

Improvement of Frictional Coefficient of Modified Shoe Soles onto Icy and Snowy Road by Tilting of Added Glass Fibers into Rubber

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Abstract—The purpose of this study is to propose an effective method to improve frictional coefficient between shoe rubber soles with added glass fibers and the surfaces of icy and snowy road in order to prevent slip-and-fall accidents by the users. The additional fibers into the rubber were uniformly tilted to the perpendicular direction of the frictional surface, where tilting angles were -60, -30, +30, +60, 90 degrees and 0 (as normal specimen), respectively. It was found that parallel arraignment was effective to improve the frictional coefficient when glass fibers were embedded in the shoe rubber, while perpendicular to normal direction of the embedded glass fibers on the shoe surface was also effective to do that once after they were exposed from the shoe rubber with its abrasion. These improvements were explained by the increase of stiffness against the shear deformation of the rubber at critical frictional state and adequate scratching of fibers when fibers were protruded in perpendicular to frictional direction, respectively. Most effective angle of tilting of frictional coefficient between rubber specimens and a stone was perpendicular (= 0 degree) to frictional direction. Combinative modified rubber specimen having 2 layers was fabricated where tilting angle of protruded fibers was 0 degree near the contact surface and tilting angle of embedded fibers was 90 degrees near back surface in thickness direction to further improve the frictional coefficient. Current study suggested that effective arraignments in tilting angle of the added fibers should be applied in designing rubber shoe soles to keep the safeties for users in regions of cold climates.

Keywords—Frictional coefficient, icy and snowy road, shoe rubber soles, tilting angle.

I. INTRODUCTION

SLIPS and falls on icy and snowy surfaces are common not only among outdoor workers in cold regions, but also among pedestrians and the general public in many parts of the world in winter season [1]-[3]. According to Sapporo City Fire Department reports in Japan, slips and falls during one winter caused 1317 injured people which were taken by ambulance in Sapporo city of Hokkaido area in 2012 [4]. Many of these slips occur on pavements or other surfaces covered by snow, water and oil, especially ice [5]. In general, slipping is due to fairly complex causal pathways, involving both environmental and human factors such as the surface state of the road, the design

of the sole, the habit of the walk [6], [7]. The relations with a road surface and the materials of the sole are an important factor in slipping [8]. Typically, various materials which including rubber have been used as a shoe sole material. Those materials exhibit high friction, while the low value of the frictional coefficient between a solid material and snow or ice has been understood due to the presence of liquid water formed at the interface between a solid material and snow or ice [9]. Recently in cold climates such as Hokkaido, it has been released slip resistant shoes to prevent slips by added material [10]. Those shoes have contributed to the fall accident prevention of pedestrian [11], [12]. The state of the added fiber in base materials is important in frictional coefficient of shoe rubber soles [13]. Despite its importance, little research has examined the influence of state of added fiber on frictional coefficient of shoe rubber soles. The purpose of this study is to improve frictional coefficient between modified shoe rubber soles with added glass fibers and the icy road surfaces in order to keep the safeties for users in regions of cold climates. The glass fibers are oriented in the direction of -60, -30, +30, +60, 90 degrees and 0 degree (as normal specimen), respectively. Static frictional coefficients of rubber specimens were determined by using universal tester with water film on stone in order to assume friction on icy road in the walking.

II. MATERIALS AND EXPERIMENTAL

A. Materials

In this study NR/SBR rubber sheet were prepared as base material of shoes soles. Fig. 1 shows appearance of NR/SBR rubber sheet. In this study glass fiber as shown in Fig. 2 were prepared as an additive material of rubber of shoe sole.



Fig. 1 NR/SBR rubber material

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Fig. 2 Glass fibers

B. Fabricating Method of Rubber Specimens

1) Kneading Method of Rubber Material and Fibers

The fibers to be added were previously cut to 5mm in length for easy kneading. The weight fraction of glass fibers was 15%. The additional fibers were compounded with raw material of rubber by a labo-scaled kneading machine (Fig. 3) for about 20 minutes to obtain the modified rubber sheets as shown in Fig. 4.

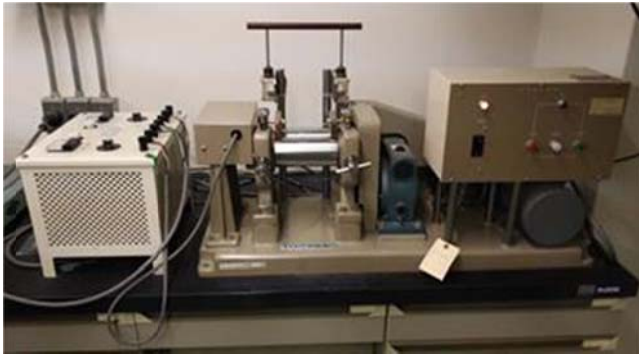


Fig. 3 A labo-scaled kneading machine



Fig. 4 Mold for vulcanizing of sheet of raw rubber materials

2) Fabricating Method of Tilted Rubber Plates

Several sheets of kneaded raw rubber material with additive material were previously fixed with tilting angle in a mold to fabricate the specimens, where the length, the width and thickness were 120mm, 120mm and 5mm, respectively. Through the method, embedded fibers were uniformly tilted in the rubber specimen to the perpendicular direction of the frictional surface of the specimen after the vulcanization shown in next session, where the conditions of tilting angle were -60, -30, +30, +60, 90 and 0 degree (as normal specimen) to as

shown in Fig. 5.

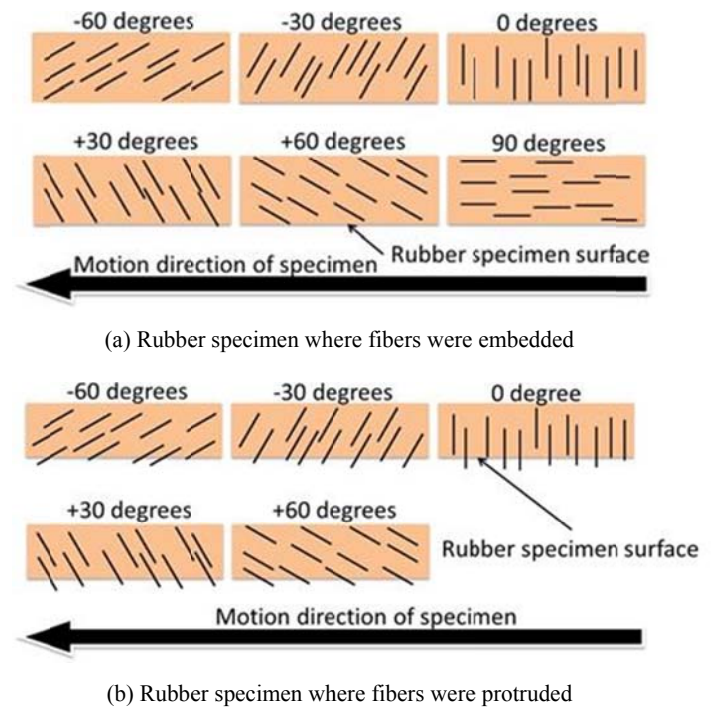


Fig. 5 Schematic view of rubber specimen where fibers were tilted in off-set angle

3) Vulcanization of Sheet of Raw Rubber Materials

The sheets of kneaded raw rubber material explained in the last session were vulcanized at 155 degree-C for 9 minutes under 5MPa with heat press machine (HP200HB, KAWANAKA SANGYO CO.).

4) Fabricating Method of Rubber Specimens where Fibers Were Embedded

All fibers in those sheets were embedded in the specimen as shown in Fig. 5 (a). In this case, with the specimen, the frictional surface of the specimen was covered with flat rubber.

5) Fabricating Method of Rubber Specimens where Fibers Were Protruded

Some vulcanized rubber sheets explained in the II-B-3 session were sliced in thickness direction with dimensions of 2.5*120*120 mm in thickness, width and length, respectively. Fibers of those sheets were protruded as shown in Fig. 5 (a) and contact surface was rough in contrast to rubber specimen where fibers were embedded.

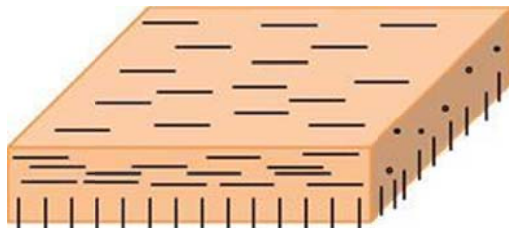
6) Modified Specimen with Combinational Technique

Further modified specimen combining in thickness direction were also fabricated where tilting angle of fibers was 0 degree in the layer group of contact surface and that was 90 degrees in another layer group as shown in Fig. 6. The dimensions of combinative modified specimen were of 7*120*120 mm in thickness, width, and length, respectively. Same processes shown in the last sessions were applied for fabricating the combinative modified specimen in vulcanization and slicing. Fibers of the layer group of contact surface were protruded in

perpendicular (0 degree) to frictional direction.



(a) Appearance



(b) Schematic view

Fig. 6 Combinative modified rubber specimen

C. Measurement Method of Static Frictional Coefficient

Static frictional coefficients between rubber specimens and a stone were determined by universal tester (AG-1 100kN, SHIMADZU CORPORATION), as shown in Fig. 7. To consider the friction at walking on practical icy road, water film was applied on the stone. In the test, the conditions of normal forces were 100, 200, 300 and 400N, applying to the back of rubber specimen. Test speed and the volume of water films in unit area were 5mm/min and 7×10^{-4} ml/mm², respectively.

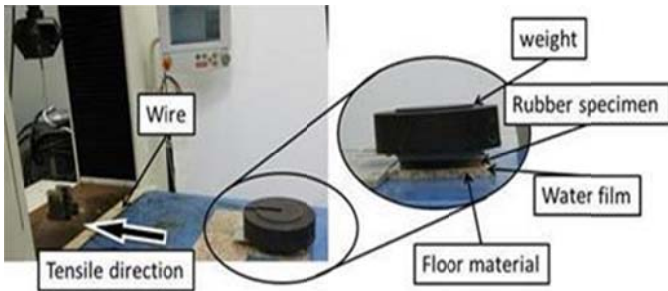


Fig. 7 Static friction test (AG-1 100kN, SHIMADZU CORPORATION)

III. RESULTS AND DISCUSSION

A. Effect of Tilting Angle of Embedded Fibers near Back Surface on Frictional Coefficients between Rubber Specimens and Floor Material

Fig. 8 shows the effect of tilting angles of embedded glass fibers on static frictional coefficients between rubber specimens and a stone under 100N. The frictional coefficient between rubber specimen and a stone was the highest when tilting angle of embedded fibers was -60 degrees. This result

was explained by the increase of stiffness against the shear deformation of the rubber at critical frictional state. In contrast, the low coefficient of static friction was observed when tilting angle of embedded fibers was -30, 0, +30, +60 degrees to frictional direction. It is thought that fibers scratched the stone insufficiently when fibers were embedded. When fibers were embedded and contact with a floor materials indirectly, effective angle of tilting of frictional coefficient between rubber specimens and a stone was parallel (= 90 degrees) to frictional direction in contrast to tilting angle of rubber specimen where fibers were protruded.

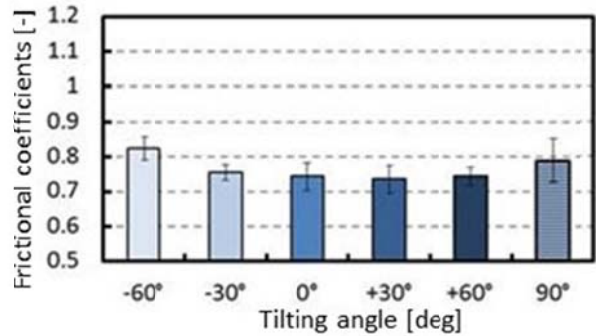
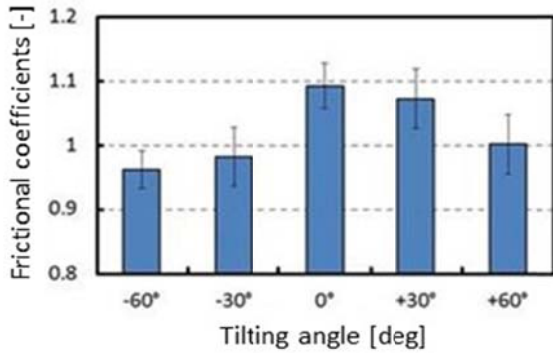


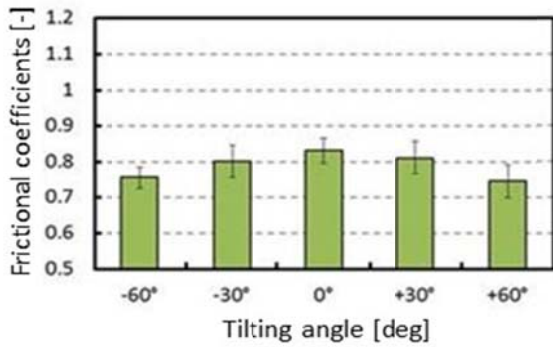
Fig. 8 Effect of tilting angles of embedded glass fibers on static frictional coefficients under 100N

B. Effect of Tilting Angle of Protruded Fibers near Contact Surface on Frictional Coefficients between Rubber Specimens and Floor Material

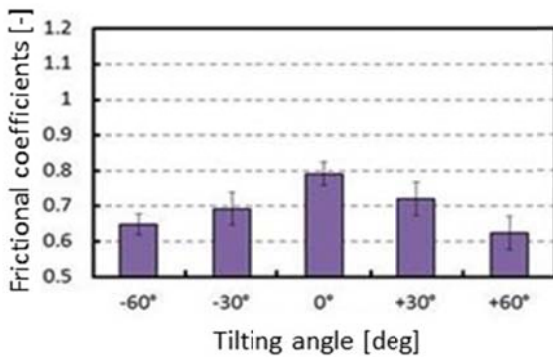
Figs. 9 (a)-(d) show the effect of tilting angles of protruded glass fibers on static frictional coefficients between rubber specimen and a stone under 100N, 200N, 300N and 400N, respectively. Frictional coefficients between rubber specimen where fibers were protruded and a stone were decreased when specimen was subjected to over 200N. Effect of tilting angle of protruded fibers near contact surface on frictional coefficients was independent on normal loading. Rubber specimen has the highest coefficient of static friction when fibers were protruded in perpendicular (= 0 degree) to frictional direction under 100, 200, 300 and 400N. It is thought that adequate scratching of fibers achieved high frictional coefficient when fibers were protruded in perpendicular (= 0 degree) to frictional direction. In contrast, low coefficients of static friction were obtained when fibers were protruded in -60 or +60 degrees to frictional direction because of kinking of fibers by normal loading. When fibers were protruded and contact with a floor materials directly, most effective angle of tilting of frictional coefficient between rubber specimens and a stone was perpendicular (= 0 degree) to frictional direction.



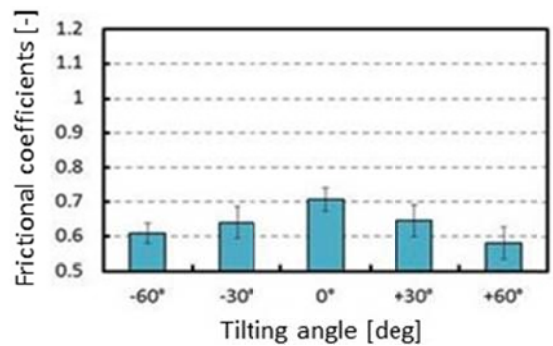
(a) Under 100N



(b) Under 200N



(c) Under 300N



(d) Under 400N

Fig. 9 Effect of tilting angles of exposed glass fibers on static frictional coefficients

C. Effect of Combining Tilting Angle of Contact Surface Layer and That of Back Surface Layer on Frictional Coefficients between Rubber Specimens and Floor Material

Further modified rubber specimen was fabricated to achieve high frictional coefficients. This specimen have combinative 2 layers where tilting angle of protruded fibers was 0 degree near the contact surface and tilting angle of embedded fibers was 90 degrees near another surface in thickness direction. Frictional coefficient between rubber specimen and a stone was improved by combining in thickness direction under 100, 200, 300 and 400N as shown in Fig. 10. Especially when specimen was subjected to 400N, frictional coefficient between rubber specimen and a stone was improved approximately 28% by combining tilting angle of protruded fibers was 0 degree near the contact surface and tilting angle of embedded fibers was 90 degrees near back surface. It is thought that combinative rubber material is suitable for shoe sole to keep the safeties for users in cold climates.

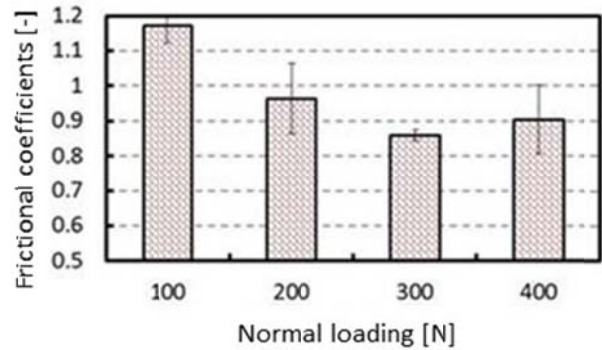


Fig. 10 Effect of combining on static frictional coefficients under 100, 200, 300 and 400N

IV. CONCLUSION

In this study, effect of tilting of glass fibers in off-set angles on static frictional coefficients of shoe rubber soles was investigated. The following conclusions were given.

- (1) When fibers were embedded, effective angle of tilting of frictional coefficient between rubber specimens and a stone was parallel (= 90 degrees) to frictional direction in contrast to tilting angle of rubber specimen where fibers were protruded.
- (2) When fibers were protruded and contact with floor materials directly, most effective angle of tilting of frictional coefficient between rubber specimens and a stone was perpendicular (= 0 degree) to frictional direction.
- (3) Combinative modified rubber specimen having 2 layers was fabricated to achieve high frictional coefficients, especially when specimen was subjected to 400N, frictional coefficient between rubber specimen and a stone was improved approximately 28% by combining. Current study suggested that effective arrangements in tilting angle of the added fibers should be applied in designing rubber shoe soles to keep the safeties for users in regions of cold climates.

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