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FRICTION COEFFICIENT OF RUBBER SLIDING AGAINST FLOORING MATERIALS

El-Sherbiny Y. M.[1], Hasouna A. T.[2] and Ali W. Y.[3]
[1]Department of Civil and Architectural Engineering, National Research Center, Dokki, Giza, Egypt
[2]El-Minia High Institute of Technology, El-Minia, Egypt
[3]Faculty of Engineering, Minia University, El-Minia, Egypt
E-Mail: yassershr@hotmail.com

ABSTRACT

The friction coefficient of rubber sliding against different types of flooring materials of different surface roughness was investigated under different sliding conditions: dry, water, water/detergent dilution, oil, water/oil dilution. The flooring materials are parquet, polyvinyl chloride (PVC), epoxy, marble, cement and ceramic. Surface roughness variations do take place by continuous rubbing during the life time of the flooring. Based on the experiments, it was found out that at dry sliding, friction coefficient decreased with increasing surface roughness. Epoxy displayed relatively higher friction than parquet and PVC, while cement tiles gave the highest friction coefficient. Ceramic showed relatively lower friction values than marble and cement. In the presence of water on the sliding surface, friction coefficient slightly increased up to maximum then decreased with increasing surface roughness. Parquet displayed the highest friction coefficient followed by PVC and epoxy. At higher roughness marble tiles gave the highest friction. Ceramic showed the lowest friction among the tested floorings. Sliding of rubber against water/detergent wetted tiles caused drastic decrease of friction coefficient. Parquet displayed the highest friction values followed by cement and marble. PVC, epoxy and ceramic represented relatively lower friction values. At oil lubricated sliding of flooring materials, friction coefficient slightly increased up to maximum then decreased with increasing surface roughness of the flooring materials. Hard floorings such as marble and ceramic showed friction increase with increasing surface roughness. Parquet and cement tiles showed the relatively highest friction. Finally, sliding of rubber against water/oil dilution wetted floorings caused significant decrease in friction coefficient. Parquet and cement tiles still displayed the highest friction.

Keywords: friction coefficient, rubber, floorings, parquet, PVC, epoxy, marble, cement, ceramic, surface roughness.

INTRODUCTION

People give little attention to the flooring unless they slip or experience fall accidents. Flooring is a critical component of the public safety. Surface roughness influences friction, where adequate flooring roughness significantly reduces slip and fall accidents.

Some hard materials, such as marble and ceramics, are polished by rubbing yielding smoother surfaces which tend to increase the falling risks especially when witted with water or other lubricating media. Others, such as cement and concrete, produce rougher surfaces by rubbing and reduce the risk factors.

The friction coefficient of rubber sliding against polymeric indoor flooring materials of different surface roughness was investigated, [1]. It was found that, at dry sliding, the friction coefficient decreased with increasing surface roughness and applied load. At water lubricated sliding, the friction coefficient increased up to maximum then decreased with increasing surface roughness. Maximum friction values were observed at surface roughness ranging from 1.5 and 2.0 µm R_a. At water-soap lubricated sliding, the friction coefficient drastically decreased with increasing the surface roughness. At oil lubricated sliding, the maximum friction values were noticed at 4.0 µm R_a surface roughness. At water and oil lubricated sliding, smooth flooring surface displayed very low values of friction coefficient (0.08) close to the ones observed for mixed lubrication where the two sliding surfaces are partially separated by a fluid film.

Experiments showed that, at dry sliding, friction coefficient of bare foot and polymeric socks, friction coefficient decreased down to minimum then increased with increasing the surface roughness, [2]. Minimum friction was observed at surface roughness ranging between 6 - 9 µm. In water lubricated sliding, friction coefficient of rubber increased up to maximum then decreased with increasing surface roughness. Maximum friction values were observed at surface roughness values ranging from 1.5 to 2.0 µm R_a. Cotton socks showed the highest friction coefficient followed by rubber, bare foot then polymeric socks at 11 µm R_a. Friction coefficient drastically decreased with increasing surface roughness at water and detergent lubricated sliding. For the tested flooring materials lubricated by oil, friction coefficient of rubber increased up to maximum values then decreased with increasing the surface roughness of the flooring materials. The maximum friction values were noticed at 4.0 µm R_a. Bare foot displayed drastic reduction in friction coefficient, while cotton socks showed the highest values. When water was diluted by 5.0 wt. % oil, rubber smooth flooring surface displayed values of friction coefficient close to that observed for hydrodynamic lubrication where the two sliding surfaces are separated by the fluid film. As the roughness increased the fluid film was broken and friction increased. Cotton socks showed the highest friction compared to bare foot and polymeric socks.

The changes in the surface properties and frictional characteristics of flooring materials can be

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expected in practical use because they are subject to mechanical wear, ageing, soiling and maintenance, [3]. In the sport halls the flooring surfaces are probably changed mainly through mechanical wear, periodic cleaning processes and material transfer from shoe soles (elastomer abrasions and dirt particles). Coefficients of friction were measured periodically over a period of 30 months on the surfaces of five types of floor coverings in a new sport complex, [4]. Surface changes through mechanical wear range from smoothing to roughening, [5, 6], depending on flooring material and surface characteristics.

Surface roughness is known to be a key factor in determining the slip resistance of floors. The effect of surface roughness of ceramic on the friction coefficient, when rubber and leather are sliding against it, was investigated, [7]. Glazed floor tiles of different roughness ranging from 0.05 and 6.0 µm were tested. The test results showed that, friction coefficient decreased down to minimum then increased with increasing the surface roughness of the ceramic surface.

Measurements of the static friction coefficient between rubber specimens and ceramic surfaces were carried out at dry, water lubricated, oil, oil diluted by water and sand contaminating the lubricating fluids. It was observed that, dry sliding of the rubber test specimens displayed the highest value of friction coefficient. For water lubricated ceramics, the value of the friction coefficient decreased compared to dry sliding. For oil lubricated ceramic, friction coefficient decreased with increasing height of the grooves introduced in the rubber specimens.

The decrease may be from the well adherence of oil on the rubber surface, where a film which is responsible for the friction decrease was formed. Besides, diluting oil by water displayed values of friction much lower than that observed for oil lubricated condition. As for ceramic lubricated by water and soap and contaminated by sand, friction coefficient increased significantly compared to the sliding conditions of water and soap only. In the presence of oil and sand on the sliding surface, the friction slightly increased.

This behavior is due to sand embedment in rubber surface and consequently the contact became between ceramic and sand. At lubricated sliding surface by oil and water contaminated by sand, the friction presented higher value than that of oil and sand sliding conditions.

Slip resistance of flooring materials is one of the major environmental factors affecting walking and materials handling behaviors. Floor slipperiness may be quantified using the static and dynamic friction coefficient, [8]. Certain values of friction coefficient were recommended as the slip-resistant standard for unloaded, normal walking conditions, [9, 10]. Relatively higher static and dynamic friction coefficient values may be required for safe walking when handling loads.

Researches revealed significant correlations between surface roughness of shoes and friction coefficient for a given floor surface, [11 - 14]. Abrasion of rubber soling in steps with increasingly coarse grit gradually raised the roughness in parallel with a rise in the friction coefficient on water wet surfaces. Dense rubbers never developed the same order of roughness, and they became smooth and polished when worn on ordinary floors or with mechanical polishing.

In the present work, the effect of the surface roughness of different indoors floorings on the static friction coefficient displayed by rubber under dry, water, water/detergent, oil, water/oil dilution sliding conditions is investigated.

EXPERIMENTAL

Experiments were carried out using a test rig designed and manufactured to measure the friction coefficient displayed by the sliding of the tested rubber specimens against the flooring materials through measuring the friction force and applied normal force. The tested materials are placed 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 (applied load). Friction coefficient was determined by the ratio between the friction force and the normal load. The arrangement of the test rig is shown in Figure-1.

The tested flooring materials were parquet, polyvinyl chloride (PVC), epoxy, marble, cement and ceramic in form of a quadratic sheet of 0.4 m × 0.4 m and 3.0 mm thickness, Figure-2. The surface roughness ranged from 0.22 to 8.9 µm R_a, (the center line average of surface heights, CLA). Smooth rubber test specimens were prepared in the form of square sheets of 100 × 100 mm and 10.0 mm thickness. Then the rubber specimens were adhered on wood blocks. The hardness of the rubber was 65 Shore-A. The flooring materials and the rubber were thoroughly cleaned with soap water to eliminate dirt as well as dust and carefully dried before the tests. The rubber test specimens were loaded against the polymeric flooring materials.

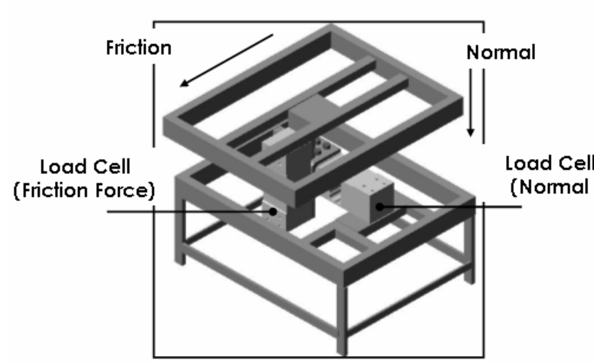

Figure-1. Arrangement of the friction tester.

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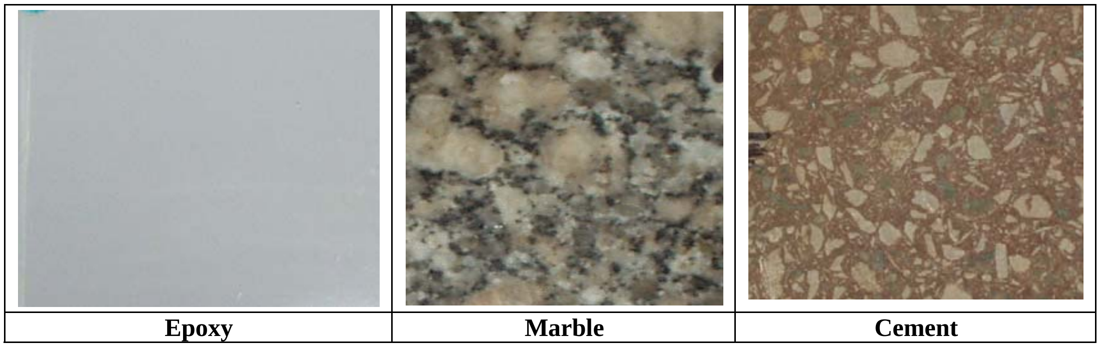

Figure-2. The tested flooring materials.

Friction test was carried out at normal load of 600 N. The sliding conditions tested in the experiment were dry, water, water/detergent dilution, oil, and water/oil dilution. Water was replenished on the tested flooring materials, at a rate of 10 ml per replenishment, to form consistent water film covering the sliding surface. In the water-detergent condition, a 1.0 vol. % detergent solution was applied to the tested floorings. In the oily condition, 2 ml of vegetable oil (sunflower oil) was spread on the flooring using a paintbrush. After each measurement, all contaminants were removed from the flooring materials and the rubber specimens using absorbent papers. Both the flooring materials and the rubber specimens were then rinsed using water. In the oily condition, the sliding surfaces were cleaned using a detergent solution to remove the oil, rinsed using tap water and blown using hair dryer after the cleaning process.

RESULTS AND DISCUSSIONS

The effect of surface roughness of the tested flooring materials is shown in Figures 3 - 12 at the tested sliding conditions. The dry sliding of rubber specimens against flooring materials is shown in Figures 3, 4. Friction coefficient decreased with increasing surface roughness. For smooth surfaces, the maximum adhesion was attained, the interfacial area had a maximum value, the mechanism of molecular stick slip process was responsible for the increased adhesion component of friction and consequently friction coefficient displayed relatively higher values. The increase of surface roughness decreased friction coefficient due to the decrease of the contact area as well as adhesion. It is clearly shown that there was a drastic decrease in the friction values with increasing normal load due to saturation of the rubber asperities and rubber filling the gaps between the track asperities, where the rubber in the contact area deformed in such a manner as to completely follow the short-wavelength surface roughness profile of the counter face. Epoxy displayed relatively higher friction than parquet and PVC, Figure-3.

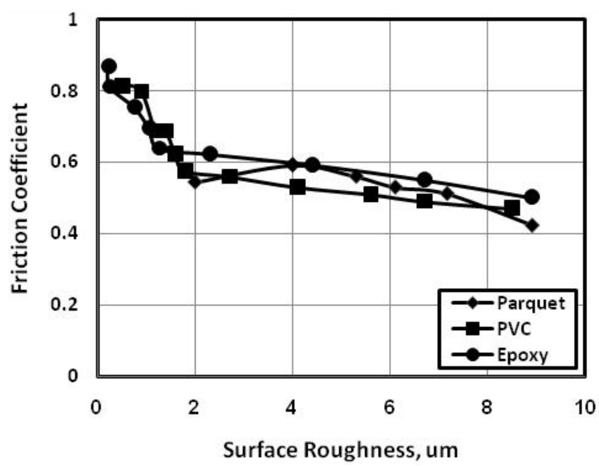

Figure-3. Friction coefficient displayed by dry sliding against parquet, PVC and epoxy floorings.

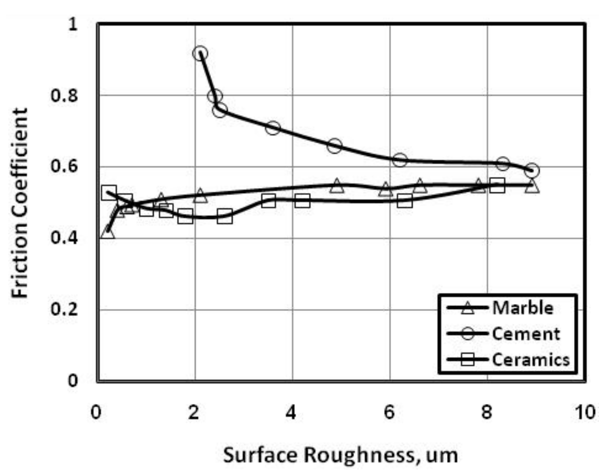

Figure-4. Friction coefficient displayed by dry sliding against marble, cement and ceramic floorings.

The highest friction values were above 0.8 displayed by the lowest roughness, while friction values higher than 0.4 were observed at the highest roughness. Figure-4 showed that cement tiles gave the highest friction coefficient, where the values were 0.92 and 0.59 at 2.2 and 8.9 µm, R_a, surface roughness respectively. Ceramic

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showed relatively lower friction values than marble and cement.

In the presence of water on the sliding surface, the effect of surface roughness on friction coefficient is shown in Figures 5, 6. Friction coefficient slightly increased up to maximum then decreased with increasing surface roughness. The friction increase might be from the breakdown of the water film and consequently a significant increase in friction coefficient was observed. The decrease of friction coefficient with increasing surface roughness can be attributed to the ability of the flooring roughness to store more water in the valleys of the voids between asperities, where they acted as reservoirs for the water, and the pressure distribution at each asperity summit promoted local drainage effects. Parquet displayed the highest friction coefficient followed by PVC and epoxy, Figure-5. At higher roughness marble tiles gave the highest friction, Figure-6. Ceramic showed the lowest friction among the tested floorings.

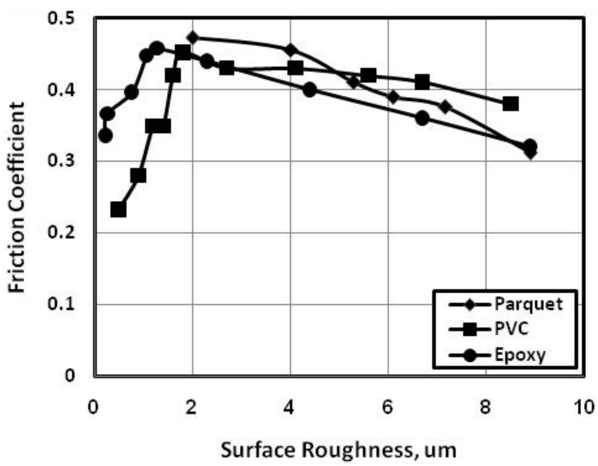

Figure-5. Friction coefficient displayed by sliding against water wetted parquet, PVC and epoxy floorings.

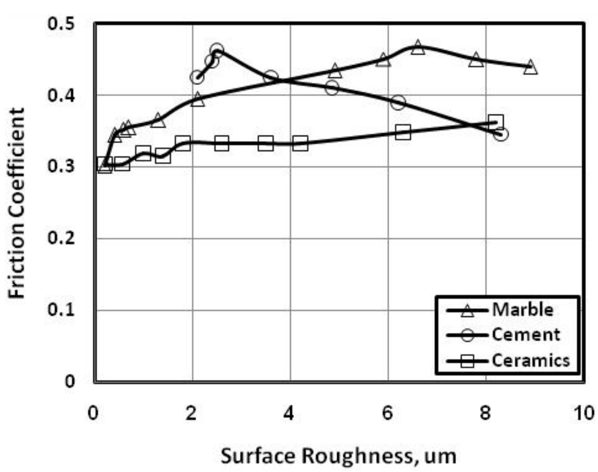

Figure-6. Friction coefficient displayed by sliding against water wetted marble, cement and ceramic floorings.

Sliding of rubber against water/detergent wetted tiles caused drastic decrease of friction coefficient, Figures 7, 8. For smooth surfaces, friction coefficient significantly increased with increasing surface roughness. The friction increase might be attributed to the enhanced adhesion of rubber to the tested floorings. As the surface roughness increased, the surface area adhered by the water film increased and consequently friction decreased. For relatively higher surface roughness values friction coefficient slightly decreases. It is noted that friction coefficient for wetted surfaces by water and detergent represented lower values than that displayed by water only. Generally, parquet displayed the highest friction values followed by cement and marble. PVC, epoxy and ceramic represented relatively lower friction.

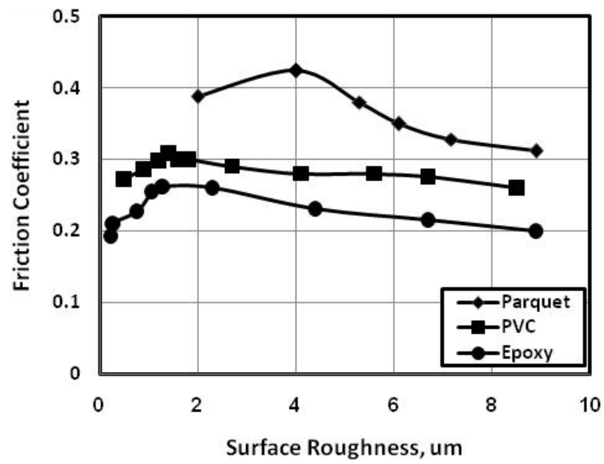

Figure-7. Friction coefficient displayed by sliding against water/detergent wetted parquet, PVC and epoxy floorings.

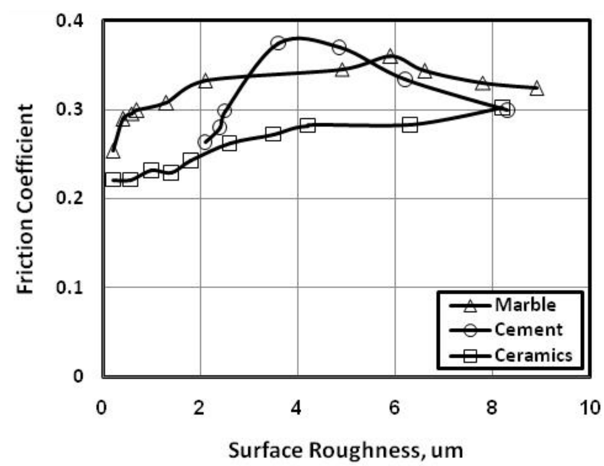

Figure-8. Friction coefficient displayed by sliding against water/detergent wetted marble, cement and ceramic floorings.

Friction coefficient generated from the sliding of rubber against oil lubricated flooring materials is shown in Figures 9, 10. Friction coefficient slightly increased up to maximum then decreased with increasing surface roughness of the flooring materials. It seems that, for smooth surfaces, the oil film formed on the sliding surface was responsible for the friction decrease. The increase of roughness helps the oil to escape from the contact area into the valleys of the roughness. Further roughness increase caused slight friction decrease. This behavior is attributed to that the valleys of the roughness that could store more oil as the roughness increased, where the oil could go up to the sliding surface as the rubber presses the flooring materials. Hard floorings such as marble and ceramic showed further friction increase with increasing surface roughness. Parquet and cement tiles showed the relatively highest friction.

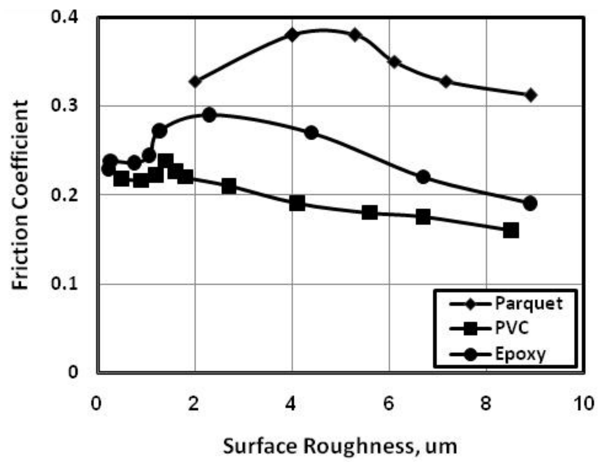

Figure-9. Friction coefficient displayed by sliding against oily parquet, PVC and epoxy floorings.

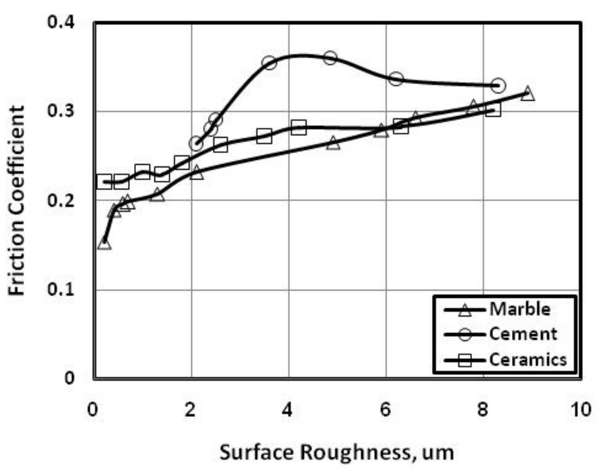

Figure-10. Friction coefficient displayed by sliding against oily marble, cement and ceramic floorings.

Sliding of rubber against water/oil dilution wetted floorings caused significant decrease in friction coefficient, Figures 11, 12. At smooth flooring surface, friction coefficient represented values close to that observed for mixed lubrication where the two sliding surfaces are partially separated by the fluid film. As the roughness increased the fluid film was broken and friction increased. Increasing the applied load caused relative friction decrease due to the increased rubber deformation which displaced the fluid up to the sliding surface, where the rubber was completely deformed and filled out the short wavelength surface roughness profile of the flooring material. This behavior gave an additional contribution to the friction force and consequently, friction coefficient increases. Parquet and cement tiles still displayed the highest friction.

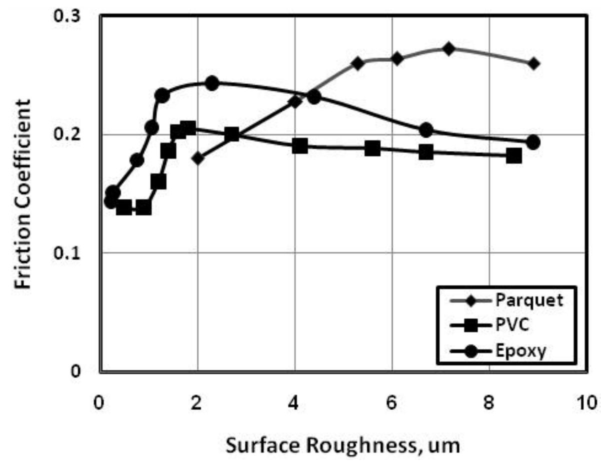

Figure-11. Friction coefficient displayed by sliding against oil/water dilution wetted parquet, PVC and epoxy floorings.

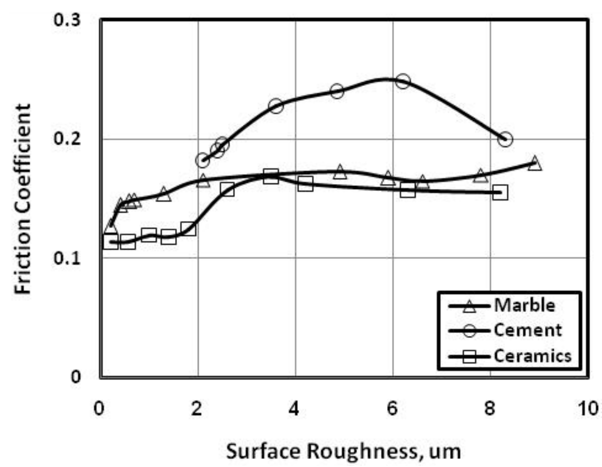

Figure-12. Friction coefficient displayed by sliding against oil/water dilution wetted marble, cement and ceramic floorings.

CONCLUSIONS

a) At dry sliding, friction coefficient decreased with increasing surface roughness. Epoxy displayed relatively higher friction than parquet and PVC, while cement tiles gave the highest friction coefficient. Ceramic showed relatively lower friction values than marble and cement.

b) In the presence of water on the sliding surface, friction coefficient slightly increased up to maximum then decreased with increasing surface roughness. Parquet displayed the highest friction coefficient followed by PVC and epoxy. At higher roughness marble tiles gave the highest friction. Ceramic showed the lowest friction among the tested floorings.
c) Sliding of rubber against water/detergent wetted tiles caused drastic decrease of friction coefficient. Parquet displayed the highest friction values followed by cement and marble. PVC, epoxy and ceramic represented relatively lower friction values.
d) In oil lubricated sliding of flooring materials, friction coefficient slightly increased up to maximum then decreased with increasing the surface roughness of the flooring materials. Hard floorings such as marble and ceramic showed friction increase with increasing surface roughness. Parquet and cement tiles showed the relatively highest friction.
e) Sliding of rubber against water/oil dilution wetted floorings caused significant decrease in friction coefficient. Parquet and cement tiles still displayed the highest friction.

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