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DRY AND WATER WETTED SLIDING OF RUBBER ON EPOXY FLOORING FILLED BY THERMOPLASTIC POLYMERS

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ABSTRACT
The aim of the present work is to investigate the friction of epoxy flooring materials filled by thermoplastic polymers and sliding against rubber. Experiments were carried out at dry and water wetted sliding conditions.

It was found that, friction coefficient caused by the dry sliding of rubber on epoxy filled by polypropylene (PP) and polystyrene (PS) showed significant increase up to maximum then decreased with increasing PP and PS contents. The highest friction coefficient was displayed at 40 wt. % PP and 20 wt. % PS. Friction coefficient increased as the load increased. Epoxy composites filled by polytetrafluoroethylene (PTFE) showed an increasing trend in friction coefficient with increasing PTFE and polyvinyl chloride (PVC) contents up to 10 wt. %. The friction increase was followed by slight decrease as PTFE and PVC increased.

In the presence of water on the sliding surfaces, friction coefficient showed the same trend observed in dry sliding. As the PP content increased friction coefficient increased up to maximum then decreased. The friction values displayed showed that the sliding condition fulfilled the slip-resistant standard for safe walking when handling loads. Besides, slight increase of the values of friction coefficient was observed for epoxy composites filled by PS, while significant friction increase was observed for PVC, where the values were much higher than that displayed by dry sliding. Friction increase may be caused by the high electric charge generated on the sliding surfaces, where the normal force increased by the action of the electric force. Epoxy composites filled by PTFE sliding against rubber showed significant friction decrease with increasing PTFE content. Based on the frictional observations composites filled by PVC can be recommended as good flooring materials.

KEYWORDS
Friction, rubber, epoxy flooring, thermoplastic polymers.

INTRODUCTION

Slipping and falling are common phenomena in both workplaces and daily activities. The risks associated with slipping and falling are related to the materials of

footwear/floor, contamination condition, and geometric design of the sole. Shoe soles of various tread design are very common, [1 - 8]. Slip resistance of flooring materials is one of the major environmental factors affecting walking and materials handling behavior. Floor slipperiness may be quantified using the static and dynamic friction coefficient. 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. There were two types of slips involved in pallet truck pulling. The slip distances of both of these slips interacted significantly with the weights of the load and the floor surface conditions, [11]. Soft material like rubber tends to a 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, [12]. This was found in the friction measurements under wet conditions. In addition, mechanical abrasions and floor surface in homogeneities had a stronger influence for rubber. In general, rubber friction is divided into two parts; the bulk hysteresis and the contact adhesive term, [13]. These two contributions are regarded to be independent of each other, but this is only a simplified assumption.

There is an increasing demand to get rid of used polymeric materials, which are often burned or end up in landfills. These methods represent serious pollution of the environment. A safe option is to recycle used polymeric materials by recompounding process, but it leads to reduced quality of the resulting granulate. The mechanical and tribological properties of four types of used polymeric materials collected from different sources were investigated, [14]. It was found that wear and friction coefficient of epoxy composites filled by recycled polymeric powders represented minimum values at 20 wt. % of polymer content, [15]. The previous conclusion has confirmed that recycled polymers can be used in different applications due to the quite good mechanical and tribological properties.

Novel thermoplastic composites made from two major industrial and consumer wastes, fly ash and waste tire powder, have been developed, [16, 17]. The morphology of the blends shows that fly ash particles have more affinity and adhesion towards the rubbery phase when compared to the plastic phase. Toughening of brittle plastics by incorporation of a small amount of waste ground rubber tire (WGRT) is a widely used commercial process, [18]. Efforts to develop recycled rubber/plastic blends have logically followed earlier blending research that produced thermoplastic elastomers and rubber-toughened plastics, [19, 20]. Results of these numerous studies on virgin materials have provided criteria for a successful blend. The olefinic types have potential uses in flexible automotive components such as bumpers and spoilers, [21].

Recently, the friction and wear of epoxy flooring materials filled by recycled thermoplastic polymers sliding against rubber were investigated, [22]. Experimental results showed that filling epoxy matrix by thermoplastic polymers can enhance both friction coefficient and wear of the tested composites to be considered as promising flooring materials. Those epoxy composites are 20 wt. % high density polyethylene, 50

wt. % polyamide, (10 – 30) wt. % polypropylene, 10 wt. % polytetrafluoroethylene, 50 wt. % polyvinyl chloride and (10 – 20) wt. % polystyrene.

In the present work, it is aimed to investigate the friction and wear of epoxy test specimens filled by thermoplastic polymers. The proposed composites are tested as flooring materials.

EXPERIMENTAL

The test rig used in the present work was designed and manufactured to measure the friction coefficient displayed by the sliding of the tested epoxy composites against the rubber surface through measuring the friction force and applied normal force. The epoxy composites in form of a tiles of 50 × 50 × 10 mm^3 were adhered into a wooden block and loaded against rubber sheet, of 5 mm thickness and 60 Shore A hardness, placed in a base supported by two load cells, the first measures the horizontal force (friction force) and the second measures the vertical force (applied load). Two digital screens were attached to the load cells to detect the friction and vertical forces. Friction coefficient is determined by the ratio between the friction force and the normal load. The arrangement of the test rig is shown in Fig. 1. The tested materials were epoxy filled by different contents of thermoplastic polymers. The thermoplastic polymers were polypropylene (PP), polystyrene (PS), polytetrafluoroethylene (PTFE) and polyvinyl chloride (PVC). 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 250 N. Then the values of friction coefficient were extracted from the figures at loads of 50, 100, 150 and 200 N.

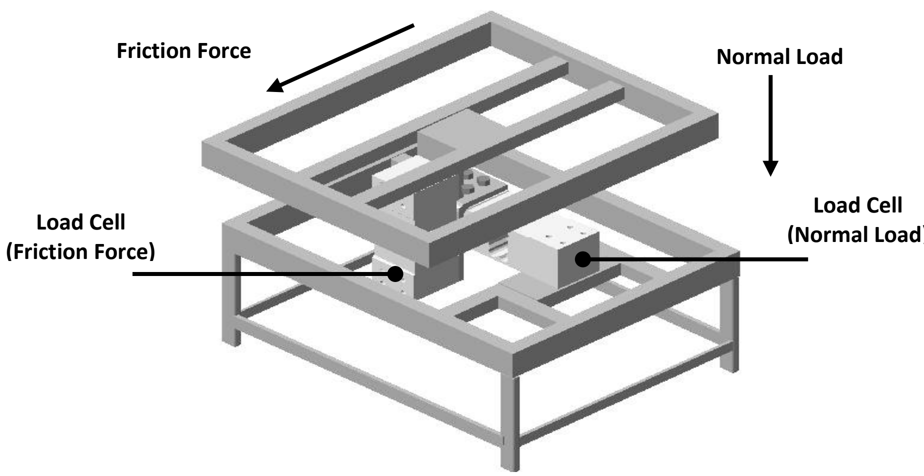

Fig. 1 Arrangement of the test rig.

RESULTS AND DISCUSSION

Friction coefficient displayed by the dry sliding of epoxy filled by thermoplastic polymers on rubber is shown in Figs. 2 – 5, while water wetted sliding is shown in Figs. 6 - 9. Friction coefficient caused by the dry sliding of rubber on epoxy filled by

polypropylene (PP) showed significant increase up to maximum then decreased with increasing PP content, Fig. 2. The highest friction coefficient was displayed at 40 wt. % PP. Friction coefficient increased with load increase.

Friction coefficient significantly decreased with increasing PS content up to maximum then slightly decreased with increasing PS content, Fig. 3. As the applied load increased, friction coefficient increased due to the increased contact area due to the increased number of contacting asperities. At 100 wt. % epoxy, friction coefficient displayed the lowest values, 0.18, 0.26 and 0.32 and 0.46 at 50, 100, 150 and 200 N loads respectively. It is well known that, friction coefficient depends on the material transfer and transfer back into the sliding surfaces. The test specimens consisted of epoxy and the filling thermoplastic polymers, while the counterface was rubber. In that condition, forces of adhesion among epoxy, thermoplastic polymers and rubber would control friction coefficient. The adhesion force depends on the normal force and electrical force generated from the electric static charge generated on the friction surface. Based on the amount and direction of charge generated from friction, different materials can be arranged in an order is called the triboelectric series, [23]. The tested materials would have relative ranking such as PS > PP > epoxy > rubber > PVC > PTFE (sorted by the ability to acquire positive charge) based on the triboelectric series, in which a material is expected to obtain a negative charge when it comes into contact with another material above it in the rank, and a positive charge after contacting with a material below it. The amount of the charge would depend on the distance between the two contacting materials.

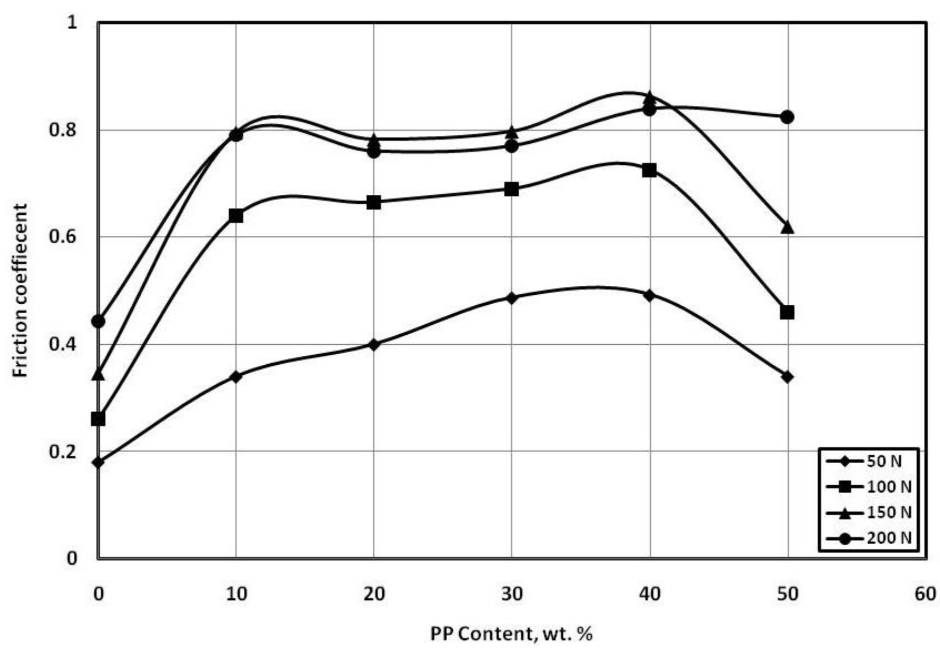

Fig. 2 Friction coefficient caused by the dry sliding of rubber on epoxy filled by polypropylene.

Epoxy composites filled by PTFE showed an increasing trend in friction coefficient with increasing PTFE content up to 10 wt. %, Fig. 4. The friction increase was followed by slight decrease as PTFE content increased. The friction increase might be attributed to the decrease of material transferred into rubber surface, while friction increase may be attributed to the decreased ability of epoxy to adhere into the rubber counterface due to the action of the PTFE that adhered to the rubber counterface and prevented epoxy from adhering. Besides, PTFE film adhered to the rubber would generate higher electric static charge and consequently the electric force as well as adhesive force increased. As a result of that it was expected that friction coefficient increased.

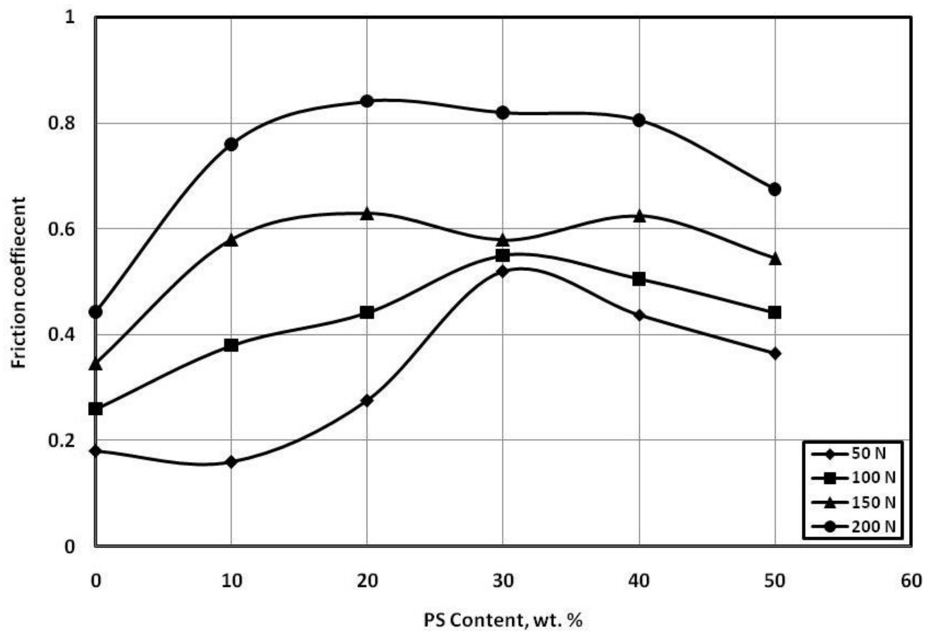

Fig. 3 Friction coefficient caused by dry sliding of rubber on epoxy filled by polystyrene against rubber.

Filling epoxy composites by polyvinyl chloride (PVC) increased friction coefficient up to maximum at 10 wt. % PVC content then drastically decreased with increasing PVC content, Fig. 5. Friction increase may be caused by the higher adhesion between PVC and epoxy from one side and rubber in the other side. This explanation can be supported by the relatively high electrostatic charge generated from the friction of PVC against rubber and epoxy. Besides, friction increase might be produced from the increased normal force as a result of the electrostatic charge.

In the presence of water on the sliding surfaces, Fig. 6, friction coefficient showed the same trend observed in dry sliding. Friction values were 0.2, 0.36, 0.52 and 0.65 at 50, 100, 150 and 200 N loads respectively. As the PP content increased friction coefficient increased up to maximum values then decreased. The maximum friction values were 0.48, 0.55, 0.68 and 0.79 at 50, 100, 150 and 200 N loads respectively. The friction values showed that the sliding condition fulfilled the slip resistant standard for safe walking when handling loads.

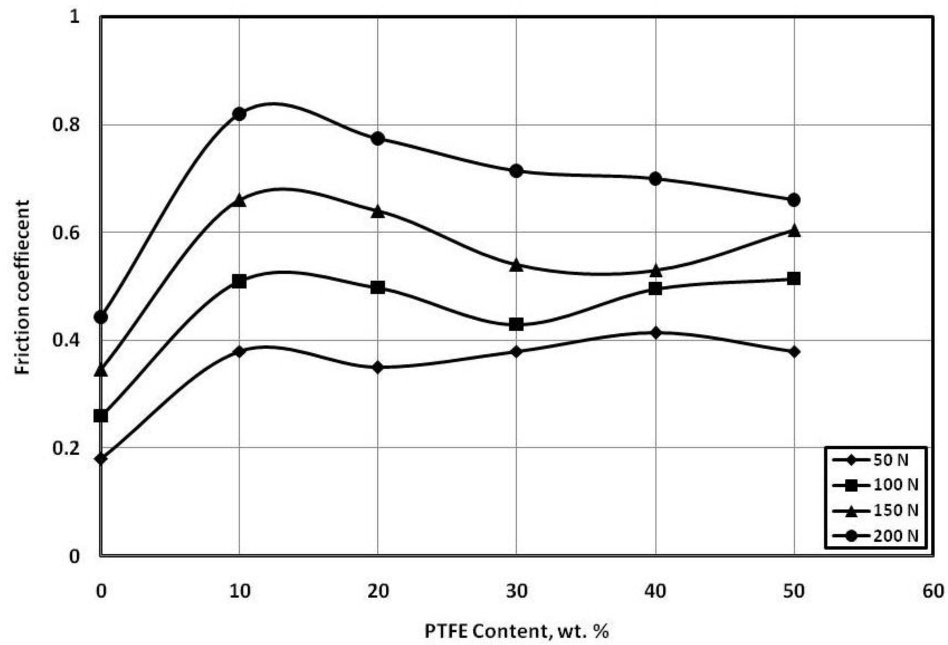

Fig. 4 Friction coefficient caused by the dry sliding of rubber on epoxy filled by polytetrafluoroethylene.

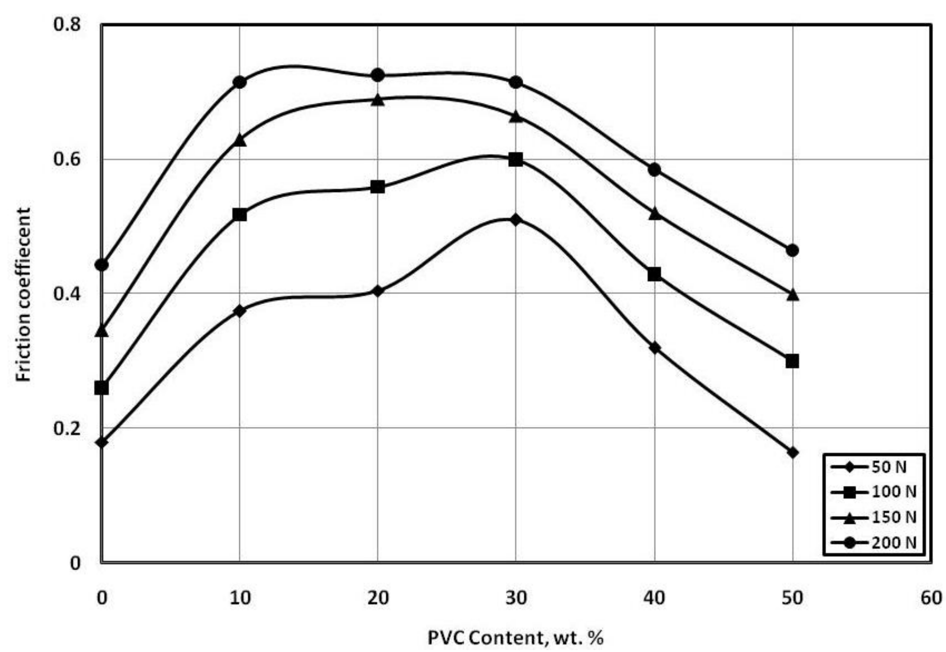

Fig. 5 Friction coefficient caused by the dry sliding of rubber on epoxy filled by polyvinyl chloride.

Slight increase of the values of friction coefficient was observed for epoxy composites filled by PS, Fig. 7. Friction values increased from 0.2, 0.35, 0.5 and 0.65 for 100 wt. % epoxy to 0.56, 0.66, 0.72 and 0.8 for composites of 50 wt. % epoxy and 50 wt. % PS at 50, 100, 150 and 200 N loads respectively. It seems that material transfer from the test

specimens into the rubber surface was limited due the presence of water so that the rubber fraction of the contact area increased. Based on the frictional observations those composites can be recommended as proper flooring materials for water wetted condition.

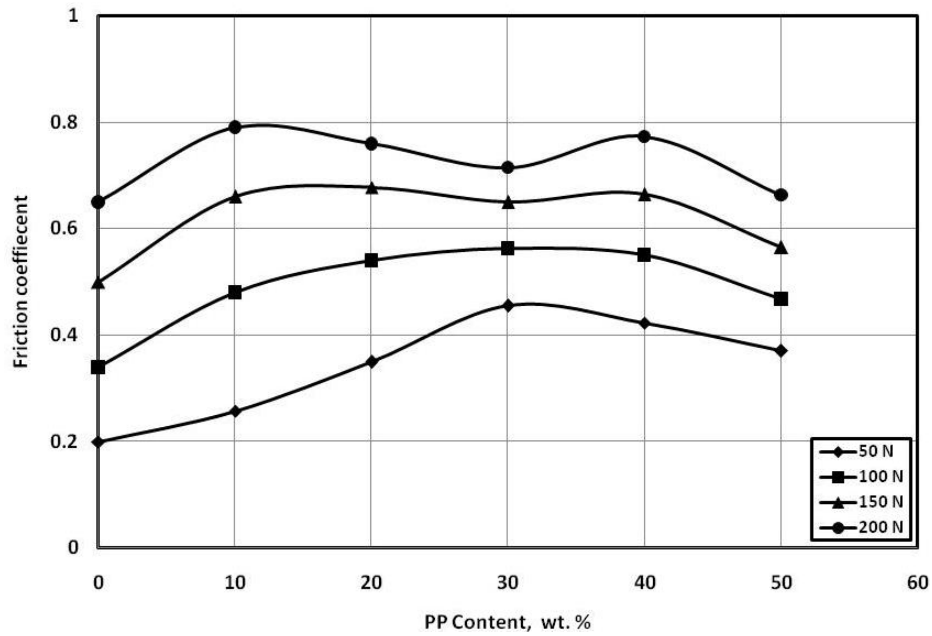

Fig. 6 Friction coefficient caused by the sliding of rubber on water wetted epoxy filled by polypropylene.

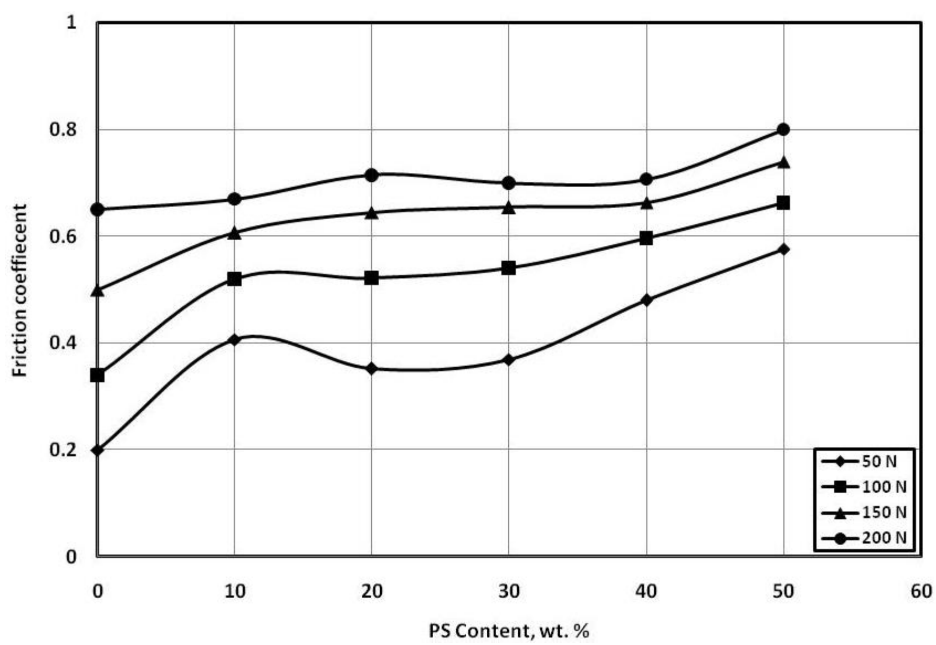

Fig. 7 Friction coefficient caused by the sliding r of rubber on water wetted epoxy filled by polystyrene.

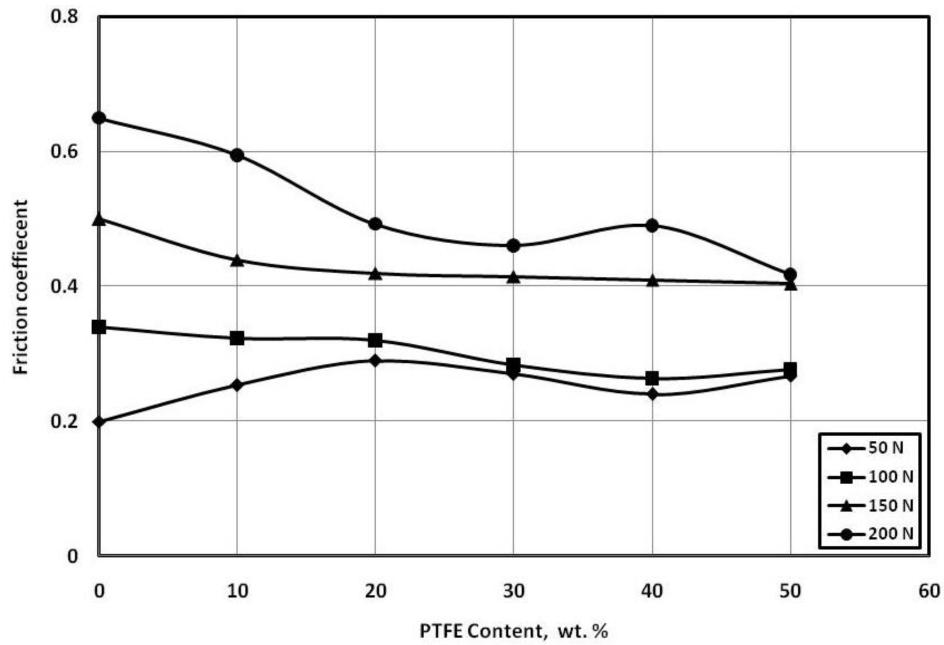

Fig. 8 Friction coefficient caused by the sliding of rubber on water wetted epoxy filled by polytetrafluoroethylene.

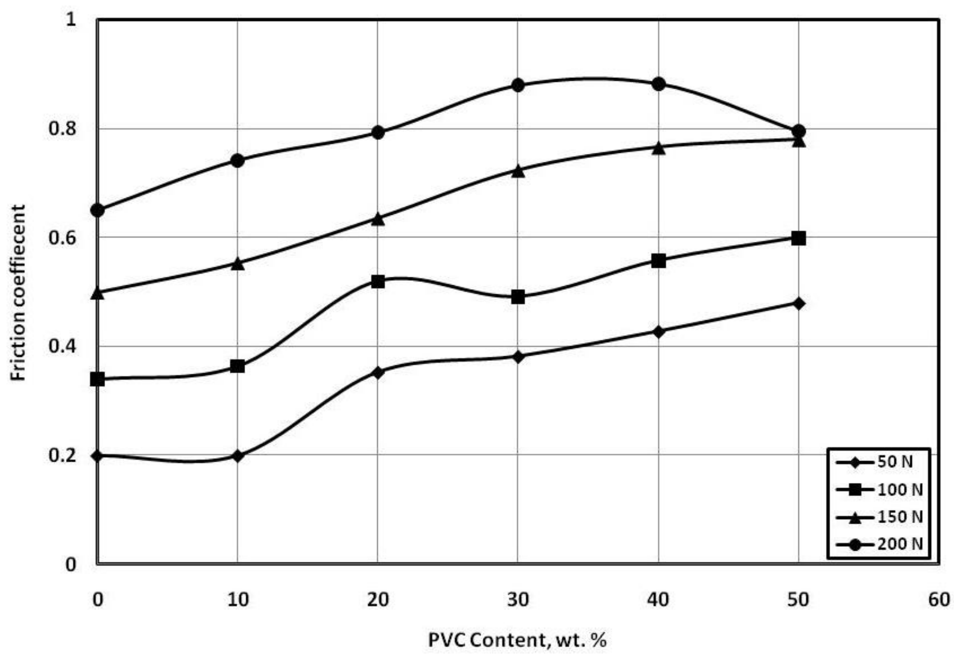

Fig. 9 Friction coefficient displayed by sliding of rubber on water wetted epoxy filled by polyvinyl chloride.

Epoxy composites filled by PTFE sliding against rubber showed significant friction decrease with increasing PTFE content, Fig. 8. Friction decrease may be attributed to

the good lubricating properties of PTFE to decrease the friction displayed by epoxy against rubber counterface, where PTFE adhered to the rubber counterface and decreased the contact area between epoxy and rubber.

Filling epoxy composites by PVC showed significant friction increase, where the values were much higher than that displayed by dry sliding, Fig. 9. Friction increase may be caused by the high electric charge generated on the sliding surfaces, where the normal force increased by the action of the electric force. This explanation can be supported by the relatively high electrostatic charge generated from the friction of PVC against rubber and epoxy. Based on the properties of the triboelectric effect, the sliding condition would generate negative charge on the PVC, whereas epoxy and rubber would generate positive charge. Therefore, an electric static force would be generated on the contact area, where the presence of water would homogeneously distribute the charge. Hence, after those interactions, a certain amount of charge might remain on the surface of the rubber, epoxy and PVC and control the electric static force that was superimposed on the normal load.

CONCLUSIONS

1. Friction coefficient displayed by dry sliding of rubber on epoxy filled by PP showed significant increase up to maximum then decreased with increasing PP content. The highest friction coefficient was displayed at 40 wt. % PP. Friction coefficient increased with load increase.
2. Friction coefficient significantly decreased with increasing PS content up to maximum then slightly decreased with increasing PS content. At 100 wt. % epoxy, friction coefficient displayed the lowest values, 0.18, 0.26 and 0.32 and 0.46 at 50, 100, 150 and 200 N loads respectively.
3. Epoxy composites filled by PTFE showed an increasing trend in friction coefficient with increasing PTFE content up to 10 wt. %. The friction increase was followed by slight decrease as PTFE content increased.
4. Filling epoxy composites by PVC increased friction coefficient up to maximum at 10 wt. % PVC content then drastically decreased with increasing PVC content.
5. In the presence of water on the sliding surfaces, friction coefficient showed the same trend observed in dry sliding. As the PP content increased friction coefficient increased up to maximum then decreased. The friction values displayed showed that the sliding condition fulfilled the slip-resistant standard for safe walking when handling loads.
6. Slight increase of the values of friction coefficient was observed for epoxy composites filled by PS. Based on the frictional observations those composites can be considered as good flooring materials.
7. Epoxy composites filled by PTFE sliding against rubber showed significant friction decrease with increasing PTFE content. Friction decrease may be attributed to the good lubricating properties of PTFE to decrease the friction displayed by epoxy against rubber counterface, where PTFE adhered to the rubber counterface and consequently decreased the contact area between epoxy and rubber.
8. Filling epoxy composites by PVC showed significant friction increase, where the values were much higher than that displayed by dry sliding. Friction increase may be

caused by the high electric charge generated on the sliding surfaces, where the normal force increased by the action of the electric force.

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