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FRICTION BETWEEN FOOT, SOCKS AND INSOLES

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ABSTRACT
The present work discusses the friction between foot, socks and insoles in order to provide comfort and avoid the blister development caused by shear. To reduce the risk of developing blisters and ulcers, it is recommended to set low friction on the interface of socks and insoles to allow foot sliding, and high friction on foot skin and the inner surface of sock to provide appropriate level of resistance to avoid excessive movement. The best friction arrangements to achieve the above assumption are to use cotton socks as well as insoles of low friction coefficient when they rub cotton surface.

The friction coefficient generated from bare foot and foot wearing socks of different cotton content when sliding against insoles is investigated. Socks of different cotton content as well as 13 types of common insoles were tested to determine friction coefficient between socks and foot skin as well as socks and insoles.

It was found that friction coefficient increased with increasing cotton content of the socks, where friction coefficient displayed maximum values for socks of 93 % cotton content, while polyamide socks showed the lowest friction coefficient. Based on the experimental observations, it can be recommended to set low friction on the interface of socks and insoles to allow foot sliding inside footwear, and high friction on foot skin and the inner surface of the socks to provide appropriate level of resistance to avoid excessive movement. The best friction arrangements to achieve the above assumption are to use cotton socks as well as insoles of low friction coefficient when they rub cotton surface. In addition to that, use of insoles of low friction coefficient can reduce the shear force on foot sole to avoid skin abrasion, friction blisters and ulcers for people who used to wear shoes without socks. The significant variation of the values of friction coefficient of different types of insoles should be considered and the friction properties of the insole materials should be developed to fit people of heavy weights.

KEYWORDS
Friction, bare foot, cotton, polyamide, socks, footwear, insoles.

INTRODUCTION

Standard socks are mostly composed of cotton, mixed with polyamide and sometimes polyester. Polyamide and polyester are then used as a strengthening component in order to increase the sock lifetime. The textile - foot skin interface was studied in order to measure and predict friction, [1 - 4]. The characteristics of mechanical contacts between foot, socks and footwear during running was determined. For the investigated cases, a good correspondence was found between calculated and measured friction forces. Polyester is less expensive but also less hard-wearing than polyamide. Specific fibres, for example polytetrafluoroethylene fibres (PTFE), have also been added to the composition in order to reduce the friction of the sock against foot skin.

The effect of insole friction characteristics on dynamic control of balance during gait perturbations was determined, [5]. The effect is likely attributed to the ability to produce shear forces at the sock-insole interface, which is reduced with low friction materials. It was found that older people exhibited a more conservative walking pattern, especially on the irregular and wet surfaces, [6]. Compared to the standard shoes, the elevated heel shoes elicited increased double-support time, heel horizontal velocity at heel strike and toe clearance. On the wet surface, the soft sole shoes led to shorter steps and a flatter foot landing. Besides, it was noticed that shoes with elevated heels or soft soles impair walking stability in older people, especially on wet floors, and that high-collar shoes of medium sole hardness provide optimal stability on level dry, irregular and wet floors.

Orthotics and other types of shoe inserts are primarily designed to reduce injury and improve comfort, [7]. The interaction between the plantar surface of the foot and the load-bearing surface contributes to foot and surface deformations and hence to perceived comfort, discomfort or pain. Consumers today are concerned with footwear fit and comfort, [8 – 10], while poorly fitting shoes can result in many different types of foot problems, [11 and 12], and leg fatigue, which may increase the risk of slips and falls, [13 and 14]. Few studies have investigated the interface shapes and the material properties of the shoes, [15 and 16], and deformation characteristics play important roles in the comfort or discomfort experienced by the shoe wearer.

It was concluded that appropriate shoes and insoles are not enough and attention must also be paid to socks [17 - 19]. Hosiery helps to remove perspiration from the skin, regulate foot temperature, provide pressure relief, and protect the skin from abrasion. The static and dynamic coefficients of friction between skin and socks and the effect of sock wearing on foot biomechanical response were not studied in terms of their frictional properties, [20]. It is estimated that an individual takes about 8000 - 10,000 steps a day. During walking, foot presses and rubs against flooring materials.

It was reported that, [21, 22], the friction coefficient between skin and Teflon fabric can be as low as 0.04 while that between skin and cotton fabric is as high as 0.54. Wearing sock can reduce friction and allow the foot to slip on the flooring, [23]. To reduce the risk of foot slip, an easy and effective approach is to increase the shear force by selecting and wearing socks with proper friction properties. Wearing sock with low friction against foot skin is effective in reducing shear on the skin than the sock with low friction against the insole, [24], hence is able to reduce the risk of developing blisters and ulcers.

Friction between the insole, sock and foot has significant impact on the perception of comfort and the risk of injury of the wearers. Low friction allows the foot to move easily in the shoe. However, excessive movement can result in feeling of insecurity and may generate pressure and rubbing between the top and upper part of the foot and the shoe, [25]. Rubbing in shoe includes friction between the foot and the inner surface of sock, and that between the outer surface of sock and shoe. Too low friction in both interfaces may lead to excessive movement of foot in shoe and induces discomfort feeling of insecurity. It was found that the difference in friction coefficient at the different interfaces provides insight into where slip occurs, [26]. It was predicted that slip would be expected at the interface of lower friction coefficient rather than the interface of higher friction coefficient. It was recommended to set low friction on one side to allow foot sliding, and high friction on the other side to provide appropriate level of resistance to avoid excessive movement.

It was found that wearing sock of low friction against the insole to allow more relative sliding between the plantar foot and footwear was found to reduce the shear force significantly, [27]. Socks are able to change the frictional properties between the foot - shoe interface. Abrasion of the foot skin can be avoided by reducing the shear between the contact interfaces with the use of socks made from textile fibers of low frictional coefficients [28]. The mechanical effect of sock with different frictional properties on foot was investigated by finite element models, [29]. Wearing sock can reduce friction and allow the foot to slip on the insole, hence to reduce the shear. It was found that, lower friction coefficient between the insole and the sock outerside was introduced. Even though the friction coefficient between the sock inside and the foot skin was still high, the foot was able to slide together with the sock on the insole and the shear force was reduced significantly. This is in consistency with the measurements, [30], which showed that the shear stresses for subjects wearing nylon hose were significantly lower than the values for hose-free subjects. It was reported that by using the Teflon fiber to the sock soles to impart an extremely low friction value, the socks reduced the occurrences of blister by around 90 vol. % in athletes, [31]. Shear is possibly a main mechanical risk factor of blister development. Therefore, reduction of shear is crucial in preventing the foot lesion development.

In the present work, it is planned to determine the friction coefficient of socks of different cotton content as well as the bare foot sliding on the common insoles materials used in footwear.

EXPERIMENTAL

Experiments were carried out using a test rig to measure the friction coefficient between the foot and the tested insoles through measuring the friction and normal forces. The tested insole sheets were adhered in a base supported by two load cells, the first could measure the horizontal force (friction force) and the second could measure the vertical force (normal load). Friction coefficient is determined by the ratio between the friction and the normal forces. The arrangement of the test rig is shown elsewhere, [32]. The insoles were thoroughly cleaned with soap water to eliminate any dirt and dust and carefully dried before the tests. Insoles were adhered to the base of the test rig, where bare foot was loaded against them to determine friction coefficient, Fig. 1, a. Friction test was carried out at different values of normal load exerted by foot. The relationship between friction coefficient and load was plotted for every test for load ranged from 0 to 700 N. Then the values of friction coefficient were extracted from the figure at 200, 400 and 600 N, which represent the average weights of the children, women and men.

The sliding conditions tested in the experiment were bare foot as well as foot wearing socks of different cotton content (0, 10, 30, 50, 70, 93 %) sliding against insole sheets, Fig. 1, b. Socks materials are a mixture of cotton and polyamide. Foot was washed by detergent to remove perspiration from the skin and carefully dried before the test.

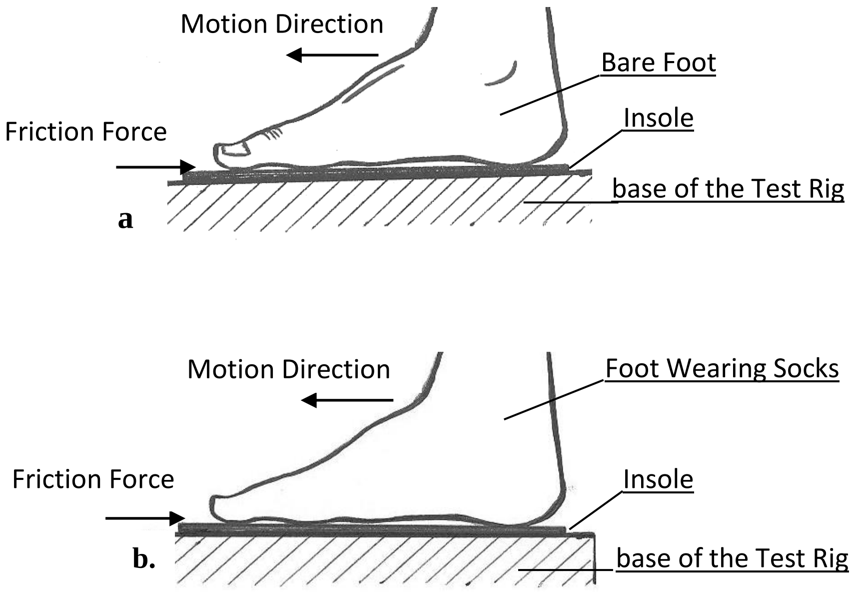

Fig. 1 Arrangement of the sliding conditions.

RESULTS AND DISCUSSION

Figure 2 illustrates the friction coefficient generated from the sliding of bare foot against the socks surface adhered to base of the test rig. Generally, friction coefficient increased with increasing cotton content of the socks. The highest values of friction were displayed by socks of 93% cotton content. As the applied load increased friction coefficient decreased. The highest friction values were 0.63, 0.48 and 0.38 at 200, 400 and 600 N respectively. The experimental observations showed that the relatively high friction between the foot skin and the cotton socks made the barefoot stick to the socks and lead to skin protection against insole abrasion. In addition to that, cotton can absorb perspiration from the foot skin and transfer it into the outer surface of the socks. Cotton is a hydrophilic fibres characterized by an absorbed water saturation pick-up rate of 8.5 %. Polyester is a low hydrophilic polymer which has a 3 % wet pick-up rate. In addition to the textile materials, the shape of the fibre cross section may influence humidity transfer. In this condition, there is a high potential of forward slippage between socks and insoles. It is required to allow the foot to slide on the insole to a certain distance in order that the shear between socks and insoles can be reduced, and consequently reduce the risk for formation of various foot lesions.

Socks are able to change the frictional properties between the foot - shoe interface. Abrasion of the foot skin can be avoided by reducing the shear between the contact interfaces with the use of socks made from textile fibers of low frictional coefficient. The results of the tests carried out to determine the friction coefficient displayed by foot wearing socks of different cotton content sliding against the tested insoles are illustrated in Figs. 3 – 11. At 200 N, friction coefficient increased with increasing cotton content, Fig. 3. The highest friction values were displayed by insole (B) followed by (A), (D) and (C). Friction coefficient displayed maximum values for socks of 93 % cotton content. Polyamide socks showed the lowest friction coefficient when sliding against insole (C). The variation of friction coefficient with the increase of cotton content showed that the lowest effect was displayed by insole (B).

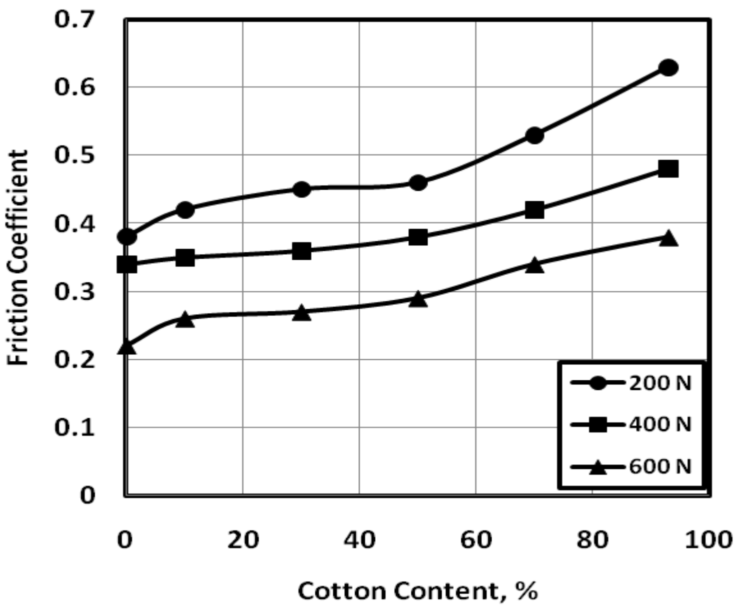

Fig. 2 Friction coefficient displayed by bare foot sliding against the tested socks.

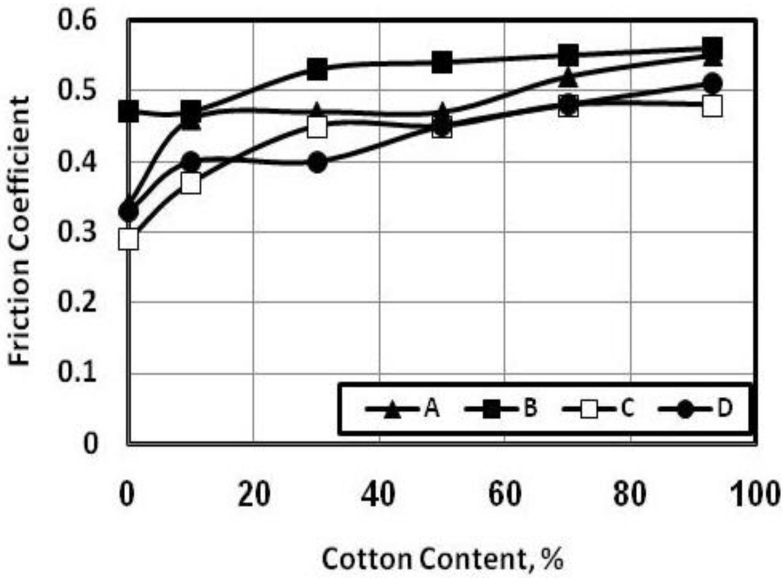

Fig. 3 Friction coefficient displayed by foot wearing socks of different cotton content sliding against insoles A, B, C and D at 200 N load.

As the load increased up to 400 N, the ranking of insoles was the same except that the friction values were relatively lower, Fig. 4. The highest friction values were 0.47, 0.39 and 0.33 at 93 % cotton content for (B), (A), (C) and (D) respectively. Friction coefficient decreased for polyamide socks too, where values ranged from 0.27 to 0.4 were observed. Friction coefficient displayed by foot wearing socks of different cotton content sliding against insoles A, B, C and D at load of 600 N is shown in Fig. 5. Friction values significantly decreased with increasing the applied load to 600 N. The frictional behaviour of insoles showed ranking change, where insole (D) displayed the highest friction coefficient of 0.34 and insole (B) showed the lowest friction coefficient of 0.26 for socks containing 93 % cotton content.

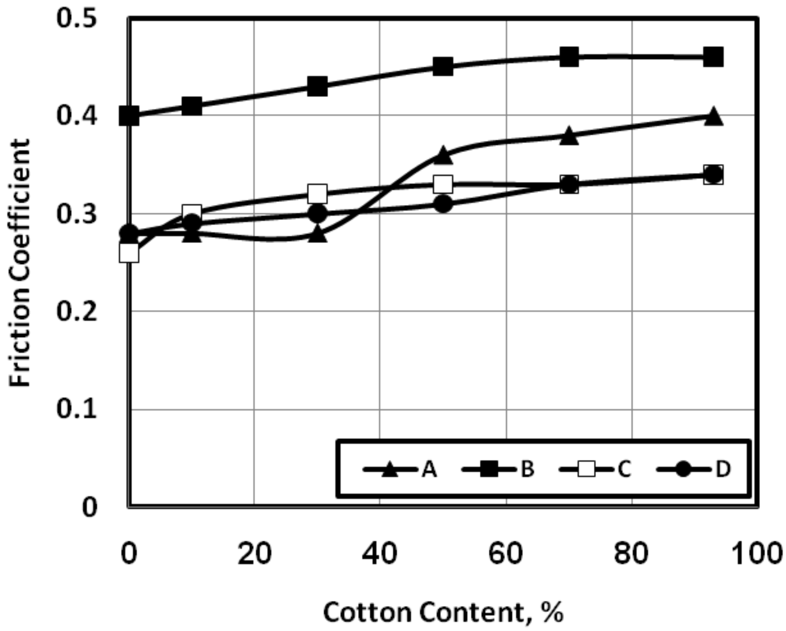

Fig. 4 Friction coefficient displayed by foot wearing socks of different cotton content sliding against insoles A, B, C and D at 400 N load.

Friction coefficient displayed by foot wearing socks of different cotton content sliding against insoles (E), (F), (G) and (H) at 200, 400 and 600 N load is shown in Figs. 6, 7 and 8 respectively. Insole (E) displayed relatively the lowest values of friction coefficient, Fig. 6, which ranged between 0.22 and 0.37. Based on this friction values, and knowing that friction in shoe includes friction between the foot skin and the inner surface of sock, and that between the outer surface of socks and insoles. Lower values of friction coefficient in the both interfaces may lead to excessive movement of foot in shoe and induces discomfort feeling of insecurity. It was found slip would be expected at the interface of lower friction coefficient rather than the interface of higher friction coefficient. Therefore, it can be recommended to set low friction on the interface of socks and insoles to allow foot sliding, and high friction on foot skin and the inner surface of sock to provide appropriate level of resistance to avoid excessive movement. The best friction arrangements to achieve the above assumption are to use cotton socks as well as insoles of low friction coefficient when they rub cotton surface.

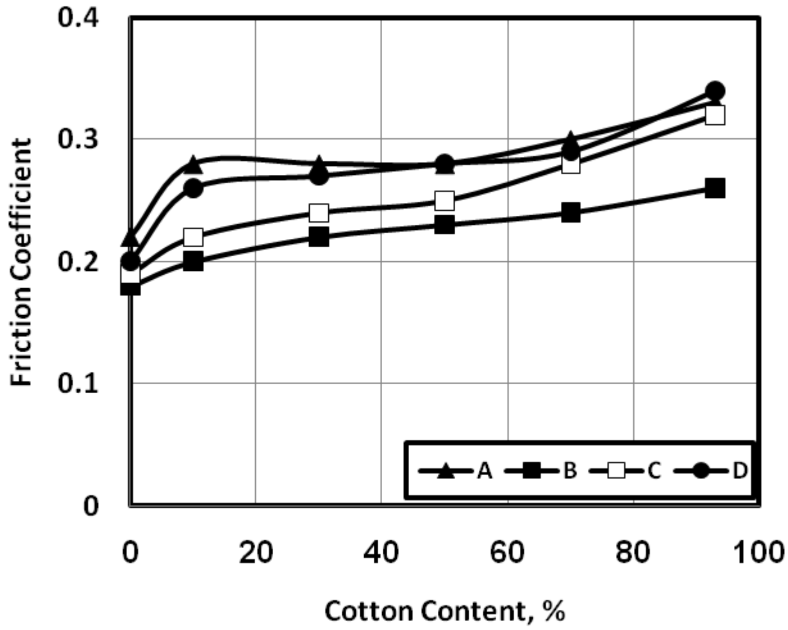

Fig. 5 Friction coefficient displayed by foot wearing socks of different cotton content sliding against insoles A, B, C and D at 600 N load.

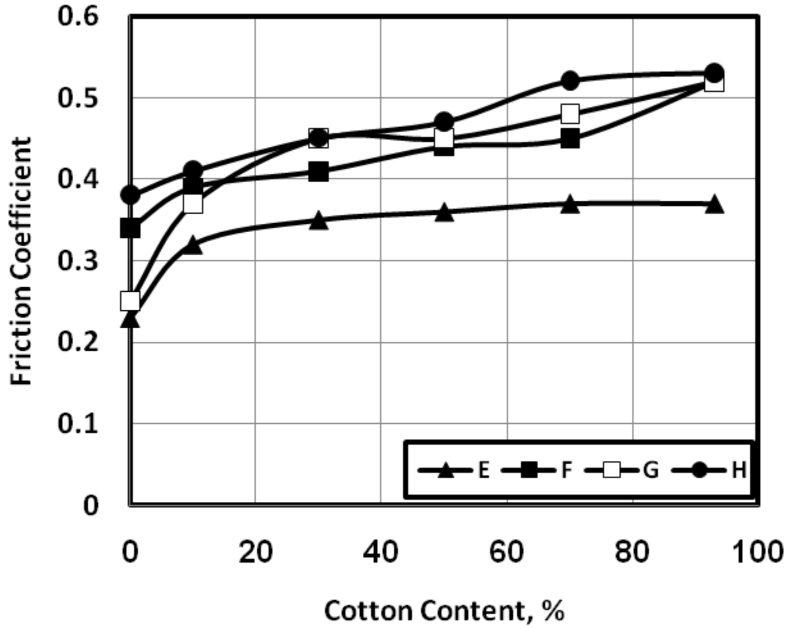

Fig. 6 Friction coefficient displayed by foot wearing socks of different cotton content sliding against insoles E, F, G and H at 200 N load.

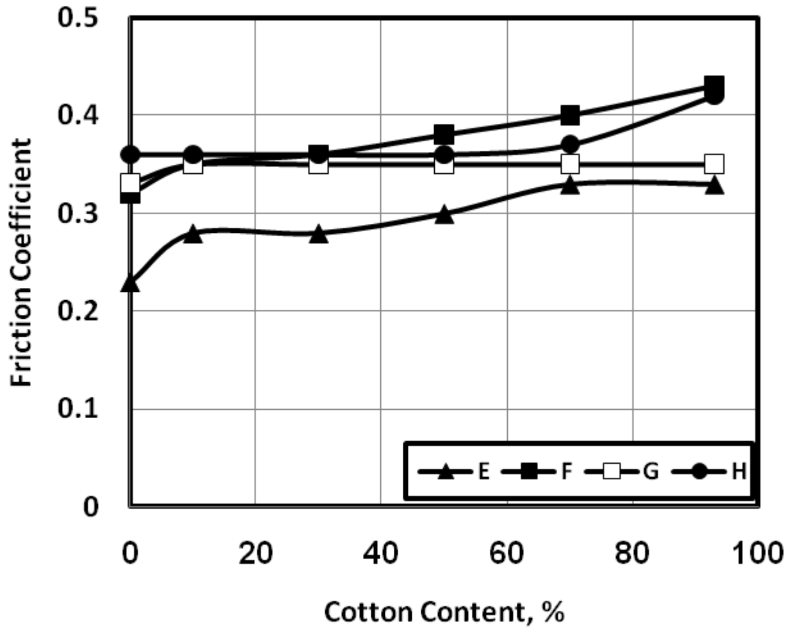

Fig. 7 Friction coefficient displayed by foot wearing socks of different cotton content sliding against insoles E, F, G and H at 400 N load.

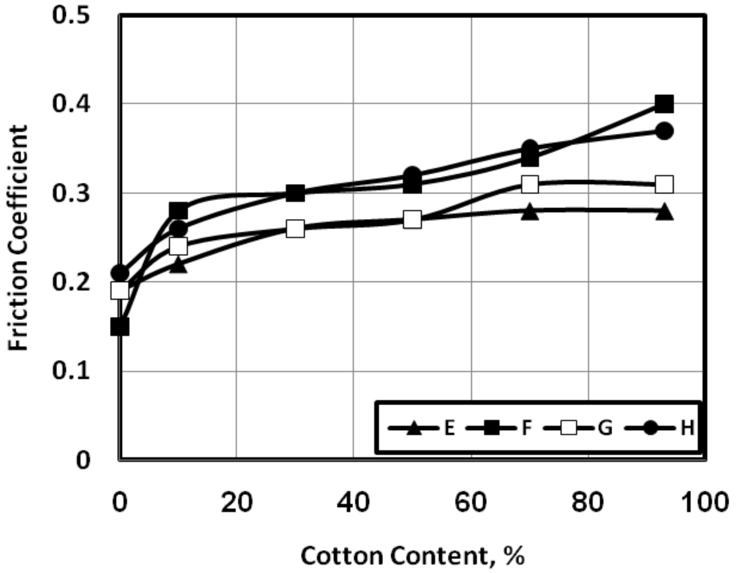

Fig. 8 Friction coefficient displayed by foot wearing socks of different cotton content sliding against insoles E, F, G and H at 600 N load.

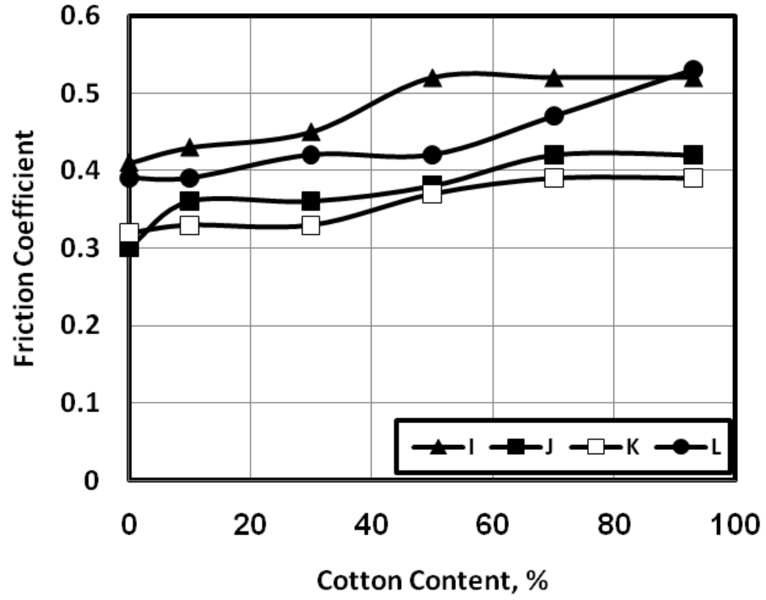

Fig. 9 Friction coefficient displayed by foot wearing socks of different cotton content sliding against insoles I, J, K and L at 200 N load.

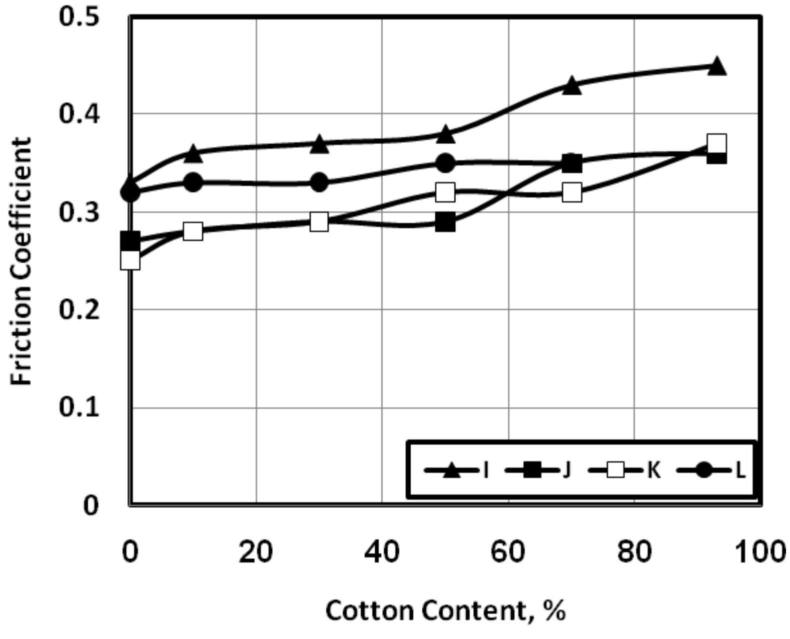

Fig. 10 Friction coefficient displayed by foot wearing socks of different cotton content sliding against insoles I, J, K and L at 400 N load.

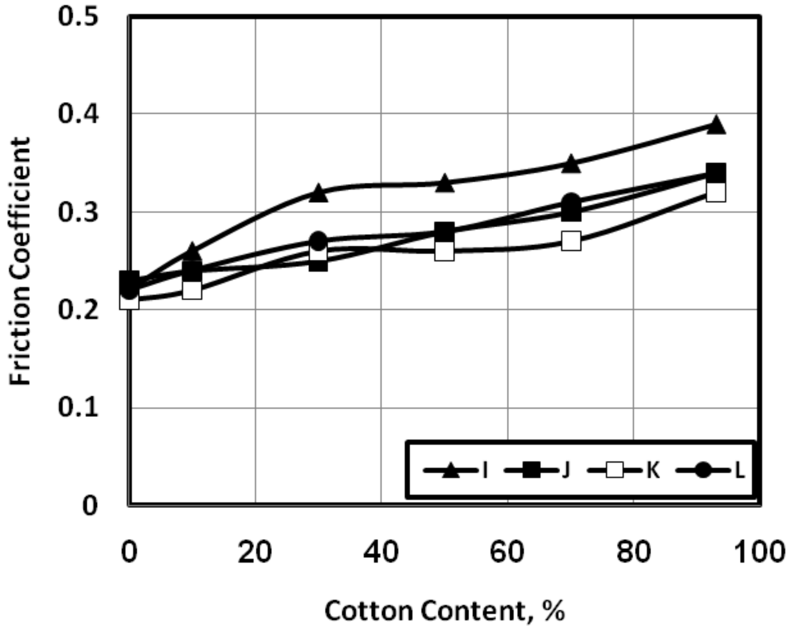

Fig. 11 Friction coefficient displayed by foot wearing socks of different cotton content sliding against insoles I, J, K and L at 600 N load.

Insoles of high friction coefficient can resist slippage and consequently high pressure and shear can results in calluses and blisters, particularly on the forefoot. If the foot is allowed to slide on the insole to a certain distance, the shear can be reduced significantly, hence to reduce the risk for formation of various foot lesions. This requires both lower friction between the socks and the insoles. But, the friction coefficient between the sock inside and the foot skin should be high, so that the foot can be able to slide together with the sock on the insole. This observation can be realized by choosing insole (E) as shown in Figs. 9, 10 and 11.

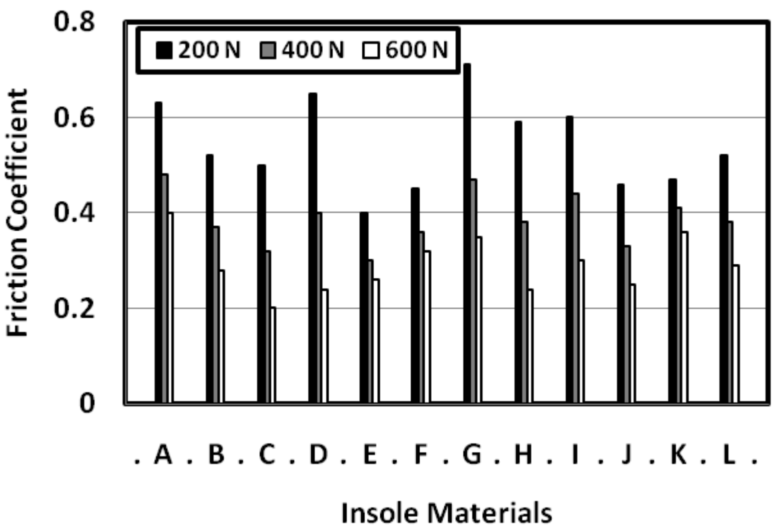

Fig. 12 Friction coefficient displayed by bare foot sliding against the tested insoles.

Appropriate shoes and insoles are not enough and attention must also be paid to socks. People with diabetes are advised not to wear shoes without socks. Hosiery helps to remove perspiration from the skin, regulate foot temperature, provide pressure relief, and protect the skin from abrasion. It is well known that high shear force on foot sole due to high friction between bare foot and insoles is a direct factor causing skin abrasion, friction blisters and ulcers. If the slippage is completely resisted by friction against insole, shoe sides and tops, the high pressure and shear can result in calluses, particularly on the forefoot. If the foot is allowed to slide on the insole to a certain distance, the shear can be reduced significantly, hence to reduce the risk for formation of various foot lesions. This requires both lower friction between foot and the insole and a certain space in shoe to allow the feet to slide. The results of the experiments carried out to determine friction coefficient displayed by bare foot sliding against the tested insoles are illustrated in Fig. 3. The tested insoles materials showed variant friction behavior, where insoles (A), (D), (G) displayed the highest friction values of 0.64, 0.66 and 0.72 respectively. Insoles (E) and (F) showed the lowest friction values of 0.4 and 0.45 respectively at load of 200 N. The significant variation of the values of friction coefficient should be considered when selecting the materials of insoles. Besides, it is noticed that load has remarkable effect on the values of friction coefficient which recommends the development of the friction properties of the insole materials to fit people of heavy weights.

CONCLUSIONS

The experimental findings in the present work develop the selection of the materials used in the design of footwear such as insoles as well as the materials of socks. The results of this study can be summarized as follows:

1. Friction coefficient decreased with increasing the applied load.
2. Friction coefficient increased with increasing cotton content of the socks, where friction coefficient displayed maximum values for socks of 93 % cotton content, while polyamide socks showed the lowest friction coefficient.
3. It can be recommended to set low friction on the interface of socks and insoles to allow foot sliding, and high friction on foot skin and the inner surface of sock to provide appropriate level of resistance to avoid excessive movement. The best friction arrangements to achieve the above assumption are to use cotton socks as well as insoles of low friction coefficient when they rub cotton surface.
4. For people who used to wear shoes without socks, it is recommended to use insoles of low friction coefficient to reduce the shear force on foot sole to avoid skin abrasion, friction blisters and ulcers.
5. The significant variation of the values of friction coefficient of insoles with respect to the type and the load should be considered. It can be recommended to develop the friction properties of the insole materials to fit people of heavy weights.

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