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RECYCLING OF THERMOPLASTIC POLYMERS BY FILLING EPOXY FLOORING MATERIALS

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ABSTRACT
Used polymeric materials are often burned or end up in landfills. Those methods represent serious pollution of the environment. The safe option is to recycle the used polymers as filling materials in epoxy flooring tiles.

The aim of this work is to study the friction and wear of epoxy flooring materials filled by recycled thermoplastic polymers sliding against rubber. It is well known that thermosetting materials such as epoxy are suffering from the inherent brittleness and relatively high wear rate while thermoplastics have favorable tribological characteristics. To enable epoxy resin to cope the more severe applications, it is proposed to use thermoplastic powders as filling material.

Experiments were carried out using test rig to measure the friction coefficient displayed by the sliding of the tested epoxy composites filled by recycled thermoplastic powders. 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. Filling epoxy composites by polymethyl methacrylate caused significant wear increase so that the possibility of using these composites as flooring materials is limited, although those composites have an increasing trend of friction with increasing polymethyl methacrylate content. Besides, composites filled by PMMA have relatively low electric static charge generated from the friction against rubber.

KEYWORDS
Epoxy, recycled thermoplastic polymers, flooring materials, friction and wear.

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 inhomogeneities 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 through 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].

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

EXPERIMENTAL

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 epoxy composites against

the rubber surface through measuring the friction force and applied normal force. The epoxy composites in form of a tile of 50 × 50 mm^2 is placed in a base supported by two load cells, the first measures the horizontal force (friction force) and the second for the vertical force (applied load). A digital screen was 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 Figs. 2and 3. The specimens were prepared for measurements in a form of a layer of 50 × 50 ×5 mm^3 adhered into a wooden block. The tested materials were epoxy filled by different contents of recycled polymers. The recycled polymers were polytetrafluoroethylene (PTFE), high density polyethylene (HDFE), polystyrene (PS), polypropylene (PP), polyvinyl chloride (PVC), polymethyl methacrylate (PMMA) and polyamide (PA 6). 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 700 N. Then the values of friction coefficient were extracted from the figures at loads of 400, 600 and 800 N.

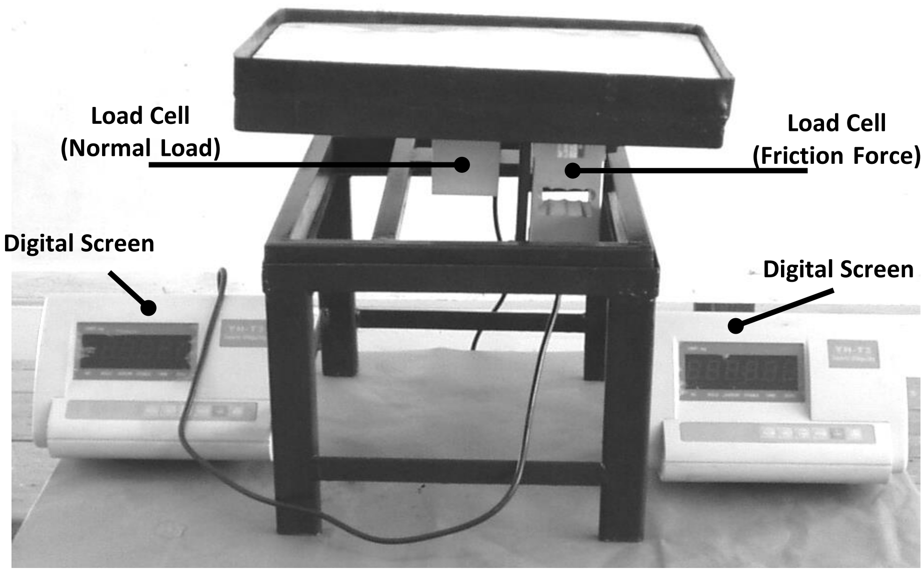

Fig. 1 Arrangement of the test rig.

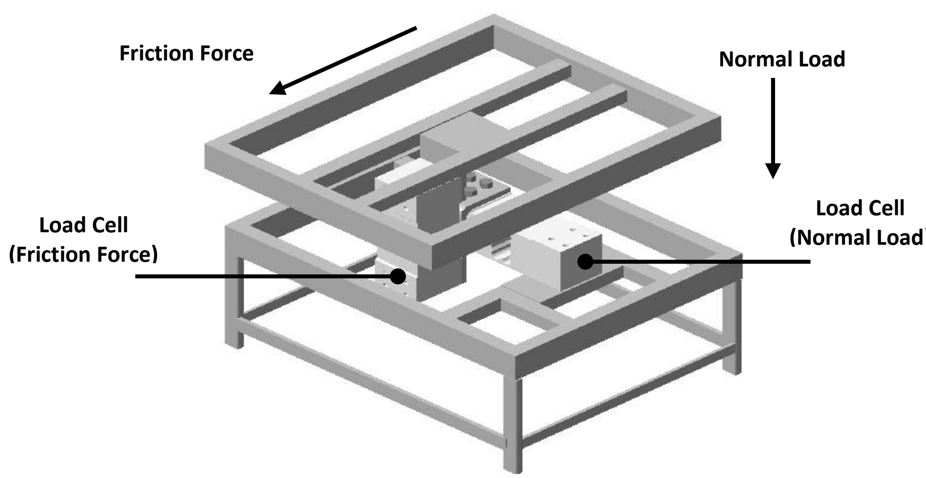

Fig. 2 Layout of the test rig.

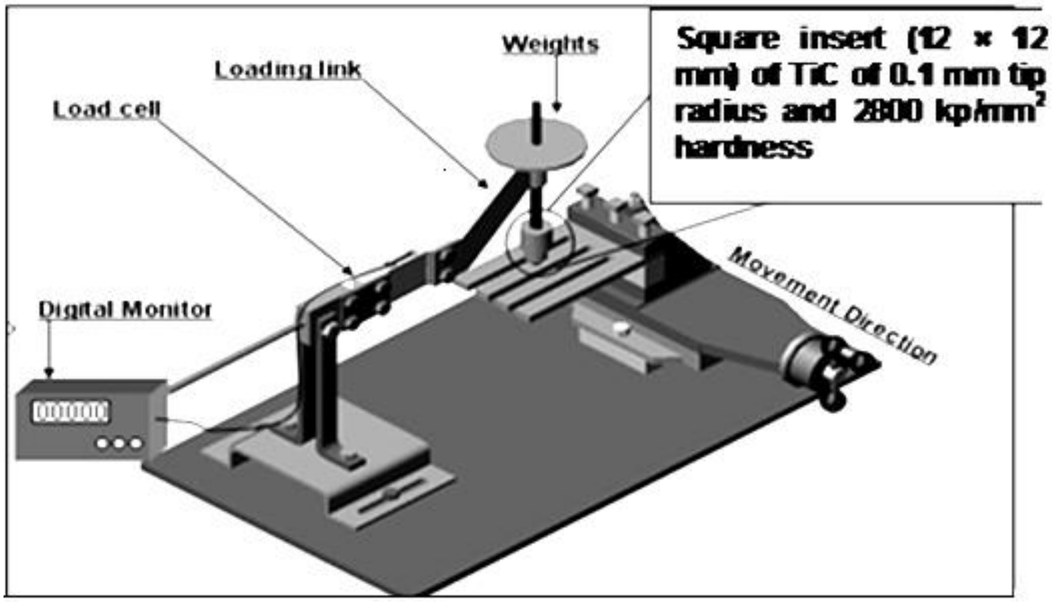

Fig. 3 scratch test rig

The test rig used in the experiments was top scratching tester equipped with an indentor to produce a scratch on a flat surface. The details of the test rig are shown in Fig. 3. The indenter, used in experiments, was a square insert (12 × 12 mm) of TiC of tip radius of 0.1 mm and hardness of 2800 kp/mm^2. The scratch force was measured by the deflection of the load cell. The ratio of the scratch force to the normal force was considered as friction coefficient. Wear was determined by the wear scar width measured by optical microscope. The weight loss was measured by digital balance with an accuracy of ± 1.0 mg. The load was applied by weights. The test speed was nearly controlled by turning the power screw feeding the insert into the scratch direction. The applied load values were 4, 6 and 8 N.

RESULTS AND DISCUSSION

Friction coefficient caused by the sliding of epoxy filled by polyethylene (HDPE) against rubber is shown in Fig. 4. Friction coefficient slightly decreased with increasing HDPE content. As the applied load increased friction coefficient decreased due to the increased plasticity of the polymeric materials. At 100 wt. % epoxy, friction coefficient displayed the highest values, 0.77, 0.7 and 0.57, at 400, 600 and 600 N loads respectively. Generally, 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, force of adhesion among epoxy, thermoplastic polymers and rubber will control the friction coefficient.

Filling epoxy composites by polyamide (PA 6), Fig. 5, showed the same trend observed for epoxy composites filled by HDPE. The decrease in the values of friction coefficient might be attributed to the transfer of both epoxy and PA 6 into the rubber surface and

consequently the contact area of rubber decreased partially. Friction values were 0.66, 0.52 and 0.43 at 400, 600 and 800 N loads respectively.

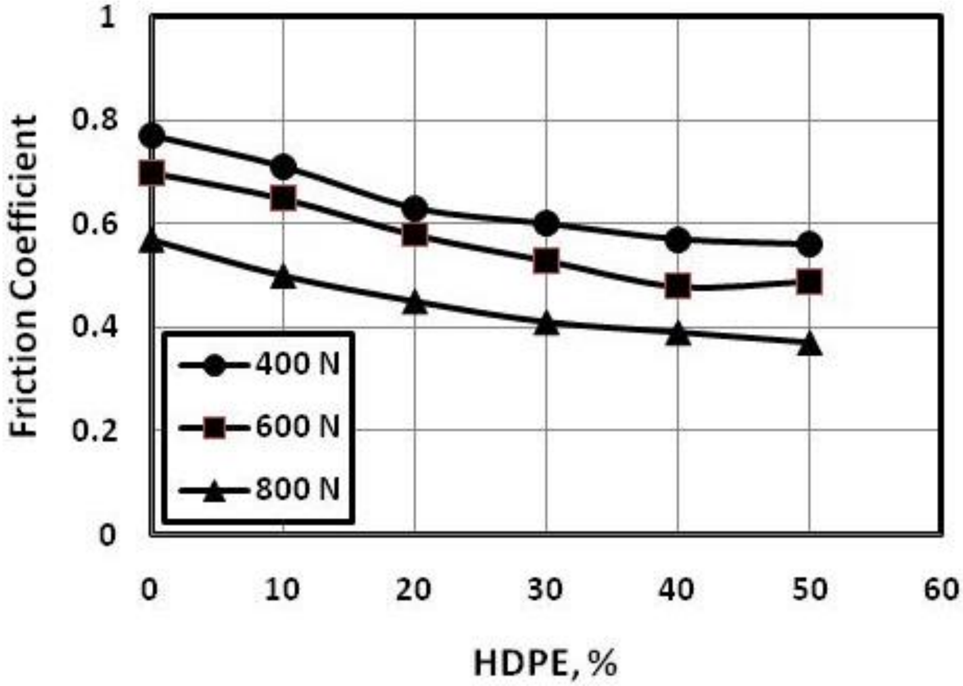

Fig. 4 Friction coefficient caused by the sliding of epoxy filled by polyethylene against rubber.

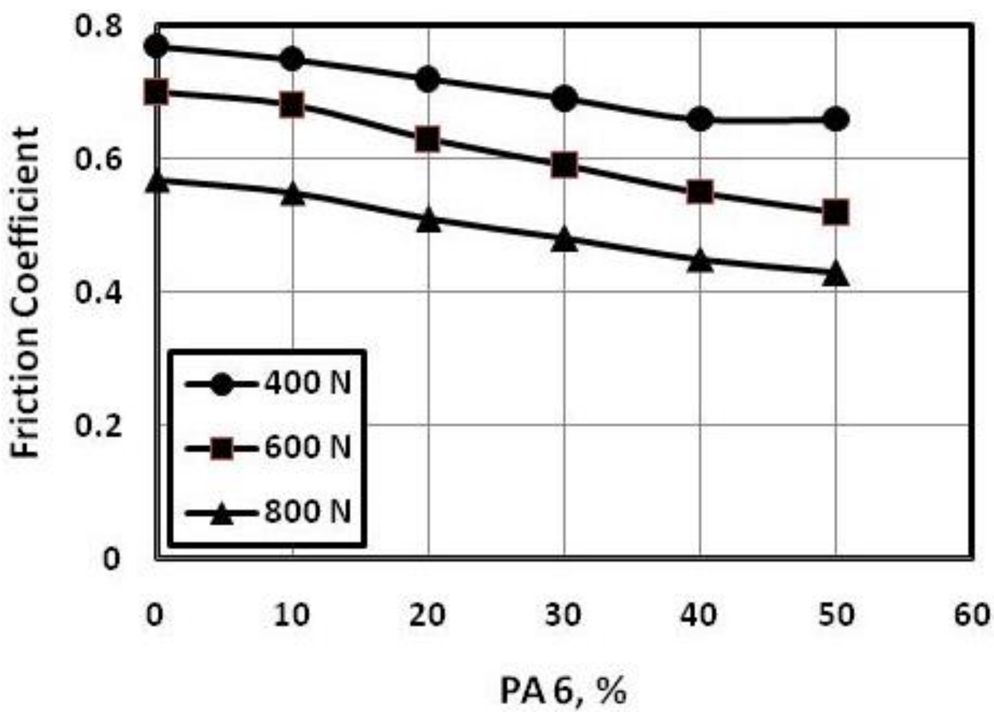

Fig. 5 Friction coefficient caused by the sliding of epoxy filled by polyamide against rubber.

Epoxy composites filled by polymethyl methacrylate (PMMA) showed an increasing trend with increasing PMMA content, Fig. 6. The friction increase recommends those composites to be used as flooring material, where friction values displayed for 400, 600 and 800 N loads were 0.86, 0.7 and 0.76 respectively. Besides, filling epoxy by PMMA will decrease the electric static charge generated from the friction against rubber surface due to their ranking in the triboelectric series. The friction increase might be attributed to the decrease of material transferred into rubber surface, where the relatively high positive electric static charge generated from PMMA during friction against rubber and epoxy forced PMMA to be adhered into epoxy rather than rubber.

Slight decrease of the values of friction coefficient was observed for epoxy composites filled by polypropylene (PP), Fig. 7. Friction values decreased from 0.77, 0.7 and 0.56 for 100 wt. % epoxy to 0.63, 0.56 and 0.6 for composites of 50 wt. % epoxy and 50 wt. % PP at 400, 600 and 800 N loads respectively. It seems that material transfer from the test specimens into the rubber surface was responsible for the friction decrease. Based on the frictional observations those composites can be considered as good flooring materials.

Epoxy composites filled by polytetrafluoroethylene (PTFE) sliding against rubber showed significant friction decrease with increasing PTFE content, Fig. 8. Friction decrease 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.

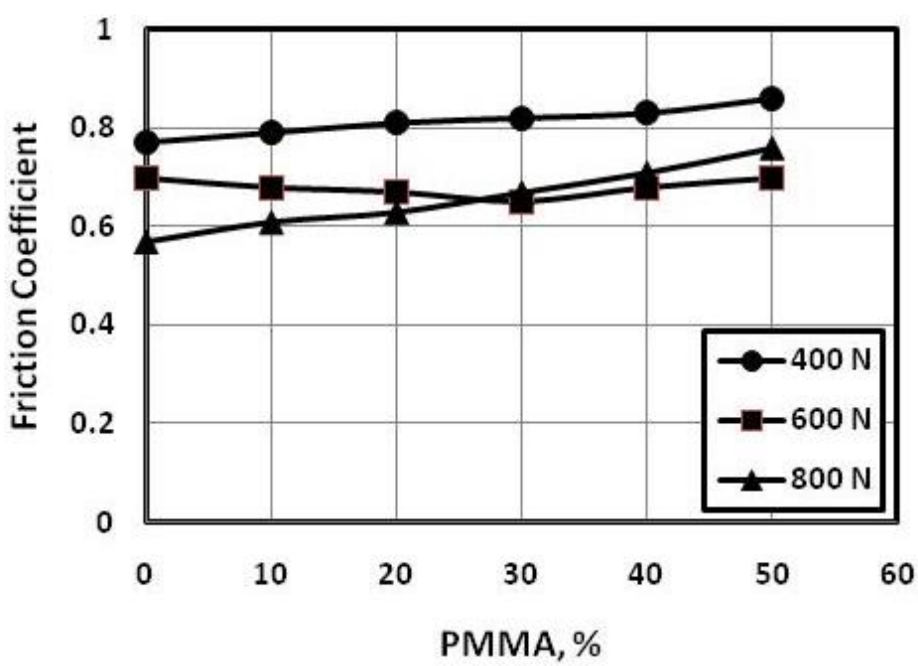

Fig. 6 Friction coefficient caused by the sliding of epoxy filled by polymethyl methacrylate against rubber.

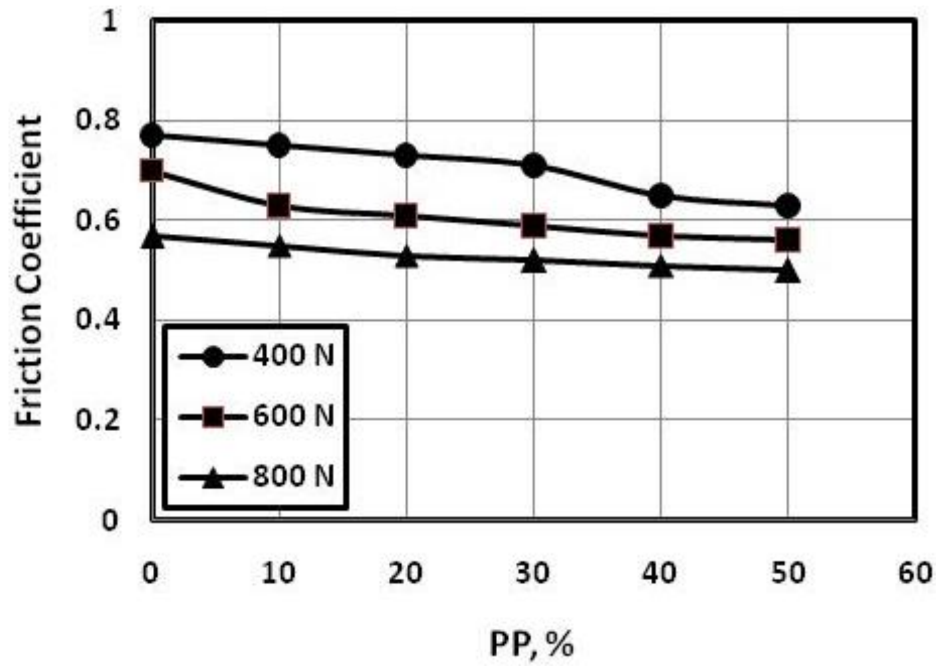

Fig. 7 Friction coefficient caused by the sliding of epoxy filled by polypropylene against rubber.

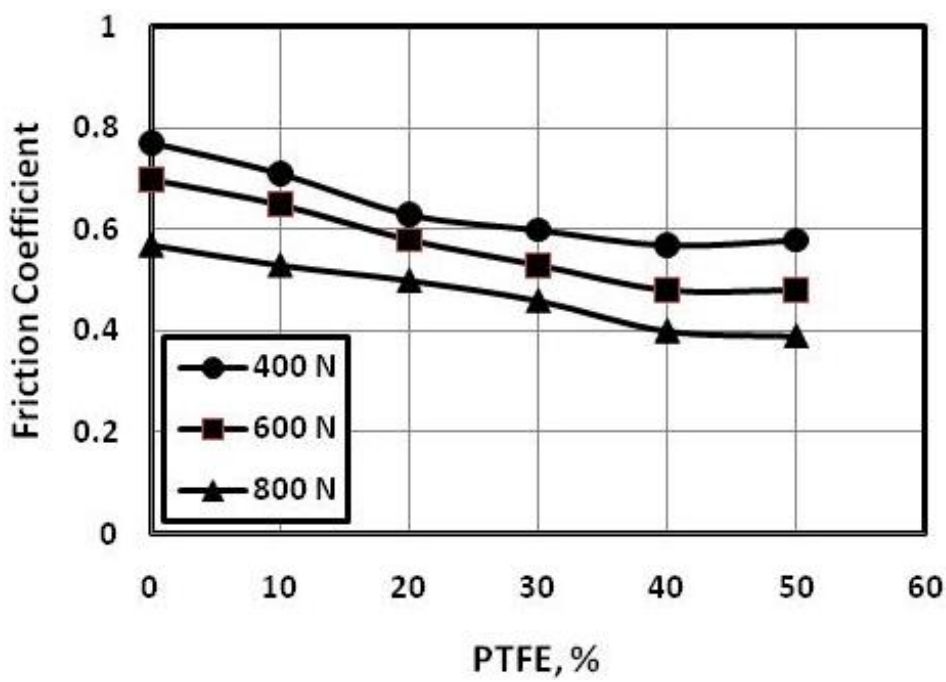

Fig. 8 Friction coefficient caused by the sliding of epoxy filled by polytetrafluoroethylene against rubber.

Filling epoxy composites by polyvinyl chloride (PVC) decreased friction coefficient down to minimum at 10 wt. % PVC content then slightly increased with increasing PVC content, Fig. 9. Friction increase may be caused by the PVC and epoxy transfer and transfer back to the surface of the test specimens. 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 forced as a result of the charge.

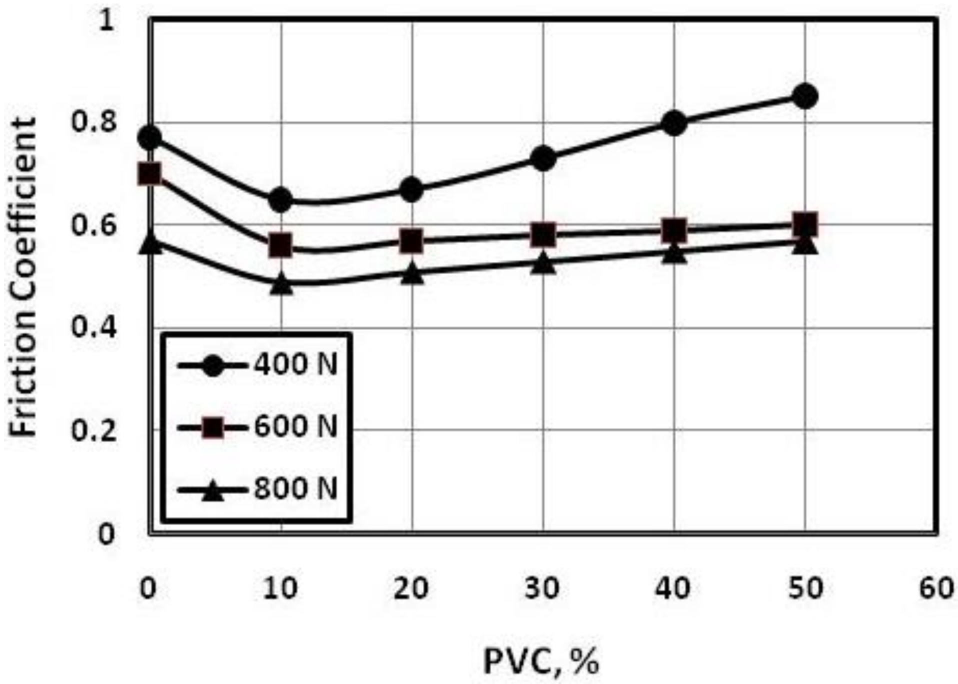

Fig. 9 Friction coefficient caused by the sliding of epoxy filled by polyvinyl chloride against rubber.

The same trend observed for epoxy composites filled by PVC was noticed for composites filled by polystyrene (PS), Fig. 10. Generally, composites containing 50 wt. % epoxy and 50 wt. % PS displayed the highest friction coefficient.

Wear of the tested flooring materials measured in the wear scar width is shown in Figs. 11 – 17. Wear of epoxy filled by HDPE decreased down to minimum then significantly increased with increasing HDPE content, Fig. 11. Minimum wear was displayed by composites of 20 wt. %. HDPE. Generally, wear increased with increasing applied load. Wear increase was caused by the decrease of cohesion force as HDPE increased.

Wear of epoxy, filled by PA 6, showed slight increase up to maximum then decreased with increasing PA 6 content, Fig. 12. Wear increase may be attributed to the relatively weak adhesion between epoxy and polyamide, while wear decrease can be explained on the relatively higher abrasion resistance of polyamide as well as the increase of the attractive force between epoxy and HDPE. Although no enhancement was observed in wear resistance, these composites can be considered as promising flooring materials due to their relatively low electric static charge generated from the friction with rubber.

Filling epoxy composites by PMMA caused significant wear increase, Fig. 13. This behaviour reduces the possibility of using these composites as flooring materials, although those composites have the same good triboelectrification properties like composites filled by PA 6 but their high wear can limit their use as flooring materials.

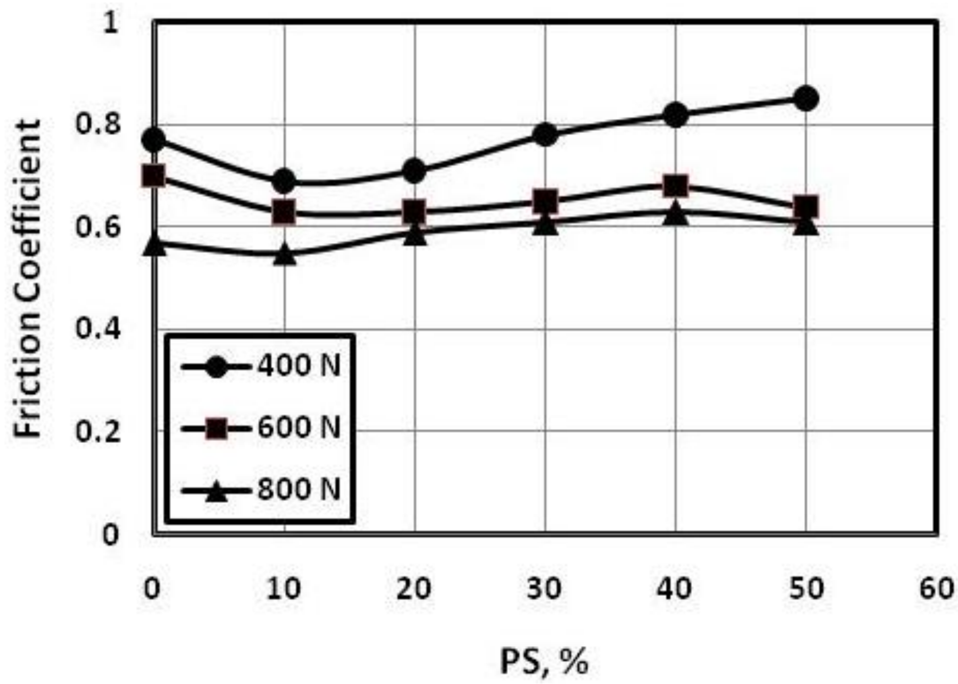

Fig. 10 Friction coefficient caused by the sliding of epoxy filled by polystyrene against rubber.

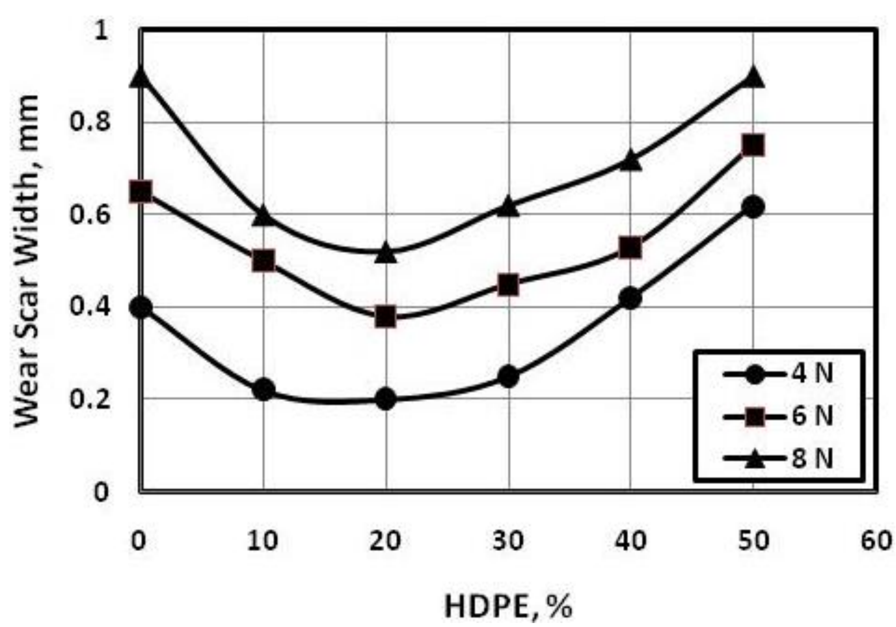

Fig. 11 Wear of epoxy filled by high density polyethylene.

Wear of epoxy filled by PP slightly decreased down to minimum at 10 - 20 wt. % PP, Fig. 14, then increased with increasing PP content. Those composites can be considered as good flooring materials due to their values of friction coefficient.

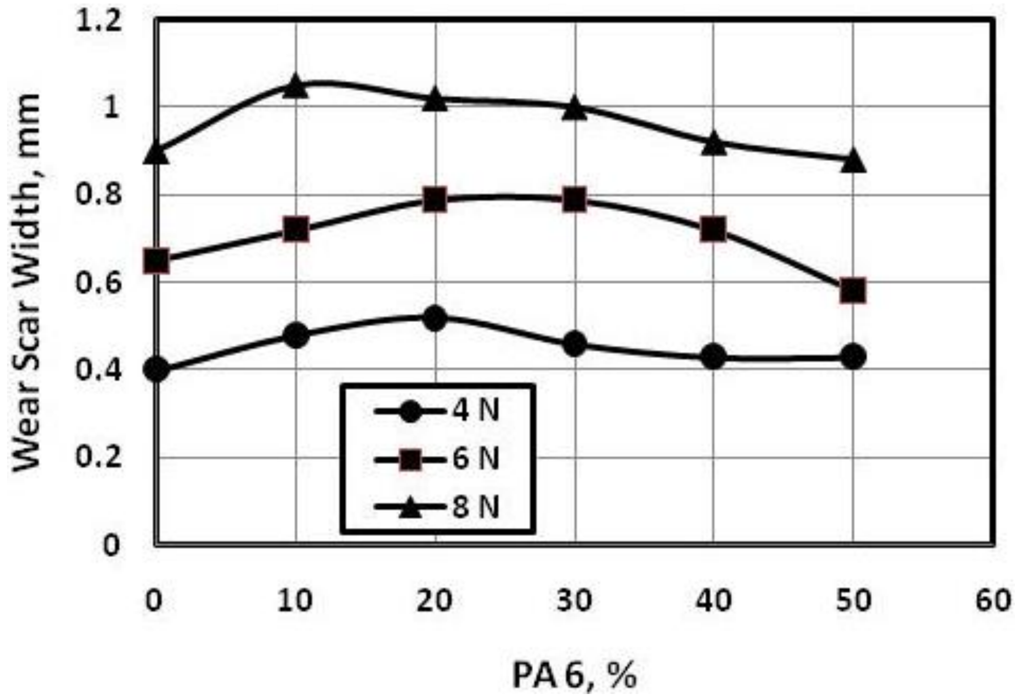

Fig. 12 Wear of epoxy filled by polyamide.

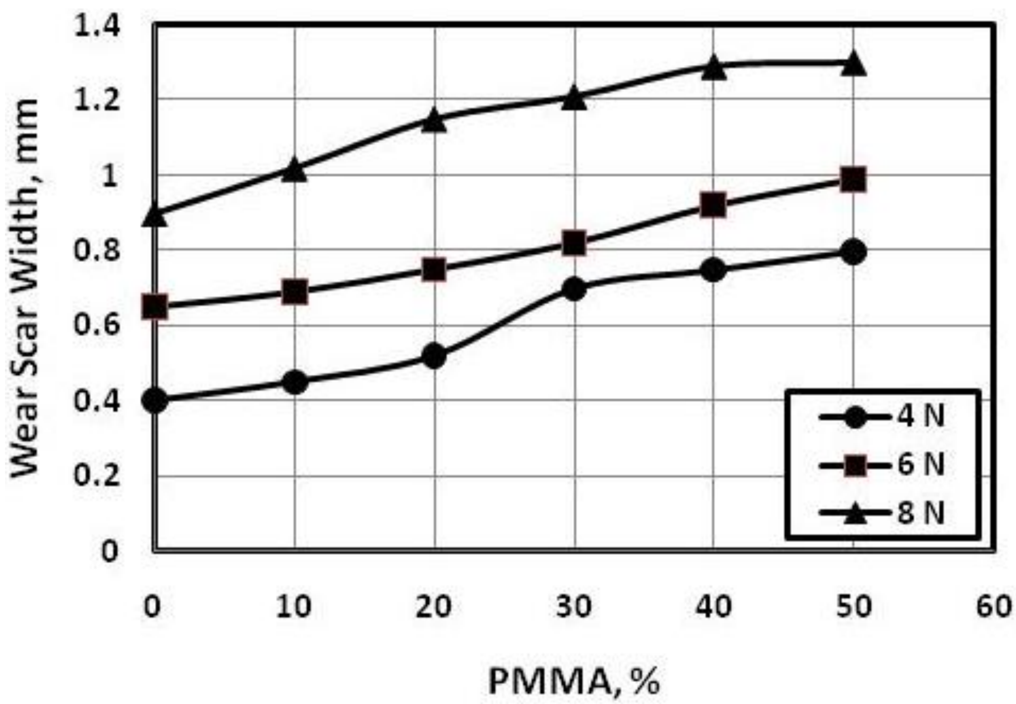

Fig. 13 Wear of epoxy filled by polymethyl methacrylate.

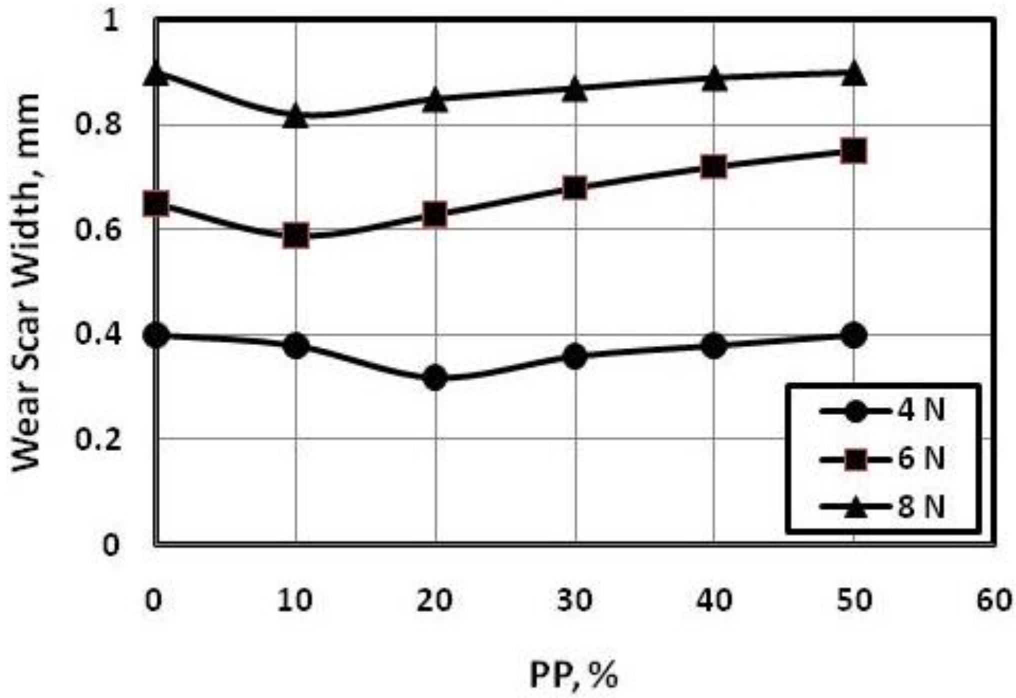

Fig. 14 Wear of epoxy filled by polypropylene.

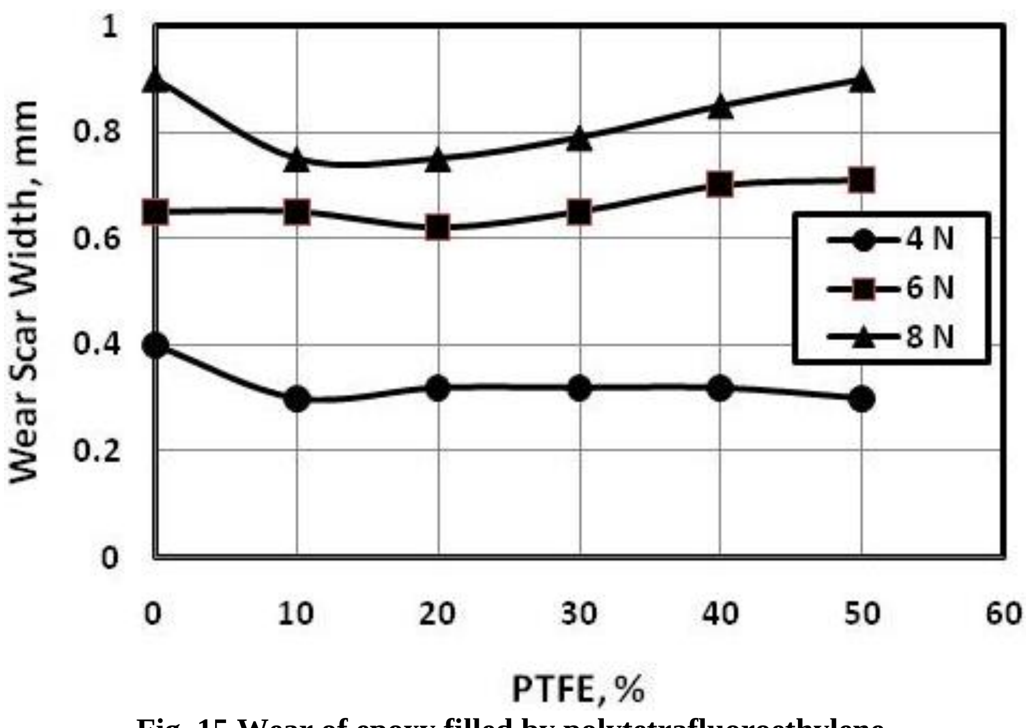

Fig. 15 Wear of epoxy filled by polytetrafluoroethylene.

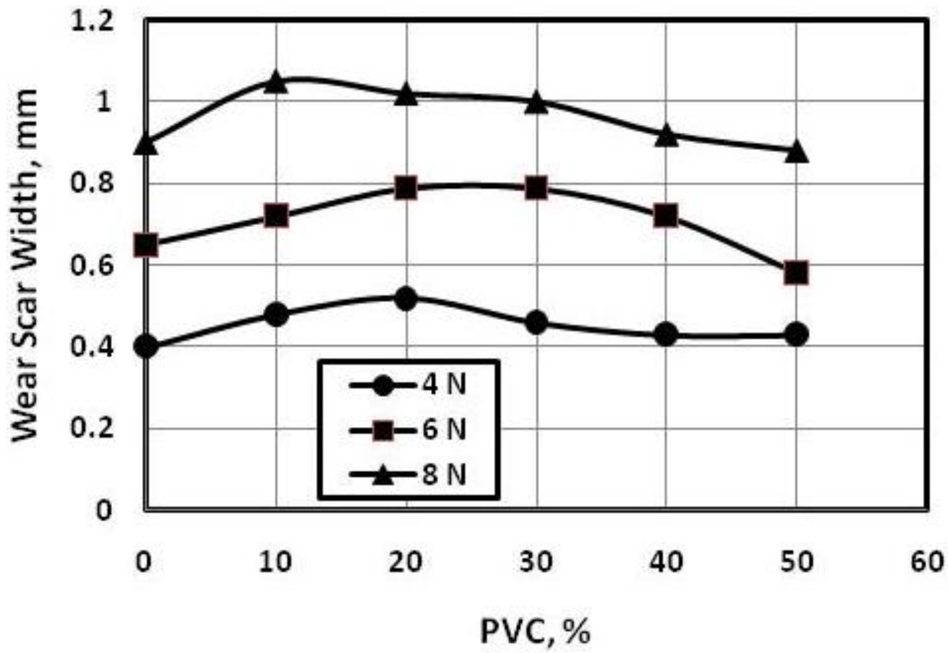

Fig. 16 Wear of epoxy filled by polyvinyl chloride.

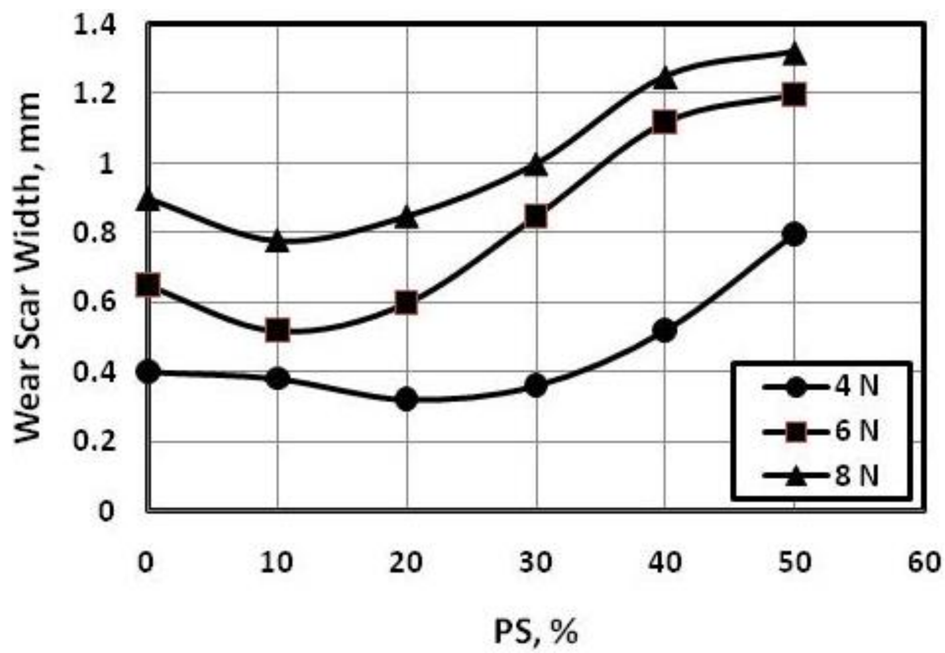

Fig. 17 Wear of epoxy filled by polystyrene.

The same trend observed for the wear behaviour of epoxy filled by PP was noticed for composites filled by PTFE, Fig. 15. Wear increased with increasing load. Epoxy composites filled by 50 wt. % PTFE showed an increased wear due to the easy material removal from the test specimens because of the weak adhesion of epoxy with PTFE.

Addition of PVC into epoxy matrix caused slight wear increase up to maximum then decreased with increasing PVC, Fig. 16. Maximum wear values were observed at 10 – 30

wt. % PVC. Generally, PVC did not improve neither the friction coefficient nor wear of the epoxy composites.

Wear of epoxy filled by PS decreased down to minimum then significantly increased with increasing PS content, Fig. 17. Minimum wear values were observed at 10 – 30 wt. % PS. Referring to the friction coefficient of the tested composites of 30 wt. % PS displayed relatively high values of 0.78, 0.64 and 0.6 at 400, 600 and 800 N respectively. Based on the experimental results those composites can be considered as promising flooring materials.

CONCLUSIONS

Based on the observation of the experiments carried out in the present it can be concluded 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. % HDPE, 50 wt. % PA 6, (10 – 30) wt. % PP, 10 wt. % PTFE, 50 wt. % PVC and (10 – 20) wt. %. Filling epoxy composites by PMMA caused significant wear increase so that the possibility of using these composites as flooring materials is limited, although those composites have an increasing trend of friction with increasing PMMA content. Besides, PMMA have the same good triboelectrification properties like their relatively low electric static charge generated from the friction against rubber.

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