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MODELING AND SIMULATION OF FRICTION OF WHEELCHAIR SLIDING ON FLOORS

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ABSTRACT
The main aim of this paper is to study the behavior of different types of floor materials suitable for wheelchair users. The study depends on determining the values of friction coefficient displayed by the wheelchair and the tested floor materials. Finite element 3D model of friction pair is introduced and analyzed using commercial finite element software ABAQUS/CAE. The friction coefficient values obtained from the experimental results are used as input data of the simulation model to achieve the same characteristics. It can be concluded that each case of the three tested rubber specimens-show friction values suitable for safe walking. Also it can be noticed that as the rubber hardness decreases friction coefficient increases. The simulation model makes it easy to determine the contact stress between friction pair and contact slip rates.

KEYWORDS
Simulation model, friction coefficient, wheelchair, rubber, ceramic, cement tiles.

INTRODUCTION
Wheelchairs used when walking is difficult or impossible due to illness, injury, or disability. Wheelchairs come in a wide variety of formats to meet the specific needs of their users. Although most wheelchair users are able to comfortably move a joystick and make a fine movement correction when driving, others are only able to click on switches. On the other hand, wheelchair users needs smooth and hard floor, where wet flat surfaces can become extremely slippery cause slip and fall accidents. For controller design therefore, it is necessary that the wheelchair model is comprehensive enough to reflect real situations. There is an increasing demand to investigate proper solutions for reducing slip and fall accidents. The friction of footwear on floor coverings is responsible of the occurrence of slips and falls. The slip resistance is normally assessed on the basis of friction coefficient measured with footwear materials sliding against floorings.

Materials that increase floor friction forces under foot pressure could reduce the risk of slipping and enhance walking safety. For reasons of technical design and economy, floor and floor systems in work places are often made from hard materials that do not deform under the pressure of the foot. Rubber mat has become some popular flooring materials due to the increased comfort, by adding a cushioning effect to the knees when walking, [1 – 7]. The effect of sand particles on friction coefficient, displayed by rubber sliding against ceramic tiles, was investigated, [8]. Experiments were carried out under dry, water, detergent, oil, soap, and water oil emulsion. It was found that, at dry sliding, dust particles caused drastic decrease in friction coefficient. In this case, it is recommended to use circular protrusion in the rubber surface.

Circular protrusions gave higher friction than flat and square protrusions. Flat rubber surfaces, lubricated by water oil emulsion and contaminated by dust particles, displayed the highest friction coefficient. Dust particles on the floor prevent direct contact between the footwear pad and floor, [9]. The number of sand particles on the floor may affect the friction. However, the largest particles dominate the effects because they will be the first ones to contact the footwear pad. It was suggested that the adhesive friction is significantly affected by particulate contaminants, while the hysteretic component is not, [10]. Three lubrication mechanisms identified as sliding, shearing and rolling have been observed depending on floor roughness, particle size and shape factor. Effects, of the tread width and depth of the shoe sole on friction coefficient displayed by shoe and ceramic floor interface, were discussed, [11]. It was found that, at dry sliding, friction coefficient slightly increased with increasing treads height. In the presence of water on the sliding surface significant decrease in friction coefficient was observed as compared to the dry sliding. Tread groove designs are helpful in facilitating contact between the shoe sole and floor on liquid contaminated surface, [12 - 20]. The effectiveness of a tread groove design depends on the contaminant, footwear material and floor. Tread groove design was ineffective in maintaining friction on a floor covered by vegetable oil. Tread grooves should be wide enough to achieve better drainage capability on wet and water–detergent contaminated floors.

In the present work, friction coefficient displayed by rubber specimens of wheelchair, of different hardness sliding against ceramic as well as cement and rubber floor tiles, has been investigated. Besides, modeling of differential drive wheelchairs has been studied.

EXPERIMENTAL SETUP

The test rig used in the present work, has been designed and manufactured to measure the friction coefficient displayed by the sliding of the tested rubber specimens against the different floor types surface through measuring the friction force and applied normal force. Experiments were carried out using test rig shown in Fig. 1. It consists, mainly, of two load cells one installed in horizontal position and other in vertical one, where the horizontal load cell measured the normal force while the vertical one measured the friction force. Also it consists of upper base that will be covered by the flooring surface, and lower base used to make the test rig fixed on floor and not move during test. Figure 2 illustrate different materials of floor and wheelchair. The effect of the rubber hardness on friction coefficient displayed by sliding against the cement,

ceramic and rubber floor tiles at dry and sand contaminated sliding conditions is investigated. The tested floor tiles are in form of quadratic tiles of 0.4 m × 0.4 m. The hardness's of the rubber test specimens representing the wheel surface are 40, 70 and 100 Shore A, which will be referred in the text as A, B and C respectively.

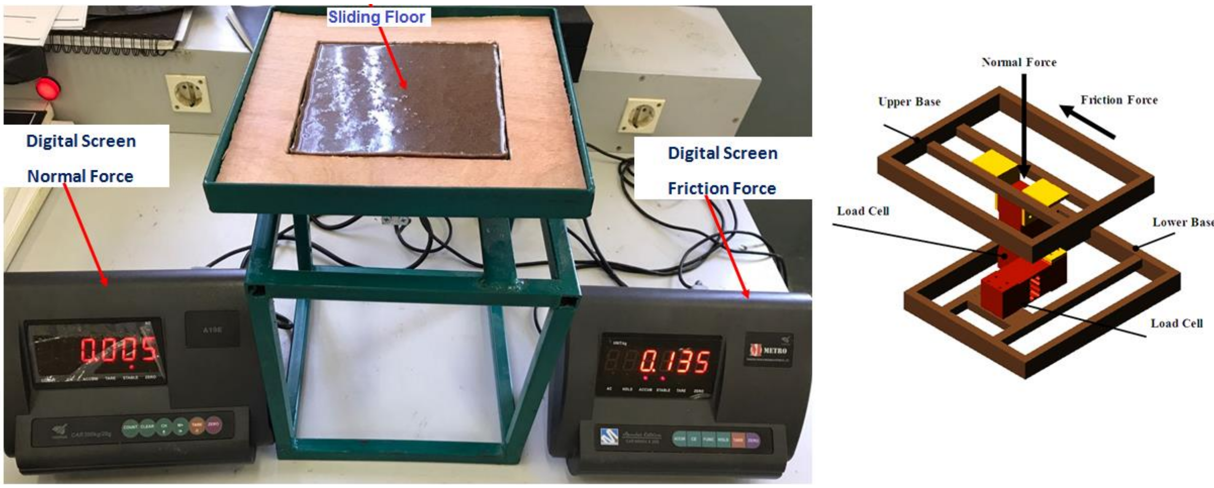

Fig. 1 Friction test rig.

Figure 2. Different materials of the floor and wheelchair pad.

Friction coefficient measurements were carried out at different load values up to 600 N. The tested tiles are adhered on the upper base of the test rig then they and the rubber specimens are cleaned with soap water to eliminate any dirt and dust and carefully dried before the test. The floor tiles are loaded by the rubber specimens by foot at dry and sand contaminated sliding. During test, horizontal and vertical load cells connected to

the two monitors detect normal and friction forces respectively. Friction coefficient is the ratio between friction and normal force. By taking five values for each test the values of friction coefficient could be calculated.

FINITE ELEMENT MODEL CREATION

In this study, a three-dimensional model of floor plate with movable pad is considered. The three-dimensional models of the friction bodies are constructed in commercial package ABAQUS/CAE, as shown in Figure3. It is assumed that the contact between the mating surfaces is perfect meaning that no relative motion is permitted on the contact surface. It is also assumed that the floors and wheelchair materials are isotropic and linear-elastic fracture mechanics with properties illustrate in Table 1. The upper surface of the floor and the lower surface of the pad defined as a surface-to-surface contact and mechanical constraint formulation defined as kinematic contact method. The floor part fixed in three mutual perpendicular displacement directions (U1, U2, and U3) as well as it is non-rotational about these axis (UR1, UR2, UR3). While the pad part is free to move in z-direction with linear velocity. The load acting on each node along the upper surface of the pad have to be developed. The mesh of explicit elements with reduced integration and eight nodes (C3D8R) are used. Both floor and pad define with the element type but using different global size.

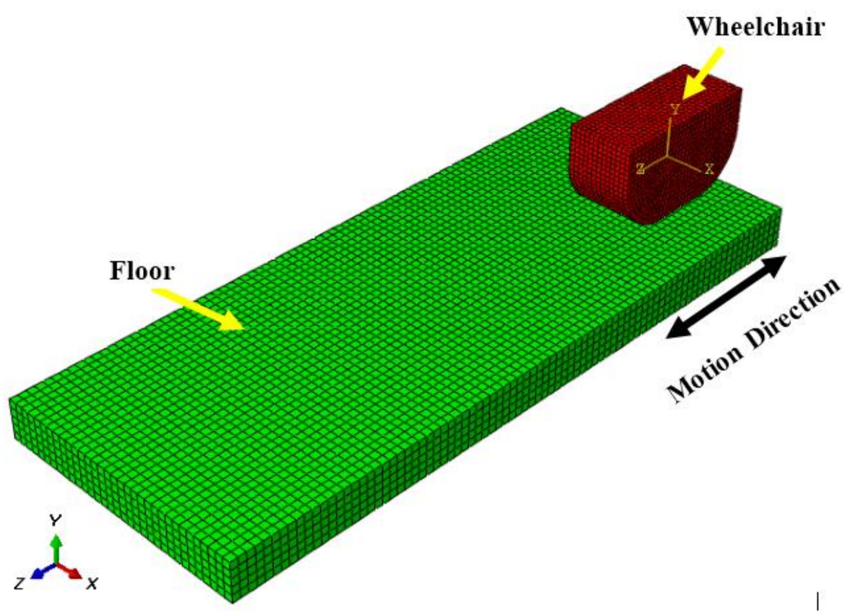

Figure 3. Three-dimensional model of the floor and pad.

Table 1. Mechanical and Thermal properties of used materials

Properties	Ceramic	Cement	Rubber
Modulus of Elasticity, MPa	$7*10^3$	$17*10^3$	$0.1*10^3$
Density, ton/mm^3	$2.3*10^{-9}$	$2.7*10^{-9}$	$1.2*10^{-9}$
Passion ratio	0.17	0.2	0.49
Thermal Conductivity, W/mm.C°	0.0015	0.00029	0.00013

Specific Heat, J/ton.C°	$1.07*10^6$	$1.55*10^6$	$2.01*10^6$

A number of running of the FE-program; at different number of elements of mesh; has been considered to determine the generated contact stress according to the FE-program. A comparison between the result of the model and the experimental results has been carried out. Figure 4 illustrates the result of mesh convergence test of the FE-model. It can be noticed that, the increase of the number of model-elements increases the calculated contact stress. This model gives small differences (less than 0.5%) with the increasing number element after the number of 400 elements, it indicates that the model already converged.

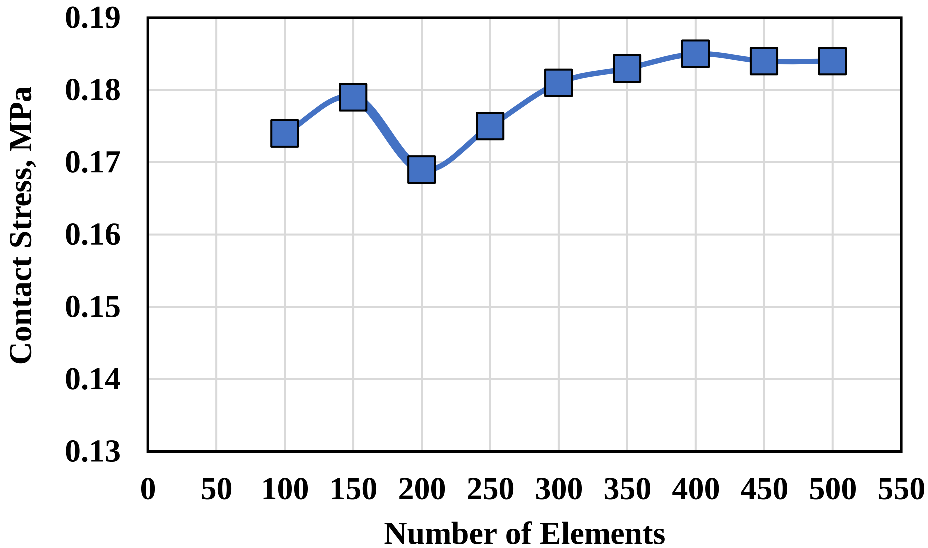

Figure 4. Mesh convergence test result.

RESULTS AND DISCUSSION

Many state laws and building codes have established that a static friction coefficient, μ ≥ 0.50 represents the minimum slip resistance threshold for safe floor surfaces, [21]. Furthermore, the Americans Disabilities Act Accessibility Guidelines, [22], contain advisory recommendations for static coefficient of friction of μ ≥ 0.60 for accessible routes (e.g. walkways and elevators) and μ ≥ 0.80 for ramps. In Europe, [23], it was suggested that a floor was ‘‘very slip-resistant’’ if the coefficient of friction was 0.3 or more. A floor with the coefficient of friction between 0.2 and 0.29 was ‘‘slip resistant’’. A floor was classified as ‘‘unsure’’ if its coefficient of friction was between 0.15 and 0.19. A floor was ‘‘slippery’’ and ‘‘very slippery’’ if the coefficient of friction was lower than 0.15 and 0.05, respectively, shown in Figure5. Rubber tends to provide higher effective contact area and more pronounced microscopic deformations when mechanically interacting with the surface asperities of a rigid material, greater friction coefficients can be expected for rubber than for plastic. The above characteristic frictional behavior of rubber was greatly disturbed when fluid film separating the two sliding surfaces.

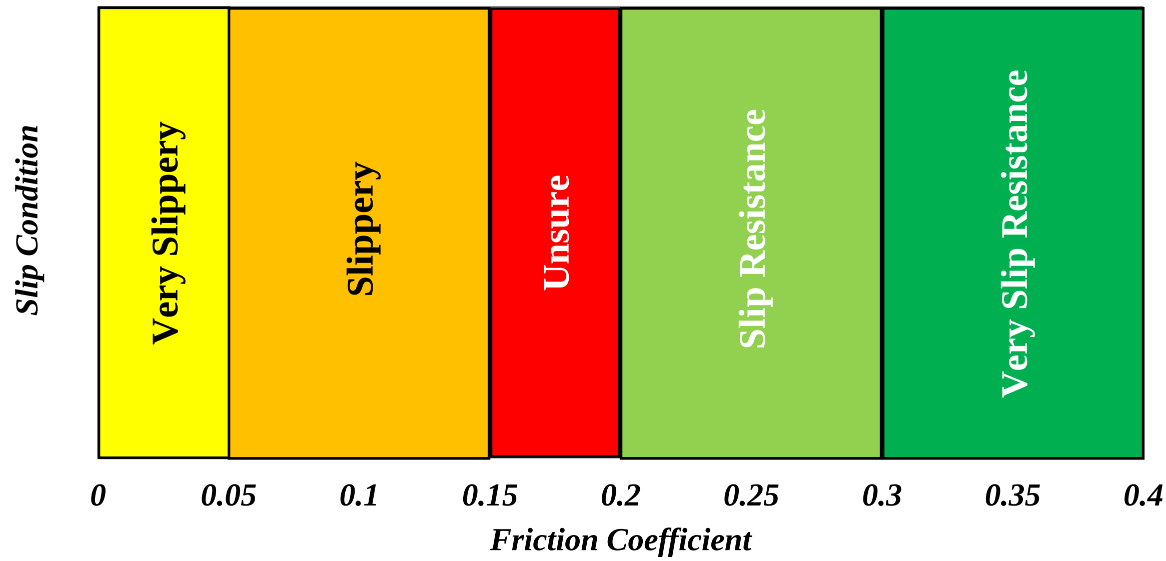

Fig. 5 Dependency of friction coefficient on the safety of walking, [23].

Friction coefficient displayed by the sliding of rubber on ceramic floor is shown in Fig. 6, where the effect of rubber hardness on friction coefficient is clearly noticed. Friction coefficient decreases with increasing rubber hardness due to decrease of deformation. Friction coefficient slightly decreases when normal load increases. Rubber of 40 Shore A hardness displays the highest value of friction coefficient. All the friction values are lower than that necessary for safe walking.

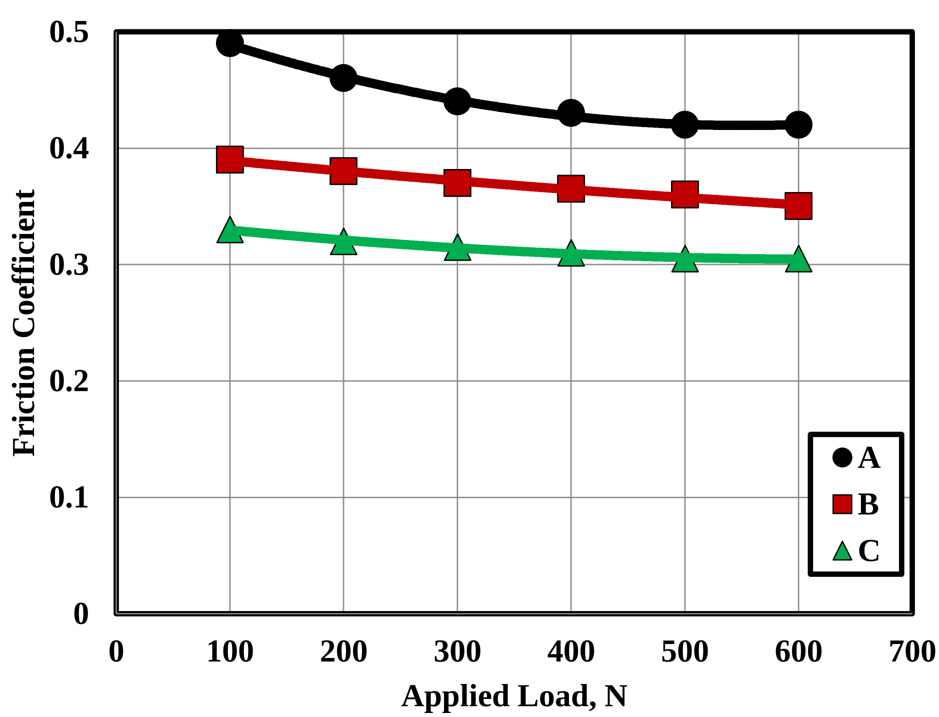

Fig. 6 Friction coefficient displayed by the sliding of rubber on ceramic floor.

Rubber tiles show relatively higher friction values than that observed for rubber tiles, Fig. 7. It is well known that the relatively high friction is attributed to the very low elastic modulus of rubber and its high internal friction. Based on that fact, rubber of low hardness exerts higher friction than the harder one. It seems that the relatively lower hardness of rubber is responsible about the friction increase due to the increase of the adhesion between the two sliding surfaces. Only rubber test specimen A fulfills the requirement of safe walking. Friction coefficient displayed by the sliding of rubber on cement tiles, Fig. 8, recorded the highest values compared to ceramic and rubber tiles. The tree tested rubber specimens show friction values suitable for safe walking. This observation confirms the recommendation of using cements tiles to reduce slip accidents. In addition to that, friction coefficient displayed by the sliding of rubber on sand contaminated cement floor recorded values ranging from 0.46 to 0.51. Those values are considered quite well for sliding against floor covered by sand particles.

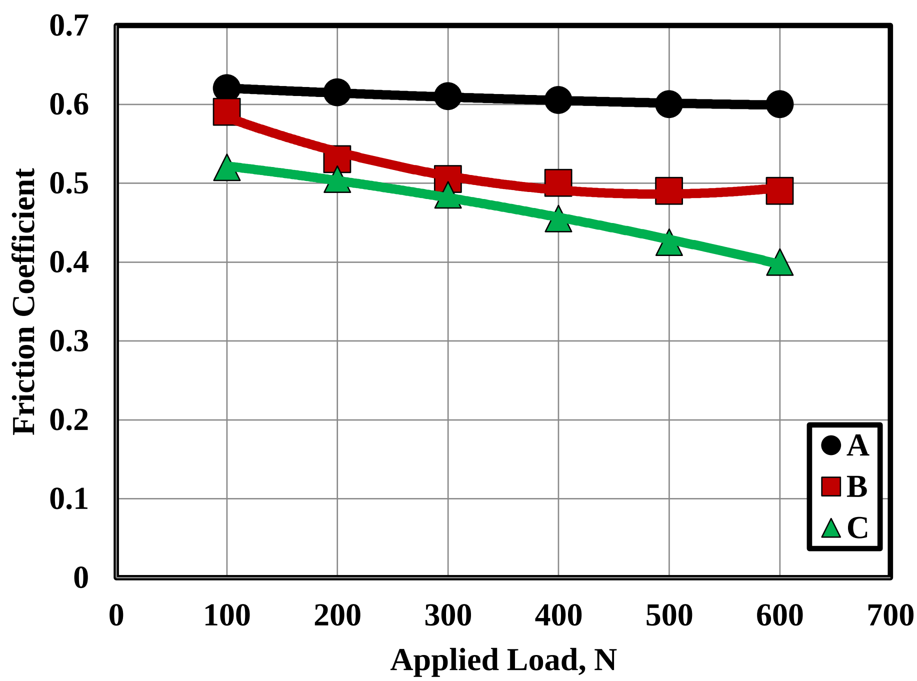

Fig. 7 Friction coefficient displayed by the sliding of rubber on rubber floor.

In this section, the proposed simulation model allows for the accurate location of the contact stress concentration areas as well as for the slipping force to the whole part, allowing avoiding the occurrence of sudden downfall. Figure 9 displays the contact stress distribution for friction pair model. It can be seen that the maximum stress located at position which the pad is pressed. Furthermore, the contact slip at surface nodes displays more detailed on Figure 10. The effect of turnover angles of the wheelchair on the contact stresses is investigated. Two types of turnover angles are consider in this study, the first angle is rotating about X-direction, as shown in Figure 11. The second one is rotating about Z-direction, as shown in Figure 12. Figure 13 shows the distribution of the contact stresses of the friction pair model. It can be noticed that

the highest value of the contact stresses are present at the front edge of the pad as result of direct reaction force. The same notice is standing for the contact stresses distribution for the pad turn with yaw angle of 1º as shown in Figures 14. It may be used to calculate the contact stress and slip before down fall.

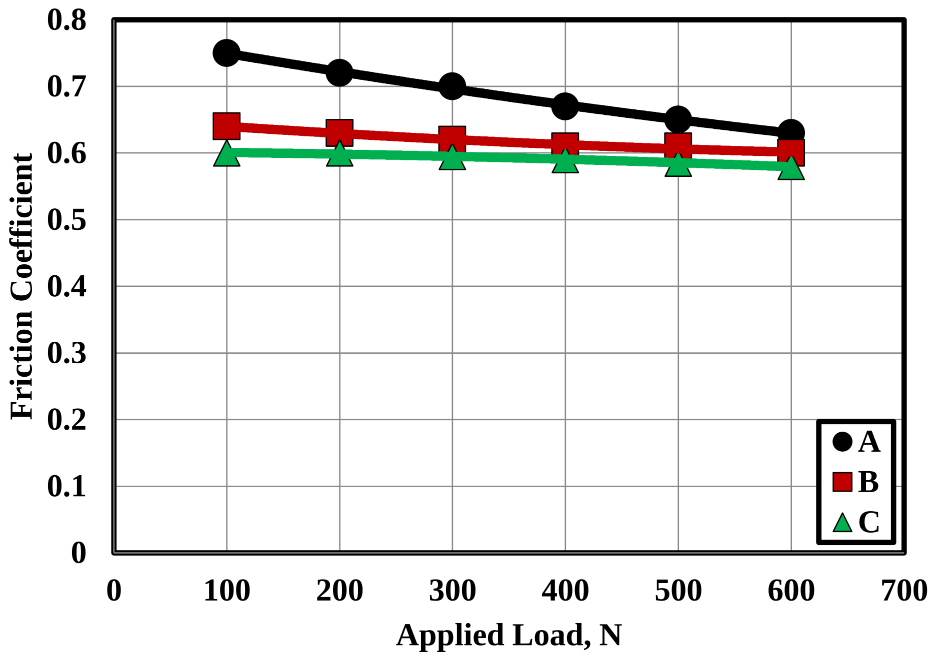

Fig. 8 Friction coefficient displayed by the sliding of rubber on cement floor.

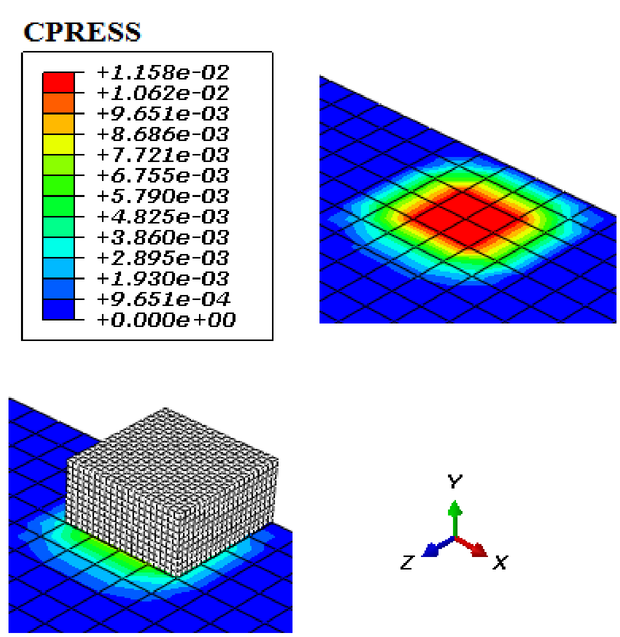

Figure 9. Contact stress distribution of friction pair model.

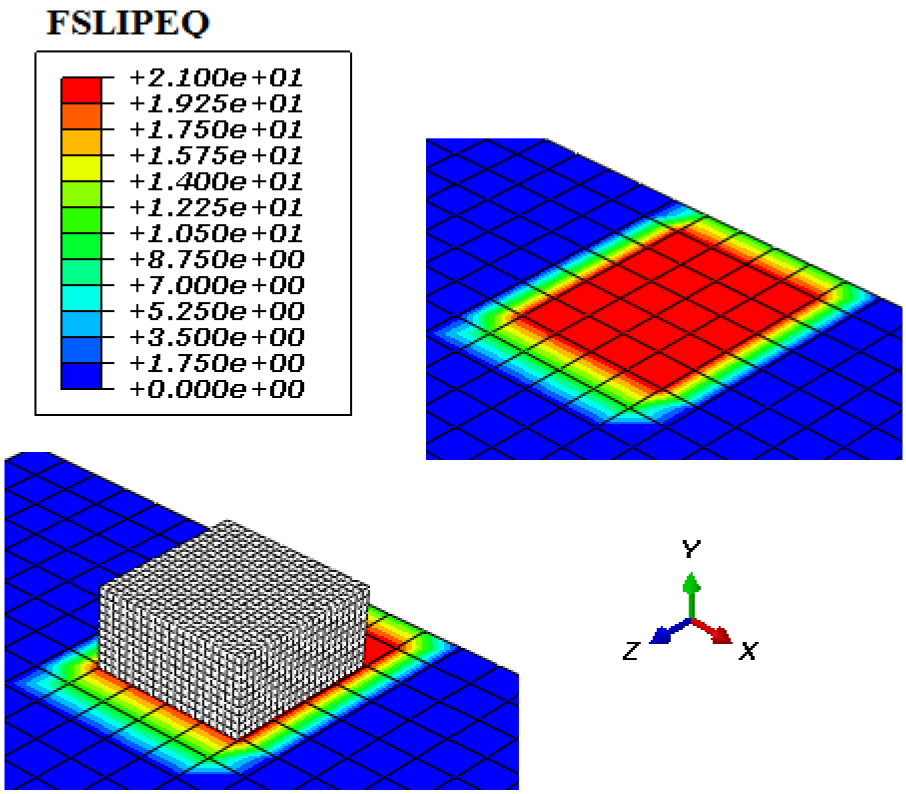

Figure 10. Contact slip at surfacenodes of friction pair model.

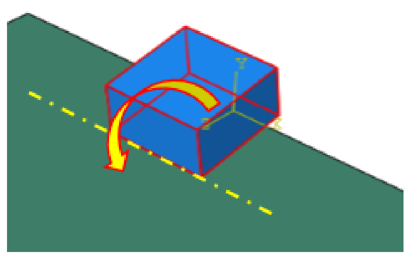

Figure 11. Model with 1º roll angle misalignment of friction pad.

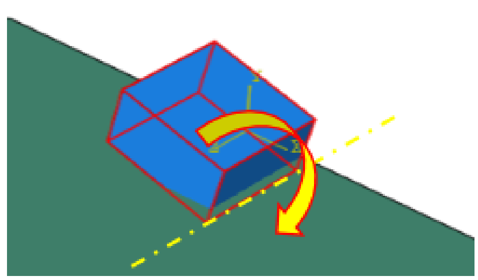

Figure 12. Model with 1º yaw angle misalignment of friction pad.

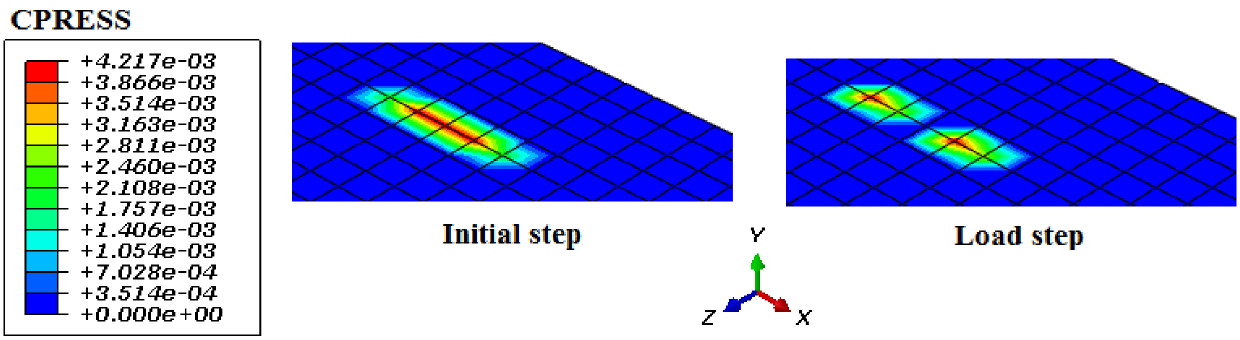

Figure 13. Contact stress ofmodel with 1º X-direction misalignment angle of friction pad.

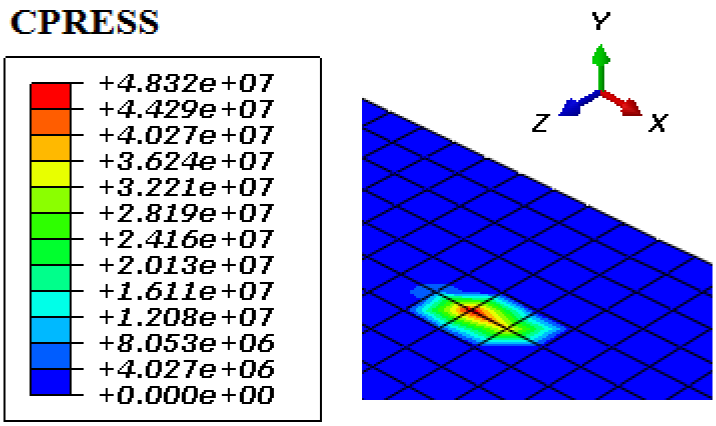

Figure 14. Contact stress of model with 1º Z-direction misalignment angle of friction pad.

CONCLUSIONS

1. Friction coefficient displayed by the sliding of rubber on cement tiles recorded the highest values compared to ceramic and rubber tiles. The three tested rubber specimens show friction values suitable for safe walking. This observation confirms the recommendation of using cement tiles to reduce slip accidents.

2. The simulation model makes it easy to know the contact stress and contact slip of between friction pair. Also, the effect of turnover angles of the wheelchair on the contact stresses is investigated.

3. Finally, the paper gives detailed method to model friction pair with real friction conditions.

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