# Tensile Properties of E-glass/Sisal/Polypropylene Hybrid Composite Laminate

*by* Harini Sosiati

# TENSILE PROPERTIES OF E-GLASS/SISAL/POLYPROPYLENE HYBRID COMPOSITE LAMINATES

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**Abstract**- Fabrication of E-glass/sisal/polypropylene (PP) hybrid composites with the fiber content of 30 % in volume fraction was carried out by sandwiching technique in a hot compression molding at 170°C for around 15 min to study tensile properties of the hybrid composites and the important factors affecting the properties. Tensile properties of E-glass/sisal/PP hybrid composites, the surface morphology of sisal and E-glass fibers and tensile fracture and surface were examined using a universal tensile machine (SFL-20-350, Shimadzu) and scanning electron microscopy (SEM, TESCAN VEGA3 LMU), respectively. Alkali treatment of sisal fibers was carried out in the 6% NaOH at room temperature for 4 h to make better bonding strength between the fiber surface and PP matrix. The ratio of E-glass/sisal was varied; i.e. 10/20, 15/15 and 20/10 (volume fraction). Increasing the ratio of E-glass fiber/sisal fiber tends to decrease tensile strength, but increase tensile modulus of the E-glass/sisal/PP composites. The results showed relatively high tensile strength, although the contribution of E-glass fibers to sisal/PP composites was relatively small owing to weak interfacial bonding between glass fiber surface and PP matrix. The composite fabrication technique, the ratio of synthetic fiber and natural fiber, treatment condition for the fibers, and fiber length are suggested to be the main factors played in affecting tensile properties of the hybrid polymer composites.

**Keywords**- Sisal fiber, E-glass fiber, hybrid composite, tensile properties, SEM

## I. INTRODUCTION

Natural fiber is one of the most natural resources in Indonesia but has still not been much harnessed for their potential applications. Low cost, light weight, the eco-friendly and high strength of the natural fiber makes it a real challenge for reinforcement material of thermoplastic composite which is potentially used in the automotive application. However, natural fiber based polymer composites have some limitations in their use such as the product quality which depends on the kind of the fibers, inhomogeneous properties of the materials which correspond to the material processing and hydrophilic characteristic of the fibers. To overcome the problem in natural fiber composite, therefore, hybrid polymer composites are recently developed.

It is well known that hybrid composite can be fabricated using two or more kinds of reinforcement material with a single matrix material or a single reinforcing material with multiple matrix materials. Hybridization of natural fiber with synthetic fiber (glass or carbon) is widely developed and used in various applications such as wind power generation, helmet, aerospace, orthopedic aids and automobile or transportation sector [1].

Sisal (Agave sisalana) fiber is abundantly available in the earth and easily cultivated [2], especially in tropical climate regions such as Indonesia, Malaysia, Bangladesh, Barzil and Tanzania. Sisal is a hard fiber and has high tensile strength (800 MPa) after hemp (5500 MPa) and flax (1400 MPa) fibers [3]. The untreated short sisal fibers (2 mm) reinforced PP composites with 30 wt% fiber content fabricated with two different methods viz. by sandwiching technique in a hot compression molding [4] and with an injection molding [5] have provided comparable result in tensile strength; around 28 MPa. The Fiber loading of 30 wt% showed the maximum value of tensile strength [5]. Besides, the influence of a fiber length from 5 to 20 mm on the tensile and flexural properties of sisal/epoxy composites fabricated by hand lay-up indicated that higher value of the mechanical properties reached with a fiber length of 10 mm [6].

On the other hand, many types of research on hybridization glass fiber and sisal fiber in epoxy resin and also polyester have been carried out and reported that the addition of glass fiber improves the mechanical properties of the hybrid composites [2, 7]. However, research on the characterization of mechanical properties of glass/sisal/PP hybrid composites is relatively scarce. E-glass and sisal fibers 4 mm in length reinforced PP composite with the fiber content of 30 wt% was fabricated by an injection molding at 170°C for 13 min. By adding a coupling agent of PP-g-MA, increasing the glass fiber content has slightly enhanced tensile strength and impact strength of the composites [8]. KC and co-workers [9] have only focused on characterization of the physical properties of glass/sisal/PP hybrid composites.

The present work examined tensile properties of E-glass/sisal fiber reinforced PP hybrid composite fabricated by sandwiching technique in a hot compression molding which was designed and built by our research group. Changes in tensile properties of the hybrid composites were characterized from SEM micrographs of a tensile fracture surface of the composite specimens and compared to the previous results. The important factors affecting the changes in tensile properties of the hybrid composites were discussed.

## II. DETAILS EXPERIMENTAL

### 2.1. Materials and Procedures

The composite materials of sisal fiber, E-glass fiber, and PP sheet with the density of 1.5, 2.5 and 0.92 g/cm$^3$ were purchased from Balittas-Malang, Indonesia, PT. Justus Kimia Raya-Semarang, Indonesia and PT. Sumber Jaya, Indonesia, respectively. As-received sisal fibers were washed with water to remove the contaminant and dirt present at the fiber surface, then soaked in 6 wt% NaOH solution for 1 h at room temperature to eliminate a part of non-cellulosic components such as hemicellulose and lignin to make better bonding strength between the fiber surface and the matrix. After that, the fibers were washed with flushing water and dried in an oven at 100°C for 30 min. Alkali treated sisal and untreated E-glass fibers were chopped into 10 mm length. PP sheets were cut into 17 mm length and 2 mm width.

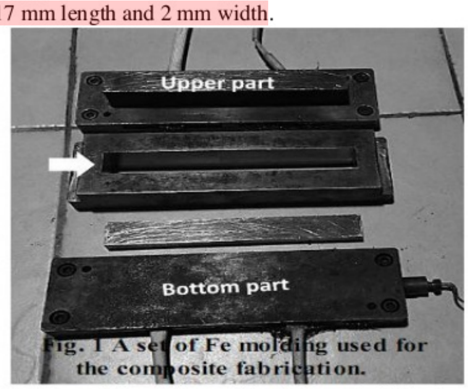


**Fig. 1 A set of Fe molding used for the composite fabrication**

**Table1: The calculated ratio of the fiber and the matrix in the composites**

| Volume fraction of fiber: matrix (30% : 70%) | Mass of E-glass fiber (gr) | Mass of sisal fiber (gr) | Mass of matrix (gr) |
|---|---|---|---|
| Vol. fraction E-glass/sisal (10/20) | 6.58 | 4.08 | 8.76 |
| Vol. fraction E-glass/sisal (15/15) | 4.94 | 3.06 | 8.76 |
| Vol. fraction E-glass/sisal (20/10) | 3.29 | 2.04 | 8.76 |

Fabrication of E-glass/sisal/PP hybrid composites were carried out by sandwiching technique in a hot compression molding, as described elsewhere [10]. E-glass and sisal fibers were mixed manually (by hand) and arranged between PP sheets into 13 laminates in a Fe-mold with the dimension of 17 cm length, 2.2 cm width, and 2 cm depth (Fig. 1, see arrow), and hot pressed at around 170°C for 15 min. The fiber content was 30% in volume fraction. The ratio of E-glass and sisal fibers were varied in volume fraction of 10/20, 15/15 and 20/10. In this study, for each variation needs at least five composite sheets (specimens) for tensile testing. The calculated ratio of materials used in the hybrid composites is summarized in Table 1.

### 2.2. Tensile Test

Tensile tests were done on the single sisal fiber and E-glass/sisal/PP hybrid composites according to ASTM C1557-03 and ASTM D638-02, respectively, using a universal testing machine (SFL-20-350, Shimadzu).

In this work, tensile test for single fiber was only conducted on sisal fiber, not on E-glass fiber, because the physical and the mechanical properties of sisal fiber is different with each other. Those depend on the origin of the fiber. Therefore, tensile test for single sisal fiber should be carried out. According to the earlier result [11], the tensile strength of used E-glass fiber was 3.71 GPa which is higher than that reported by Holbery et al. [2006]: i.e. 2.0 GPa [12].

The hybrid composite specimens were tensile tested at a maximum load cell of 2 kN, a crosshead speed of 3 mm/min and a gauge length of 50 mm. Before testing, the fabricated hybrid composite sheets which are represented in Fig. 2a was prepared to be tensile test specimens using a computer numerical control (CNC) machine (Fig. 2b). Fig. 2c showed the tensile tested hybrid composite specimens.

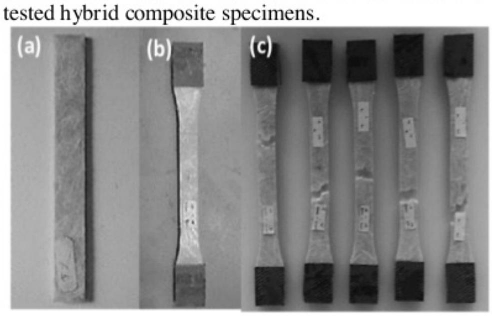


**Fig. 2 (a) Produced E-glass/sisal/PP composite, (b) a tensile test specimen and (c) tensile tested composite specimens**

### 2.3. Characterization

Scanning electron microscopy (SEM, TESCAN VEGA3 LMU) operating at 15 kV was employed to characterize the surface morphologies of sisal and E-glass fibers, and tensile fracture surface of the hybrid composite specimens. Before SEM observation the specimen surface was metallic coated with Au-Pd.

## III. RESULTS AND DISCUSSION

### 3.1. Tensile properties

The tensile strength of sisal fiber used in this work (337 MPa) was much lower in comparing with that in the literature (800 MPa) [3] and (484 MPa) [13], but higher than that reported by Ezema et al., (174.8 MPa) [14]. The physical and mechanical properties of single natural fiber could not be accurately compared with each other because they are influenced by many factors such as the fiber origin, the age of the fiber and harvest time. Even, the fibers that are including in one fiber bundle would possibly have the different properties due to differences in cellulosic and non-cellulosic contents [15].

The tensile strength of PP hybrid composites reinforced with E-glass and sisal fibers in various ratios (Fig. 3) revealed that increasing the ratio of E-glass fiber/sisal fiber decreases tensile strength (Fig 3a). The trend of this result disagrees with that of a nearly similar research reported by Jarukumjorn et al., [8] and others [2, 7], although the enhancement of tensile strength due to increasing glass fiber content (ratio of glass fiber/sisal fiber) [8] was insignificant. Also, the present result (Fig. 1a) indicated that incorporation of E-glass fiber and sisal fiber reinforced PP composite had improved the tensile strength value in comparison with the previous result of sisal fiber/PP composite by a similar method [4].

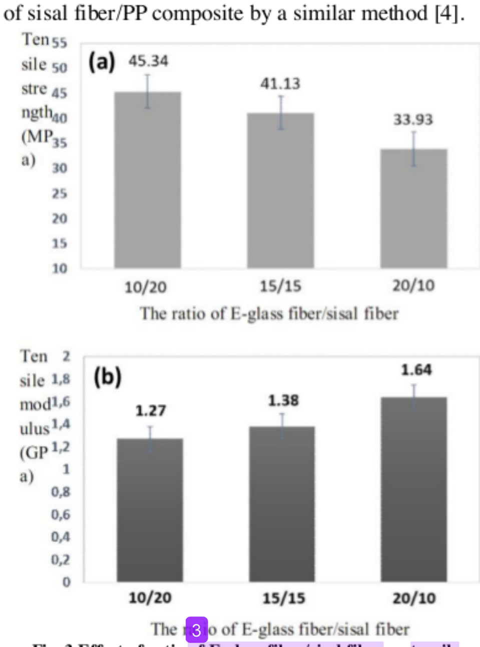


**Fig. 3 Effect of ratio of E-glass fiber/sisal fiber on tensile strength (a) and tensile modulus (b) of the E-glass/sisal/PP hybrid composites**

Besides, increasing ratio of glass fiber/sisal fiber enhanced the tensile modulus (Fig. 3b). Jarukumjorn et al. [8] indicated that increasing glass fiber content had no effect on the tensile modulus. However, the value of tensile modulus shown in this work was lower than that in Ref. [8] (Table 3). It might be because using the untreated E-glass fiber.

Results in this work and that in Ref. [8] are discussed in detail to gain understanding the important factors that play a crucial role in affecting the mechanical properties of the hybrid composite. We have considered that our hot compression molding seemed to be able to compete with an injection molding machine in producing the hybrid composites. The differences in process parameters and compare the tensile strength, and tensile modulus of both results (in present work and Ref. [8]) are listed in Table 2 and Table 3, respectively.

**Table2: The differences in process parameters**

| Process parameters | Present work | Jarukumjorn et al. [8] |
|---|---|---|
| Fiber length | 10 mm | 4 mm |
| Treatment for sisal fiber | 6 wt% NaOH, 4 h | 2 wt% NaOH, 2 h |
| Treatment for E-glass fiber | Untreated | Heated 500°C, 4 h |
| Coupling agent (CA) | Without CA | PP-g-MA |
| Composite fabrication | Hot compression molding | Injection molding |

**Table3: Comparison of tensile strength and tensile modulus resulted in present work and the previous work [10].**

| The ratio of the fiber/the matrix = 30/70 (volume fraction) | | | | |
|---|---|---|---|---|
| The ratio of E-glass fiber/sisal fiber | Present work | | Jarukumjorn et al. [10] | |
| | Tensile strength (MPa) | Tensile modulus (GPa) | Tensile strength (MPa) | Tensile modulus (GPa) |
| 10/20 | 45.34 | 1.27 | 29.70 | ~ 2.3 |
| 15/15 | 41.13 | 1.38 | ~ 31 | ~ 2.4 |
| 20/10 | 33.93 | 1.64 | ~ 31 | ~ 2.4 |

The research data in Table 2 and 3 evidently showed that tensile strength value of E-glass/sisal/PP hybrid composite in this work was higher than that in Ref. [8] for each ratio of glass fiber/sisal fiber, especially in the ratio of 10/20 (0.5) and 15/15 (1). In this case, the ratio of glass fiber/sisal fiber is considered to be more important rather than the addition of the amount of E-glass fiber, as indicated in a literature studied on hemp/glass/PP composites [16]. An increase of the glass fiber content that was equivalent to increase of glass fiber/hemp fiber ratio of 5/35, 10/30 and 15/25 implied the highest value of tensile strength on the ratio of 15/25 (0.6). The maximum value of tensile strength of the hybrid composites reached at the ratio of glass fiber/sisal fiber of 0.5 (this work) and glass fiber/hemp fiber of 0.6 [16], which is near similar.

But, the highest value of tensile strength in Ref. [16] (~ 59 MPa) was greater than that in this work (45.34 MPa). This discrepancy is attributed to be a much higher tensile strength of hemp fiber than that of sisal fiber [3]. Except for the ratio of E-glass fiber/sisal fiber, the surface morphology of the fiber and distribution of the fibers in the matrix are other important factors contributed to the changes in the tensile properties of the hybrid composites.

### 3.2. Morphology of the fiber surface

SEM micrographs (Fig. 4a, 4b, 4c) demonstrated surface morphology of untreated sisal fiber, alkali treated sisal fiber and untreated E-glass fiber, respectively. Surface morphology of untreated sisal fibers or as received sisal fibers (Fig. 4a) seem to be dirty because some contaminant and the non-

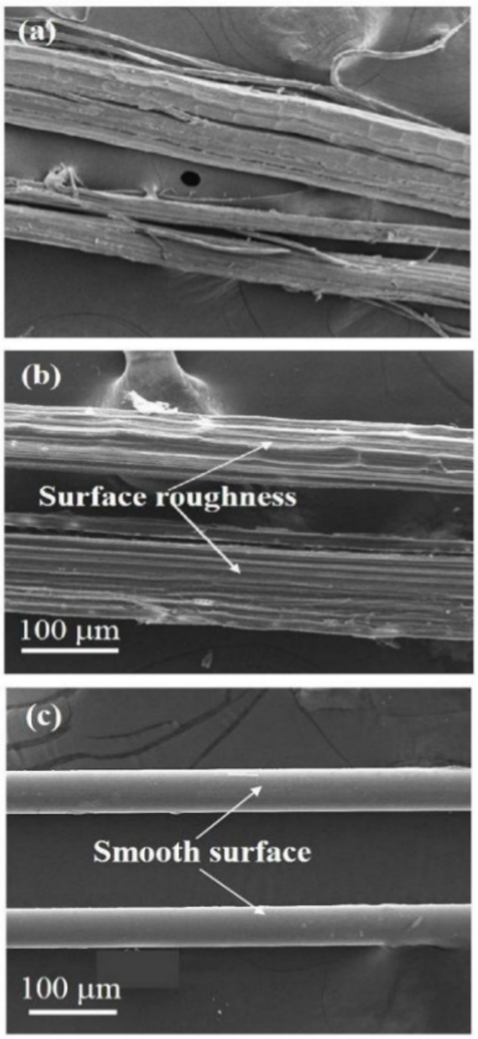


**Fig. 4 SEM micrographs of a morphology of the fiber surface. (a) Untreated sisal fiber, (b) alkali treated (6% NaOH, 4h) sisal fiber and (c) untreated E-glass fiber**

cellulosic components still covered the fiber surface. After alkali treatment in 6% NaOH for 4 h (Fig. 4b) the fiber surface appear clearer than the untreated one (Fig. 4a). Parallel lines created on the fiber surface (see arrows) exhibited the surface roughness. During the alkalization cleavage of a part of hemicellulose and lignin occurred and then they are flowing in the flushing water when the fibers washed. In this case, Lignin only dissolved in hot alkali solution [17]. Thus the residual lignin remains at the fiber surface if the fiber washing was not entirely clear.

Alkalization at high temperature lead to dissolved lignin. Lignin is hydrophobic in nature [17], thus dissolved lignin containing in the natural fiber reduces the compatibility of the fiber and the matrix which behaves hydrophobic as well. It is a reason why alkalization in this study was carried out at ambient temperature.

According to Manikandan et al. [18] alkalization in 5% NaOH for 3 h is the optimal treatment condition in achieving high tensile strength and tensile modulus of the natural fiber composites. Six (6)% or near 6% NaOH is also a good value for alkalization of kenaf fiber [19, 20]. The concentration of alkali solution and period of alkalization are important factors in affecting the quality of fiber. Incorrect the alkalization condition leads to fiber degradation which decreases the mechanical properties [21]. Inversely, the surface morphology of untreated E-glass fiber (Fig. 4c) appears very smooth. There is no surface roughness seen on the fiber surface. The influence of surface morphologies of sisal and E-glass fibers on the tensile properties of this work can be studied by the following tensile fracture surface.

### 3.2. The tensile fracture surface

Figure 5 represented the tensile fracture surface of E-glass/sisal/PP hybrid composites. The SEM images (Fig. 5a and 5b) obtained from a composite specimen with the ratio of E-glass fiber/sisal fiber of 10/20. In the present work E-glass fibers and sisal fibers were mixed by hand as mentioned in the previous paragraph. As a result, the distribution of sisal fibers and E-glass fibers are seen inhomogeneous (Fig. 5a). A group of E-glass fibers seems separated from a group of sisal fibers. Detail observation on Fig. 5b showed that interface bonding strength between sisal fiber and PP matrix appeared better than that of E-glass fiber and PP matrix. Debonding E-glass fiber and the matrix, and E-glass fiber pulled out were distinctly observed (see arrows). Some glass fibers are present with very weak bonding with the matrix. It can be understood, therefore, increase the ratio of E-glass fiber/sisal fiber indicates an increase of the volume fraction of E-glass and also the volume fraction of voids due to the glass fibers pulled out. In this case, there is no contribution of glass fibers to withstand the applied load. Consequently, the higher the ratio E-glass fiber/sisal fiber reduces tensile strength. Thus, the treatment on the glass fiber is recommended to be carried out to make better interfacial bonding between glass fiber surface and PP matrix.

Tensile strain (not shown here) and tensile modulus of the present hybrid composites tended to increase with enhancing the ratio of E-glass fiber/sisal fiber. Thus, a hybrid composite which has the lowest tensile strength showed the highest tensile strain and tensile modulus. These results indicated that in the elastic region both E-glass fiber and sisal fiber have enough substantial contribution to withstand the applied load. When the applied load was continued, the hybrid composite specimen failed at the beginning the plastic area due to insufficient bonding strength between the untreated glass fiber surface and PP matrix leads to glass fibers pulled out. The hybrid composite specimen with the ratio of E-glass fiber/sisal fiber of 10/20, therefore, was more ductile in comparing with that of 15/15 and 20/10.

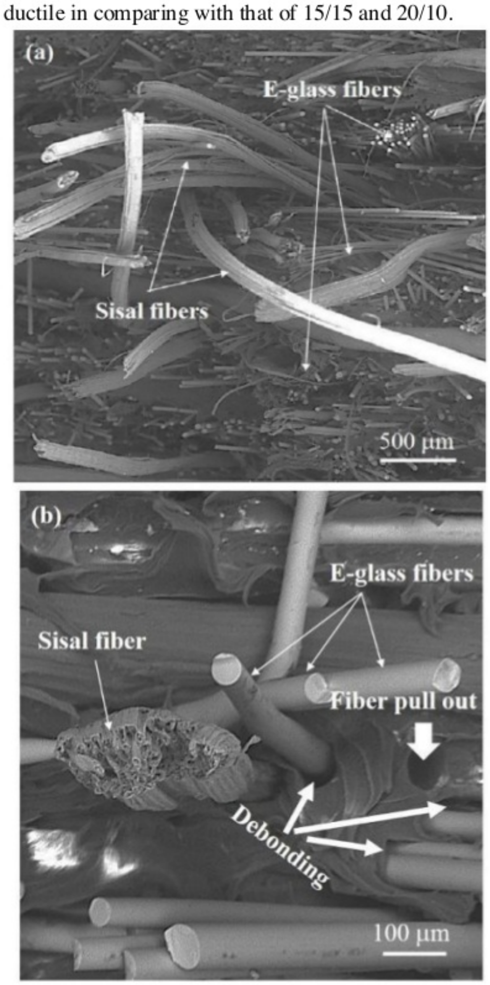


**Fig. 5 SEM micrographs of the tensile fracture surface of an E-glass/sisal/PP hybrid composite specimen with the ratio of E-glass fiber/sisal fiber 10/20 showing the distribution of the fibers in the PP matrix (a) and bonding of the fiber surface and PP matrix**

Furthermore, an insignificant increase of tensile strength and constant tensile modulus due to increasing the ratio E-glass fiber/sisal fiber reported by Jarukumjorn et al., [8] are possible because of the alkalization condition with the low concentration of NaOH and a short period of alkalization, even though used the treated glass fibers. With those alkalization conditions, residual waxes and other components remain slightly covered the sisal fiber surface, leading to decrease interfacial bonding between sisal fiber and PP matrix. Also, fiber length used in Ref. [8] was shorter than that in present work and an optimum fiber length reported by Maurya et al., [6].

Based on the current results, it is summarized that the disadvantage of hot compression molding resulted in the inhomogeneous fiber distribution within the matrix. Thus, fabrication technique by this method should be improved. The glass fiber has to be heated at around 500-600°C for about 4 – 6 h to get good bonding strength with the matrix because the inorganic glass fiber has insufficient bonding strength with the matrix. However, the alkalization condition used for sisal fiber treatment seemed to be suitable.

## CONCLUSIONS

We have successfully fabricated the E-glass/sisal/PP hybrid composites with relatively high tensile strength, although the contribution of E-glass fibers to sisal/PP composites was relatively small owing to poor interfacial bonding between glass fiber surface and PP matrix. The composite fabrication technique, the proportion of synthetic fiber and natural fiber, treatment condition for both synthetic fiber and natural fiber, and fiber length are suggested to be the main factors acted in affecting tensile properties of synthetic and natural fibers reinforced hybrid polymer composites.

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