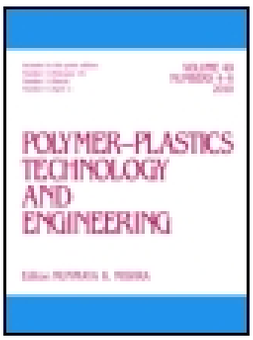

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POLYPROPYLENE HYBRID COMPOSITES: A PRELIMINARY STUDY ON THE USE OF GLASS AND COCONUT FIBER AS REINFORCEMENTS IN POLYPROPYLENE COMPOSITES

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Abstract

Polypropylene hybrid composites were made using coconut and glass fibers as reinforcing agents in the polypropylene matrix. The incorporation of both fibers into the PP matrix has resulted in the reduction of flexural, tensile, and impact strengths and elongation at break. The reduction has been attributed to the increased incompatibility between the fibers and the PP matrix, and the irregularity in fiber size, especially for biofibers as shown by scanning electron micrographs. Both the flexural and tensile moduli have been improved with the increasing level of fiber loading. Most of the properties tested for composites with high glass fibers/low biofiber loading are comparable with the ones with low glass fiber/high biofiber loading. The results show that more biofibers could be incorporated in hybrid composites which would give the same range of properties as the composites with higher loading of glass fibers.

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Key Words: Hybrid; Composites; Polypropylene; Thermoplastic; Lignocellulosic.

INTRODUCTION

Recent developments in plastic composites give emphasis on the use of various materials for reinforcement. Lignocellulosic–plastic composites, in particular, have received a lot of attention, particularly on the types of fiber, filler characteristics, and so forth. The utilization of wood or, in general, lignocellulosic material as a reinforcing component in polymer composites has become more attractive, particularly for price-driven, high-volume applications (1–10). However, the use of high-density inorganic fillers, such as glass fiber or mica, in thermoplastic composites also offers a wide variety of property improvements, particularly in the ultimate strength of the material. Nevertheless, their incorporation may not be favorable in terms of cost-effectiveness on a volumetric basis. Thus, the growth of lignocellulosic–plastic composites has been attributed to the density factor of the lignocellulosic filler, in addition to other advantages such as greater deformability, less abrasiveness to expensive molds and mixing equipments, and, of course, lower cost. Hence, it would be possible to utilize both inherent characteristics of lignocellulosic and glass fiber to produce composites which have a more favorable balance of properties. Therefore, hybrid composites of glass and lignocellulosic fibers as reinforcements in a common thermoplastic matrix would provide versatility in the properties of the composite materials.

As can be seen by recent trends, lignocellulosic materials have been the subject of intensive investigations, either in replacing existing wood species in making conventional panel products (11) or producing plastics composites (12–16). The increasing trend in using nonwood materials has been induced by the growing demand for lightweight, high-performance materials coupled with the abundant supply of lignocellulosic fibers. The escalating costs of raw materials and energy add further impetus to such an investigation. Controlled biodegradability after effective use is another important factor in favor of biofiber composites. Thus, it is to be believed that hybrid composites would enlarge the domain of applications shown by the existing conventional composites.

EXPERIMENTAL

Materials

Coconut fiber was obtained from Butterworth Fibre Sdn. Bhd. (Malaysia). The fiber was cut into strands about 3 cm in length. The polypropylene (PP)

used was purchased from Polypropylene Malaysia Sdn. Bhd. (Malaysia) with a melt flow index and density of 12.0 g/10 min and 0.903 g/cm^3, respectively. The glass fiber was obtained from Fibre Glass Pilkington Limited (India), with an average size of $\frac{1}{8}$ in.

Compounding and Processing

The compounding of coconut and glass fibers was carried out using a Haake Rheocord System consisting of a Haake Rheodrive 5000 (drive unit) and Haake Rheomix 600 with a roller blade (mixer). Prior to mixing, the fibers and PP were hand mixed into different loadings of fibers [mixture of coconut fiber (biofibers) and glass fibers] in the composite; the overall fiber contents (by weight) were 10%, 20%, 30%, and 40%. The proportion of the biofibers and glass fibers for each of the fiber loadings mentioned are shown in Table 1.

The mixing was carried out at 170°C for 20 min at a rotor speed of 25 rpm. The compound in granulated form was then transferred to a mold with dimensions 160 × 160 × 3 mm. The compound was preheated for 10 min at 170°C followed by hot pressing at the same temperature for another 10 min. Cooling was carried out for 5 min under pressure.

Testing

The sheet produced was cut into three types of test samples: flexural, tensile, and impact tests. Tensile tests were carried out according to ASTM D618 on samples with dimensions 15 × 1.9 × 0.3 cm (length × width × thickness), using Instron machine model 1114 at a crosshead speed of 5 mm/min. The flexural test was conducted according to ASTM D790 (i.e., a three-point bending system), using Universal Testing machine model STM-10. The samples with dimensions 15 × 1.5 × 0.3 cm were tested at a crosshead speed of 2.0

TABLE 1
Proportion of Biofiber/Glass Fiber

Types of sample	Proportion of the fiber	Designation on the graph
1	0% biofiber/100% glass	0% biofiber
2	25% biofiber/75% glass	25% biofiber
3	50% biofiber/50% glass	50% biofiber
4	75% biofiber/25% glass	75% biofiber
5	100% biofiber/0% glass	100% biofiber

mm/min. The Izod impact test was carried out according to ASTM D256 on unnotched samples with dimensions 6.5 × 1.5 × 0.3 cm, using Zwick Impact Pendulum Tester model 5101. A minimum of six samples were tested in each case. The calculations for flexural strength (modulus of rupture, MOR) and modulus (modulus of elasticity, MOE) are obtained by the following:

$$\text{MOE} = \frac{L^3\,\Delta W}{4bd^3\,\Delta S}$$

where L is the span between the centers of supports (m), ΔW is the increment in load (N), b is the mean width of the sample (m), d is the mean thickness of the sample (m), and ΔS is the increment in deflection (m).

$$\text{MOR} = \frac{3WL}{2bd^2}$$

where W is the ultimate failure load (N).

Morphological Study

The fracture surface of the composites from the tensile test were investigated with a Leica Cambridge S-360 scanning electron microscope. Samples were chosen from composites with 10% and 40% overall fiber content, which consists of 100% biofiber, 50% biofiber, and 0% biofiber (100% glass fiber). The objective was to get some information regarding fiber dispersion adhesion between fiber and matrix and to detect the presence of microdefects, if any. The fracture ends of the specimens were mounted on aluminum stub and sputter-coated with a thin layer of gold to avoid electrostatic charging during examination.

RESULTS AND DISCUSSION

The performance of hybrid composites in flexural strength is presented in Fig. 1. The results show a common phenomenon as shown by conventional thermoplastic composites (17), where the flexural strength decreases as the overall fiber content is increased. Composites with 100% glass fiber (0% biofiber) as the reinforcement agent display a significantly higher strength than the composites with biofibers only. It can be seen that the strength is reduced as the amount of biofibers in the composites is increased. However, it is obvious that the strength of all hybrid composites fall within the same range.

Flexural modulus results show that the stiffness of a composite increases as the amount of total reinforcement (biofiber and glass fiber) is increased (Fig.

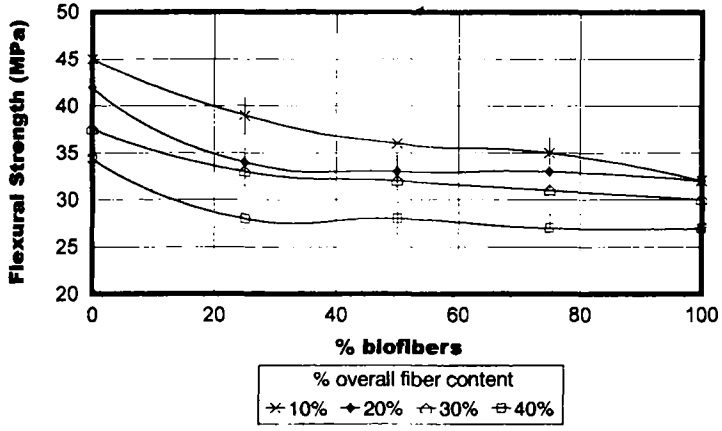

FIG. 1. The effect of biofiber loading on the flexural strength.

2). This agrees with the observation of various studies on the thermoplastic composites (13). The stiffness of the sample, however, is reduced as the biofiber content in the total reinforcement is increased in the matrix. Samples with 30% and 40% overall fiber content show a higher degree of reduction (by comparing samples with 25% and 75% biofibers) as compared to the lower ones. This shows that the modulus of composites with higher overall fiber content is more susceptible to the changes in the modulus with respect to the incorporation of biofiber in the composites than the lower ones.

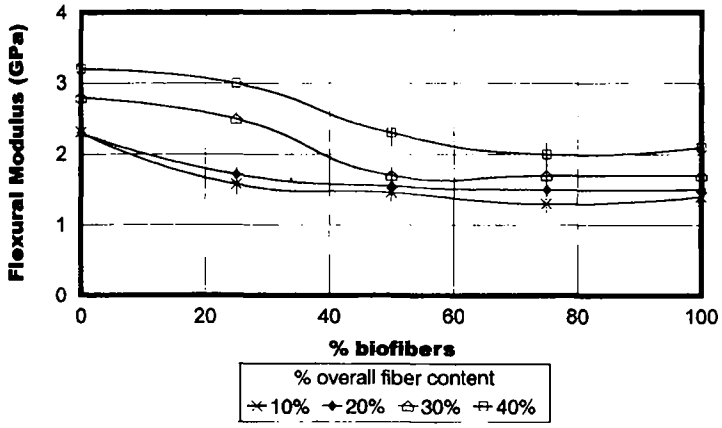

FIG. 2. The effect of biofiber loading on the flexural modulus.

Figure 3 shows the results of tensile strength. Overall, it appears that the tensile strength of all types of composite decrease as the fiber loading is increased. Most of the significant reduction in the strength occurs for the 25% biofiber content, whereas the further addition of fiber does not result in significant changes in the strength (as compared to the composites with 25% biofiber). Thus, this may indicate the possibility of the creation of more stress points in the composite. This may be brought about by the increased incompatibility in the interfacial region between the matrix and the fibers. The tensile strength of composites with 10% overall fiber content is higher than the 40%. The scanning electron micrographs (comparing Figs. 4a and 4b for 10% fiber content) and 5a and 5b for 40% fiber content) have shown a better adhesion between the fiber and matrix in the former than the latter composites. This shows that at a lower percentage of reinforcement, there is adequate and effective adhesion between the fiber and matrix. As the percentage of overall fiber increases, there are possibilities of starvation of the matrix material on the fiber surface, which reduces the adhesion between them. The random orientation of fiber at high overall fiber content may further aggravate the starved condition by physically preventing the matrix from having full access to the surface of the fiber.

Figure 6 illustrates the results of tensile modulus as a function of fiber loading. The tensile modulus increases as more fiber is added in the composite. This behavior is consistent with the earlier studies on filled-thermoplastic composites (17). As shown by the flexural modulus results, the composites also show a reduction in the tensile modulus as biofibers are incorporated in the composites.

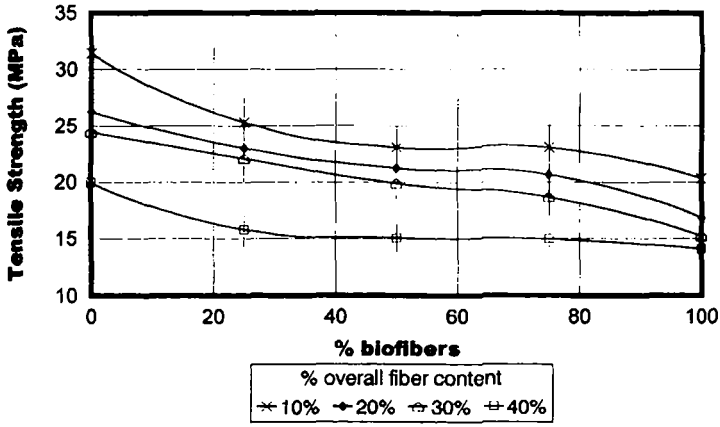

FIG. 3. Tensile strength as a function of biofiber loading.

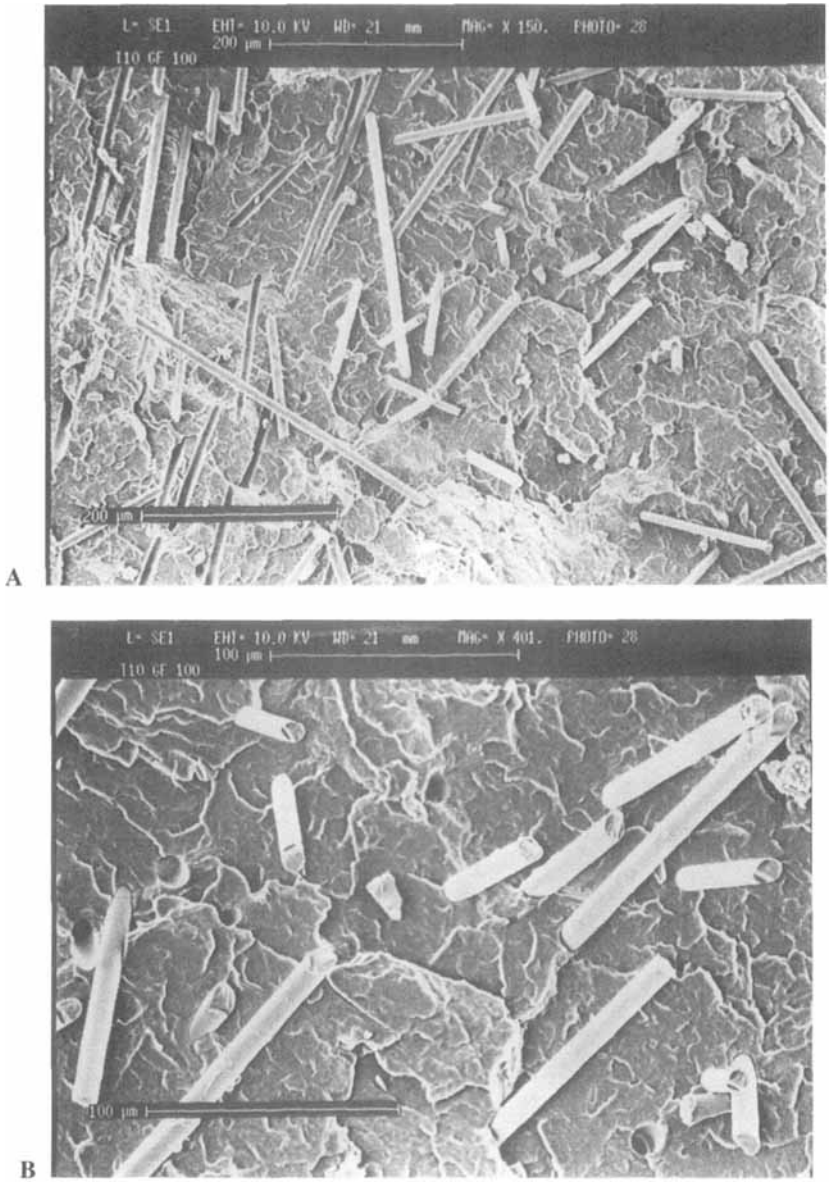

FIG. 4. (A) Scanning electron micrograph for composites with 10% overall fiber content; 100% glass fiber loading (magnification 150×). (B) Scanning electron micrograph for composites with 10% overall fiber content; 100% glass fiber loading (magnification 401×).

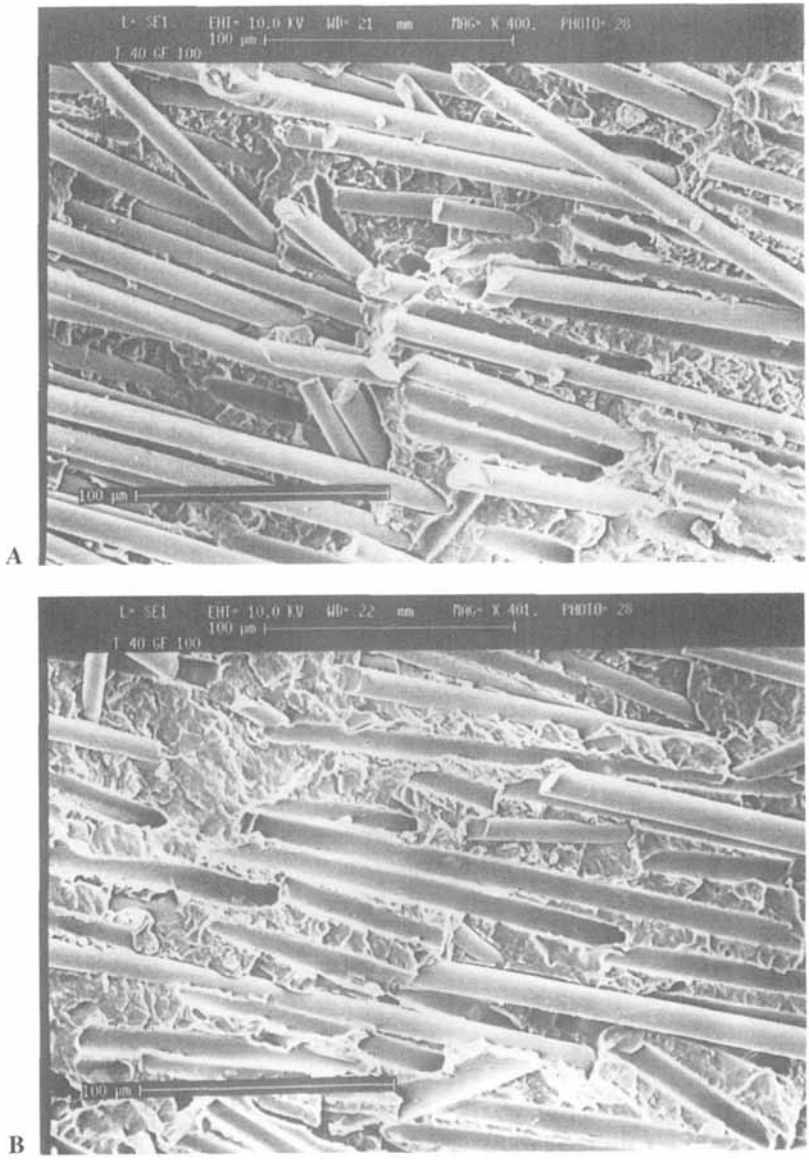

FIG. 5. (A) Scanning micrograph for composites with 40% overall fiber content; 100% glass fiber loading (magnification 400×). (B) Scanning electron micrograph for composites with 40% overall fiber content; 100% glass fiber loading (magnification 401×).

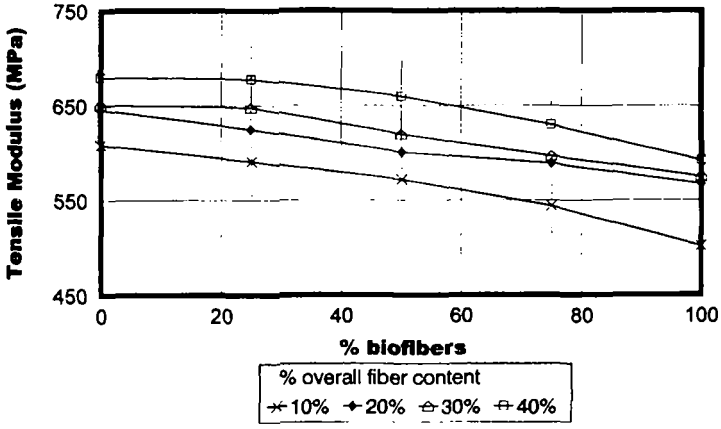

FIG. 6. Tensile modulus as a function of biofiber loading.

The incorporation of biofibers into the polymer matrix reduces the elongation at break of the composites (Fig. 7). This is a common observation with almost all filled composites where elongation decreases monotonically with the addition of more fiber to the polymer (4,5). Reduction in elongation is due to the decreased deformability of a rigid interface between the fiber and the matrix material. The reduction is enhanced when biofibers are added to the matrix.

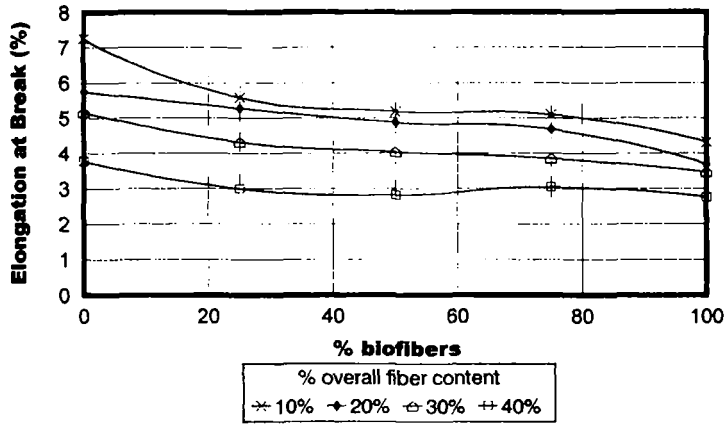

FIG. 7. Elongation at break as a function of biofiber loading.

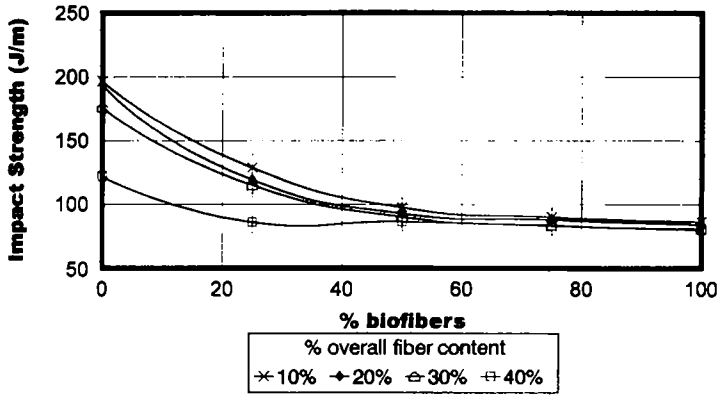

FIG. 8. Impact strength versus biofiber loading.

The impact strength of composites decreases as the fiber loading is increased (Fig. 8). This reflects the reduction in energy absorption at the crack tip. The poor bonding quality between the fibers and the polymer matrix creates weak interfacial regions which will result in debonding and frictional pull out of fiber bundles. These failure mechanisms, which inhibit the ductile deformation and mobility of the matrix, will obviously lower the ability of the composite system to absorb energy during fracture propagation (18). The results indicate that composites with only fiber glass as the reinforcing agent are able to absorb more energy as compared to the ones with biofibers. The extensive fiber bundles pull out as observed from the scanning electron micrographs in Figs. 9a and 9b, which clearly provide supportive evidence for the poor impact properties of the composites.

Scanning electron microscopy (SEM) was employed to study the tensile fracture surfaces of composite samples based on composites with 10% and 40% overall fiber content for various levels of biofiber/glass fiber ratio.

It is known that good dispersion and wetting of fibers in the matrix are the criteria to produce strong interfacial adhesion, which, in turn, would produce composite materials with satisfactory mechanical properties. Figures 10a and 10b for composites with 10% overall fiber content with 100% biofiber show the evidence of fiber pull-out. It is clear that the inner surface of the pull-out holes is rather smooth. This indicates the absence of good interfacial adhesion between the biofiber and the matrix. Irregularity in fiber size as shown by the micrographs is believed to have reduced the efficiency of stress transfer in the matrix, which subsequently lowers the strength of the material.

Figure 9a and 9b show that the failure for composites with 10% overall fiber content with 50% biofiber and 50% glass fiber are attributed to pull-out

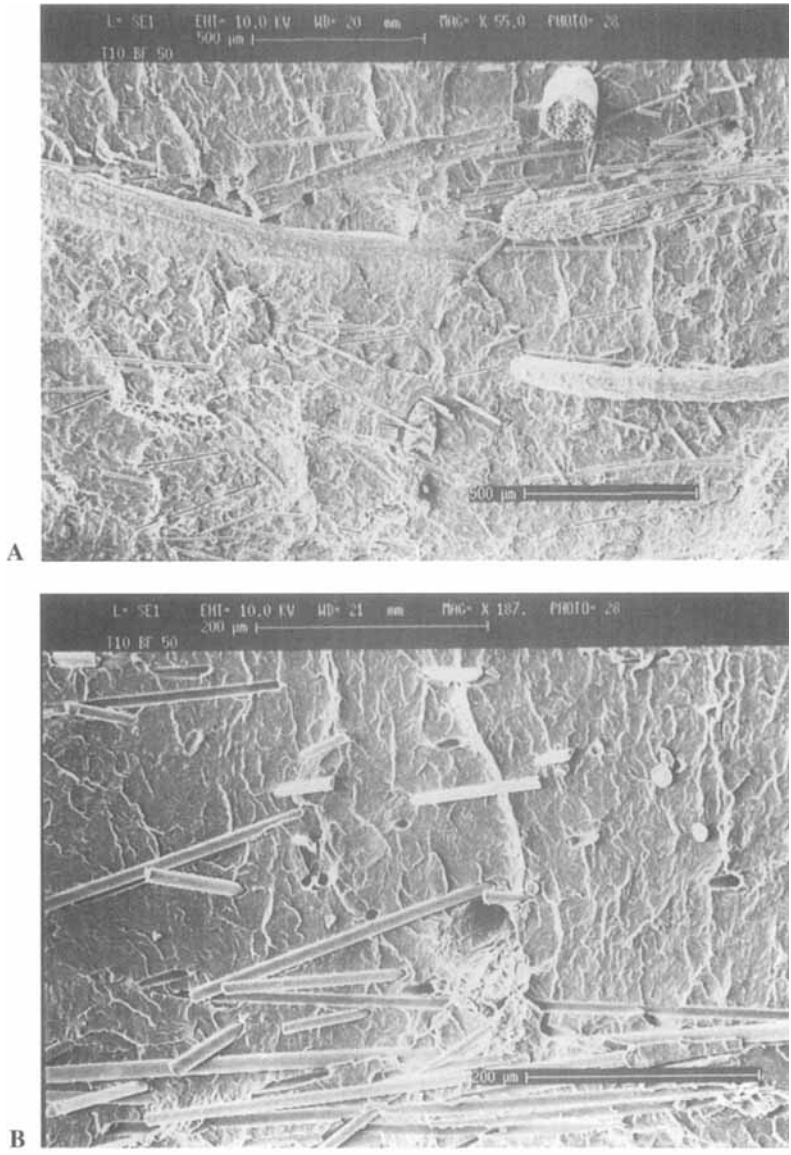

FIG. 9. (A) Scanning electron micrograph for composites with 10% overall fiber content; 50% biofiber/50% glass fiber loading (magnification 55×). (B) Scanning electron micrograph for composites with 10% overall fiber content; 50% biofiber/50% glass fiber loading (magnification 187×).

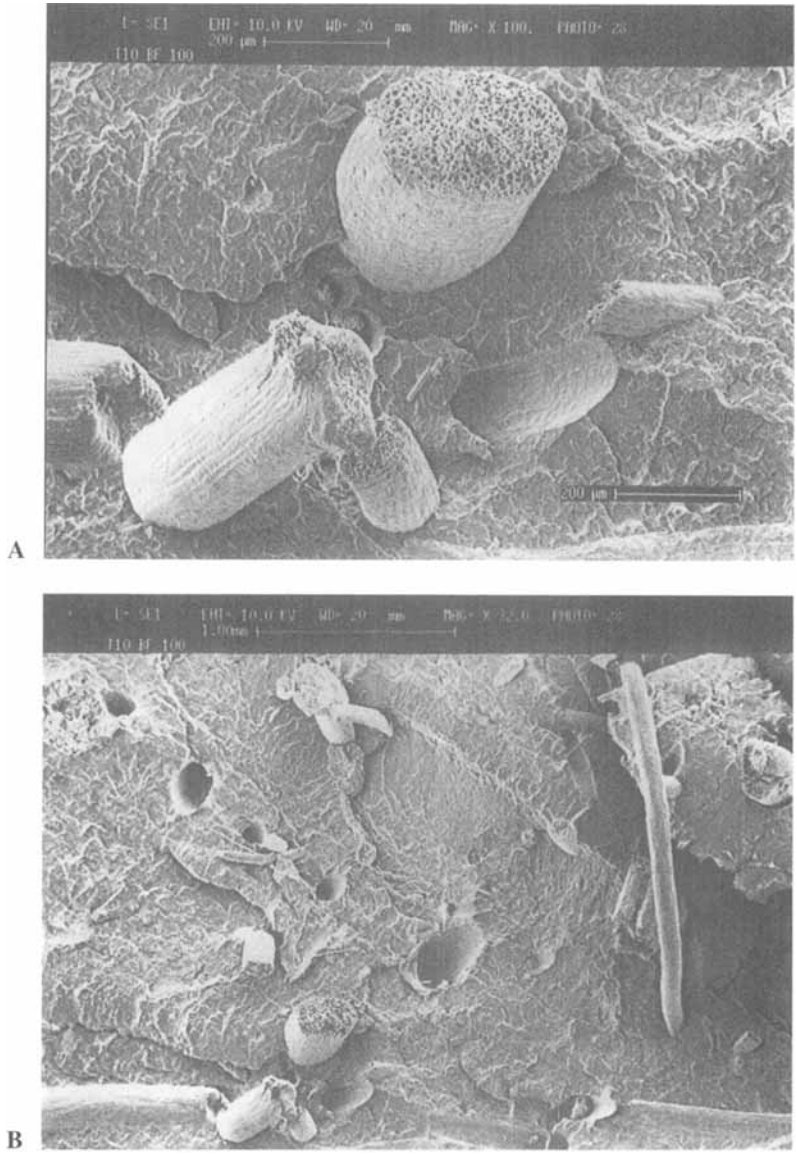

FIG. 10. (A) Scanning electron micrograph for composites with 10% overall fiber content; 100% biofiber loading (magnification 100×). (B) Scanning electron micrograph for composites with 10% overall fiber content; 100% biofiber loading (magnification 32×).

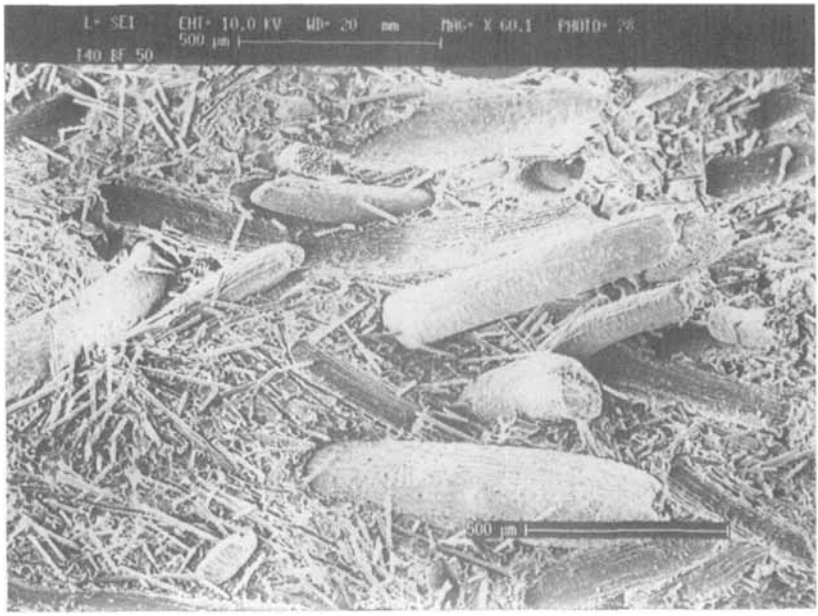

FIG. 11. Scanning electron micrograph for composites with 40% overall fiber content: 50% biofiber/50% glass fiber loading (magnification 60.1×).

and debonding of fibers. It is also clear that for a unit area, there are more glass fibers than the biofibers. The same phenomena are also shown in Fig. 11. It is interesting to note that although there are more glass fibers than biofibers per unit area, in general, the strength of composites with high glass fibers/low biofibers loading are comparable with the ones with low glass fibers/high biofibers loading. Thus, the results show that more biofibers could be incorporated in a hybrid composite which would give the same range of properties as the composites with a higher loading of glass fibers.

CONCLUSIONS

This article reports on the use of glass fibers and coconut fiber as reinforcements in polypropylene composites. The conclusions from this study are summarized as follows:

1. The incorporation of both biofibers and glass fibers into the PP matrix has resulted in the reduction of flexural, tensile, and impact strengths and elongation at break. This has been attributed to the increased in-

compatibility between the fibers and the PP matrix, and the irregularity in fiber size, especially for biofibers as shown by the micrographs. It is believed that these factors have reduced the efficiency of stress transfer in the matrix, which subsequently lower the strength of the material.

2. Both the flexural and tensile moduli have been improved with the increasing level of fiber loading.
3. Most of the properties tested for composites with high glass fibers/low biofibers loading are comparable with the ones with low glass fibers/high biofibers loading. The results show that more biofibers could be incorporated in hybrid composites, which would give the same range of properties as the composites with a higher loading of glass fibers.

Further study is being carried out to look into the effect of various coupling agents and compatibilizers on the mechanical and physical properties of the composites.

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