DEVELOPMENT OF HEMP FIBRE REINFORCED POLYPROPYLENE COMPOSITE

Hajnalka Hargitai[1], Ilona Rácz[1] and Rajesh Anandjiwala[2]

[1]*Bay Zoltán Institute for Materials Science and Technology*
H-1116. Budapest, Fehérvári u. 130. Hungary
[2] *National Fibre, Textile and Clothing Centre, CSIR M&MTek*
Port Elizabeth 6000, South Africa

SUMMARY: Nonwoven mats from hemp and polypropylene fibres in various proportions were produced and hot pressed to make composite material. The effect of fibre content and the anisotropy in nonwoven mat resulting from the carding technology were examined on the three-point bending, tensile and impact properties of resultant composite material. 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 the distilled water for 19 days, while the impact strength increased. Double carding of raw materials resulted into decreased anisotropy in composite material.

KEYWORDS: Hemp fibre reinforced polypropylene, nonwoven mat, mechanical properties, water sorption kinetics

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, 2]. 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 [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 focusing 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, 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 [11, 12].

In our earlier studies, short fibre reinforced flax-PP composites were prepared, and the best properties were found at 20-30% fibre content [6]. A slight effect of water uptake on the mechanical properties was pointed out [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 by 30-50 % of reinforcement by weight [14].

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.

EXPERIMENTAL

Materials, preparation

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 hybrid mats at a temperature of 190ºC. The test specimens were cut by a TRUMPF CO_2 laser equipment in machine and cross-machine directions of the carding machine used for making the mat.

Testing methods

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

The tensile test was performed on ZWICK tensile tester at 23±2 °C according to MSZ ISO 527 standard. 5 repetitions were done for each sample.

The three point bending test was carried out on ZWICK bending tester at 23±2 °C according to MSZ ISO 892-78 standard. The specimens were tested in dry and also in wet states (after immersion for 17 days in distilled water). 5 repetitions were done for each sample.

The impact strength was tested on ZWICK equipment at 23±2 °C according to MSZ ISO 180 standard. The test was carried out in dry and also in wet states. 5 repetitions were done for each sample.

RESULTS AND DISCUSSION

Water sorption, swelling

The water sorption characteristics were not affected by the fibre content of 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 our earlier studies [9], water uptake of nonwoven composites is not linear as a function of square root of time as shown in Fig.1.

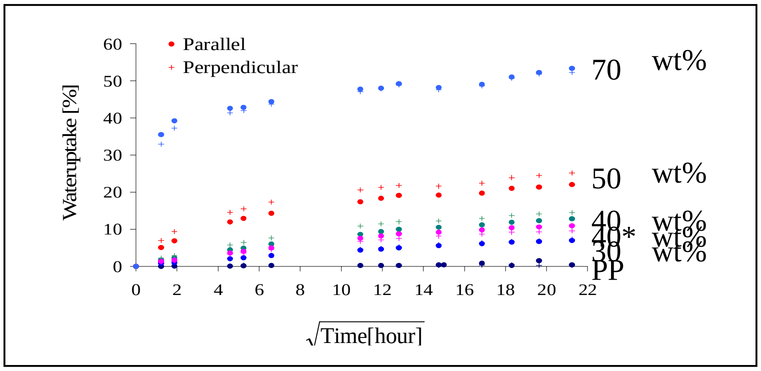

Fig.1: The correlation between wateruptake and square root of time in parallel and in perpendicular to the direction of carding

At higher fibre content higher **wateruptake** is noticed, and differences were found even after the first day of immersion in water. For example, the weight of composites increased by 2.4%, 6%, 13% and 42%, for the hemp fibre content of 30%, 40%, 50% and 70%, respectively. 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.

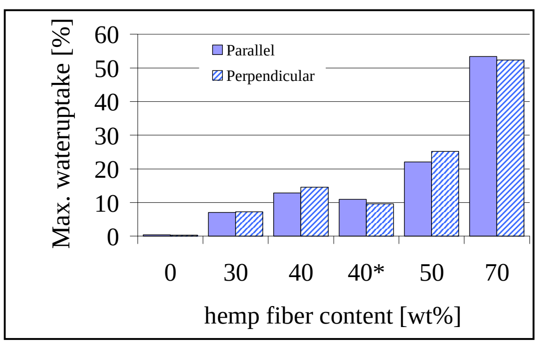

Fig. 2: The maximum wateruptake as a function of fibre content in parallel and in perpendicular to the directions of carding

For assessing the influence of anisotropy resulting from the carding technology, specimens were cut in parallel and also in perpendicular to the direction of carding from the composite sheets. The real effect of anisotropy in wateruptake was found in the case of 50% hemp fibre by weight in reinforced composites, samples cut in perpendicular to the direction of carding showed 5% higher wateruptake than in parallel direction. Almost 53% **wateruptake** was measured at the highest fibre content of 70% by weight whereas only 7% wateruptake was noticed in composites made by using 30% hemp fibre by weight as shown in Fig. 2. Composites prepared by double carding showed about 1 to 5% lower wateruptake than that made by single carding. Short fibre reinforced injection moulded composite samples (20% flax fibre by weight) picked up only about 1% water after 31 days immersion as discussed in our previous study [9].

The **thickness** of composites increased to maximum by 18% for 70% hemp fibre content, and by 6, 8, and 10% for composites made from 30%, 40%, and 50% hemp fibre content, respectively. The effect of double carding was minimal, about 1 to 2% lower relative thickness was observed.

Mechanical properties

The **Young's modulus** and the **tensile** strength values of composites are shown in Figure 3(a).

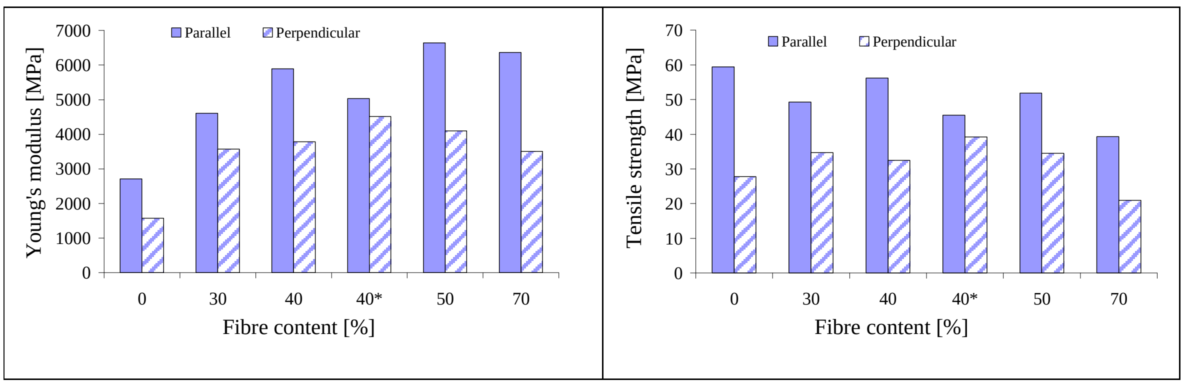

Fig.3(a): Young's modulus (left) and tensile strength (right) as a function of fibre content in parallel and in perpendicular to the direction of carding (double carded sample)*

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. A minimum decrease was observed by increasing the fibre content from 50 to 70%. 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. 3(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. Fig. 3(b) shows the effect of anisotropic behaviour in the tensile parameters of the composite materials. The value of the ratio of tensile parameter in the parallel to perpendicular direction indicates the extent of anisotropy, the value of one means the isotropicity. Double carding of raw materials 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 Fig. 3(b). 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.

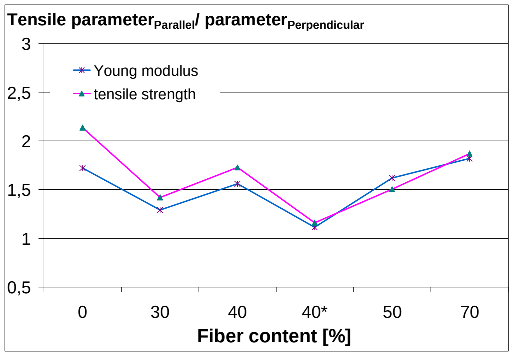

Fig.3(b): The relation of the tensile parameters in parallel to perpendicular to the direction of carding as a function of fibre content

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. 3(a)**.** 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. Higher strength in perpendicular direction and lower in parallel direction was observed than that of in the case of single carding as shown in Fig. 3(b).

The **modulus** (Fig.4.) 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. Double carding has 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 ratio, thus being 35% lower than that of only PP. In perpendicular direction also a decreasing tendency was found, for example, 30-60% lower values were found than that of in the dry state.

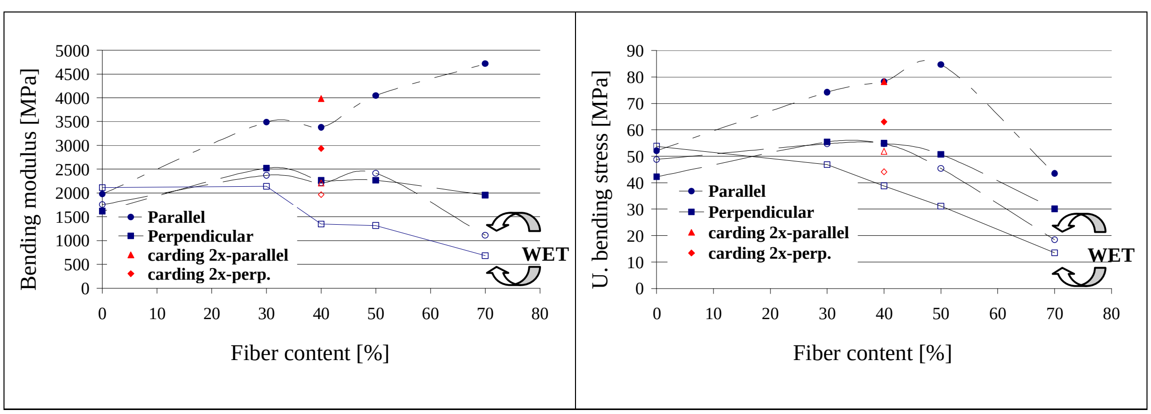

Fig.4: Bending modulus (left) and ultimate bending stress (right) as a function of fiber content in parallel and in perpendicular to the direction of carding tested in dry and in wet state

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. 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. Ultimate bending stress decreased by 25-30% in the perpendicular direction when compared to the parallel direction.

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. Similarly to the other properties higher 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.

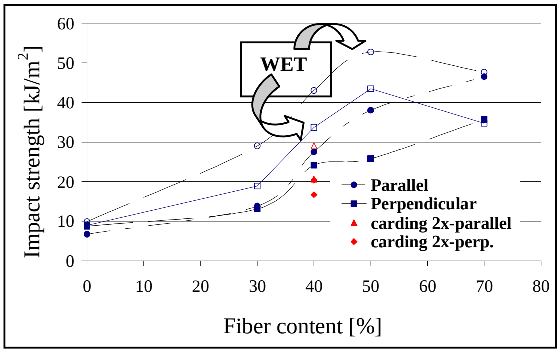

Fig.5: Izod impact strength as a function of fibre content in parallel and in perpendicular to the direction of carding tested in dry and in wet state

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.

CONCLUSIONS

Hemp-PP nonwoven mats were produced and hot pressed by changing the mass ratio of the fibres. Tensile, three point bending and impact tests were carried out in dry and also in wet state to study the effect of fibre content and structural anisotropy resulting from the carding technology. The sorption characteristics and swelling of composites were also investigated. The results of this study are as follows:

- The water uptake increased significantly after 19 days immersion, the maximal water uptake is lower at all fibre contents than that of in the case of flax-PP composites reported in our earlier studies [14]. The strongest effect of anisotropy was observed at 50% hemp fibre content, similar to the flax reinforced systems.
- Summarised the results of mechanical tests 40-50% fibre content seemed to be optimal.
- Strong decrease was observed in bending properties by testing the composite samples in the wet state, nearly the same or lower values were found than that of PP, while the impact strength increased significantly.
- Weaker mechanical properties were found in the perpendicular direction, the water uptake

was nearly the same in both directions.

- Composites from double-carded mats showed higher water resistance, and better bending properties than that of made from single carding mats. In tensile properties higher values in perpendicular and lower in parallel was found, which indicate the less anisotropic nature of the system. 25-30% decrease was detected for impact strength by double carding.

ACKNOWLEDGEMENTS

Supports by the Hungarian Ministry of Education (NKFP 3A/0036/2002) and by the Hungarian Science and Technology Foundation (DAK-2/03) and National Research Foundation of South Africa for Science & Technology Bilateral Exchange Programme are gratefully acknowledged.

REFERENCES

1. Peijs, T., Melick, H. G. H., Garkhail, S. K., Pott, G. T., Baille, C. A., "Natural-fibre-mat-reinforced thermoplastics based on upgraded flax fibres for improved moisture resistance", *Proceedings of the European Conference on composite Materials: Science, Technologies and Applications*, (Visconti, C. ed.), Woodhead Publishing, ECCM-8 3-6 June, Vol. 2, 1998**,** pp 119-126.

2. Oksman, K., Nilsson, P., "Thermoplastic composites based on natural fibres", *Proceedings of the European Conference on composite Materials: Science, Technologies and Applications,* (Visconti, C. ed.), Woodhead Publishing, ECCM-8 3-6 June, Vol. 2, 1998, pp 133-140**.**

3. Young, R. A., "Utilization of Natural Fibres: Characterization, Modification and Application", *Lignocellulosic-Plastic Composites* (Rowell, R. M., Schultz, T. P., Narayan, R. eds.)**,** VSP, Sao Paulo, Brazil, 1997, pp. 1-21.

4. Rowell, R. M., "Composite materials from agricultural resources", *Research in industrial application on non-food crops, I. plant fibres* (Olesen, Ole, Rexen, Finn, Larsen, Jorgen, eds.), Proceedings of a seminar, Copenhagen, Denmark. Lyngby, Denmark Academy of Technical Science, 1995, pp 27-41.

5. Bledzki, A. K., Gassan, J, "Natural fibre reinforced plastics", *Handbook of Engineering Polymeric Materials* (Cheremisinoff, N. P. Ed.) Marcel Dekker, New York, Basel, Hong Kong, 1997**,** pp 787-809.

6. Rowell, R. M., "A new generation of composite materials from agro-based fiber", *Proceedings of the 3rd international conference on frontiers of polymers and advanced materials - Polymer and other advanced materials: emerging technologies and business opportunities* (Prasad, P. N., Mark, James, E., Fai, Ting Joo, eds.), January, *1995.*

7. Hatakeyama, H., Hatakeyama, T., Nakamura, K., "Relationship between hydrogen bonding and water in cellulose", *Journal of Applied Polymer Science: Applied Polymer Symposium,* Vol. 37**,** 1983, pp. 979-991.

8. Sanadi, A., Caulfield, D. F., Jacobson, R. E., “Agro-Fiber/Thermoplastic Composites”, *Paper and Composites from Agro-Based Resources* (Rowell, R. M. et al. Ed.), Lewis Publishers, New York, 1997, p. 377.

9. Hargitai, H., Rácz, I., “Development of flax fiber reinforced polypropylene composites”, *7. Internationale Tagung Stoffliche Verwertung Nachwachsender Rohstoffe*, Chemnitz, Germany, 2000.

10. Czvikovszky, T., Hargitai, H., Rácz, I., Csukat, G., “Reactive compatibilization in polymer alloys, recyclates and composites”, *Nuclear Instruments and Methods in Physics Research*, B151, 1999, pp. 190-195.

11. Köhler, E., Bergner, A., Odenwald, S., “Forming of hybrid nonwovens made from natural and thermoplastic fibers”, *Proceedings of 2nd International Wood and Natural fibre Composites Symposium*, Kassel, Germany, 1999, p. 19-1.

12. Wielage, B., Köhler, E., Odenwald, S., Lampke, Th., Bergner, A., *Kunststoffe*, Vol. 89, 1999, pp. 60-62.

13. Hargitai, H., Rácz, I., “Influence of water on properties of cellulosic fibre reinforced polypropylene composites”, *International Journal of Polymeric Materials,* Vol. 47, 2000, pp. 667-674.

14. Hargitai, H., Rácz, I., “Development of flax-PP composites”, *Proceedings of Fourth Conference on Mechanical Engineering*, Budapest, Hungary, Springer Verlag Hungarica, Vol.1, 2004, pp. 87-9