Performance and Evaluation of Low Cost Sugarcane Bagasse – Polypropylene Biocomposites as Candidate Material for Automotive Parcel Tray

by Juliana A15

Materials Science Forum
ISSN: 1662-9752, Vol. 923, pp 40-46
doi:10.4028/www.scientific.net/MSF.923.40

Submitted: 2017-11-28
Accepted: 2017-12-04
Online: 2018-05-21

Performance and Evaluation of Low Cost Sugarcane Bagasse – Polypropylene Biocomposites as Candidate Material for Automotive Parcel Tray

JULIANA Anggono[1,a], SUWANDI Sugondo[1,b], RASSY Alim[1,c], HARIYATI Purwaningsih[2,d], and ARIA Wibawa[3,e]

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

[2]Department of Materials and Metallurgical Engineering, Sepuluh Nopember Institute of Technology, Surabaya 60111, Indonesia

[3]Dasa Windu Agung, Bekasi 17151, Indonesia

[a]julianaa@petra.ac.id, [b]aeusug@indo.net.id, [c]rassyalim@gmail.com, [d]hariyati@mat-eng.its.ac.id, [e]aria.wibawa@dwa.co.id

Keywords: sugarcane bagasse, parcel tray, biocomposites, flexural strength.

Abstract. Many auto manufacturers such as Mercedes Benz, Toyota and DaimlerChrysler have already embraced natural fiber composites into both interior and exterior parts and are looking to expand the uses of this composites. They have to balance the changing public demands of greater comfort, better driving performances, and higher safety standards with the environmental requirements. Based on the preliminary study using 20 to 30 wt.% NaOH treated sugarcane bagasse fibers to make biocomposites with polypropylene matrix, the tensile strength obtained was variably, in the range between 8.31 to 20.59 MPa. A further study was required to improve the strength of the composites in comparison with the specified flexural strength required by the industry for automotive parcel tray. The sugarcane bagasse fibers obtained from the sugar mill were used and alkali treated with 10% v/v NaOH at various soaking time of 2, 4, and 6 hours. Biocomposite samples were prepared from 25/75 wt.% ratio sugarcane fibers/polypropylene (PP). The highest tensile strength of 14.35 MPa was obtained from the samples with sugarcane fibers receiving two-hour alkali treatment. However, the highest flexural strength (37.78 MPa) was gained on the samples made from sugarcane fibers with 4 hours alkali treatment. This value has met the strength specification of two materials for current parcel trays which were made from monomaterial of polypropylene and woodboard composite which their flexural strengths were 35.6 MPa and 37.57 MPa, respectively. Structural studies using scanning electron microscopy (SEM) on the fracture surface of tensile tested samples show two different orientations of bagasse fibres in PP matrix, i.e. a group was in longitudinal orientation and other in transversal orientation.

Introduction

The need for a global response with reference to energy security concerns and CO_2 reduction puts further pressure to the automotive industry. Legislation and regulations have been issued in improving the fuel economy of automobiles and reduction in greenhouse gas emissions thus the carmakers have two major challenges arise: fuel efficiency and emission reduction - two different problems, leading to the same challenge of how to make vehicles 'green' and more efficient, while keeping additional costs at an acceptable level. In the US, regulations in the form of Corporate Average Fuel Economy (CAFE) has increased its standard of average mileage for 2025 to 55 mpg (miles/gallon) – an increase of 57% from the target set for 2016 (35 mpg) [1]. European legislation in the formula of the End of Life Vehicle (ELV) directive states that by 2015 vehicles must be constructed of 95% recyclable materials, with 85% recoverable through reuse or mechanical recycling and 10% through energy recovery or thermal recycling [2]. The directive aims to reduce the amount of waste from vehicles (which includes automobiles and vans) and also includes requirements for member states to introduce strict standards for the treatment of ELVs at authorized treatment facilities. Meanwhile Japan is already on the path to more stringent fuel economy standards by having Japanese vehicle fuel economy regulations as part of the "Law Concerning the Rational Use of Energy" (Energy Conservation Law) [3]. The Japanese system sets average fuel economy targets for different vehicles based on weight. The Japanese fuel efficiency target for passenger vehicles (703-827 kg) in 2010 was 18.8 km/L (5.3 L/100 km or 44 mpg US) and the target was raised 12% for 2015 to a value of 21 km/L (4.8 L/100 km or 49 mpg US). Besides Europe, US, and Japan there is one rapidly growing country, namely, China, which has established standard of maximum values for fuel consumption (in L/100 km) according to weight categories. The Chinese fuel consumption standards for light-duty vehicles (750 < Curb Mass (kg) ≤ 865) in 2009 was 6.9 L/100 km and the target was raised 14% for 2012 to a value of 5.9 L/100 km [4].

In the response to the government legislation on environmental issues, carmakers employ several approaches; among the major pathways are transmission, electrification, hybrid technologies, and lighweighting. There is a significant growth in recent years for the use of natural fibers as a result of automotive lighweighting. Material substitution, specifically the utilization of natural fiber-polymer composites have prompted tremendous weight reduction without trading off on safety. Bigger reduction can be realised in structural and nonstructural parts such as underbody cover, dashboards, parcel tray, roof, frontend, and door modules.

Historically, the use of natural fiber composites in the car industry was from 1942 when Henry Ford unveiled the first prototype composite car made from hemp fibers and cellulose-based plastics [5, 6]. The car, unfortunately, did not make it into general manufacture because of economic constraints at the time. In Europe, the East German "Trabant" car body, manufactured between 1950 and 1990, was one of the first to use materials containing natural fibers, i.e. cotton fibers set in a polyester matrix. Mercedes-Benz, a subsidiary company of Daimler-Benz has pioneered to use coconut fibers in their commercial automobiles over a 9-year period. Jute-based door panels were first used by Mercedes E-class vehicles in 1996. Then in September, 2000, DaimlerChrysler started employing sisal grown by local farmers for their vehicle production situated in East London, South Africa [6].

History has seen various attempts to integrate natural materials into car parts. Some have been more effective than others; the environmental issue coupled with consumer pressure are a major driver for the uptake of natural fiber composites. This research work shared the same concerns, particularly important for a highly populated country like Indonesia, in which the cars production for domestic demands is high. As indicated by market research consultation firm Frost & Sullivan, Indonesia has one of the biggest automotive prospect in ASEAN after Thailand. They also predicted that Indonesia will be the region's biggest automotive market by 2019 [7]. Analysis by Association of Indonesian Automotive Manufacturers (Gaikindo) chief Jongkie D. Sugiarto stated that the sales of domestic car could have 5 % increment to 1.05 million units in 2017 [8].

Natural fibres, such as hemp, flax and wood have already found applications in the automotive industry, primarily in non-structural parts such as interior panels, parcel trays, etc. [9]. In this study, biocomposites using sugarcane bagasse fibers obtained from a sugarmill factory in East Java were combined with polypropylene (PP) matrix. Sugarcane fibers are one of the many natural fibers grown in Indonesia. Indonesia is rank ninth as major sugarcane producers after Brazil, India, China (mainlands), Thailand, Pakistan, Mexico, Colombia, Philippines with a crop production of 28.7 million tons in 2012 [10]. The bagasse fibers have been mainly used as fuel for boilers in sugarmills and they are also the raw materials for particle board manufacturing, compost, and animal feeding. The utilization of bagasse fibers as reinforcing fiber materials for biocomposites will have a significant value in terms of utilization of waste from sugarmills in Indonesia. Previous research [11] has used bagasse fiber as reinforcing fibers for PP matrix composites by varying the fiber length and the wt.% ratio of bagasse fiber to polypropylene (PP) matrix. It was found that a variability in the fibre properties can lead to variability of mechanical properties (tensile strength was in the range of 8.31 to 20.59 MPa) besides the importance to achieve a homogeneous mixing between the natural fibers and the matrix materials. In this study, bagasse fibers were given NaOH treatment with various soaking time, i.e. 2 hours, 4 hours, and 6 hours. The wt.% ratio of sugarcane/PP studied was 25/75. The composites' strength performance was evaluated using tensile and flexural tests and the results were compared with the strength specification of two industrial products for parcel tray (Fig. 1) made from monomaterial PP and woodboard composite. SEM study was conducted to evaluate the composites structure and to relate it with strength gap existed between the samples and the materials provided by the industry.

Fig. 1 Rear parcel tray as car's interior part [12].

Research Method

Materials and Preparation. There were two materials required for making biocomposite samples, i.e. sugarcane bagasse and PP fibers. Sugarcane bagasse fibers were obtained from a sugarmills, P.T. Candi Baru in Sidoarjo - Indonesia. The PP fibers were supplied by a local carpet industry, P.T. Classic Prima Carpet Industries in Surabaya - Indonesia. PP fibers were cut in 1 cm length to ensure they were homogeneously mixed with the bagasse.

The bagasse fibers had to go a two-step treatment, i.e. 1) neutralization using ethanol 70% in which each kg of bagasse was soaked in 2.5 litres of ethanol for one hour. Upon soaking, the bagasse were dried in the oven (Memert UN 55) at temperature 110 °C for 4 hours, followed by 2) an alkali treatment using NaOH 10% v/v at a temperature 70°C with various soaking time of 2, 4, and 6 hours. After treatment, the bagasse were water rinsed several times to ensure the NaOH solution had been washed away by checking the pH of the rinsed water to get pH = 7. After rinsing and draining the water, then the bagasse were dried in the oven at temperature of 110 °C for 4 hours.

Mixing and Hotpressing. PP fibers and dried baggasse fibers were loaded into a mixer with a composition of a wt.% ratio of bagasse fibers/PP: 25/75 (16.23 volume fraction of bagasse fibers). The mixture was arranged and prepared on a thin galvanized steel plate measuring 38 x 15 cm^2. Hotpressing was performed in two steps: 1) The PP/bagasse fibers mixture was placed between two flattened steel mould of the hotpress machine and pressed using a compressive stress of 136.7 kPa at 100 °C for 6 minutes to make a flat panel preform. 2) The preform was further hotpressed using compressive stress of 136.7 kPa at 200 °C for 6 minutes to form a flat panel of biocomposites sample. The hot panel was kept in between the steel plates to receive a 40 kg load for 15 minutes to avoid bending during cooling.

Strength and Structural Characterisation. Samples for tensile and flexural tests were prepared from the biocomposites panels made through hotpressing. Each panel which was made from bagasse fibers with different treatment time in NaOH was cut with CNC machine to make five samples for tensile test and other five for flexural test. The sample dimensions and the test procedure referred to ASTM D 638-03 and D 790-10 for tensile and flexural tests respectively. Both tests were conducted using universal testing machine, Shimadzu with a capacity of 10 and 50 kN at Polymer Technology Center in Tangerang - Indonesia. Structural evaluation on fractured surfaces of tensile samples was performed using SEM (Scanning Electron Microscope) of FEI type Inspect S50.

Results and Discussion

Characterization on Sugarcane Bagasse. Sugarcane stems consist of three major components: the pith (5 %), fibers (73 %), and the rind (22 %) [13]. Bagasse fibers were reported to have considerably low elongation (1.1 %) and tensile strength of about 222 MPa and modulus Young of 27 MPa [14]. The fiber length was not controlled in this research as the as-received fibers were directly used. However, to know the length of the bagasse fibers used, around 600 bagasse fibers were picked as sampling for length measurement. The measurement identified that majority of fibers (73%) were less than 3 cm, about 26% had a length of 3-5 cm and a few (1 %) were fibers with a length more than 5 cm.

Composites Thickness. Fig. 2 shows the thickness of the composites produced. The thickness was in the range of 2.01 to 2.21 mm with the thickest composites was measured in the samples made from sugarcane fibers after 2-hour NaOH treatment. The thickness trend decreases with the increase of soaking time during alkali treatment due to a decrease in fibre diameter [11, 15]. The decrease in fibre diameter is due to the removal of lignin and hemicellulose from the fiber during NaOH treatment. The work of Rezendel *et al.* (2011) reported a very efficient alkaline pretreatments using NaOH solutions (40 minutes) with concentration 1% where up to 85% lignin fractions were removed from the solid fraction [11, 16]. In comparison with the thickness of monomaterial PP produced by the industry, the sample thickness is close and needs only a small adjustment through the reduction amount of the raw materials and/or the pressure. Similar solutions with adding more raw materials of sugarcane fibers/PP to gain a woodboard thickness of 3 mm.

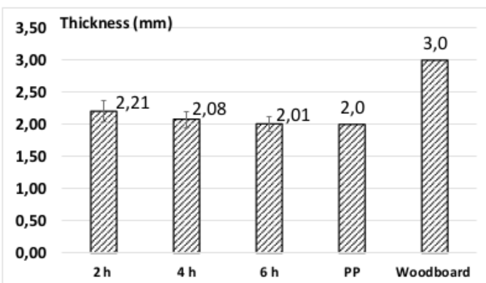


Fig. 2 Thickness of composite samples in comparison with the thickness of PP and woodboard from the industry

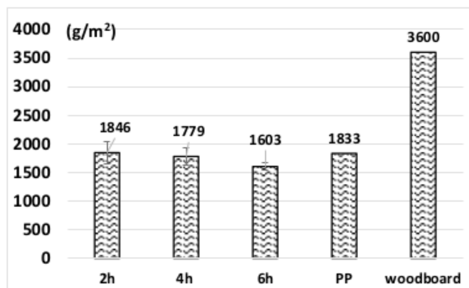


Fig. 3 Areal density of composite samples in comparison with the same density of PP and woodboard from the industry

Areal Density Measurement. Areal density measurement was done to all flexural test samples with a dimension of 120x13 mm or each has an area of 1560 mm^2. Fig. 3 shows the areal density of all samples produced together with the areal density values of PP and woodboard samples. As the thickness was reduced when the bagasse fibers were alkali treated longer, this also had the effects on their areal density due to the weight loss experienced by the bagasse fibers after longer period of alkali treatment. Lightweight materials as indicated by areal density measurement are required by the automotive industry to achieve fuel efficiency.

Strength Characterization. Tensile strength of the woodboard was used for a comparative study with the strength of the samples. The tensile strength of all samples shown in Fig. 4 was in the range of 13.95 MPa to 14.38 MPa. These values are still 5.9 to 9.2 % less than the strength of the woodboard (15.23 MPa).Wood like other natural fibers, such as hemp and flax has found applications in the automotive industry, mainly in non-structural parts such as interior panels and parcel trays as these products do not experience high stresses in service, their mechanical properties can be moderate to low.

The flexural strength reported in Fig. 5 shows quite promising results where the flexural strength of the samples were in the range of 32.19 to 37.78 MPa. The samples using 4-hour treated bagasse fibers have the highest flexural strength (37.78 MPa) and the lowest flexural strength was found in composites samples reinforced with 6-hour NaOH treated bagasse fibers (32.19 MPa). The tensile strength obtained indicates a similar trend with the flexural strength, which are shown a decrease in strength with extending soaking time of NaOH treatment though there is an exception for flexural strength with the samples using 4 hour-treatment which it shows the highest flexural strength.

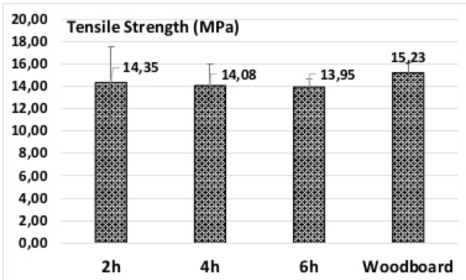


Fig. 4 Tensile strength of the composite samples in comparison with the strength of woodboard from the industry

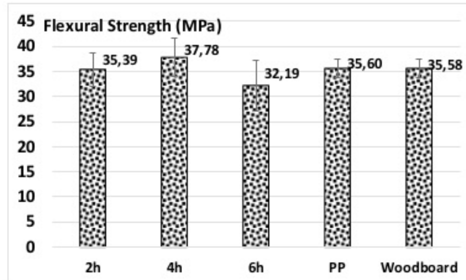
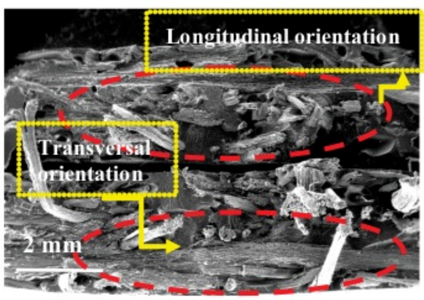
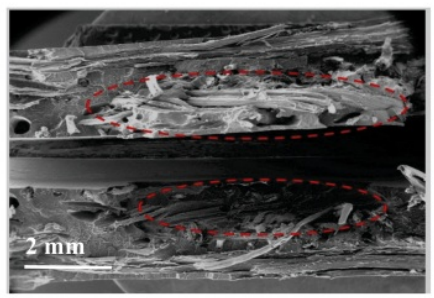


Fig. 5 Flexural strength of the composite samples in comparison with the strength of woodboard from the industry

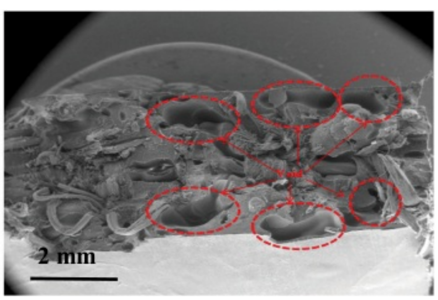
Structural Characterization. Fig. 6 shows tensile fractured surfaces of the composites observed using SEM. In general, the micrographs show the oriention of the fibers, some are in the longitudinal direction and some are in transversal direction (Fig. 6 (a) and 6 (b)).



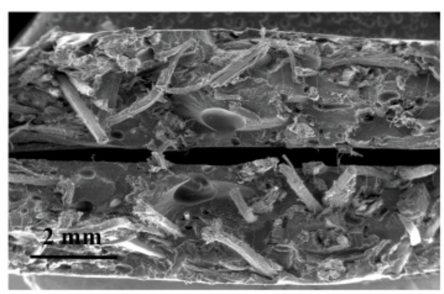
a)



b)



c)



d)

Fig. 6 SEM micrographs on tensile fractured surfaces on samples a) with 2-hour treated bagasse fibres, b) with 4-hour treated bagasse fibres, c) and d) with 6-hour treated bagasse fibres.

As these bagasse fibers had a length only less than 3 cm thus their orientation could not be arranged and they were randomly distributed in the PP matrix. In the composites made from 6-hour treated bagasse fibers, voids dominated in the PP matrix. These voids might form from the air trapped in the PP matrix during it melted at hotpressing process and was not able to escape upon cooling.

The fiber pull-out were found only minor in the structure of all composites using treated bagasse fibers in all variant of treatment time though more fibers pull-out were found at Fig. 6(c) and (d) from samples using 6-hour treated bagasse fibers. Less fiber pull-out indicates a good interfacial bond between the bagasse fibers and the PP matrix. These findings are in agreement with the lowest tensile and flexural strength obtained in these samples. The six hours soaking time can weaken and damage the bagasse fibers.

Conclusion

The sugarcane bagasse-PP composites are suitable candidate material to replace PP or another choice of material besides woodboard composite. The tensile and flexural strength of the sugarcane fibers/PP composites made from two-hour and four-hour NaOH treated bagasse fibers are very close to and even higher than the strength of current materials, PP and woodboard used by the automotive industry for parcel tray application.

Acknowledgements

The authors sincerely express their gratitude to Ministry of Research, Technology and Higher Education of Republic of Indonesia for the research funding on scheme “Penelitian Produk Terapan” by under grant no. 002/SP2H/P/K7/KM/2016 and 002/SP2H/K7/KM/2017. We also wish to thank P.T. Classic Prima Carpet Industries in Surabaya for providing the polypropylene fibers. Ms. Russava Istiani is gratefully ackowledged with the assistance in using scanning electron microscope.

References

[1] U.S. Environmental Protection Agency, Office of Transportation and Air Quality, “EPA and NHTSA Set Standards to Reduce Greenhouse Gases and Improve Fuel Economy for Model Years, 2017-2025 Cars and Light Trucks,” (pdf file, 2012).

[2] Information on http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02000L0053-20130611&qid=1405610569066&from=EN (retrieved on 19 August 2017)

[3] Information on https://www.dieselnet.com/standards/jp/fe.php (retrieved on 19 August 2017)

[4] Information on http://www.transportpolicy.net/standard/china-light-duty-fuel-consumption/ (retrieved on 19 August 2017)

[5] S. Pilla and Y.C. Lu, in: Biocomposites in Automotive Applications, SAE International, Warrendale (2015), pp. 1–2.

[6] B. C. Suddell and W. J. Evans, in: Natural Fiber Composites in Automotive Applications, in Natural Fibers, Biopolymers, and Biocomposites edited by A.K. Mohanty, M. Misra and L.T . Drzal, CRC Press (2005).

[7] Information on https://ww2.frost.com/ news/press-releases/ positive-outlook-indonesian-automotive-market/ (retrieved on 19 August 2017)

[8] Information on http://www.thejakartapost.com/adv/2016/04/24/ the-growth-of- the-automotive-industry-and-car- ownership-in-indonesia.html (retrieved on 19 August 2017)

[9] H. Hoydonckx, in: Renewable Furan Resins in Composite Applications, Composites Innovation 2001 Conference Proceedings, www.netcomposites.com.

[10] Information on http://faostat.fao.org/site/339/default.aspx (retrieved on 24 July 2016).

[11] J. Anggono, S. Sugondo, S. Sewucipto, H. Purwaningsih, and S. Henrico: AIP Conference Proceedings 1788, 030055 (2017)

[12] Information on http://rica.org.uk

[13] N. Reddy and Y. Yang, in: Innovative Biofibers from Renewable Resources, Springer-Verlag, Heidelberg (2015), pp. 29-30.

[14] J.L. Guimaraes, E. Frollini, C.G. Silva, F. Wypych, K.G. Satyanarayana: Ind. Crop. Prod. 30, 407 (2009).

[15] J. Anggono, N. R.Habibi, and S. Sugondo, in: Alkali Treatment on Sugarcane Bagasse to Improve Properties of Green Composites of Sugarcane Bagasse Fibers-Polypropylene, in Ceramic Engineering and Science Proceedings, 35, 139–149. American Ceramic Society and John Wiley (2014).

[16] C. A. Rezende1 et al., in: Biotech. For Biofuels 4 (2011), p 54.

Performance and Evaluation of Low Cost Sugarcane Bagasse – Polypropylene Biocomposites as Candidate Material for Automotive Parcel Tray

ORIGINALITY REPORT

16%	9%	7%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.scientific.net Internet Source	9%
2	Suddell, Brett, and William Evans. "Natural Fiber Composites in Automotive Applications", Natural Fibers Biopolymers and Biocomposites, 2005. Publication	7%

Exclude quotes	On	Exclude matches	< 5%
Exclude bibliography	On		