DEVELOPMENT OF RUBBER SHOE SOLE CONTAINING BAMBOO FIBERS FOR FROZEN ROADS

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Abstract

Short bamboo fibers were put in the rubber sole of a shoe to enhance the gripping with respect to frozen road, aligned perpendicularly to the shoe sole Young's modulus and Vickers hardness of bamboo fibers were measured in order to establish the proper method of processing bamboo fibers mixed in shoe soles. High Young's modulus and stiffness are required for the fibers mixed in the shoe sole for use on frozen road. Phenol resin treatment improved the Young's modulus and the stiffness. The improvement in both Young's modulus and Vickers hardness were due to the phenol resin treatment since it helped to constrain the transverse deformation of bamboo fibers in a bundle. The slide resistance coefficient of the sole on frozen surface was measured. The rubber containing bamboo fibers treated with phenol resin (PTBF) was used. The rubber containing PTBF indicated the optimum index. It is due to the spike effect of stiff PTBF, namely, bamboo fibers appearing from the rubber surface were penetrated in to ice.

1. Introduction

Shoe soles play an important role in our daily lives. They are used not only to absorb impact force from the ground while walking, but also to prevent slipping. Thus, as shoe soles are such daily things, we hardly pay much attention to them. Reconsidering the importance of shoe soles and improving the quality of them can decrease the number of serious accidents that are caused by slipping. Therefore, the aim of this research is to show how bamboo fibers can be the key to improve the quality of shoe soles, and to establish an appropriate way to produce bamboo fibers put in the rubber soles.

The general features of accidents leading death disasters are given in Fig.1[1)]. As can be seen in the graph, there are many injuries due to slipping; especially on frozen roads in winter. Accidents caused by slippage are extreme because of the low coefficient of friction[2)]. Due to the countless accidents on bad-conditioned roads, people want to have proper shoes safely enough on the frozen roads slightly covered with water skin. To answer this expectation, numerous studies have been conducted on this topic[3-4)]. Various materials are now put into the soles' rubber to improve the wear resistance. However, such materials often reduce the frictional coefficient under water lubricant condition. In order to achieve a higher friction on frozen roads, glass fibers are often compounded into rubber shoe sole. Although glass fibers have such advantage, their use should be reduced as long as the global environment is concerned. Even for shoe soles, environmentally gentle composites can be made by replacing glass fibers with various types of natural fibers. Among natural materials, bamboo fiber is expected to be a good alternative instead of glass fibers, due to its excellent mechanical properties[5)]. Bamboo fibers are in fact often referred as the "natural glass fibers". Although there are some studies on polymer composites using bamboo fibers, they are still a trial phase[5)]. Bamboo fiber primarily consists of cellulose, hemi-cellulose and lignin. Lignin is hydrophobic while cellulose and hemi-cellulose are hydrophilic. Therefore, bamboo fibers absorb appreciable water, and they become soft and weak. An appropriate treatment is desired to improve the water resistance of bamboo fiber for practical use of shoe soles reinforced with bamboo fibers on wet and frozen roads.

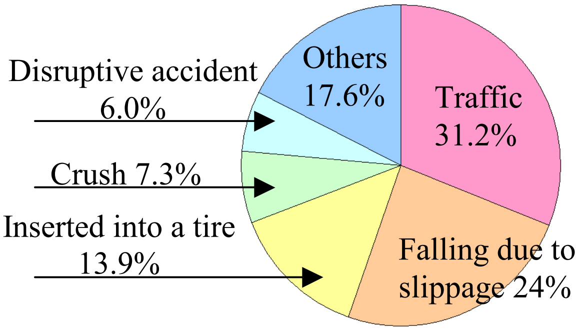


Fig.1 General features of accidents leading to death.

2. Materials

Some mechanical properties of bamboo fibers and glass fibers used in this study are shown in Table 1. Bamboo fibers (they were correctly fiber bundles) came from Indonesia and were extracted by alkali treatment. The average diameter of fibers was 200μm. Discards were removed by boiling the bamboo fibers. Four types of fibers were used. They are

i) Bamboo fibers thermally treated at 453K for 3 minutes.
ii) Bamboo fibers dipped in a 10% dilute sulfuric acid solution at 363K for 120 minutes.
iii) Bamboo fibers treated with a silane coupling agent.
iv) Bamboo fibers treated with a phenolic resin.

Treated bamboo fibers were stored in a box controlled at a certain humidity for a fixed period of time, in order to assure the constant moisture content in the fibers. Then, they were mixed with raw rubber and kneaded. Sample soles were molded according to the conventional procedure (vulcanized at 482K under 9.8MPa).

Table 1 Mechanical properties of Bamboo fiber and E-glass.

	Specific gravity	Tensile strength [MPa]	Young's modulus [GPa]	Specific modulus [GPa]
Bamboo	1.1	319-1000	12-55	48-89
E-Glass	2.5	1000-1600	72	28

3. Experimental method

Tensile tests for bamboo fibers were conducted by using a displacement control machine at 0.5mm/min. The specimens were prepared based on JIS 7606. The bamboo fiber diameter was measured by using an optical microscope before testing.

In order to measure the hardness in the longitudinal direction of bamboo fiber, bamboo fibers were firstly molded with polyester resin. A micro Vickers machine was used to measure the hardness. The compressive load for the Vickers' indenter was 98.1mN and hold for 15 seconds.

The frictional force of fabricated rubber samples (a rectangular parallelepiped) containing bamboo fibers with respect ice surface was measured and the frictional coefficient was estimated. A sample is perpendicularly pressed onto the ice plate and the ice plate is moved back and forth. The load moving the ice plate is measured via a load cell attached to the linear actuator powered with high pressure air. The compression force of the sample rubber onto the ice is constant and given by the dead weight. The sample rubber and the ice plate are kept in the heat isolated transparent box into which cool gas from liquid nitrogen is supplied. The experimental apparatus is shown in Fig.2. A rubber sample containing glass fibers was also prepared and tested as a control.

The surface topology of the sample rubbers was observed by using a SEM while the averaged surface roughness was estimated by using an optical microscope. The slide resistance coefficient (CSR index) of the shoe sole with respect to frozen surface was measured using a testing machine shown in

Fig.3 (O-Y・PSM). For this machine, a relatively large ice is used, enough to cover all the surface.

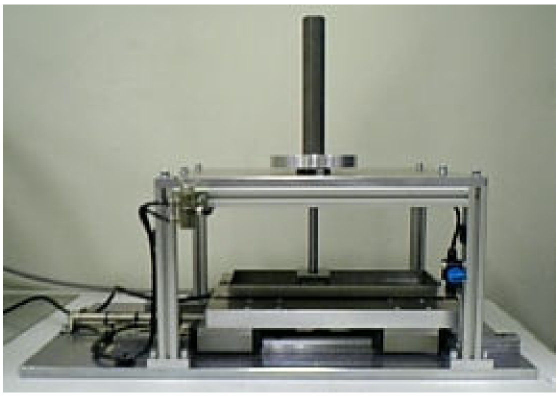


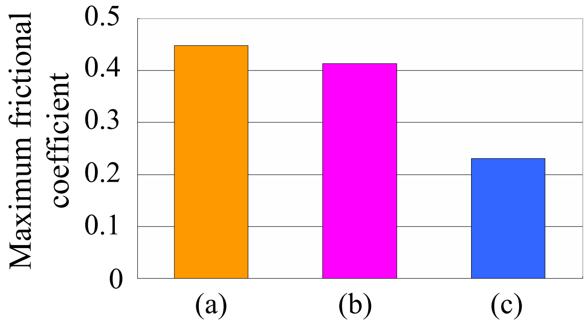
Fig.2 Experimental apparatus measuring the frictional coefficient of rubber sample with respect to ice surface.

Fig.3 Testing machine to estimate CSR index for shoe soles

4. Experimental results and discussion

4.1 Influence of frictional force on sliding, using rubber with untreated bamboo fibers.

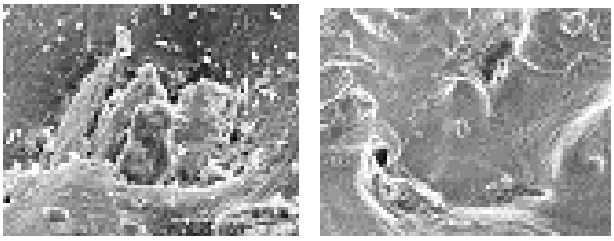
The coefficient of friction with respect to water ice is shown in Fig.5 for the rubber containing untreated bamboo fibers (UTBF). In the case of (a), the observed coefficient of friction is highest while coefficient of friction after 100 cycles became almost a half as low as that of the virgin rubber sample. During cyclic testing, bamboo fibers embedded in sole rubber must have gradually absorb water, resultantly the fibers may have been soft loosing stiffness and hardness. Therefore, coefficient of friction might have decreased as the number of sliding cycles increased due to water absorption of bamboo fibers.



(a) First cycle (virgin, no water
(b) Second cycle (a little water
(c) after 100 cycles of sliding on the

Fig.5 Variation of the maximum frictional coefficient with respect to test cycle for the rubber sample containing untreated bamboo fibers (UTBF).

The sample rubber surfaces containing UTBF are shown in Fig.5. The reciprocating motions were conducted up to 100 cycles at the test. Before the test, bamboo fibers were protruding from the rubber. Yet, none were observed after the test.

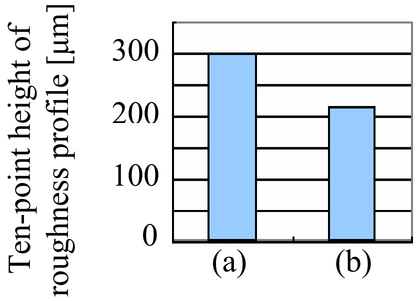


(a) (b)

(a) Rubber containing UTBF before friction test
(b) Rubber containing UTBF after friction test

Fig.5 Photograph of surface state of shoe sole.

The ten-point height of roughness profile of the rubber containing UTBF before and after 100 cycles of the frictional test is shown in Fig.6. Looking at Fig.7, it is clear that the material had worn out and the surface of the shoe sole was smoothed. It is possible to think that the material's wear was caused by water absorption softening the bamboo fibers.

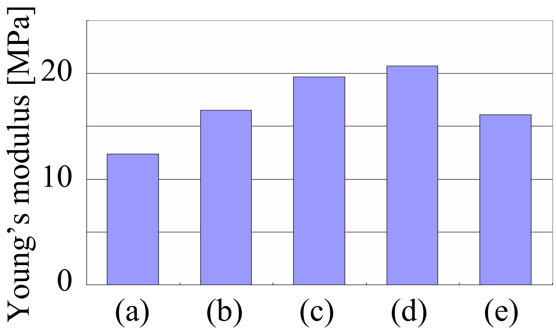


(a) Before friction test
(b) After friction test

Fig.6 Ten point height of roughness profile of rubber containing UTBF.

4.2 Effects of fiber treatment on Young's modulus and Hardness of bamboo fiber.

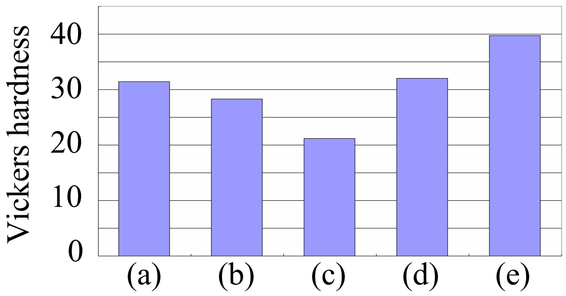
Relation between Young's modulus and the processing method is shown in Fig.7. All fiber treatments improve the observed Young's modulus. We may suppose that the Young's modulus has improved because heated lignin filled the gap between the fibers, restoring the fibers' elasticity. During the acid treatment, unnecessary lignin, hemi-cellulose, and amorphous cellulose were removed. Consequently, the relative degree of crystallization of bamboo fiber cellulose was improved. The improvement in the Young's modulus might be due to much remain of cellulose's crystalline material having higher rigidity. However, in many cases, bamboo fibers were damaged by this acid treatment, and thus the Young's modulus greatly varied. This result shows that the acid treatment is not a suitable technique for industry. In the experiment using bamboo fibers permeated with a silane coupling agent, silicon compound had formed on its' surface. Silicon compound formed on the bamboo fibers' surface improved the Young's modulus. In this study, bamboo fiber bundles were used because a single bamboo fiber is only about 10µm, which makes it terribly undersized to examine any changes caused by the treatment. Nonetheless, adhesion between fibers is not strong enough to tolerate the treatment. Thus, when bamboo fibers are used as a bundle, dissociation of fibers occurs as incipient damage; reducing the bending rigidity. It is thinkable that the improvement in the Young's modulus was caused by the phenol resin since it helps restrain the bamboo fibers in a bundle, due to its stiffness, during the phenol treatment.



(a) Untreated (b) Thermally treated
(c) Acid solution (d) Silane coupling agent
(e) Phenol resin treatment

Fig.7 Relationship between Young's modulus and processing method.

The relation between hardness and processing method is shown in Fig.8. Considering Fig.8, it is clear that when fibers were put through acid treatment or were given heat treatment, the hardness of the fibers marked lower figures compared to those of untreated materials. In the case of acid treatment, the hardness of the fibers decreased because the compositions of the bamboo melted away due to the action of the acid. On the contrary, there was scarcely any change in the figures in the heat treatment. During the experiment, some parts of heated lignin flowed, but it had no effect on the quality of the bamboo itself. Consequently, the hardness of the fibers did not show more than a slight change in the numbers. The hardness of bamboo fibers on which silicon compound was formed, was unchanged and almost same as the untreated ones. When silicon compound forms on the surface, it does not necessarily mean that the hardness of the fiber increases automatically, because the silane compound does not, in any case, form inside the fiber. If there were no change in the fiber itself, it would not be hardened. Naturally, the hardness of the bamboo fiber did not differ in a way we expected. Bamboo fibers which had phenol resin treatment showed a great improvement in the hardness of the fibers. The reason for this improvement is thought to be the same reason when the Young's modulus increased.



(a) Untreated (b) Thermally treated
(c) Acid solution (d) Silane coupling agent
(e) Phenol resin treatment

Fig.8 Relationship between Vickers hardness and processing method.

4.3 Effect of phenol treatment on wear of bamboo fibers in shoe soles.

Young's modulus and Vickers hardness of the UTBF and phenol resin treated bamboo fibers (PTBF) are shown in Figs.9 and 10. When PTBF absorbed water, Young's modulus decreased at some degree. Thus still, Young's modulus of PTBF that absorbed water showed superior results compared to that of UTBF. It is probable that the phenol resin could constrain the bamboo fiber bundle. When PTBF absorbed water, PTBF did not show any change in the Vickers hardness before and after absorbing water. Contrastively, UTBF that absorbed water showed conspicuous decrease in the Vickers hardness. It is likely that the phenol resin could impregnate into bamboo fibers and make them cured. Therefore, it is possible that the phenol resin could maintain the mechanical properties of the bamboo fibers after the absorption of water.

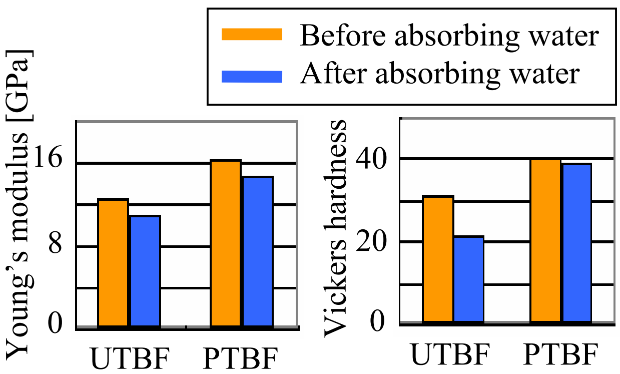
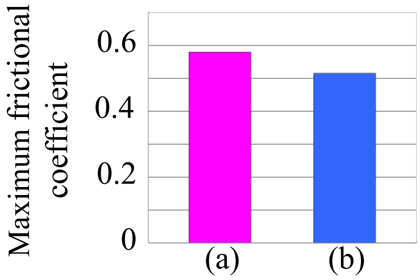


Fig.9 Young's modulus. Fig.10 Vickers hardness.

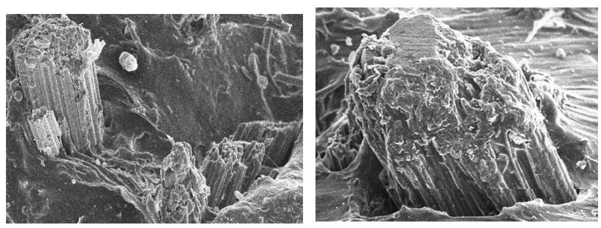
The maximum frictional coefficient using rubber with PTBF is shown in Fig.11. Compared to the coefficient of friction in earlier stages, rubber containing PTBF showed low static coefficient of friction after 100 cycles. Nonetheless, the maximum coefficient of friction shows that this shoe sole is sufficient.



(a) Before friction test
(b) After friction test

Fig.11 Maximum frictional coefficient gained from testing water absorption using rubber which contains PTBF..

Surfaces of rubber, containing PTBF, before and after 100 cycles of the frictional test are shown in Fig.12. After 100 cycles of frictional tests, the tips of PTBF became flat. Yet, PTBF still protruded from the sliding surface of the rubber.

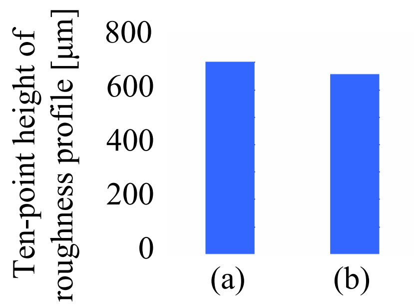


(a) (b)

(a) Rubber containing PTBF before friction test
(b) Rubber containing PTBF after friction test

Fig.12 Photograph of surface conditions of shoe sole which contain PTBF.

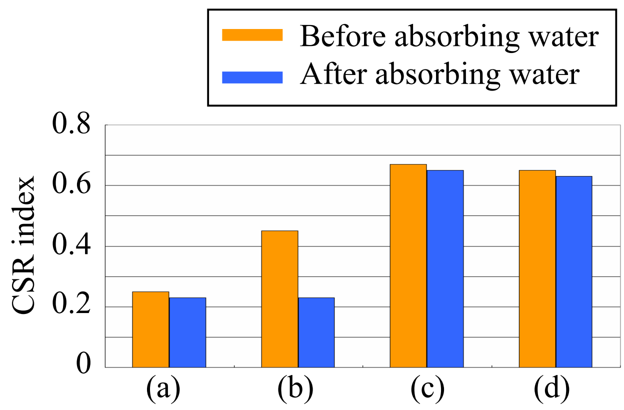
The ten-point height of roughness profile of rubber containing PTBF is shown in Fig. 13. Although there was only a slight change in the ten-point height, rubber containing PTBF that absorbed water maintained high performance after 100 cycles of periodic frictions.



(a) Before friction test
(b) After friction test

Fig.13 Ten-point height of rubber containing PTBF.

CSR index of each shoe sole material is shown in Fig.14. The CSR index is an indicator of the shoes' slipperiness. Generally, the optimum range of the CSR index is between 0.46 and 0.9, for slippage sensation while walking. Rubber containing PTBF indicated optimum index. And it indicated an almost equal CSR index to rubber containing glass fibers. Evidently, if bamboo fibers are treated with phenol resin, the stiffness of bamboo fibers would be maintained, and abrasion would be prevented even after the fibers absorb water.



(a) Original rubber
(b) Rubber containing UTBF
(c) Rubber containing PTBF
(d) Rubber containing glass fibers

Fig.14 Effect of phenol resin treatment on CSR

5. Conclusion

1) After absorbing water, the surface of the shoe sole is smoothed, and the coefficient of friction decreases.
2) Young's modulus and hardness of bamboo fibers are appreciably improved by phenol treatment.
3) Even after absorbing water, PTBF could maintain mechanical properties only if phenol treatment was performed to bamboo fibers. Rubber containing PTBF indicated optimum index

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