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Use of Natural and Synthetic Fibers as Co-reinforcing Agents on Abrasive Wear Behavior and Flexural Strength of Wood/PVC Composites

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Abstract. Incorporations of synthetic fiber into wood polyvinyl chloride composites (WPVC) were investigated for the effect of co-reinforcing fillers on wear behavior of WPVC materials. Physical and mechanical properties of the composites were also analyzed and discussed in association with wear behavior of co-reinforced WPVC. Three different types of synthetic fibers, namely, E-glass fiber, S-glass fiber and Carbon fiber, having an average fiber length of 3 mm, were used to study the effect of type of synthetic fiber. The concentration of synthetic fiber was varied from 0-20 pph in the WPVC composites. Natural wood flour with an average particle size of less than 250 micron was introduced into the PVC compound at a fixed concentration of 40 pph to produce the WPVC composites. Various kinds of wood flour, including, *Xylia Kerri* Craib & Hutch (XK), *Hevea Brasiliensis* Linn (HB) and *Mangifera Indica* Linn (MI), were also studied for the influence of wood type. Wear behavior of the composites was employed by monitoring the specific wear rate at different sliding distances (2.0 and 4.0 km), using Taber wear tester. The results found that flexural properties of the composites were improved by addition of synthetic fibers. The carbon fiber-co reinforced WPVC composites showed the highest flexural properties. Among natural wood types used, the co-reinforced WPVC with HB exhibited the most improvement of flexural properties, particularly when higher loading of the synthetic fiber. It was observed that addition of synthetic fiber can enhance wear resistance of materials, the effect being more pronounced at the higher sliding distance (4 km). S-glass fiber-co reinforced WPVC with XK showed the best wear resistance property and the optimum concentration of S-glass fiber used was 10 pph.

Introduction

Use of natural wood flour into PVC materials to produce wood/poly(vinyl chloride) (WPVC) composite products has been increased at the present because of many benefits from WPVC productions, such as cost reduction, dimension stability, versatile properties, recycling purposes, and environmentally friendly. In the past, applications of WPVC products have been usually used indoor, but recently, they can also be used for outdoor applications due to improved durability for sunlight with higher service temperature, higher resistance to biological attacks, and lower humidity absorption. The previous studies [1-2] also demonstrated the high dimension stability of WPVC and the ability to prevention from moisture and fungal attack of WPVC composites. Nevertheless, until the present, the WPVC productions are being developed in order to improve their properties appropriate to more specific applications. Incorporation of synthetic fibers into WPVC materials is one of the property improvement methods for wood polymer composites. A study by Tungjitpornkull *et al* [2] improved the impact strength and flexural properties of WPVC by adding glass fibre (E-chopped strand) as co-reinforcing agent and also noted that the flexural strength of the composites was influenced by the initial fibre length. Jeamtrakull *et al* [3] studied wear behaviors of WPVC at different wood types and suggested that among wood types used in the study, namely *Xylia kerrii* Craib & Hutch. (XK), *Hevea brasiliensis* Linn. (HB), and *Mangifera* *indica* Linn. (MI), the WPVC with XK wood at 40 pph in concentration showed the best wear resistance property of composites, the improvement being more significant with incorporation of E glass fiber in the WPVC composites.

This present study was aimed to continue to improve the triboligical properties of WPVC materials through co-reinforcing fibers between synthetic fibers (E-glass fiber, S-glass fiber and carbon fiber) and natural fibers (*Xylia kerrii* Craib & Hutch. (XK), *Hevea brasiliensis* Linn. (HB) and *Mangifera indica* Linn. (MI)).

Experimental

WPVC formulations: Lists of chemicals and raw materials used for WPVC formulations were used as given in our previous works [2-3]. Before mixing and specimen preparation steps, all ingredients were dried at 80^{o}C for 24 h in order to eliminate residual moisture in the PVC and WPVC materials.

Natural and synthetic fibers (Used as co-reinforcing fillers): Three different types of natural wood flours, including, *Xylia kerrii* Craib & Hutch. (XK), *Hevea brasiliensis* Linn. (HB) and *Mangifera indica* Linn. (MI), were supplied by Phongsiri Ltd., Part. Ratchaburi, Thailand. Before introducing wood flour into the PVC formulations, the wood flours with an average particle size of less than 250 micron had been surface-chemical treated using silane coupling agent (Si69) [2-3]. The E-glass and S-glass fiber (purchased from Pongpana Co., Ltd, Bangkok, Thailand) and Carbon fiber (Kongkaitkanjana Co., Ltd, Bangkok, Thailand) were used as synthetic fibers in this study and the specific information of those synthetic fibers are given in Table 1. In this study the wood flour was introduced into the PVC compound at a fixed concentration of 40 pph and the concentrations of synthetic fiber in WPVC were varied in a range from 0-20 pph.

Table 1. Specific information of the synthetic fibers used

Property	E – glass fiber	S-glass fiber	Carbon fiber
Diameter (μm)	13.0	13.0	7.0
Length (mm)	3.0	3.0	3.0
Aspect ratio ($\times 10^6$)	2.31	2.31	4.29
Density (g/cm^3)	2.55	2.49	1.80
Young’s Modulus (GPa)	81	89	240-300
Tensile Strength (GPa)	3.45	4.59	4.3-7.1
Strain to failure (%)	4.9	5.7	1.7-2.4

Specimen preparations: The test specimens were prepared by compression molding technique. The mixtures were put into a steel mold cavity and the dimensions of cavity were 180×180×3 mm^3. The molding conditions for the compression molding step were 180^{o}C mold temperature, 18 Mpa molding pressure and holding time of 7 min before cooling down to room temperature using water coolant for 5 min. Finally, the molded specimens were cut into the standard test pieces as given by the mechanical and wear testing methods.

Mechanical properties: Mechanical properties of co-reinforced WPVC composites were investigated throug flexural properties of materials in terms of flexural modulus and strength according to ASTM D790 (2003).

Specific wear rate: Wear behaviors of materials were studied via the specific wear rate which was performed under a contact load of 250 g using Taber 5130 Abraser (Taber Industries, North Tonawanda, NY) for sliding distances of 2 and 4 km.

Results and discussion

Fig.1 and 2 demonstrate the flexural modulus and strength of WPVC co-reinforced between natural and synthetic fibers, respectively. It can be noted that addition of synthetic fibers in the composites resulted in considerable increases of the flexural modulus and strength of materials. The WPVC with HB wood exhibited the most flexural properties as compared with the WPVC with XK and MI woods, particularly when higher loadings of synthetic fibers in the composite. The explanation for this involved the lower melt viscosity and subsequent a tiny failure of the synthetic fiber during manufacturing [4], owning to the lower aspect ratio of HB wood as compared with XK and MI woods. For the effect of synthetic fiber type, the carbon fiber-WPVC composites had the most promising flexural modulus and strength, followed by the S-glass and E-glass reinforced composites. This would be due to the results of the initial strength and modulus as well as the aspect ratio of the carbon fiber when compared with the both types of S-glass and E-glass fibers.

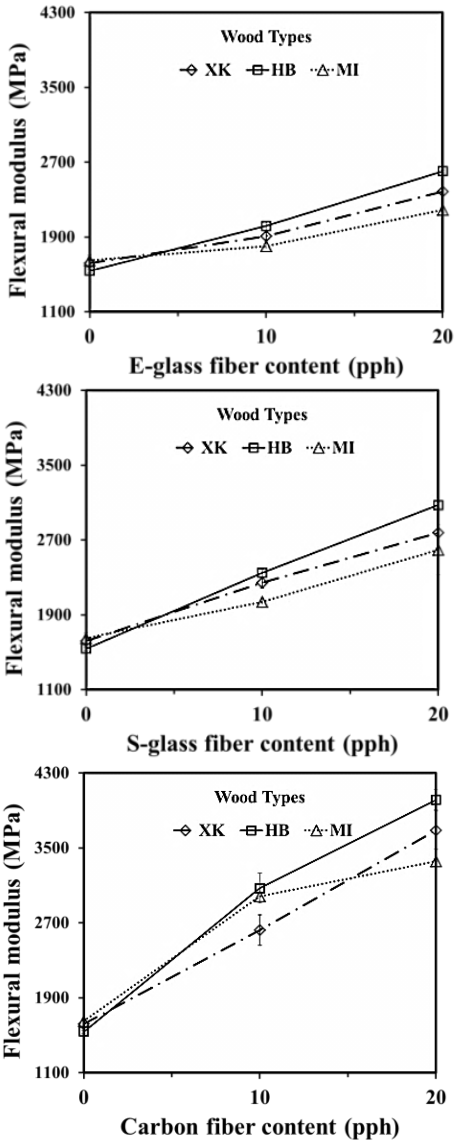

Figure 1 Flexural modulus of co-reinforced WPVC

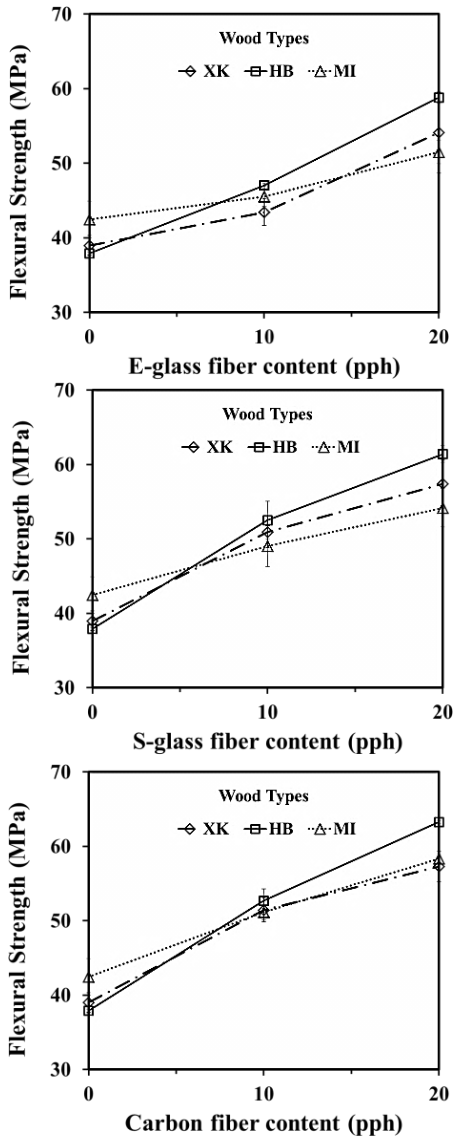

Figure 2 Flexural strength of co-reinforced WPVC

Fig. 3 shows the specific wear rate of the WPVC composites co-reinforced between natural and synthetic fibers for sliding distances of 2 and 4 km. The specific wear rate values were found to reduce when increasing sliding distance. This was because, at higher sliding distance the embedded fiber in the composite matrix tended to expose at the specimen surface, and subsequently the specimen encountered the abrasive wear of the counter face of the Taber Abraser wear tester. For the influence of synthetic fiber, the WPVC co-reinforced with S-glass fiber showed the best wear resistance as compared with the E-glass and carbon fiber composites. The explanation for the results could be substantiated by mechanical properties of synthetic fibers as given in Table 1. Owning to having the lowest failure strain value of the carbon fiber, the WPVC co-reinforced with carbon fiber exhibited significantly poorer wear resistance when comparing with the S-glass fiber co-reinforced WPVC, even though the carbon fiber had the highest modulus and strength. Fig. 3

also shows that S-glass fiber-co reinforced WPVC with XK at 10 pph of S-glass fiber was the most appropriate formulation to resist the mechanical wear. From the results of wear behavior study, it was able to be concluded that wear resistance properties did not necessarily depend on the mechanical properties of the composites.

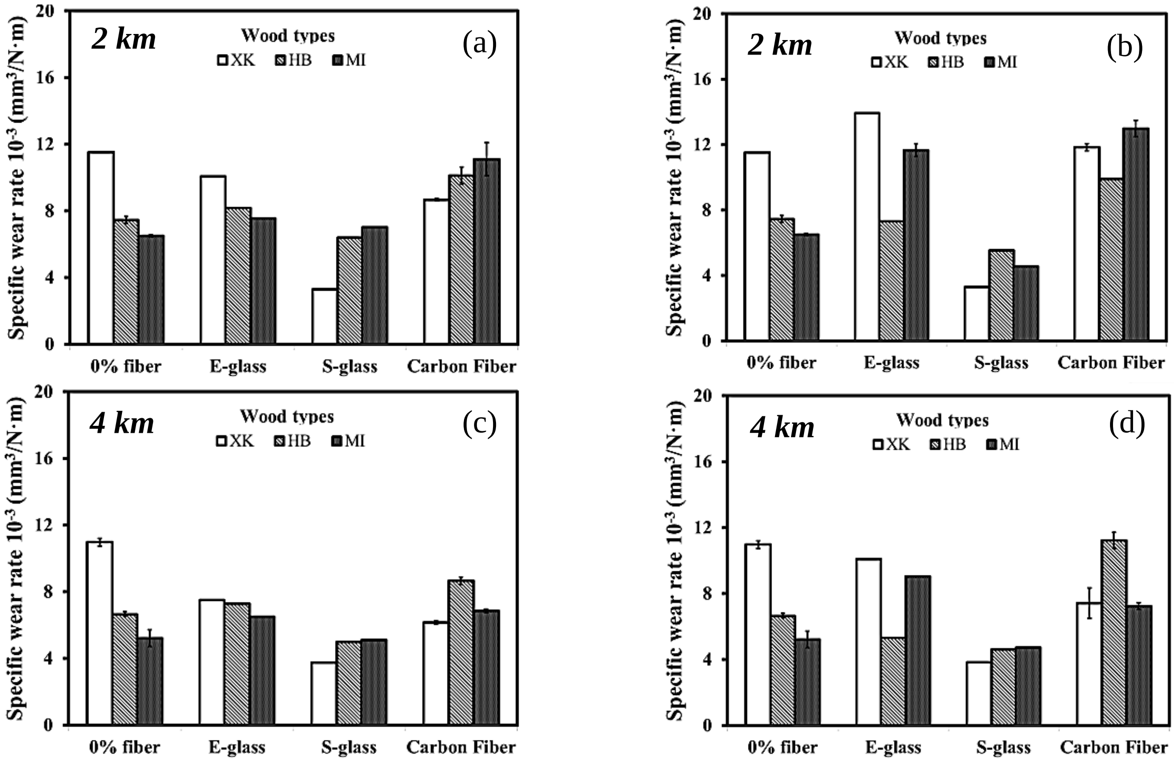

Figure 3 Specific wear rate of co-reinforced WPVC at sliding distances of 2 and 4 km; where 10 pph of synthetic fiber: (a) and (c) and 20 pph of synthetic fiber: (b) and (d)

Conclusion

Incorporations of synthetic fiber (used as co-reinforcing agent in this study), namely, E-glass fiber, S-glass fiber and carbon fiber, were found to improve the flexural modulus and strength of wood/polyvinyl chloride (WPVC) composites. The WPVC co-reinforced with carbon fiber exhibited the most flexural properties whereas that with 10 pph S-glass fiber WPVC showed the most promising wear resistance. The wear rate was found to decrease with sliding distance.

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