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FRICTION COEFFICIENT DISPLAYED BY FOOT SLIDING ON THE SURFACE OF SKATEBOARD

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ABSTRACT
Skateboarding is a sport ofan increased rate of injuries. One of the main reasons of injuries is the low friction coefficient displayed by foot against the surface of the skateboard. The surface of the skateboard is coated by emery paper of certain grit size to roughen the surface and increase friction coefficient. The aim of the present work is to select the grit size of the emery paperwhich displays higher friction coefficient.The effect of surface roughness of the skateboard on the frictioncoefficient displayed by bare foot and two shoes is discussed. Experiments were carried out by the sliding of the bare foot and foot wearing shoes against emery papers of different grit sizes. The friction coefficient was investigated.

Based on the experimental observations, it was found that,at dry sliding of bare foot and foot wearing shoes, the reference tested emery paper displayed lower friction values than the majority of the tested emery papers. The highest friction values were displayed by 100 grit number emery paper. Shoe 1 displayed relatively lower friction values than bare foot. Shoe 2 displayed lower friction values than that displayed by shoe 1. At water wetted sliding, friction coefficient displayed by bare foot and foot wearing shoes presented lower values than that observed at dry sliding. The majority of the tested emery papers gave higher friction coefficient values than the reference one. Based on that observation, skateboarding could be dangerous using the reference emery paper and emery paper of 100 grit number can be recommended to provide the highest values of friction coefficient and the lowest slip.

KEYWORDS
Friction coefficient, bare foot, shoes,emery paper, dry, water sliding.

INTRODUCTION
Skateboarding is one of the most popular extreme sports of today. The basic mathematical model, describing the motion of a skateboard with the rider has been proposed, [1 - 3]. Recently this model has been developed, [4 - 6]. Various schemes for the control of a skateboard were discussed. Obviously, it is possible to use the simple feedback control for stabilization of the skateboard with the rider. At the same time it is clear that essentially all the degrees of freedom of the system experience hard servo-control on the part of the rider. The method of control of a skateboard with the help of servo-constraints was proposed.

The dynamics of the propulsion mechanism of a two-wheeled skateboard by measurements of human skateboard motion and computer simulations using a simplified model were investigated, [7]. This model expresses the board motion within the horizontal plane.

The rotation of the passive wheels requires some kinds of forces from the outside instead of the direct driving force of the wheel axis. A roller skate is an example of a device that consists of all passive wheels, where the propelling power isproduced from the leg motion kicking the ground: the wheels under the supporting leg rotate by the propulsion of ground reaction force, which the other leg generates by directly pushing the ground backward, [8 – 10]. However, the effective use of degrees of freedom (DOF) of motion of a mechanism mounted on passive-wheel systems can propel the wheeled system without kicking the ground.

Computational Fluid Dynamics was used to perform a detailed aerodynamic analysis of a downhill skateboarder, [11]. The study was also conducted into the influence of drafting, a tactical manoeuvre used in the race by skateboarders. This revealed how drafting skaters should position themselves behind a lead skater to minimize the drag force acting upon them.

The engineering analysis of skateboarding in general is limited. Studies on skateboard dynamics have been reported, [12, 13], and a study into the composite structure of a slalom board was presented, [14]. Aerodynamics play a significant role in this gravity sport, as speeds in excess of 75 mph are reached in competition.

Skateboard injuries have been described in the media and scientific journals as a problem prevalent among children and adolescents, [15]. Recently, surgeons at one trauma centre at an urban hospital noted an increase in the number of older skateboarders with life-threatening injuries.

Skateboarding is a popular recreational activity and a part of a lifestyle among young people,[16, 17]. The incidence (among all skateboarders) of skateboard-associated injuries(SAIs) was estimated to be 10 injuries per year per skateboarder,[16]. Increased rates of injuriesare occurring in adolescent and young adult skateboarders,[16, 18].

Floor slip-resistance is quantified by the static friction coefficient. In the USA, the static friction coefficient of 0.5 was recommended as the slip-resistant standard for unloaded, normal walking conditions, [19]. Higher the static friction coefficient values may be required for safe walking when handling loads. In Europe, [20], it wassuggested that a floor was ''very slip-resistant'' if the friction coefficient was 0.3 or more. A floor with the friction coefficient between 0.2 and 0.29 was ''slip resistant''. A floor was classified as ''unsure'' if its friction coefficient was between 0.15 and 0.19. A floor was ''slippery'' and ''very slippery'' if the friction coefficient of was lower than 0.15 and 0.05, respectively. The subjective ranking of floor slipperiness was compared with the static friction coefficient (μ) and found that the two measures were consistent, [21, 22]. It was concluded that human subjects could discriminate floor slipperiness reliably. Many state laws and building codes have established that a static $\mu \geq 0.50$ represents the minimum slip resistance threshold for safe floor surfaces. Furthermore, the Americans with Disabilities Act Accessibility Guidelines, [23] contain advisory recommendations for static friction coefficient of $\mu \geq 0.60$ for accessible routes (e.g. walkways and elevators)

and μ ≥ 0.80 for ramps. The effect of surface roughness of ceramic on the friction coefficient, when rubber and leather are sliding against it, was investigated, [24]. 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.

In the present work, friction coefficient displayed by bare foot and footwear sliding against emery papersof different grit number at dry and water sliding conditionsisinvestigated.

EXPERIMENTAL

Experiments were carried out using a test rig designed and manufactured to measure the friction coefficient displayed by the sliding of the bare foot against the surface of the skateboard through measuring the friction and normal forces. The tested emery papersof different grit number were adhered in a base supported by two load cells, the first can measure the horizontal force (friction force) and the second can measure the vertical force (normal load), Fig. 1. Friction coefficient was determined by the ratio between the friction force and the normal load.

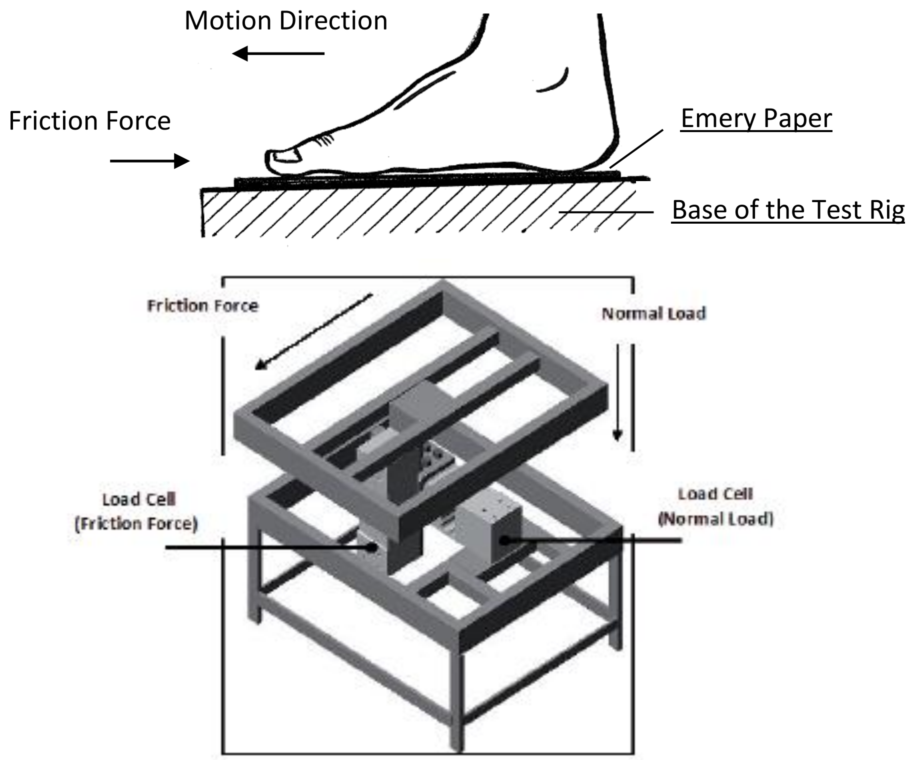

Fig. 1 Arrangement of the sliding conditions.

Fig. 2 The tested skateboard.

Friction testswere carried out using bare foot and two shoes, one was normal and the other was sport by applying variable forces up to 700 N. Friction coefficient was plotted against load then friction values were extracted at 400, 600 and 800 N. The load valued were chosen to simulate the weights of children, ladies and gentlemen respectively. The bare foot and foot wearing shoes were loaded against dry and water wetted emery papers. The grit number of the emery paper was 60, 80, 100, 120, 150, 180, 220, 320, 400, 600, 10 00, 1200 as well as the reference one which was provided by the manufacturer, Table 1. After each measurement, all contaminants were removed from the bare foot and shoes using absorbent papers. Both the bare foot and tested shoes were then rinsed using water and dried by using hair dryer after the cleaning process. For every experiment a new emery paper was used.

Table 1 Emery papers used in the experiments.

	
Grit No. 60	**Grit No. 80**
	
Grit No. 100	**REFERENCE**

RESULTS AND DISCUSSION

The results of experiments carried out in the present work is shown in Figs. 3 – 8. Friction coefficient displayed by bare foot sliding against dry emery paper of different number of grits is illustrated in Fig. 3. It is interesting to notice that the reference tested emery paper displayed lower friction values than the majority of the tested emery papers. The highest friction values were displayed by 100 grit number emery paper. The values were 1.44, 1.42 and 1.4 at normal load 400, 600, 800 N respectively.

Friction coefficient displayed by the normal shoe that sliding against dry emery paper of different number of grits is shown in Fig. 4. Normal shoe displayed relatively lower friction values than bare foot. The majorityof the tested emery papers showed higher friction coefficient than the reference one. The emery paper of 100 grit number gave the highest friction coefficient.

Sport shoe displayed the same trend observed for normal shoe 1, Fig. 5. The values of friction coefficient were lower than that displayed by normal shoe. The reference emery

paper exhibited lower values than all the tested emery papers. Based on that observation, skateboarding could be dangerous using the reference emery paper.

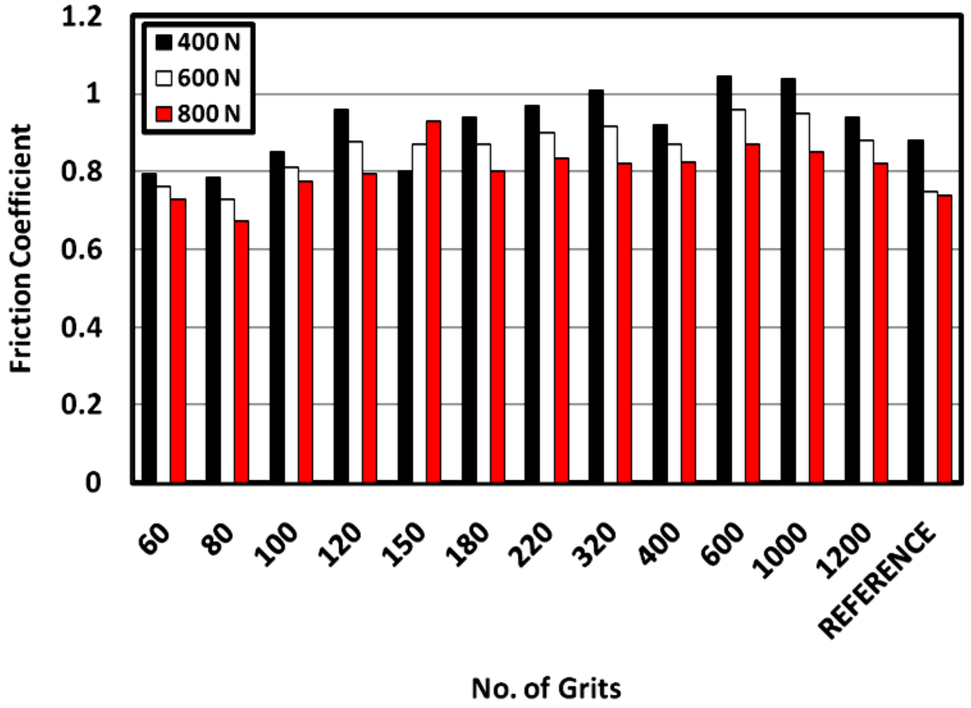

Fig. 3 Friction coefficient displayed by bare foot sliding against dry emery paper of different number of grits.

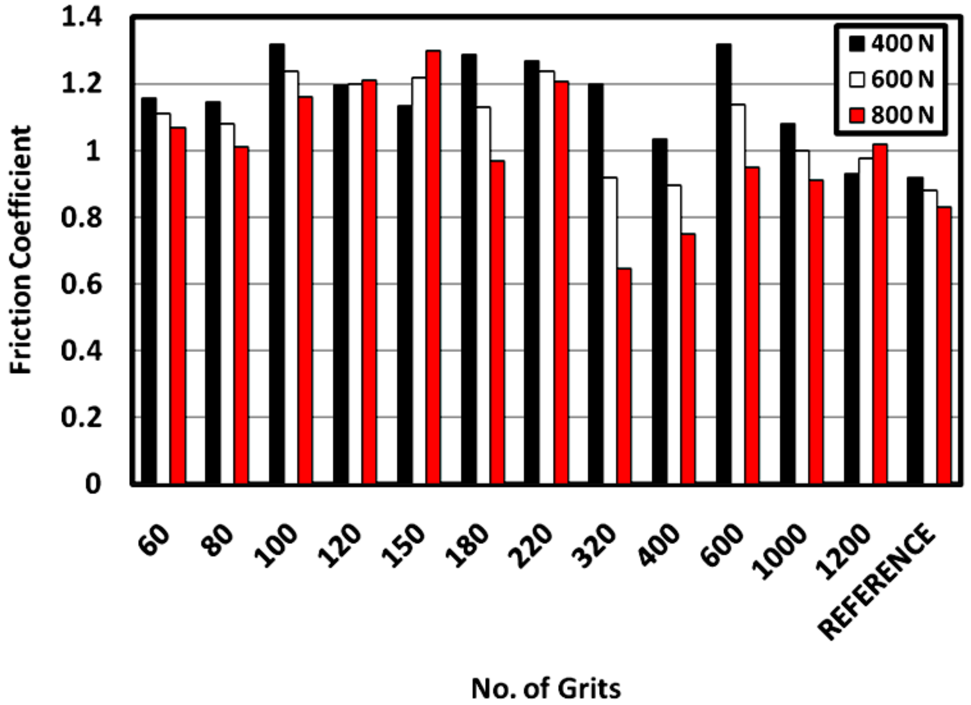

Fig. 4 Friction coefficient displayed by normal shoe sliding against dry emery paper of different number of grits.

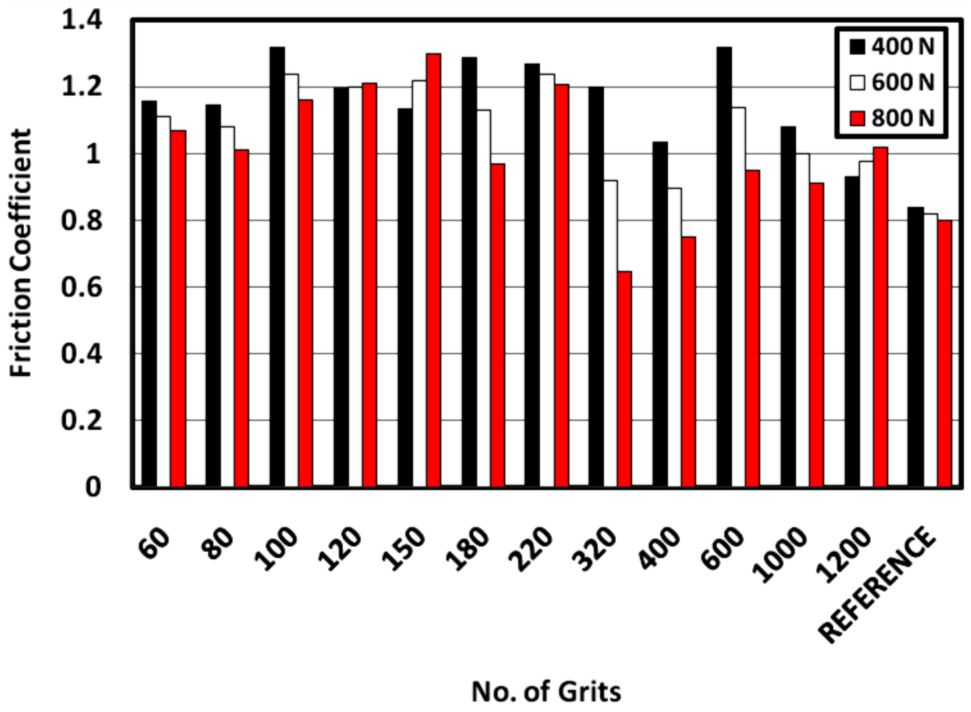

Fig. 5 Friction coefficient displayed by sport shoe sliding against dry emery paper of different number of grits.

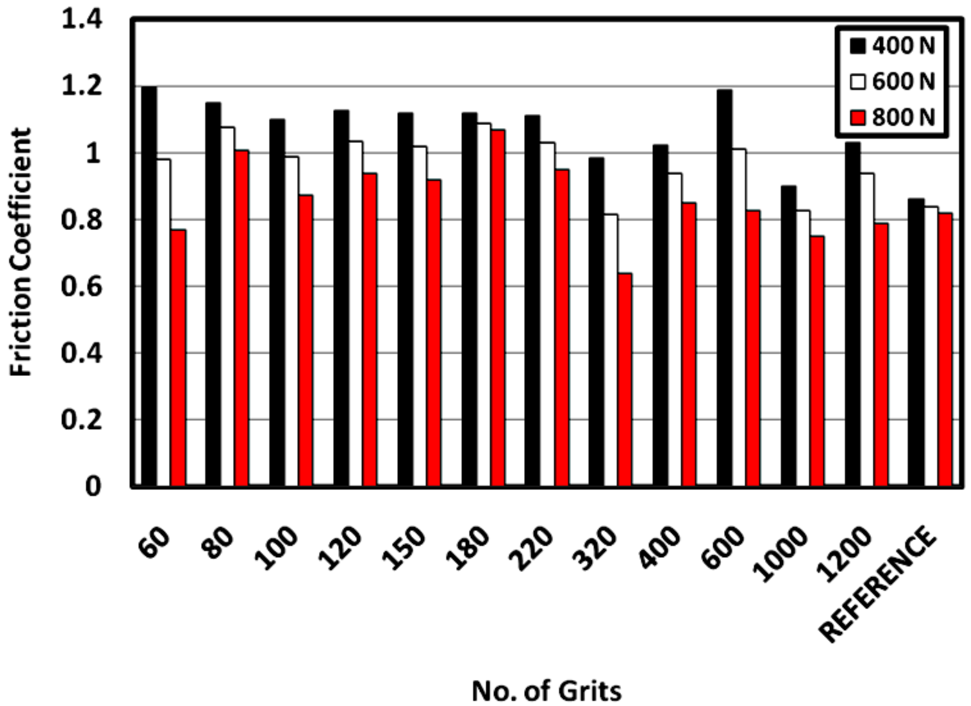

Fig. 6 Friction coefficient displayed by bare foot sliding against water wetted emery paper of different number of grits.

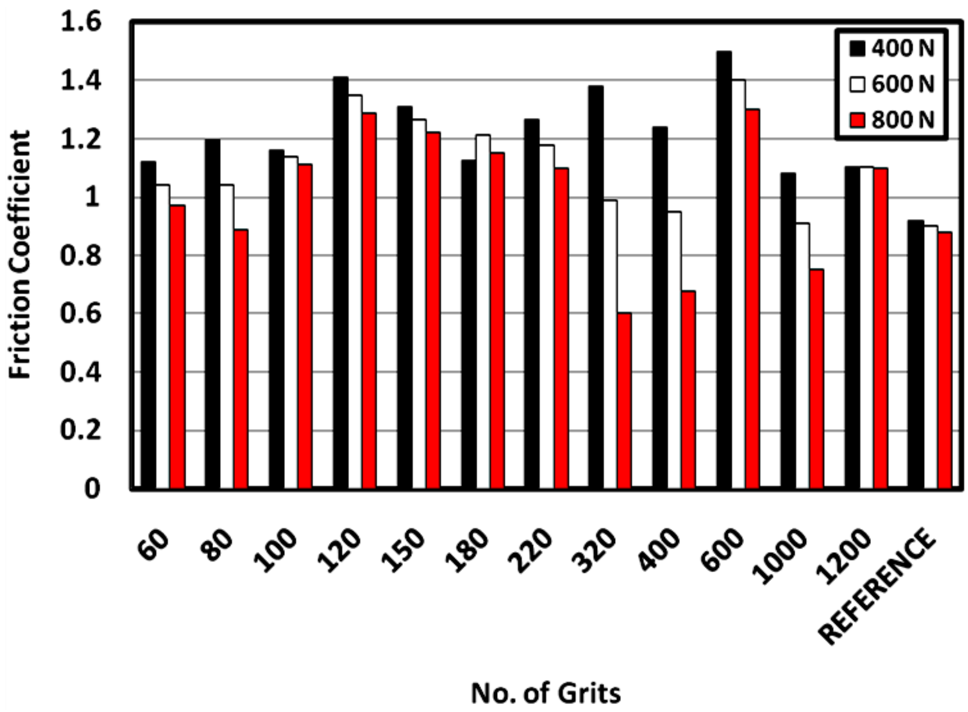

Fig. 7 Friction coefficient displayed by normal shoe sliding against water wetted emery paper of different number of grits.

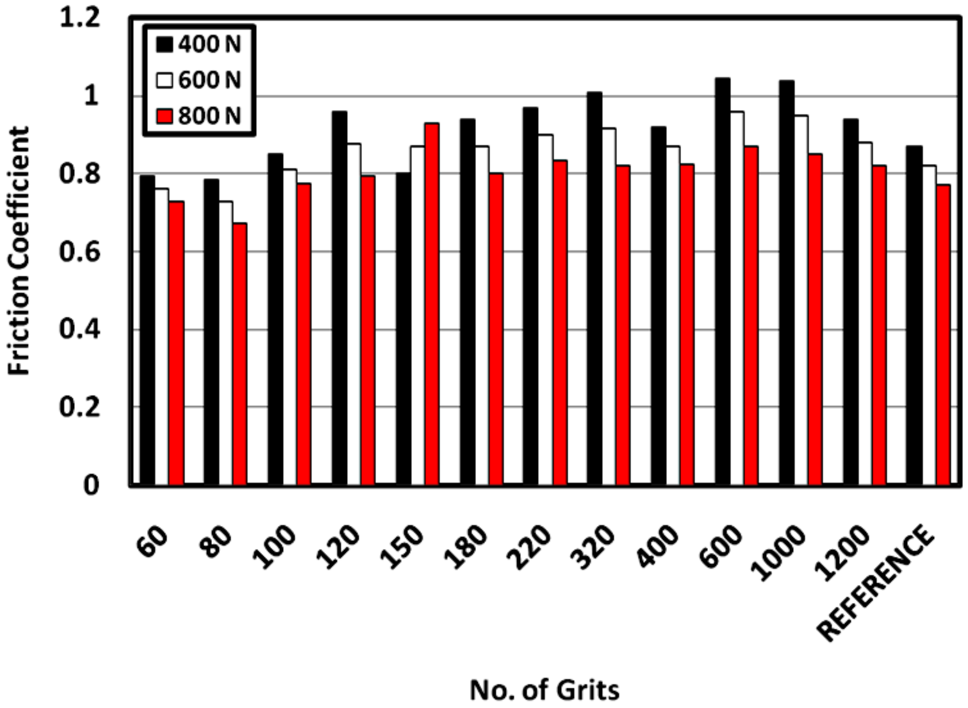

Fig. 8 Friction coefficient displayed by sport shoe sliding against water wetted emery paper of different number of grits.

At water wetted sliding, Fig. 6, friction coefficient displayed by bare foot showed lower values than that observed at dry sliding. The difference in the values of friction was not high because water could escape from the contact area to the valleys between the

asperities of the grits. The majority of the tested emery papers gave higher friction coefficient values than the reference one.

Friction coefficient displayed by normal shoe sliding against water wetted emery paper of different number of grits, Fig. 7, showed slight friction decrease compared to bare foot. Reference emery paper gave lower friction values than emery papers of 60, 80, 100, 120, 150, 220 and 320 grit number, while it showed higher friction than 400, 600 and 1000 grit number emery papers.

As for sport shoe, friction coefficient showed lower values than that displayed by bare foot and foot wearing normal shoe, Fig. 8. Reference emery paper displayed higher friction than emery papers of 60 and 80 grit number, while it showed lower friction than the other tested grit number emery papers.

CONCLUSIONS

1. At dry sliding of bare foot, the reference tested emery paper displayed lower friction values than the majority of the other tested emery papers. The highest friction values were displayed by 100 grit number emery paper. Normal shoe displayed relatively lower friction values than bare foot. The majorityof the tested emery papers showed higher friction coefficient than the reference one. Sport shoe displayed lower friction values than that displayed by normal shoe. The reference emery paper exhibited lower values than all the tested emery papers. Based on that observation, skateboarding could be dangerous using the reference emery paper.

2. At water wetted sliding, friction coefficient displayed by bare foot presented lower values than that observed at dry sliding. The majority of the tested emery papers gave higher friction coefficient values than that observed for the reference one.Friction coefficient displayed by normal shoe showed slight decrease compared to bare foot. Reference emery paper gave lower friction values than emery papers of 60, 80, 100, 120, 150, 220 and 320grit number.Sport shoe showed lower friction values than that displayed by bare foot and foot wearing normal shoe. Reference emery paper displayed higher friction than emery papers of 60 and 80 grit number, while it showed lower friction than the other tested grit number emery papers.

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