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Impact behavior of apus bamboo (*Gigantochloa apus*) fiber/epoxy green composites

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Abstract. The objective of this work is to investigate the impact behavior of bamboo fiber/epoxy composites. The test was carried out in accordance with the ASTM D5941 Izod impact test standard. Whilst the fiber was obtained from local bamboo the matrix being used is Eposchon general purpose Bisphenol A-epichlorohydrin epoxy resin mixed with Eposchon general purpose Polyaminoamide epoxy hardener. The specimens were cut from nine bamboo fiber/epoxy composite panels. Each panel contains either random or unidirectional fiber orientation of four different volume fraction, *i.e*. 10, 20, 30 and 40%, of fiber, along with a pure epoxy, without fiber, panel board as reference. According to the adopted standard, the specimens are of prismatic bars of 85 [mm] long × 10 [mm] wide × 5 [mm] thick. Photo macrographs of selected samples were analyzed to describe their failure modes. It was revealed that both the impact strength and energy absorption capacity of the samples increase with the increase of fiber content up to 40%, for both unidirectional and randomly oriented fiber arrangement. In addition, unidirectional fiber composite samples show higher values in both impact strength and energy absorption capacity (0.162 [J.mm^{-2}] and 8.5 [J], respectively) in comparison with those of randomly oriented fiber composite samples (0.144 [J.mm^{-2}] and 7.6 [J], respectively).

Introduction

Considering synthetic fibers take longer time to degrade, and the need for good environment, people have turned into natural fibers for alternative substitution for synthetic reinforcing fiber in producing composite materials [1]. Natural fibers including bamboo fibers are low cost, and light weight yet moderately strong compared to other construction materials [2] resulting in low price material combined with high specific strength and stiffness. Bamboo fibers which can easily be found in Daerah Istimewa (Special District of) Yogyakarta and its surrounding region may be one of prospective candidates for such substitution. Although a number of findings have been reported [3-5], limited number of reports can be found on the investigation of impact behavior of bamboo fiber/epoxy composite systems that is required to optimally harness such mechanical property. This work has been focused on the evaluation of impact behavior of bamboo fiber/epoxy green composite containing two different fiber arrangements, *i.e*. randomly oriented and unidirectional. Such data can be utilized as reference in order to optimally harness the properties of bamboo fiber.

Experimental Procedure

Constituent Materials. The fiber being used was obtained from local sources by combination of mechanical and degumming processes. Prior to being used as reinforcement, the fibers underwent alkaline treatment, *i.e*. submerged in 5 wt% alkaline solution for 4 hours followed by neutralizing by submerging them in water for two days where the water was replaced every six hours, and washing them in flowing water. The resulted fibers were then dried at room temperature instead of sun-dried or oven dried, to prevent them from surface defect, for three days. The matrix being used is Eposchon general purpose Bisphenol A epichlorohydrin epoxy resin mixed with Eposchon general purpose Polyaminoamide epoxy hardener obtained from P.T. Justus Kimiaraya. The mixing ratio is 1:1 by weight as suggested by the manufacturer.

Specimen Preparation. Composite plate panels of 75 [mm] × 85 [mm] × 5 [mm] and containing either randomly oriented or unidirectional fibers of different fiber contents, and that without fiber were produced by press-mould process. The magnitude of pressure is ~2 [MPa]. The mould loaded with the casted plate panels was left over night before the plate was taken out from the mould. The panels were then post-cured at ~50 [°C] for ~2 hours, then cut into specimens according to the ASTM D5941 standard [6], using diamond-tipped circular blade rotating at ~10000 [rpm]. The final dimensions of the unnotched specimens were ~85 [mm] × 10 [mm] × 5 [mm] as has been presented in Fig. 1. Physical and mechanical characteristics of bamboo fiber and a typical cured epoxy presented in Table 1 may be utilized as references.

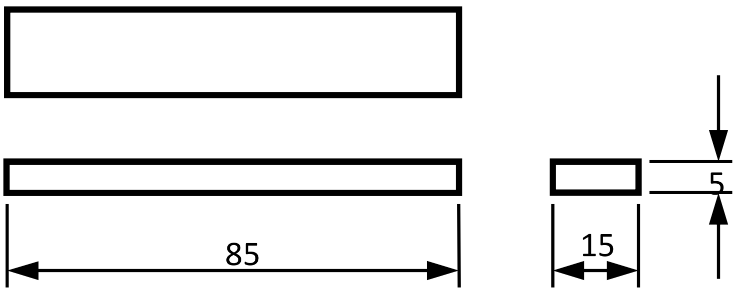

Fig. 1. Specimen geometry, dimensions [mm]

Table 1. Physical and mechanical characteristics of bamboo fiber and epoxy resin

Properties	Bamboo fiber	Cured epoxy
Tensile strength [MPa]	504 [7]	70 [8]
Tensile modulus [GPa]	10.1 [7]	2.25 [8]
Density [g.cm^{-3}]	0.91 [2]	1.2 [8]

Mechanical Characterization. Mechanical characterization, *i.e.* Izod impact test, was carried out at the Mechanical Engineering Laboratory, Universitas Gadjah Mada Yogyakarta. The testing machine being used was equipped with a 20 [kgs] pendulum attached to a 0,8 [m] long moment arm. The amount of energy being absorbed of a specimen can be calculated as follows [6]

$$E_{\text{abs}} = m\, g\, R\, (\cos\beta - \cos\alpha). \tag{1}$$

where E_{abs}, m, g, and R are the amount of energy being absorb [J], the mass of the pendulum [kg], the gravitational acceleration [m.s^{-2}], and the length of moment arm [m], respectively, and β and α are the final and initial angles of the moment arm [°], respectively. By definition, impact strength of a particular material can be defined as the specific energy absorption capacity, thus it can be written as [6]

$$I_{\text{s}} = \frac{E_{\text{abs}}}{b\, h}. \tag{2}$$

where I_{s}, b and h are the spesific energy absorption capacity [J.m^{-2}], the width [mm] and the thickness [mm] of the specimen, respectively.

Failure Mode. A number of specimens after being tested were selected and photographed using a Canon D7000 digital camera possessing 16 [MPx] maximum resolution. The photo macrographs were evaluated to determine the physical characteristics, such as the presence of void and fiber alignment, as well as the macro failure mode of the impacted specimens. In addition, a number of other fractured specimens were prepared for being captured under a Zeiss microscop equipped with an Axiolab pol 0.5 digital camera having maximum resolution of 5 [MPx]. The resulted photo micrographs were then evaluated to determine their micro failure mode, such as fiber-matrix interfacial characteristics, of the fractured specimens.

Result and Discussion

Failure Mode. Representative photographs of fractured specimens have been presented in Fig. 2. The figure shows that void content is considerably low and unidirectional fiber composite specimens contains quite significant amount of misalignment fibers as depicted in Figs. 2(d) and 2(e). Unlike higher strength synthetic fiber composites containing E-glass and carbon fiber hybrid composites that failed initiated in compressive side by fiber buckling and kinking [9], these lower strength natural fiber composite specimens failed initiated in their tensile sides by fiber pull-out.

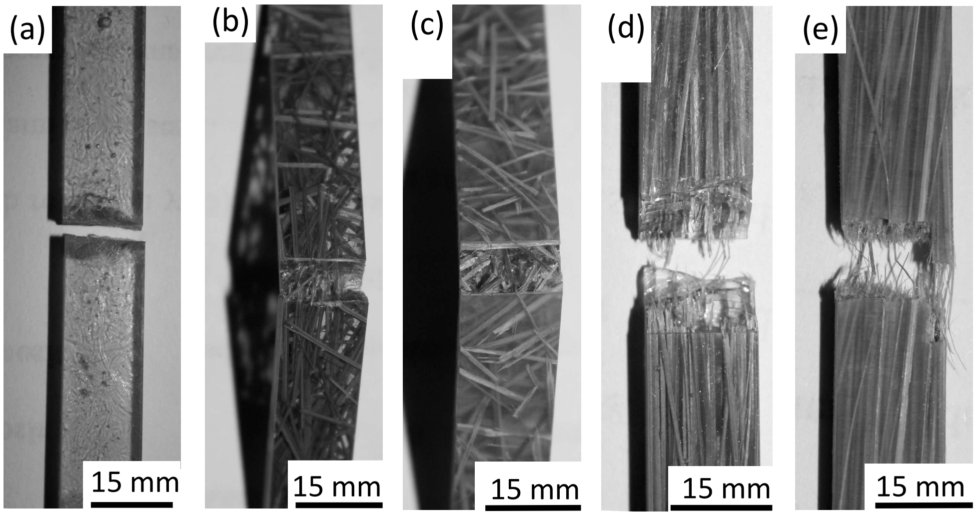

Fig. 2. Representative fractured specimens. (a) $V_f = 0$ %, (b) $V_f = 10$ % randomly oriented fiber, (c) $V_f = 40$ % randomly oriented fiber, (d) $V_f = 10$ % unidirectional fiber, (e) $V_f = 40$ % unidirectional fiber.

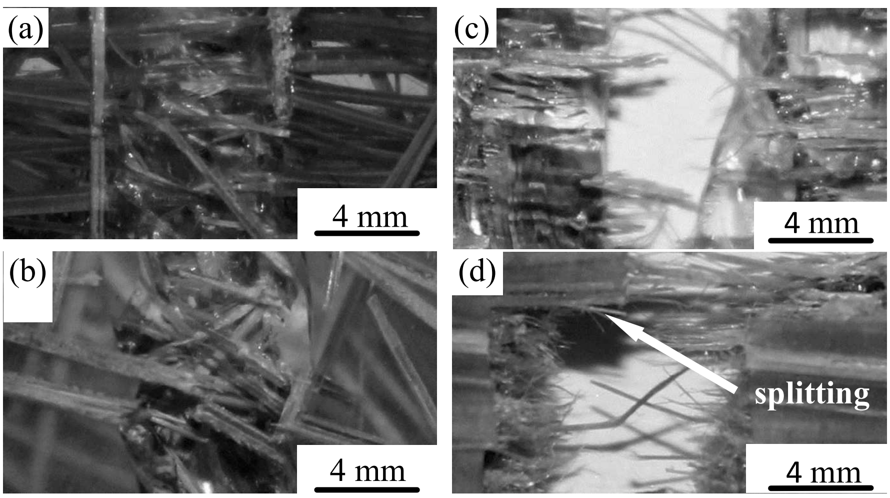

Fig. 3. Microstructure characteristics of fractured specimens. (a) $V_f = 10$ % randomly oriented fiber, (b) $V_f = 40$ % randomly oriented fiber, (c) $V_f = 10$ % unidirectional fiber, (d) $V_f = 40$ % unidirectional fiber.

It can also be noted that pure epoxy specimen and randomly oriented fiber specimens underwent single-plane fracture, while those of unidirectional fiber failed by multiple fracture planes. Closer observation, Fig. 3, demonstrates microstructure characteristics of fiber-matrix interface. Fig 3(a) shows dense fiber loading that may result in higher E_{abs}, but with clean fiber surface indicating weak fiber-matrix interfacial bonding leading to possible low E_{abs} that is in the contrary to the former. It is shown by the E_{abs} increase in a noticeably linear pattern with the increase of fiber content as depicted in Fig. 4. Unlike Fig. 3(a), Fig. 3(b) shows a large portion of fiber surface covered with thin layer of matrix indicating stronger fiber-matrix interfacial bonding. Failure mode of unidirectional fiber composite sample was observed being dominated by fiber interfiber splitting followed by fiber breakage and fiber pull-out as depicted in Figs. 3 (c) and 3(d). Another characteristic that can be noticed for higher fiber content, Fig. 3(d), is the presence of longitudinal splitting as has been observed by Lee and his colleagues for higher fiber content of unidirectional GFRP composites [10].

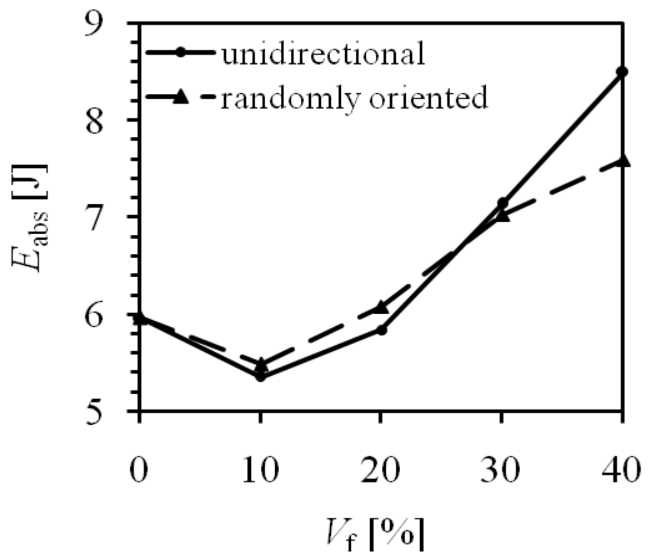

Fig. 4. Effect of fiber content on energy absorption capacity (E_{abs})

Energy Absorption Capacity (E_{abs}). The increase of V_f results in the increase of E_{abs} for both unidirectional and randomly oriented fiber arrangements (Fig. 4). It also shows that at higher fiber content, specimens with unidirectional fiber arrangement exhibits higher E_{abs} compared to those of randomly-oriented fiber arrangement. Such result may be attributed to the effect of fiber arrangement where unidirectional fiber composites are most likely possesses superior mechanical properties in comparison with other fiber arrangements [11]. The decrease of E_{abs} at low fiber content, 10%, can be caused by the synergestic effect of fiber incorporation is suppressed by the effect of discontinuity, due to the introduction of fibers, on the mechanical properties of the resulted composites. The data spreads are considerably narrow, ranging from 5.82 % for randomly-oriented arrangement at V_f = 30% to 16.97% for unidirectional fiber arrangement at V_f = 10%.

Impact strength (I_s). Considering impact strength is the specific energy being absorbed of a specimen, the pattern of the impact strength increase with respect to the increase of fiber content is found to be very much similar with that for energy absorption capacity. The magnitude of impact strength and their respective spread in terms of deviation standard (*SD*) for various fiber content of both randomly oriented and unidirectional fiber arrangements has been presented in Table 2. In addition, bamboo fiber/epoxy composite specimens show higher impact strength in comparison with those of unidirectional cocofiber/epoxy composite reported by Atmaja [12] and woven water hyacinth fiber/polyester composites reported by Veri [13]. This finding is much higher than that of bamboo fiber/polyprophylene composite containing 30 vol.% of bamboo fiber (~32 [J/m]) [14].

Table 2. Impact Strength, I_s [J.m^{-2}]

V_f	Randomly oriented		Unidirectional	
(%)	I_s	*SD*	I_s	*SD*
0	1144.5	113.42	1144.5	113.42
10	1072.5	124.60	1040.3	187.66
20	1152.4	150.05	1106.3	113.79
30	1330.6	77.55	1374.9	124.10
40	1437.1	131.27	1620.4	117.41

Conclusion

Both energy absorption capacity and impact strength of bamboo fiber/epoxy composite specimens increase with the increase of fiber content. Impact strength of bamboo fiber/epoxy composite specimens was found being higher than that of cocofiber/epoxy and water hyacinth/polyester composites. Unlike higher strength synthetic fiber composites, bamboo fiber composite specimens were to found fail initiated in its tensile side followed by fiber breakage and fiber pull-out.

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