Paper from Benny's work

by Juliana Anggono

Submission date: 18-Apr-2020 11:04AM (UTC+0700)
Submission ID: 1300749718
File name: draft_paper_Benny_to_journal.pdf (220.36K)
Word count: 5832
Character count: 31528

REINFORCEMENT OF POLYPROPYLENE WITH ALKALI TREATED SUGARCANE BAGASSE FIBERS: MECHANISM AND CONSEQUENCES

András Bartos[1,2], Benny Putra Utomo[3], Barnabás Kanyar[1,2], Juliana Anggono[3], Felycia Edi Soetaredjo[4], János Móczó[1,2] and Béla Pukánszky[1,2]

[1]Laboratory of Plastics and Rubber Technology, Department of Physical Chemistry and Materials Science, Budapest University of Technology and Economics, H-1521 Budapest, P.O. Box 91, Hungary

[2]Institute of Materials and Environmental Chemistry, Research Centre for Natural Sciences, Hungarian Academy of Sciences, H-1519 Budapest, P.O. Box 286, Hungary

[3]Department of Mechanical Engineering, Petra Christian University, Jalan Siwalankerto 121-131, Surabaya 60236, Indonesia

[4]Department of Chemical Engineering, Widya Mandala Surabaya Catholic University, Jalan Kalijudan 37, Surabaya 60114, Indonesia,

Corresponding author: András Bartos, Tel: +36-1-463-4337, E-mail: bartos.andras@mail.bme.hu

ABSTRACT

Polypropylene composites were prepared from neat and alkali treated sugarcane bagasse fibers. The results showed that alkali treatment leads to an increase in composite stiffness and strength. A maximum is achieved in these properties at 5 wt% NaOH content of the treating solution. The increase in properties was assigned to the improvement in inherent fiber characteristics. Acoustic emission testing and electron microscopy showed that the two main processes related to the fibers are their fracture and debonding; the latter is accompanied by the shear yielding of the matrix. Increased inherent strength of the fibers results in an increase of the initiation stress and fracture energy of the composites. Interfacial adhesion has a slight effect on stiffness, but more significant on strength and impact resistance. Changing adhesion modifies the relative importance of local deformation processes. It improves stress transfer and the load bearing capacity of the fibers, but suppresses matrix yielding.

KEYWORDS: A: fibres; D: acoustic emission; D: mechanical testing, E: injection moulding

1. INTRODUCTION

Polypropylene (PP) is a commodity polymer with one of the best price/performance ratios among all structural materials. It is used in large quantities in all areas of life including the building and the automotive industry [1, 2]. One of the advantages of PP is that its properties can be further modified in several ways including blending with elastomers [3], adding fillers [4] or reinforcing it with fibers [5-7]. Fiber modification increases the stiffness [6], but often also the strength of PP [7]; several short fiber reinforced grades are used in the automotive industry [2], for example. Traditionally glass [6, 7] (GF) and occasionally carbon fibers (CF)[8-10] are used as reinforcing material, achieving a stiffness as large as 13 GPa at least with carbon fibers [9, 10]. Recently, traditional fibers are often replaced with natural fibers or wood flour [11-17]. These fibers have various advantages including their natural origin, beneficial effect on carbon footprint, they are light and cheap, and have reasonable stiffness and strength as well [11, 12]. On the other hand, natural fibers have several drawbacks like the dependence of properties on the source of the fiber, the year of the harvest and on climatic conditions They are also sensitive to water and heat, they have poor adhesion to the polymer matrix and small transverse strength [11, 12].

Because of the benefits of natural fibers, many attempts are made to compensate for their weaknesses in one way or other. The diameter of the fibers or the size of wood particles is large and weak adhesion leads to the easy debonding of the matrix and the fiber under the effect of external load leading to small tensile strengths [18]. The easiest way to compensate for weak interfacial adhesion is the surface modification of the fibers [19-23]. Many approaches are used for surface treatment, the simplest is the coating of the fiber with a surfactant, often stearic acid [19, 23]. However, this treatment decreases the surface energy of the fiber leading to a further decrease in composite strength. Coupling is often achieved with the use of organosilanes [24, 25], isocyanates [25, 26] or other reactive compounds [27-29]. In polyolefins, efficient coupling can be achieved with the use of functionalized polymers, mainly with maleated PE or PP [19, 30-33]. Coupling suppresses debonding in a large extent, but frequently the fracture of the fibers or wood particles becomes the dominating failure mechanism as a result [18, 34, 35].

In the case of good adhesion, the poor transverse strength of fibers or wood particles leads to the failure of the composites and it is much more difficult to compensate for this weakness. The inherent strength was improved by the impregnation of wood particles with a phenolic resin in one case [36]. A slight improvement in strength was obtained in poly(lactic acid)/wood composites as the result. Very few other examples are found for the increase of fiber strength apart from the alkali treatment of lignonellulosic

fibers, which is an approach applied quite often used for the improvement of fiber and thus composite strength [37-41]. A wide variety of NaOH contents and treatment times is used in this procedure and various extent of improvement was observed in composite properties, mostly in strength [38, 42, 43]. The explanations are also diverse and sometime controversial, relating the improvement of properties to changing crystal modification [44], crystallinity [39-41], microfibrillar angle [40, 41], surface quality [20, 38], etc.

In a previous project, we subjected sugarcane bagasse fibers to alkali treatment and determined the composition and structure of the fibers [45]. NaOH content changed from 1 to 40 wt% and treatment time was 1 hour. A maximum was found in the stiffness and a more pronounced one in the strength of the fibers and the analysis of the results showed that the changes in properties can be related less to the modification of structure than to changing chemical composition. Although fiber strength increased considerably, we could not be certain that this increase is transferred also to the composites. Consequently, the goal of this study was to prepare composites with fibers treated with NaOH and determine their properties. The effect of concentration of the treating NaOH solution on the properties of composites with 20 wt% fibers was determined in preliminary experiments and then a more detailed study was carried out to define the influence of fiber content on composite properties. Untreated fibers were used as reference and composites were prepared with and without a coupling agent, i.e. at good and poor adhesion. Special attention was paid to local deformation processes and the mechanism of failure as well as the change in the inherent strength of the fibers were estimated from the study of local deformation processes. Consequences of the results for practice are also briefly mentioned at the end the paper.

2. EXPERIMENTAL

2.1. Materials

A polypropylene (PP) homopolymer, the Tipplen H649 FH (MFR: 2.5 g/10 min, 230 °C, 2.16 kg, ρ: 0.9 g/cm^3) grade produced by the Mol Group Ltd., Hungary was used as matrix in this study. Sugarcane bagasse fibers were used as reinforcing material, which were obtained directly from the sugar mill. They were washed with ethanol, dried, cut up and sieved. The average length of the fraction used during the work was 4560 ± 1870 μm and its average diameter was 340 ± 156 μm. A maleic anhydride grafted polypropylene (MAPP) was used as coupling agent to enhance the adhesion between the matrix and the lignocellulosic fibers. The grade used was the Scona TPPP 2112 FA produced by Byk-Chemie GmbH.

MAPP was added to the composites at 10 wt% calculated for the amount of the sugarcane bagasse. The MFR of the coupling agent was 3.5 g/10 min (190 °C, 2.16 kg) and its maleic anhydride content was 0.9-1.2 %. The NaOH flakes and the acetic acid solution of 96 wt% concentration used in the alkali treatment procedure were purchased from Molar Chemicals, Hungary.

2.2. Sample preparation

Before treatment, sugarcane bagasse was dried at 105 °C for 24 hours and then it was sieved to separate the material to a fiber like and a powdery fraction. 300 g of sieved fibers were placed into a bucket and 5 liter sodium hydroxide solution of 5 wt% concentration was poured on them. Another bucket contained 5 liter acetic acid solution of 10 wt% concentration diluted from the concentrated solution, and another bucket was filled with 10 liter of distilled water. The suspension was stirred occasionally during the 1 hour of the treatment. Subsequently the fibers were separated and placed into the acetic acid solution and let them soak for 10 min. The fibers were washed several times with tap water after neutralization and then they were placed into the bucket containing the distilled water. Fibers were prepared in a similar way for the preliminary study, but with NaOH solutions of different concentrations and in smaller amounts.

Right before extrusion, the fibers were dried again (4 hours, 105 °C) to evaporate the water traces absorbed in the lab during storage. A Brabender DSK 42/7 (Brabender, Germany) twin-screw extruder was used for homogenization with the temperature profile of 170-180-185-190 °C and screw speed of 40 min^{-1}. Extrusion was repeated twice for better homogeneity. ISO 527 1A type standard dog bone specimens (thickness 4 mm; width 10 mm) were injection molded from the granules using a Demag IntElect 50/330-100 injection molding machine. The temperature profile was 170-180-185-190 °C, the temperature at the hopper was 40 °C and the temperature of the mold was 40 °C as well. Injection speed was 50 mm/s and, depending on the composition, the injection pressure was 300-700 bar, while back pressure was 50 bar. Holding pressure was 2/3 of the injection pressure and holding time was set to 25 s. Cooling time was 30 sec. The injection molded specimens were left standing for a week at 23 °C and 50 % humidity before characterization.

2.3. Characterization

Mechanical properties (Young's modulus, yields stress and strain, as well as tensile strength and elongation-at-break) were determined using a universal Instron 5566 testing machine. The distance between

the grips was 115 mm and the rate of test was set to 5 mm/min. Acoustic emission (AE) testing was carried out simultaneously with tensile testing in order to follow the local deformation processes. The measurements were done by using a Sensophone AED 404 device. The AE signals were recorded by the help of an a11 type resonance detector (resonance frequency 150 kHz). The detector was clipped to the middle of the specimen and silicon grease was used to promote the propagation of ultrasonic sound between the specimen and the detector. The threshold level was set to 23 dB in order to filter out the noises. A Ceast Resil 5.5 impact tester was used to determine the impact resistance of the samples. The specimens were prepared according to the ISO 179 standard (Charpy impact test with a notch depth of 2 mm). A 4J hammer with a piezoelectric sensor was used for instrumented impact testing. A strip of silicone rubber was glued onto the hammer in order to reduce dynamic resonances. The morphology of fracture surfaces (after both tensile and impact testing) was studied by scanning electron microscopy using a Jeol JSM 6380 LA apparatus (Jeol Ltd., Tokyo, Japan).

3. RESULTS AND DISCUSSION

The results are presented in several sections. The conclusions of the preliminary experiments are reported first and then the composition dependence of properties are shown in the next section. Deformation and failure mechanisms are discussed subsequently followed by the presentation of general correlations and practical consequences in the last section of the paper.

3.1. Effect of alkali concentration

The study of the effect of alkali treatment on fiber characteristics indicated a maximum in fiber stiffness and strength at around 5 wt% NaOH content of the treating solution [45]. We could not assume a priori that the optimum in composite properties will be reached at the same degree of treatment, at the same alkali concentration. Consequently, the goal of the preliminary study was to identify the existence of an extremum in properties and its location on the NaOH concentration scale. Fibers were treated with solutions of different alkali concentration and then composites were prepared at 20 wt% fiber content from them. The tensile strength of the composites is plotted against the concentration of the treating solution in **Fig. 1**. A maximum is detected at around 5 wt% NaOH content indeed. Apparently, the improvement in the stiffness and strength of neat fibers as an effect of alkali treatment is transferred to the composites as well. The extent of increase is smaller than in the case of the fibers, strength increased from around 400 to 600

MPa there, but a maximum clearly exists, the strength of composites containing the treated fibers is definitely larger than that of the materials prepared with the neat fiber.

The increase of composite stiffness and strength as the result of the alkali treatment of natural fibers has been shown before [40, 41, 45] and it was more or less expected also in the case of bagasse fibers. On the other hand, impact resistance also increased considerably, from around 2.5 kJ/m^2 to a value around 4 kJ/m^2 (**Fig. 2**), which is rather surprising, since increased stiffness and strength are usually accompanied by smaller impact resistance. We must call the attention here to the fact that the preliminary experiments were done at good adhesion, with a coupling agent, which decreases debonding and usually increases the number of fiber fractures [18, 35]. One might assume that the improved impact resistance results from the modification of the inherent strength of the fibers, which hinders the failure of the fibers and thus fracture initiation and propagation in the composites. However, this tentative explanation must be checked and proved in the further course of the study.

3.2. Composition dependence of properties

The effect of fiber treatment on composite properties was studied at various fiber contents at good and poor adhesion. The NaOH concentration of the solution used for the treatment was 5 wt%. The Young's modulus of composites containing the treated and untreated fibers is plotted against fiber content in **Fig. 3**. Composites containing the alkali treated fibers are clearly stiffer than those prepared with the neat fibers. Adhesion has practically no effect on stiffness in the case of the treated fibers, which is in agreement with previous experience [18, 19, 34]. On the other hand, coupling resulted in the decrease of stiffness for the neat fibers that is difficult to explain. The premature failure of fibers with large diameter parallel to their axis is one possible explanation, which, however, needs further confirmation.

Alkali treatment has a similar effect on the tensile strength of the composites; composites containing the treated fibers are stronger than materials prepared with the neat fibers (**Fig. 4**). The difference is not large, but the increase is unambiguous. As expected, coupling has a much larger influence on strength than on stiffness. Composite strength increases considerably with fiber content in the case of good adhesion, while it remains practically constant in the absence of the coupling agent. The phenomenon was observed before and was explained with changing local deformation processes [30, 34, 35]. However, the better inherent properties, i.e. larger strength, of the fibers is evident also at poor adhesion.

The preliminary experiments indicated an interesting increase in the impact resistance of

composites prepared with the treated fibers. However, composites contained the fibers at a single composition, at 20 wt% fiber content in those experiments. The effect of fiber content on the impact resistance is presented in **Fig. 5** for the four series of composites. Treatment improved impact resistance indeed and the effect depended also on the presence or absence of the coupling agent. The largest impact resistances were measured for the composites containing the treated fibers at poor adhesion, while the smallest for the untreated fiber at good adhesion. The treated fibers with coupling, as well as the untreated fibers without the coupling agent gave more or less similar impact resistance values somewhere between the extreme cases. Obviously, the combined effect of fiber treatment and interfacial adhesion determines impact resistance, which changes in a range somewhere between 2 and 4.5 kJ/m^2. The change is influenced by inherent fiber properties and local deformation processes discussed in the next section. We must emphasize here, though, that the impact resistances measured are moderate, and much larger values are required in certain applications.

3.3. Deformation and failure mechanism

Experience shows that in heterogeneous polymeric materials macroscopic properties are determined by local deformation processes taking place during deformation. These processes can be related to the matrix or to the heterogeneities. Certain processes can be followed by acoustic emission testing, by the measurement of elastic waves resulting from a local process. These waves can be picked up by piezoelectric sensors placed on the specimen during tensile testing. Such processes can be the debonding of the matrix from the filler or reinforcement, cracking or fiber fracture. The result of such a test is presented in **Fig. 6a**. The measurement was done on the composite containing 20 wt% of the treated fiber in the absence of the coupling agent, i.e. at poor adhesion. The small circles in the figure are individual events or signals indicating the occurrence of at least one local process. The signals can be divided into two main groups. The first group is located at small deformations, below 2 %. The amplitude of these signals (vertical location) is small compared to the group detected at larger deformations. The distribution of the signals indicates the occurrence of two local events and according to previous experience [18, 34, 35] these might be assigned to the debonding of the fibers and to fiber fracture or pullout. The construction of the cumulative number of signal trace (continuous correlation, right axis) also indicates the two stages and thus the two processes, debonding in smaller numbers and more events in the second process. The other continuous line (left axis) shows the corresponding stress vs. elongation trace as reference. Adhesion changes the

correlations considerably (see **Fig. 6b**). Stronger interfacial adhesion led to the development of larger stresses and also to a larger number of events with slightly larger amplitude. The first group of events disappeared; only one local process takes place during deformation. Changing interfacial adhesion obviously changed local deformation processes and the modification of these later led to the changes in properties. Acoustic emission testing yielded very similar results for the untreated fiber, differences can be observed mainly in the distribution, as well as in the number and amplitude of the events recorded.

Acoustic emission testing showed that two local processes take place in the studied composites during deformation, the relative number of which depends on adhesion. However, the unambiguous identification of the two processes is difficult or even impossible based on these experiments. Scanning electron microscopy might offer further information on the processes mentioned. Two typical micrographs are presented in **Fig. 7**, again for the treated fiber with and without the coupling agent. The debonding of large particles can be seen in **Fig. 7a** confirming the occurrence of this process in the absence of the coupling agent. At good adhesion, mainly the fracture of the fibers occurs as shown by **Fig. 7b**. The aspect ratio of the fibers is small and they even twist during processing thus we conclude that less pullout takes place, but the fracture of the fiber is the dominating process in the presence of the coupling agent

The study of local deformation processes by acoustic emission testing proved that in the presence of the coupling agent the dominating local process is fiber fracture, which thus determines both the strength and impact resistance of the composites. The results unambiguously proved that treated fibers are stronger and this can be explained only with an increase in the inherent strength of the fibers. Previous experience showed that acoustic emission testing allows the estimation of inherent fiber strength. Extrapolation of the characteristic stress determined from the cumulative number of signal vs. elongation traces in the way indicated in **Fig. 6a** to the volume fraction of 1 gives fiber strength [46]. An earlier study showed that fiber strength extrapolates to the same value in different polymer matrices [46] thus validating the procedure. In **Fig. 8** characteristic stresses are plotted against the volume fraction of the fiber in the way suggested above. An exponential function was fitted to the characteristic stresses derived from AE testing and the result of the fitting clearly shows that treated and untreated fibers extrapolate to different values to 45.0 and 38.7 MPa, respectively. The determination coefficient indicating the goodness of the fit was 0.9947 and 0.9977, respectively, in the two cases. The difference of about 6 MPa does not seem to be large, but sufficient to bring about the moderate changes observed in the strength and impact resistance of the composites as the result of the alkali treatment of the fibers.

3.4. Correlations, consequences

The alkali treatment of sugarcane bagasse fibers resulted in the increase of their stiffness and strength; a maximum was observed in these characteristics as a function of the NaOH concentration of the treating solution. A similar maximum was observed in the stiffness, strength and even the impact resistance of the composites indicating that inherent fiber characteristics strongly influence composite properties and the effect of treatment was transferred from the fibers to the composites. In order to check the relationship, the tensile strength of the composites at good adhesion was plotted against the strength of the fibers in **Fig. 9**. Although the standard deviation of fiber strengths is quite large, the correlation is unambiguous, composite strength increases with increasing fiber strength.

In practice, often the combination of large stiffness and impact resistance is required for structural materials. The two quantities are plotted against each other in **Fig. 10**. Increased modulus is accompanied by increased impact strength in three of the series. Increasing fiber content leads to increased stiffness (see **Fig. 3**). Debonding and the fracture of the fibers proved to be the main local deformation processes related to the fibers. On the other hand, debonding facilitates the shear yielding of the matrix, which consumes considerable amount of energy during fracture. However, increased adhesion hinders the shear yielding of the polymer. The increased inherent strength of the fibers leads to increased fracture resistance in the case of the treated fibers, but the effect was reduced somewhat by good adhesion. Large extent of debonding of the untreated fibers resulted also in reasonable impact resistance, but coupling decreased shear yielding and the smaller strength of the untreated fibers led to decreased fracture strength. Although modulus and impact resistance could be increased simultaneously and the alkali treatment of the fibers was beneficial for composite properties, the impact resistance values obtained are moderate at most. The composites prepared in this study can be used in structural applications in which stiffness and strength are required and a smaller fracture resistance suffices.

4. CONCLUSIONS

The study of PP composites reinforced with sugarcane bagasse fibers treated with NaOH showed that alkali treatment results in increased composite stiffness and strength compared to materials prepared with the untreated fibers. A maximum is achieved in these properties at around 5 wt% NaOH content of the

treating solution. The increase is moderate, but clear. The reason for the increase in these properties could be identified as the result of the improvement in inherent fiber properties. Acoustic emission testing and electron microscopy showed that the two main processes related to the fibers are their fracture and debonding, the latter accompanied by the shear yielding of the matrix. Increased inherent strength of the fibers results in an increase in the initiation strength and fracture energy of the composites. Interfacial adhesion has a slight effect on stiffness, but much more significant on strength and impact resistance. Changing adhesion modifies the relative importance of local processes. It improves stress transfer and the load bearing capacity of the fibers, but suppresses matrix yielding. Using the sugarcane bagasse fibers results in a simultaneous increase of stiffness and impact strength in PP composites, but the combination of properties, especially impact resistance, is not exceptional. Although alkali treatment is beneficial for composite properties as claimed in the literature, its application needs serious considerations, the slight improvement achieved might not be always worth the effort.

5. ACKNOWLEDGEMENTS

The authors thank Judit Kócs for her help in the sieving and handling of the fibers. The National Research, Development and Innovation Fund of Hungary (OTKA K 120039 and FK 129270) is greatly acknowledged for the financial support of the research. We are also grateful to the Ministry of Research, Technology and Higher Education of the Republic of Indonesia for the research grant 002/SP2H/LT/K7/KM/2017. The Candi Baru Sugar Factory, Indonesia is acknowledged for providing the sugarcane bagasse fibers.

6. REFERENCES

1. Güneri A. Polymers in construction. Shrewsbury: Rapra Technology Limited; 2005.

2. Flowers B. Automotive applications for polypropylene and polypropylene composites. In: Karian H, editor. Handbook of polypropylene and polypropylene composites, revised and expanded. Boca Raton: CRC Press; 2003. p. 578-86.

3. Chow WS. Polypropylene blends: properties control by design. In: Karger-Kocsis J, Bárány T, editors. Polypropylene handbook: morphology, blends and composites. Cham: Springer International Publishing; 2019. p. 419-80.

4. Móczó J, Pukánszky B. Particulate filled polypropylene: structure and properties. In: Karger-Kocsis J, Bárány T, editors. Polypropylene handbook: morphology, blends and composites. Cham: Springer International Publishing; 2019. p. 357-417.

5. Chu FP. Glass fiber–reinforced polypropylene. In: Karian H, editor. Handbook of polypropylene and polypropylene composites, revised and expanded. Boca Raton: CRC Press; 2003. p. 281-351.

6. Thomason JL, Vlug MA. Influence of fibre length and concentration on the properties of glass fibre-reinforced polypropylene: 1. Tensile and flexural modulus. Compos Part A Appl Sci Manuf 1996;27(6):477-84.

7. Thomason JL, Vlug MA, Schipper G, Krikor HGLT. Influence of fibre length and concentration on the properties of glass fibre-reinforced polypropylene: Part 3. Strength and strain at failure. Compos Part A Appl Sci Manuf 1996;27(11):1075-84.

8. Xiaochun Y, Youhua Y, Yanhong F, Guizhen Z, Jinsong W. Preparation and characterization of carbon fiber/polypropylene composites via a tri-screw in-line compounding and injection molding. Adv Polym Tech 2018;37(8):3861-72.

9. Fu S-Y, Lauke B, Mäder E, Yue C-Y, Hu X. Tensile properties of short-glass-fiber- and short-carbon-fiber-reinforced polypropylene composites. Compos Part A Appl Sci Manuf 2000;31(10):1117-25.

10. Fu S-Y, Lauke B, Mäder E, Yue C-Y, Hu X, Mai Y-W. Hybrid effects on tensile properties of hybrid short-glass-fiber-and short-carbon-fiber-reinforced polypropylene composites. J Mater Sci 2001;36(5):1243-51.

11. Rowell RM. Natural fibres: types and properties. In: Pickering KL, editor. Properties and performance of natural-fibre composites. Boca Raton: Woodhead Publishing; 2008. p. 3-66.

12. Clemons C. Raw materials for wood-polymer composites. In: Oksman K, Sain M, editors. Wood-polymer composites. Boca Raton: CRC Press LLC; 2008. p. 1-22.

13. Keledi G, Sudár A, Burgstaller C, Renner K, Móczó J, Pukánszky B. Tensile and impact properties of three-component PP/wood/elastomer composites. Express Polym Lett 2012;6(3):224-36.

14. Dai D, Fan M. Wood fibres as reinforcements in natural fibre composites: structure, properties, processing and applications. In: Hodzic A, Shanks R, editors. Natural fibre composites. Sawston: Woodhead Publishing; 2014. p. 3-65.

15. Sobczak L, Lang RW, Haider A. Polypropylene composites with natural fibers and wood – General mechanical property profiles. Compos Sci Technol 2012;72(5):550-7.

16. Várdai R, Lummerstorfer T, Pretschuh C, Jerabek M, Gahleitner M, Pukánszky B, et al. Impact modification of PP/wood composites: A new approach using hybrid fibers. Express Polym Lett 2019;13(3):223-34.

17. Bledzki AK, Franciszczak P, Mamun A. The utilization of biochemically modified microfibers from grain by-products as reinforcement for polypropylene biocomposite. Express Polym Lett 2014;8(10):767-78.

18. Dányádi L, Renner K, Móczó J, Pukánszky B. Wood flour filled polypropylene composites: Interfacial adhesion and micromechanical deformations. Polym Eng Sci 2007;47(8):1246-55.

19. Dányádi L, Móczó J, Pukánszky B. Effect of various surface modifications of wood flour on the properties of PP/wood composites. Compos Part A Appl Sci Manuf 2010;41(2):199-206.

20. Liu XY, Dai GC. Surface modification and micromechanical properties of jute fiber mat reinforced polypropylene composites. Express Polym Lett 2007;1(5):299-307.

21. Zafeiropoulos NE. Engineering the fibre – matrix interface in natural-fibre composites. In: Pickering KL, editor. Properties and Performance of Natural-Fibre Composites. Boca Raton: Woodhead Publishing; 2008. p. 127-62.

22. Raj RG, Kokta BV, Daneault C. Polypropylene-wood fiber composites: effect of fiber treatment on mechanical properties. Int J Polym Mater 1989;12(3):239-50.

23. Raj RG, Kokta BV, Dembele F, Sanschagrain B. Compounding of cellulose fibers with polypropylene - Effect of fiber treatment on dispersion in the polymer matrix. J Appl Polym Sci 1989;38(11):1987-96.

24. Raj RG, Kokta BV, Maldas D, Daneault C. Use of wood fibers in thermoplastics. VII. The effect of coupling agents in polyethylene–wood fiber composites. J Appl Polym Sci 1989;37(4):1089-103.

25. Lu J, Wu Q, McNabb H. Chemical coupling in wood fiber and polymer composites: a review of coupling agents and treatments. Wood Fiber Sci 2000;32(1):88-104.

26. Maldas D, Kokta BV. Effect of fiber treatment on the mechanical properties of hybrid fiber reinforced polystyrene composites: III. Use of mica and sawdust as hybrid fiber. J Reinf Plast Comp 1991;10(1):42-57.

27. Alila S, Ferraria AM, Botelho do Rego AM, Boufi S. Controlled surface modification of cellulose fibers by amino derivatives using N,N′-carbonyldiimidazole as activator. Carbohydr Polym 2009;77(3):553-62.

28. Zadorecki P, Flodin P. Surface modification of cellulose fibers. II. The effect of cellulose fiber treatment on the performance of cellulose–polyester composites. J Appl Polym Sci 1985;30(10):3971-83.

29. Faludi G, Dora G, Renner K, Móczó J, Pukánszky B. Improving interfacial adhesion in pla/wood biocomposites. Compos Sci Technol 2013;89(0):77-82.

30. Dányádi L, Janecska T, Szabó Z, Nagy G, Móczó J, Pukánszky B. Wood flour filled PP composites: Compatibilization and adhesion. Compos Sci Technol 2007;67(13):2838-46.

31. Li Q, Matuana LM. Effectiveness of maleated and acrylic acid-functionalized polyolefin coupling agents for HDPE-wood-flour composites. J Thermoplast Compos Mater 2003;16(6):551-64.

32. Mutje P, Vallejos ME, Girones J, Vilaseca F, Lopez A, Lopez JP, et al. Effect of maleated polypropylene as coupling agent for polypropylene composites reinforced with hemp strands. J Appl Polym Sci 2006;102(1):833-40.

33. Keener TJ, Stuart RK, Brown TK. Maleated coupling agents for natural fibre composites. Compos Part A Appl Sci Manuf 2004;35(3):357-62.

34. Dányádi L, Renner K, Szabó Z, Nagy G, Móczó J, Pukánszky B. Wood flour filled PP composites: adhesion, deformation, failure. Polym Adv Technol 2006;17(11-12):967-74.

35. Renner K, Kenyó C, Móczó J, Pukánszky B. Micromechanical deformation processes in PP/wood composites: Particle characteristics, adhesion, mechanisms. Compos Part A Appl Sci Manuf 2010;41(11):1653-61.

36. Csizmadia R, Faludi G, Renner K, Móczó J, Pukánszky B. PLA/wood biocomposites: Improving composite strength by chemical treatment of the fibers. Compos Part A Appl Sci Manuf 2013;53:46-53.

37. Van de Weyenberg I, Chi Truong T, Vangrimde B, Verpoest I. Improving the properties of UD flax fibre reinforced composites by applying an alkaline fibre treatment. Compos Part A Appl Sci Manuf 2006;37(9):1368-76.

38. Gassan J, Bledzki AK. Possibilities for improving the mechanical properties of jute epoxy composites by alkali treatment of fibres. Compos Sci Technol 1999;59(9):1303-9.

39. Sawpan MA, Pickering KL, Fernyhough A. Effect of various chemical treatments on the fibre structure and tensile properties of industrial hemp fibres. Compos Part A Appl Sci Manuf 2011;42(8):888-95.

40. Mwaikambo LY, Ansell MP. Mechanical properties of alkali treated plant fibres and their potential as reinforcement materials. I. hemp fibres. J Mater Sci 2006;41(8):2483-96.

41. Mwaikambo LY, Ansell MP. Mechanical properties of alkali treated plant fibres and their potential as reinforcement materials II. Sisal fibres. J Mater Sci 2006;41(8):2497-508.

42. Rajesh G, Prasad AVR. Tensile properties of successive alkali treated short jute fiber reinforced PLA composites. Proc Mater Sci 2014;5:2188-96.

43. Oushabi A, Sair S, Oudrhiri Hassani F, Abboud Y, Tanane O, El Bouari A. The effect of alkali treatment on mechanical, morphological and thermal properties of date palm fibers (DPFs): study of the interface of DPF-Polyurethane composite. S Afr J Chem Eng 2017;23(1):116-23.

44. Sreenivasan S, Iyer PB, Iyer KRK. Influence of delignification and alkali treatment on the fine structure of coir fibres (Cocos Nucifera). J Mater Sci 1996;31(3):721-6.

45. Bartos A, Anggono J, Farkas ÁE, Kun D, Soetaredjo FE, Móczó J, et al. Alkali treatment of sugarcane bagasse fibers: composition, structure, properties. Submitted to Int J Biol Macromol 2019.

46. Faludi G, Link Z, Renner K, Móczó J, Pukánszky B. Factors determining the performance of thermoplastic polymer/wood composites; the limiting role of fiber fracture. Mater Des 2014;61:203-10.

CAPTIONS

Fig. 1 Correlation between the concentration of the NaOH solutions used for the alkali treatment of sugarcane bagasse fibers and the tensile strength of their PP composites. Fiber content: 20 wt%.

Fig. 2 Effect of the concentration of the treating solution on the impact resistance of PP/sugarcane bagasse fiber composites at 20 wt% fiber content.

Fig. 3 The stiffness of PP/sugarcane bagasse fiber composites plotted against fiber content. Effect of alkali treatment and coupling. Symbols: (□) untreated, (■) untreated, MAPP, (○) alkali treated, (●) alkali treated, MAPP.

Fig. 4 Correlation between the tensile strength of PP/sugarcane bagasse fiber composites and fiber content. Symbols are the same as in **Fig. 3**.

Fig. 5 Impact resistance of PP composites reinforced with sugarcane bagasse fibers plotted as a function of fiber content. Symbols are the same as in **Fig. 3**.

Fig. 6 The result of the acoustic emission testing of a PP composite reinforced with alkali treated sugarcane bagasse fiber. Fiber content: 20 wt%. Symbols: (○) individual acoustic signals, solid lines: cumulative number of signal trace (right axis), stress vs. elongation correlation (left axis). a) poor adhesion (no MAPP), b) good adhesion (MAPP)

Fig. 7 SEM micrographs recorded on the fracture surface of PP composites reinforced with 20 wt% alkali treated sugarcane bagasse fiber. a) no MAPP, b) with MAPP.

Fig. 8 Estimation of the inherent strength of sugarcane bagasse fiber used for the reinforcement of PP. Characteristic stress plotted against fiber content. Good adhesion. Symbols: (□) untreated, (○) alkali treated (5 wt%). The solid lines are exponential functions fitted to the measured data to determine fiber strength.

Fig. 9 Correlation between the strength of sugarcane bagasse fibers treated with alkaline solutions of different concentrations and that of the PP composites prepared from them. Fiber content: 20 wt%.

Fig. 10 Correlation between the stiffness and impact resistance of PP composites reinforced with sugarcane bagasse fibers. Effect of alkali treatment and interfacial adhesion. Symbols are the same as in **Fig. 3**.

Paper from Benny's work

ORIGINALITY REPORT

18%	12%	17%	7%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Imre, B., and B. Pukánszky. "From natural resources to functional polymeric biomaterials", European Polymer Journal, 2015. Publication	1%
2	Sudár, András, Christoph Burgstaller, Károly Renner, János Móczó, and Béla Pukánszky. "Wood fiber reinforced multicomponent, multiphase PP composites: Structure, properties, failure mechanism", Composites Science and Technology, 2014. Publication	1%
3	www.misuremeccaniche.it Internet Source	1%
4	repozitorium.omikk.bme.hu Internet Source	1%
5	A. Sudár, K. Renner, J. Móczó, T. Lummerstorfer, Ch. Burgstaller, M. Jerabek, M. Gahleitner, P. Doshev, B. Pukánszky. "Fracture resistance of hybrid PP/elastomer/wood composites", Composite Structures, 2016	1%

Publication

6	R. Csizmadia, G. Faludi, K. Renner, J. Móczó, B. Pukánszky. "PLA/wood biocomposites: Improving composite strength by chemical treatment of the fibers", Composites Part A: Applied Science and Manufacturing, 2013 Publication	1%
7	"Polypropylene Handbook", Springer Science and Business Media LLC, 2019 Publication	1%
8	Gupta, . "Trends in the Research of Natural Fibre–Reinforced Composites and Hybrid Composites", Engineering Materials, 2014. Publication	1%
9	Brúnó Bozsódi, Vivien Romhányi, Piroska Pataki, Dávid Kun, Károly Renner, Béla Pukánszky. "Modification of interactions in polypropylene/lignosulfonate blends", Materials & Design, 2016 Publication	1%
10	www.mdpi.com Internet Source	1%
11	journals.sagepub.com Internet Source	1%
12	Renner, K.. "Micromechanical deformations in PP/lignocellulosic filler composites: Effect of	1%

matrix properties", Composites Science and Technology, 201007
Publication

13	onlinelibrary.wiley.com Internet Source	1%
14	Dóra Andrea Kajtár, Csaba Kenyó, Károly Renner, János Móczó, Erika Fekete, Christoph Kröhnke, Béla Pukánszky. "Interfacial interactions and reinforcement in thermoplastics/zeolite composites", Composites Part B: Engineering, 2017 Publication	<1%
15	hal.archives-ouvertes.fr Internet Source	<1%
16	biblio.ugent.be Internet Source	<1%
17	eprints.usq.edu.au Internet Source	<1%
18	Submitted to University of Auckland Student Paper	<1%
19	res.mdpi.com Internet Source	<1%
20	"Cellulose Fibers: Bio- and Nano-Polymer Composites", Springer Science and Business Media LLC, 2011 Publication	<1%

21	John O. Akindoyo, Mohammad D.H. Beg, S. Ghazali, Hans P. Heim, Maik Feldmann, M. Mariatti. "Oxidative induction and performance of oil palm fiber reinforced polypropylene composites – Effects of coupling agent and UV stabilizer", Composites Part A: Applied Science and Manufacturing, 2019 Publication	<1%
22	Péter Polyák, Dóra Szemerszki, György Vörös, Béla Pukánszky. "Mechanism and kinetics of the hydrolytic degradation of amorphous poly(3-hydroxybutyrate)", Polymer Degradation and Stability, 2017 Publication	<1%
23	Pozsgay, A.. "Gallery structure and exfoliation of organophilized montmorillonite: effect on composite properties", European Polymer Journal, 200401 Publication	<1%
24	József Hári, Flóra Horváth, Károly Renner, János Móczó, Béla Pukánszky. "Comparison of the reinforcing effect of various micro- and nanofillers in PA6", Polymer Testing, 2018 Publication	<1%
25	Suryaputra, Wijaya, Indra Winata, Nani Indraswati, and Suryadi Ismadji. "Waste capiz (Amusium cristatum) shell as a new	<1%

heterogeneous catalyst for biodiesel production", Renewable Energy, 2013.
Publication

---

26 R. N. Kumar, A Pizzi. "Adhesives for Wood and Lignocellulosic Materials", Wiley, 2019 <1%
Publication

---

27 Juliana Anggono, Resmana Lim, Frans Limbong, Herry Christian Palit, Poedi Soenarjo Wartono. "Diversity, Unity, and Global Citizenship Education: A Case Study in Community Outreach Program in Indonesia", SHS Web of Conferences, 2018 <1%
Publication

---

28 Faludi, Gábor, Zoltán Link, Károly Renner, János Móczó, and Béla Pukánszky. "Factors determining the performance of thermoplastic polymer/wood composites; the limiting role of fiber fracture", Materials & Design, 2014. <1%
Publication

---

29 Submitted to University of Sydney <1%
Student Paper

---

30 Bengtsson, M.. "Extrusion and mechanical properties of highly filled cellulose fibre-polypropylene composites", Composites Part A, 200708 <1%
Publication

Jawaid, M.. "Cellulosic/synthetic fibre reinforced

31	polymer hybrid composites: A review", Carbohydrate Polymers, 20110801 Publication	<1%
32	Gábor Faludi, Zoltán Link, Károly Renner, János Móczó, Béla Pukánszky. "Factors determining the performance of thermoplastic polymer/wood composites; the limiting role of fiber fracture", Materials & Design, 2014 Publication	<1%
33	Gábor Szabó, Vivien Romhányi, Dávid Kun, Károly Renner, Béla Pukánszky. "Competitive Interactions in Aromatic Polymer/Lignosulfonate Blends", ACS Sustainable Chemistry & Engineering, 2016 Publication	<1%
34	docplayer.fr Internet Source	<1%
35	Faludi, G., G. Dora, K. Renner, J. Móczó, and B. Pukánszky. "Improving interfacial adhesion in pla/wood biocomposites", Composites Science and Technology, 2013. Publication	<1%
36	Fayçal Mijiyawa, Demagna Koffi, Bohuslav V Kokta, Fouad Erchiqui. "Formulation and tensile characterization of wood–plastic composites", Journal of Thermoplastic Composite Materials, 2014	<1%

Publication

37	Submitted to University of Ulster Student Paper	<1%
38	akademiai.com Internet Source	<1%
39	Parul Sahu, MK Gupta. "A review on the properties of natural fibres and its bio-composites: Effect of alkali treatment", Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 2019 Publication	<1%
40	Lívia Dányádi. "Wood flour filled PP composites: adhesion, deformation, failure", Polymers for Advanced Technologies, 11/2006 Publication	<1%
41	M. Hetzer. "Thermal Dependence of Young's Modulus of Wood/Polymer/Clay Nanocomposites", Journal of Composite Materials, 09/01/2009 Publication	<1%

Exclude quotes	On	Exclude matches	< 10 words
Exclude bibliography	On		