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THE FRICTION OF DIFFERENT FLOOR FINISH-REDUCING INDOOR SLIPS AND FALLS

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ABSTRACT

Slips and falls can happen in any part of the flat or home, but is more common on stairs and in the kitchens and bathrooms. The present paper investigates the friction between rubber and leather footwear on one side and different flooring materials on the other side. Ceramics, Concrete and Granite tiles are tested. Both dry and wet contamination agents are considered. The ultimate results are set limits and measures, for walking speeds and step size, which may guide the approach of reducing indoor slips and fall injuries.

Keywords: indoor slip, friction, ceramic tiles, concrete tiles, granite tiles.

1. INTRODUCTION

Slips, trips and falls can happen in any part of the flat or home, but is more common on stairs and in the kitchens and bathrooms. Slips and trips often result in falls of more serious outcomes, including disabling injuries and even death. The costs can be great, including pain, loss of incomes due to resting at home or at hospitals, temporary or permanent disability, reduced quality of life, and depression. On the national level, the cost is loss of productivity and high expenditure for the health and insurance sectors. The most affected parts of the body are knee, ankle, foot, wrist, elbow, back, shoulder, hip, and head.

Slip occurs when there is too little friction or traction between ones feet (footwear) and the walking or working surface, and he loses balance. On the other hands, trip occurs when the foot (or lower leg) hits an object and the upper part of the body continues moving, throwing the person off balance. It also takes place when stepping down unexpectedly to a lower surface (Misstep) resulting in loss of balance, e.g., stepping off a curb or stairs step or floor level end. Falls, however, occur when the person is too far off his center of balance. These include two simple types of falls. The first is when ones fall to the surface he is walking or standing on, or fall into or against objects at or above the surface (fall at the same level). The second however, happens when ones fall to a level below the one on which he is walking, or standing, (fall to lower level). This paper is concerned with fall due to footwear slip on floor of different finishes.

Some common causes of slips include the following dry and wet conditions. Dry contaminations making surfaces slippery such as dusts, powders, granules, wood, lint, plastic, etc, which are common for dry slipping? Whilst, wet contaminations/spills on smooth floors or surfaces such as water, fluids, mud, grease, oil, food, etc, are common causes for wet slipping. Highly polished floors, such as marble, terrazzo, or ceramic tile (can be extremely slippery even when dry). Freshly waxed surfaces as well as transitioning from one floor type to another (e.g., carpeted to vinyl/ smooth surface flooring), are also possible dry causes.

The coefficient of friction (COF) is a common performance measurement. Friction is defined as the resistance to lateral movement caused by contact between two surfaces, while the COF is the division of the horizontal force by vertical or normal force. Static measure of 0.5 has become a working definition under many codes. Certain areas and circumstances such as wet flooring require a higher dry coefficient of friction, to retain a reasonable value when become wet.

Granite, cement and glazed ceramics are extensively used as flooring materials. The effect of contaminating cleaners on the friction coefficient when walking with bare foot is discussed [1]. Skin friction with smooth flooring surfaces are reported [2]. Introducing grooves in the surface of rubber and leather significantly decreased friction coefficient [3]. Experiments [4 - 9], showed that minimum friction was observed in dry sliding at 6 - 9 μm surface roughness of the tested flooring materials. In water lubricated sliding, cotton socks showed the highest friction coefficient.

The effect of holes, cylindrical and square protrusions of rubber surface sliding on ceramics under dry, water, water-detergent, oil, water oil emulsion, sand and water contaminated by sand sliding conditions was investigated, [9 - 15]. It was found that friction coefficient increases as the height of the cylindrical protrusions increases. At dry sliding, the optimum contact area of cylindrical protrusions is ranging from 20 - 30 % of the smooth one. It was found that the circular protrusions give higher friction than square ones for all the sliding conditions. It was found that a higher friction could potentially improve slip resistance [9 - 11]. It was observed [11 - 13], that dynamic friction is more applicable to human walking than static friction.

The present paper is devoted for investigating the friction between rubber and leather footwear on one side and different flooring materials on the other side. Both dry and wet contamination agents are considered. The ultimate aim is to set some limits and measures, which may guide the approach of reducing indoor slips and fall injuries.

2. MATERIALS AND METHODS

The present work considered different low cost flooring materials for bathrooms and kitchens such as concrete, granite, and ceramics. These are shown in Figures 1 to 5. Concrete flooring are common cheap flooring type and can be used for low cost housing such as in social programs of providing housing for youth as in the case of build your own home projects. Ceramics are common flooring material for the middle class, and are considered for above average housing. Finally, granite is used in many luxe and super luxe finished housings. These were tested for the static friction under both dry conditions, contaminated with dust, and flour powders, and in wet conditions with water contaminations. The mating sliding surface was either leather or rubber to simulate different footwear materials. The contact pressure was set to be 2.5 grams/mm^2. This bearing pressure assumes a weight of a person of 75 kg supported on one footing area of 300 cm^2. Contamination of the flooring surface with dry powders or dust was achieved by blowing the powder or dust by a hair styling blower from a distance of 200 mm, where a thin film of dust was deposited on the rubbing surface. Water contamination however, was achieved by spraying thin water film on the surface by a detergent spraying bottle filled with water.

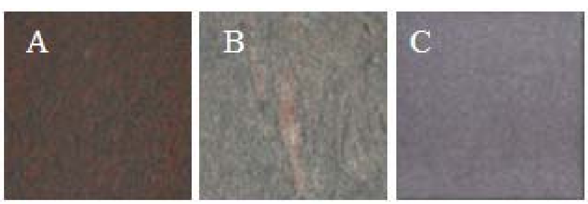

Figure-1. Concrete flooring.

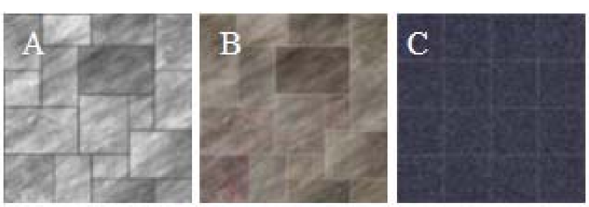

Figure-2. Ceramic-1 flooring tiles.

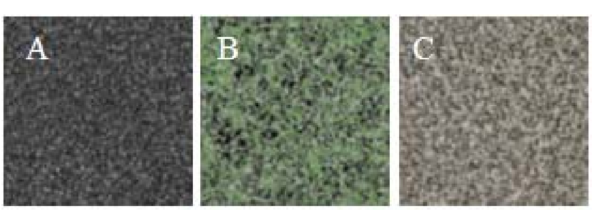

Figure-3. Granite tiles.

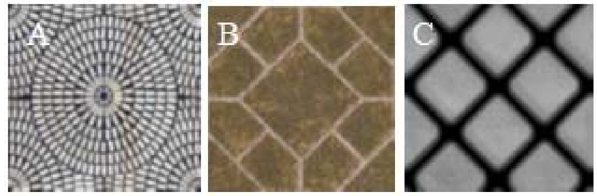

Figure-4. Ceramic-2 flooring tiles.

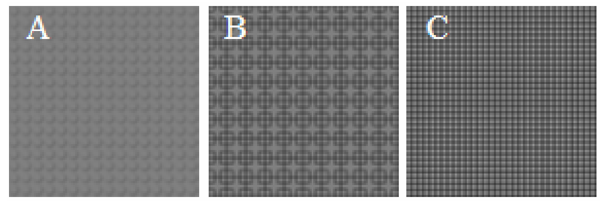

Figure-5. Ceramic-3 flooring tiles.

3. RESULTS

Among the set of flooring materials, ceramics is known to be the most slippery flooring, especially when wetted with thin layer of water. The dry coefficient of friction of clean plane ceramic tiles is evaluated to be 0.6. Testing of the plane ceramic with leather and rubber riders, Figure-6, showed that at low speeds of up to 0.2 m/s there is no significant differences. However, at higher speeds, leather materials will tend to create lower friction values. Testing the same material under boundary lubricated conditions, Figure-7, showed that rubber generally exhibit lower friction values. Therefore, it was planed to evaluate the different ceramics materials for leather rubbing in dry conditions and for rubber rubbing in wet conditions. In order to have consistent set of results, all dry testing was performed with leather mating surface, while all wet tests of all types of tiles was performed with rubber mating surface.

3.1 Ceramic tiles

Each set was evaluated separately to define the most slippery one and then the three most slippery ones were compared to define the most slippery tile of all the ceramics types. Figures (8), (9), and (10) show the results for the three groups of the selected tiles in dry dust-contaminated conditions with sand dust, whilst Figures (11), (12), and (13) shows the results for water contaminated conditions. The slip limiting coefficient of friction is set on each graph to show the limiting speed for nonslip conditions. For dusted tiles of the group 1, it is shown that the limiting nonslip speed of the tile A is 4.3 m/s, and for tile B is 0.5 m/s. Type tile C does not show slipping tendency at speeds of up to 0.5 m/s. Groups 2 and 3 did not show any slip tendency under dust contaminating conditions within the testing speed range of up to 0.5 m/s. The tested tiles of the lowest coefficient of friction of the three groups are compared in Figure-14. Therefore, the only slippery type of tiles under dry testing with dust contamination is shown to be tiles C of group 1.

Wetting the ceramic tiles with sprayed water showed different performance. All group 1 tiles showed slippery performance at speeds of 0.35 - 0.4 m/s. In group 2, tile C showed slippery performance at speeds exceeding 0.5 m/s, whilst tiles A and B did not demonstrate slipping performance within the tested speed range. Group 3 tiles showed slippery performance with water contamination at speeds exceeding 0.25 m/s. Tile C however showed some retarded slippery tendency as compared with tiles A and B.

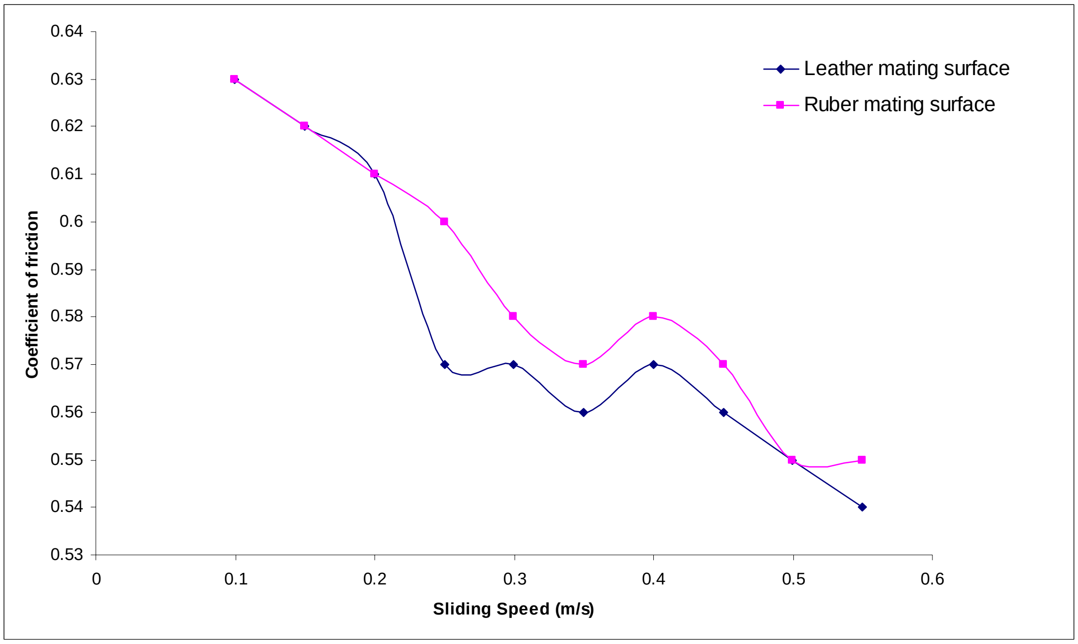

Figure-6. Clean dry test results of dust contaminated plane ceramic tiles.

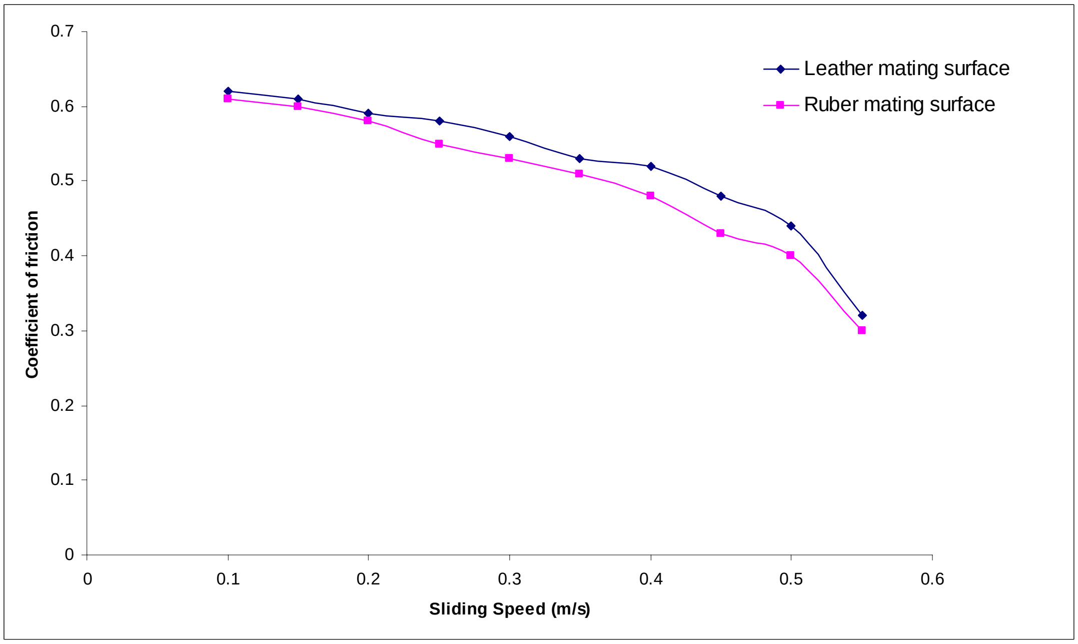

Figure-7. Clean water contaminated test results for plane ceramic tiles.

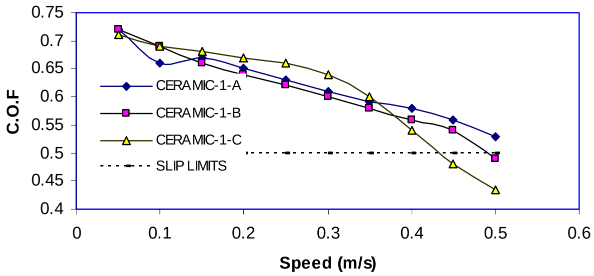

Figure-8. Dry tests for ceramic-1 with sand contaminating dust rubbing against leather.

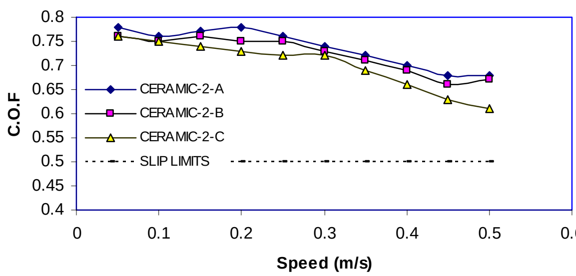

Figure-9. Dry tests for ceramic-2 with sand contaminating dust rubbing against leather.

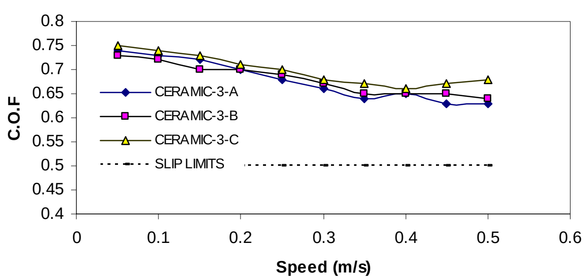

Figure-10. Dry tests for ceramic-3 with sand contaminating dust rubbing against leather.

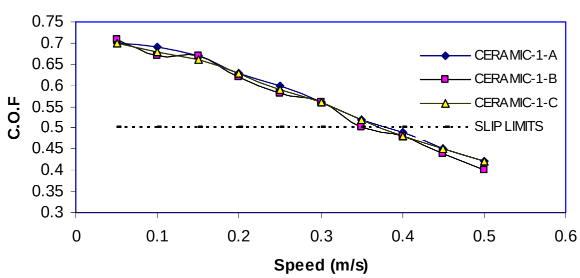

Figure-11. Wet tests for ceramic-1 with water contamination, rubbing against rubber.

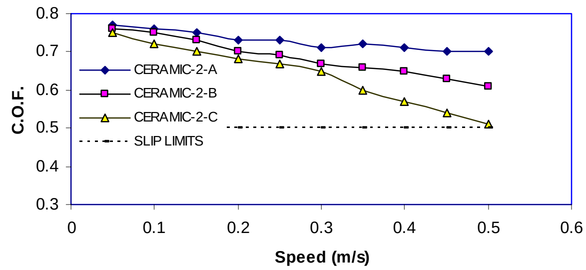

Figure-12. Wet tests for ceramic-2 with water contamination, rubbing against rubber.

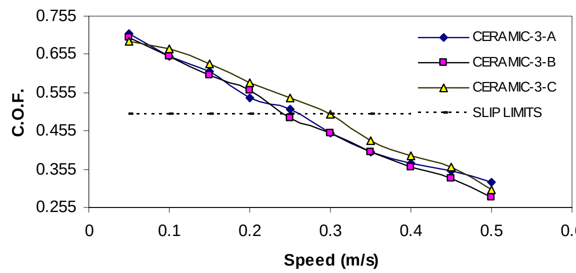

Figure-13. Wet tests for ceramic-3 with water contamination, rubbing against rubber.

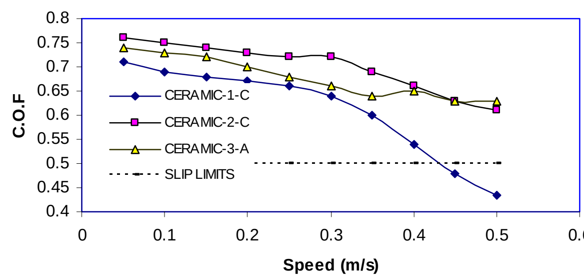

Figure-14. The lowest friction of ceramics in dry dust contaminated tests on leather.

The tiles of the lowest coefficient of friction of the three groups are compared in Figure-15. Tile B of group 3 show slipping tendency at speeds exceeding 0.25 m/s, while tile B of group 1 show the slipping tendency at speeds exceeding 0.35 m/s. Tile C of group 2 showed the same tendency at speeds exceeding 0.48 m/s.

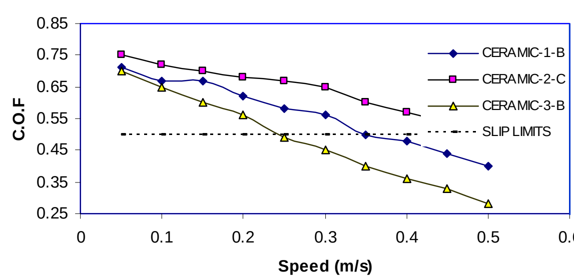

Figure-15. The lowest friction of ceramics in wet tests on rubber.

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3.2 Concrete tiles

Concrete is known to have rough surface textures and exhibits a stable high value of friction. Contaminating the concrete with fine sand dust does not alter its Tribological behavior, since the dust is usually trapped inside the surface bores. It does not lead to three body frictional contact as in the case of glazed ceramic tiles. Concrete can also absorb reasonable amount of water within the bores and pin holes. Therefore, it is difficult to create a water lubrication regime on its rough porous surface. However, in special floor finishing practices concrete tiles may be toped with polymer-based mixtures to introduce surface coloring and to create smooth sound finishes. In such cases, water contamination may allow some degree of boundary lubrication. Dust contamination of such smooth finishes however may not change the frictional behavior.

Figure-16 shows the coefficient of friction of concrete tiles contaminated with fine sand dust when rubbing against a leather counter face. It is shown that the three types of concrete tiles exhibit almost the same frictional behavior and to great extent have almost the same coefficient of friction. Most important however is that the slip limiting friction is far below the tested values, i.e., none of these tiles exhibited the slippery performance.

Figure-17 shows the coefficient of friction of concrete tiles contaminated with water when rubbing against rubber interfaces. The water film was adsorbed quickly within the surface bores leaving no boundary lubrication regime, but more of a humid interface. The coefficient of friction is therefore somewhat lower, but still too high with respect to the slip speed limit. Therefore, it was evident that concrete tiles with smooth surface finishes would be recommended for elderly people homes, and walking tracks.

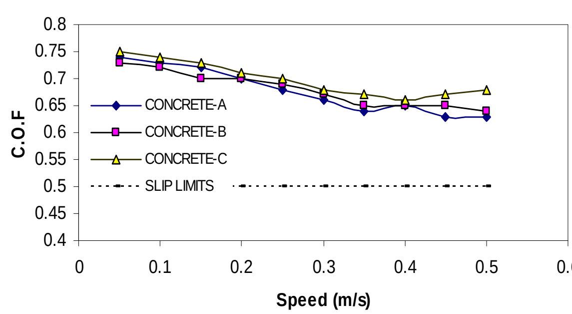

Figure-16. Dry tests of leather rubbing against concrete flooring.

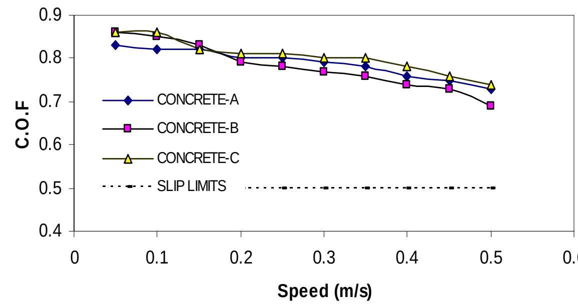

Figure-17. Wet tests of concrete flooring with rubber.

3.3 Granite tiles

Granite, when polished and waxed, has a very shiny and slippery surface. Surface dents and defects are common in granite, but usually these are filled with adhesives and granite powders in such way to achieve mirror like surfaces. When granite is contaminated with sand fine dust, it tends to be imbedded into such filled dents and faults creating somewhat rougher surfaces. Fine dust does also work as an abrasive for the leather-mating surface. Rough surfaces would generally produce high friction. Figure-18 shows the coefficient of friction of contaminated granite tiles with sand fine dust when rubbing against leather. The coefficient of friction did not fall beyond a value of 0.6 at speeds of up to 0.5 m/s. with significant difference from the slipping speed of 0.5. Therefore, the dry testing of these tiles contaminated with sand dust against leather counter face did not show any slippery performance. Granite tiles contaminated with sprayed water however produce thin film fluid lubrication, which would reduce the friction significantly. Figure-19 shows the results of these tests when rubbing against rubber. It is shown that type A exhibited slippery performance at speeds exceeding 0.4 m/s. Types B and C showed the same tendency at speeds exceeding 0.35 m/s.

4. COMPARISON OF SLIPPERY TILES

In order to assess the relative slippery behavior of the three types of tiles (Ceramics, Concrete and Granite), the most slippery tile of each type was compared in both situations of dry dust contamination and wet contamination with water. Figure-20 shows the dry test results when rubbing against leather with dust contaminations. Among the three types, only ceramics 1-C showed slippery behavior at sliding speeds exceeding 0.45 m/s. Both concrete and granite did not show this tendency within the range of test speeds of up to 0.5 m/s. Water contamination however, resulted in thin film fluid lubrication for both ceramics and granite, while exhibited a boundary lubrication regime with concrete. Figure-21 shows these results when rubbing against rubber counter surface. Ceramic 3-B tiles started to create slipping behaviors at speed of 0.25 m/s, while granite C type tiles created slipping performance at speeds exceeding 0.35 m/s. Concrete however maintained higher friction than the slip limits.

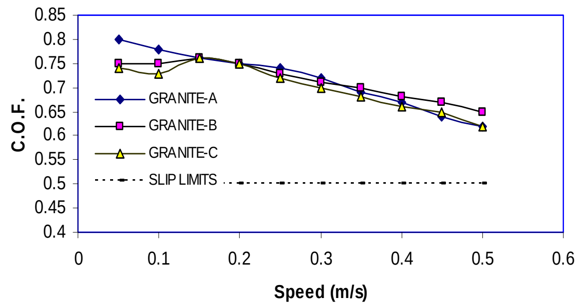

Figure-18. Dry test of leather rubbing against granite.

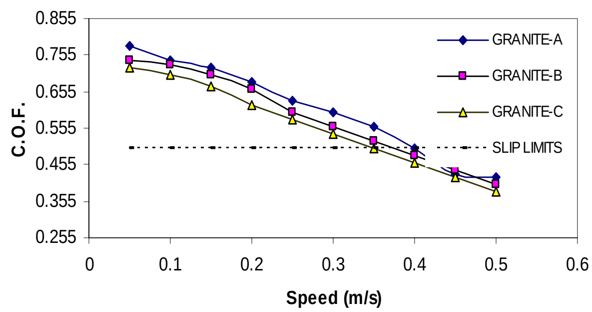

Figure-19. Wet testing of rubber rubbing against granite.

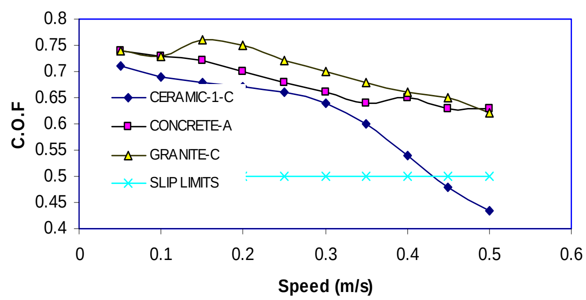

Figure-20. Lowest dry friction of the three flooring types.

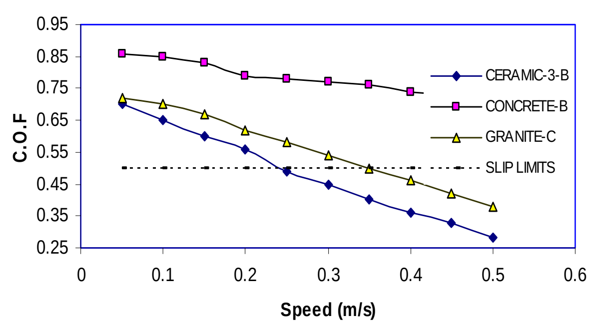

Figure-21. Lowest wet friction of the three flooring types.

The friction coefficient was shown to be some what reduced when sand particles contaminated the original flooring surface. The results indicated that the effect of sand grains trapped between the footwear and the floor at the interface were more effective in abrasion of the mating surface when the tiles were hard and glazed, e.g. with ceramics and granite. The boundary-lubricated interface produced by slightly wetting the concrete lowered the friction but did not reduce it enough to the slip limits. Fluid film lubrication was observed with water contaminated ceramics and granite.

5. CONCLUSIONS

A method of assessing the slippery characteristics of finished flooring materials is presented. Slip limit curves for some flooring materials are demonstrated. These graphs can help in the proper selection of flooring materials for different functional use. Limiting walking speeds and step width values can be critically determined for safe walking and movements in kitchens and bathrooms. Finished Concrete tiles were shown to be the most suitable for elderly people either in indoors or outdoor areas. Plane granite and ceramics are very slippery flooring materials and should be used carefully in the different functional spaces of homes.

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