight.
Composites prepared by double carding showed about 1 to 5% lower water uptake than that made by single carding.
The real effect of anisotropy resulting from the carding technology in water uptake was found in the case of 50% hemp fibre reinforced composites, samples cut in perpendicular to the direction of carding showed 5% higher water uptake than in parallel direction.

3.2. Mechanical properties

The Young's modulus and the tensile strength values of composites are shown in Fig. 2.



a.



b.

Fig.2: (a) Young's modulus (top) and (b) tensile strength (down) as a function of fibre content in parallel and in perpendicular to the direction of carding (double carded sample)*

In general, the **Young's modulus** of the composite materials increases with the increase in the fibre content – reaching the maximum value at 50% fibre content and slightly lower there after at 70% fibre content. Almost two and half times higher modulus has resulted at 50% fibre content in comparison to that of pure PP (0% fibre content) as shown in Fig. 2(a).
About 15% lower modulus was found in the parallel direction and 20% higher in the perpendicular direction in the case of double carding in comparison to single carding. 20-40% lower values were found in perpendicular than in parallel to the direction of carding.

Double carding of raw materials resulted in less anisotropic composite material, indicated by the lower difference between the properties measured in parallel and perpendicular directions. The reduction in the modulus is attributed to poor wetting of fibres by polymer matrix. The un-wetted or poorly wetted fibre bundles can be easily pulled out of the composite matrix due to lack of cohesiveness.
By increasing the hemp fibre content in the composite a decreasing tendency (maximum decrease of 34 % at 70% of hemp by weight) was observed in the case of **tensile strength** as shown in Fig. 2(b)**.** In the perpendicular direction a reverse tendency was found, the tensile strength changed via maximum with the increasing fibre content. About 20-40% lower values were measured in the perpendicular direction. Since the fibres lay perpendicular to the direction of load, they cannot act as load bearing elements in the composite matrix structure which is a potential defect causing failure. The same effect of double carding was found in the strength as in the case of modulus.

The **modulus** (Fig.3.) calculated from three point **bending** test increased continuously in the parallel direction as a function of fibre content, and at the highest fibre content (70%) two and a half times higher values for bending modulus were found in comparison to that of only PP, while in the case of perpendicular direction no significant increase was found above 30 % fibre content.

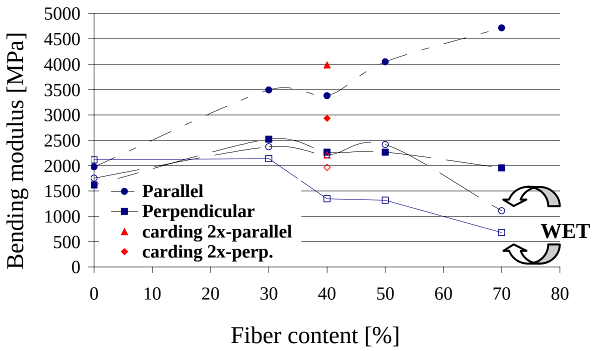


Fig.3: Bending modulus as a function of fiber content in parallel and in perpendicular to the direction of carding tested in dry and in wet state

Double carding has positive effect in both directions. The bending modulus decreased dramatically after 19 days immersion in water, for example by 77% at the highest ratio, thus being 35% lower than that of only PP. In perpendicular direction also a decreasing tendency and 30-60% lower values were found than that of in the dry state.
The **ultimate bending stress** (calculated from the stress-strain curve at 10% deflection) changed via maxima, the maximum increase (63%) was found at 50% fibre content as shown in Fig.4. At maximum fibre content lowest value was found than that of pure PP, and almost half stress than that of at the lowest investigated fibre content.

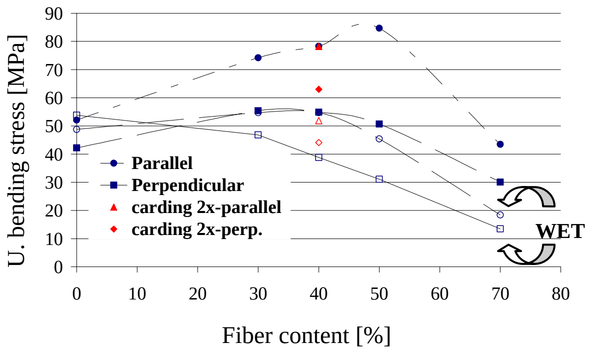


Fig.4: Ultimate bending stress as a function of fiber content in parallel and in perpendicular to the direction of carding tested in dry and in wet state

As it was shown in the case of other properties lower values were found in perpendicular direction. Ultimate bending stress of double-carded composites showed higher values than in the case of simple carding. Similarly to the bending modulus, a higher decrease (28-60%) in bending strength can be seen in the wet state.

Fig. 5. shows the results of **Izod impact test**. Impact strength of dry composites increased by increasing fibre content, almost 4 and 5 times higher values were found at 50% and 70% fibre content than that of PP alone.
The impact strength decreased by about 25-30% in both directions due to double carding.

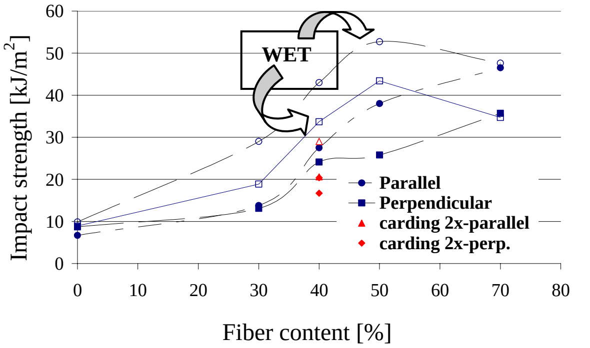


Fig.5: Izod impact strength as a function of fibre content in parallel and in perpendicular to the direction of carding tested in dry and in wet state

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 fibre showed the same result also in parallel and perpendicular direction than in the dry state.

4. Conclusion

Sorption characteristics and mechanical properties (in dry and also in wet state) of nonwoven hemp-PP composites were investigated. The effect of fibre content and structural anisotropy resulting from the carding technology was also studied.

The results of this work are as follows:

- significant increase of water uptake after 19 days immersion;
- the strongest effect of anisotropy at 50% hemp;
- 40-50% fibre content seemed to be optimal based on the mechanical properties;
- strong decrease in bending properties tested in the wet state (nearly the same or lower values than that of PP), significant increase in impact strength;
- weaker mechanical properties in the perpendicular direction, while nearly the same water uptake in both directions;
- double carding: less anisotropic nature, positive effect on wateruptake and bending properties, decrease in impact strength.

Acknowledgements

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