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ABRASION RESISTANCE OF RECYCLED POLYMERIC COATING

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ABSTRACT

There is an increasing demand to reduce the abrasion of engineering surfaces caused by sand particles. The present work discusses the application of recycled polymers to coat the moving surfaces of bearings, gears and other machine elements to resist abrasion and pitting. The friction and abrasion resistance of the recycled polymers were investigated. The purpose of using recycled polymers is to reduce the pollution and clean the environment.

Friction and abrasive wear resistance of virgin and recycled as well as the mixtures of polymeric coatings such as low density polyethylene (LDPE), high density polyethylene (HDPE), polyvinyl chloride (PVC), and polypropylene (PP) were tested.

The test results showed that, friction coefficient displayed by virgin LDPE coatings was lower than that observed for recycled coatings. The virgin LDPE coatings displayed higher wear than the recycled ones. Friction coefficient of 100 % recycled HDPE coatings displayed the lowest friction. Wear resistance of coatings containing recycled polymer was much better than that observed for virgin HDPE. Besides, recycled PVC coatings showed the lowest friction values. Virgin PVC coatings experienced the lowest wear. Generally, the wear of PVC coatings was much lower than the other tested polymers. Friction coefficient displayed by recycled PP displayed lower values than virgin one, where the wear showed relatively higher values than that observed for the other tested polymers.

KEYWORDS

Recycled polymers, coatings, abrasion resistance, friction, wear, polyethylene, polypropylene, polyvinyl chloride.

INTRODUCTION

In recent decades, plastics have benefited manufacture. Plastics play a major role in enhancing fuel efficiency through mass reduction and aerodynamic improvement in automotive industry. Automotive plastics also improve safety, durability, and design freedom, while offering opportunities for parts consolidation and reduce manufacture cost. Plastics use increased from 86 kg per vehicle in 1980 to 102 kg in 1990, [1]. Polypropylene is one of the more easily recycled thermoplastics and among the lowest in cost. It is well known that polypropylenes are susceptible to heat and scratching and so have not been particularly successful in the U.S. A and Europe for car applications. But the Japanese have designed round weak points and companies in other countries should learn from the example, [2]. The recyclability now is considered as an additional design criterion, but not at the expense of performance or quality, and with cost, as always, a key issue. Recycling of polyurethane materials lowers the energy. Inclusion of 10 % recycled process scrap into the formulation results in a corresponding 10 % reduction in the energy requirements for the part The most prominent of these is the successful use of flexible foam scrap from slab and molded seat operations. This is adhered into carpet underlay. Other foam recycle applications include flexible foam for hydroponic gardening and rigid foam as an adsorbent of oil spills, [3]. The behaviour of pure and 80 % recycled UHMWPE was described in terms of friction coefficient - temperature and wear - temperature relations. From the viewpoint of thermal load ability it may well be advantageous to use the recycled product, [4].

Sorting and separation of the different types of polymers is very expensive process. The cheaper solution is to recycle polymeric materials as they are in a state of blend. It is possible to produce useful polymers by joining different mers. Blending is combining of two polymer molecules to form new copolymer with different characteristics, [5]. Polymer blends are considered an alternative method to improve friction and wear behavior and also extend the range of polymer applications. The mechanical properties of high density polyethylene (HDPE) were increased by adding polyamide (PA6) to it while keeping its good frictional and wear resistance characteristics, [6]. The addition of recycled polymers to fresh ones can improve wear resistance and reduce friction. The improvement in wear resistance was observed for polypropylene (PP) and high density polyethylene (HDPE) while low density polyethylene (LDPE) and polypropylene (PP) containing recycled polymers showed significant reduction in friction, [7]. Polymer blends had been considered to improve the mechanical and tribological properties through combining the best properties of the blended plastic materials. Polyurethane (PU) elastomers were blended physically with various ratios of polydisophenylsulphone terephthalamide (PSA) to form PU/PSA polyblends in order to modify their mechanical properties, [8]. At low content of PSA (below 10 wt. % PSA), PU/PSA polyblend showed improved stress relaxation properties.

The addition of thermoplastics into epoxy matrix decreased friction coefficient. Friction coefficient of epoxy blends containing (HDPE) and polytetrafluoroethylene (PTFE) decreased to a constant value. Epoxy blends of polymethylmethacrylate (PMMA) and polystyrene (PS) showed constant values of friction coefficient. Epoxy containing (PA6) and (PP) represented continuous decrease in friction coefficient, while epoxy with PVC blends displayed a reduction in friction coefficient followed by an increase with increasing (PVC) concentration in the blends, [9 - 11]. The improvement of wear resistance can be achieved by impregnating the polymer by oil. Experiments on both of oil filled polyamide and polyacetal have been made, [12]. The wear rate for low density polyethylene with 10 wt. % silicone fluid was lower than that measured for the polyamides, [13]. The friction and wear properties for series of blends of polyether ether ketone (PEEK) and polyether imide (PEI) were determined. The wear rates increased as the amount of (PEI) in the blends increased. It was observed that the microhardness of polymeric surfaces decreased as cooling rate increased, [14]. This behaviour was found when the microhardness of polyamide coatings was measured to investigate the effect of the metallic reinforcement on the cooling rate during preparation.

The physical and mechanical properties of polyamides are considerably affected by the degree of crystallization, which can be controlled by the change of cooling rate during the production process. Presence of small particles such as fine silica dust in polyamide matrix can alter the nucleation and cause significant increase in tensile strength and hardness accompanied by reduction in the ductility and impact strength. It is essential to consider the variation of the morphology of the cast polymer because of the differences in the cooling rate from the surface to the centre, where the outer surface will be less crystalline due to the rapid solidification rate and may be less resistant to wear, [15, 16]. Recently, it was concluded that blending PMMA with PE produced new composites of favourable wear and friction characteristics, [17].

The mechanical and tribological properties of four types of used polymeric materials collected from different sources were investigated, [18]. The results showed that the reduction of maximum compressive strength observed for recycled polymers was ranging from 32 – 40 % compared to the fresh polymer. In order to improve the maximum compressive strength and decrease the difference between fresh and recycled polymers to 12 % the recycled polymers should be heated up to 100 ºC followed by sudden cooling in water. It was observed that recycled polymers displayed an increase in friction coefficient and wear rate of 12 and 13 % respectively. Besides, quenching of recycled polymers in water caused significant reduction in friction and wear.

In a recent research, [19], 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. The previous conclusion has confirmed that recycled polymers can be used in different applications due to the quite good mechanical and tribological properties, where the addition of the recycled polymers into epoxy showed significant decrease in both of modulus of elasticity and compressive strength, where minimum values were observed for composites containing 30 wt. % of recycled polymers.

Recently, It was concluded that the thermal properties of the metallic powders play major role in controlling the mechanical as well as tribological properties more than the amount of the content. Friction coefficient and wear of the tested polyethylene composites increased with increasing the thermal conductivity of the metallic powders, [20]. Also, it was found that the amount of plastic deformation increased with increasing the thermal expansion of the metallic powders. Friction and wear of filled polyethylene composites were much influenced by the addition of low content of metallic powders through affecting the degree of crystallization, which can be controlled by altering the cooling rate during production technique. Thermal properties of the metallic powders play major role in controlling the mechanical as well as tribological properties more than the amount of the metallic content. Friction coefficient and wear of the tested polyethylene composites increased with increasing the thermal conductivity of the metallic powders. In addition to that the amount of plastic deformation increased with increasing the thermal expansion of the metallic powders.

In order to reduce the effect of the polymeric wastes, in particular discarded PET bottles and automobile tires, on polluting the environment, it is necessary to recycle and reuse in designing economical buildings, [21 - 26]. Rubber tires have been used in a variety of rubber and plastic products, burning for production of electricity, or as fuel for cement kilns, as modifiers in asphalt concrete. Products made from recycled PET bottles include carpeting, concrete, insulation and automobile parts. Recycled PET bottles are also used in drainage filtration systems, asphalt concrete-mixes and road stabilizations.

In this work, the abrasion resistance of LOPE, HDPE, PVC and PP coatings containing different concentrations of recycled polymers has been tested.

EXPERIMENTAL

Polymeric coatings have been prepared from low density polyethylene (LDPE), high density polyethylene (HDPE), polyvinyl chloride (PVC) and polypropylene (PP). These four types are representing the most widely used polymers, [27]. The recycled polymer was mixed with every tested polymer. The concentration of the recycled polymer in the pure one was 0, 25, 50, 75 and 100 %. The thickness of coatings was controlled to be 1.0 + 0.1 mm. The coatings were deposited on the surface of steel substrate of 0.8 mm thickness. The abrasion test has been carried out using an abrasion wear tester. The details of the test rig and the insert are shown in Fig. 1. It consists of a turntable driven by a variable speed motor via a belt drive.

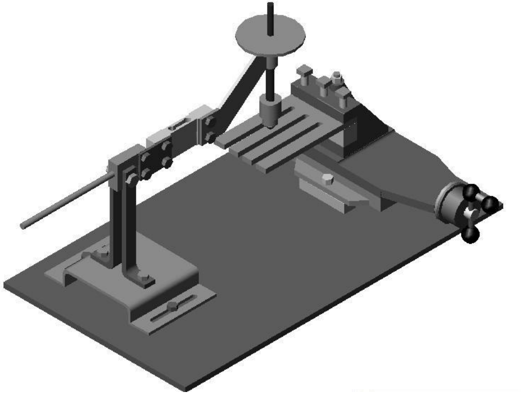

Fig. 1 Arrangement of the test rig.

The test speed was 2.0 mm/s. Square carbide insert was used to abrade the polymeric coatings. The insert was mounted in a holder supported to the loading lever through spring steel sheet. The load was applied by weights. Strain gauges fixed to the spring steel sheet were used to measure the tangential force. The ratio of the tangential force to the normal force applied by weights will be considered as the friction coefficient. The weight loss was measured after the experiment using an electrical balance of + 0.1 mg accuracy.

RESULTS AND DISCUSSION

Friction coefficient and wear of the tested polymeric coatings are represented in Figs. 2-9. The 100 % content means that the coating contains no recycled polymer, it will be mentioned in this work as pure polymer, while the 0 % concentration represents coating prepared completely from recycled polymer. Generally, the friction coefficient increased with increasing the load and decreased after reaching a maximum. The rise of friction is attributed to the increase in the contact area due to the load increase. The decrease in friction after the maximum is due to the excessive heat generated during sliding at loads higher than a critical value. As a result of heat generation, a polymeric layer of low shear strength will form at the interface and provide low values of friction, [28]. This behaviour is shown for low density polyethylene coatings, Fig. 2, while the friction coefficient resulted from recycled coating increased with load. This behaviour observed for recycled polymers indicated the loss of the elastic property and crystalline structure. It seems that solid contaminants in the recycled polymers are responsible for the change in the frictional behaviour. Polymers are significantly influenced by the rate of cooling after molding. Foreign particles would alter the rate of cooling as well as the crystallinity of the polymers. The relative high values of friction coefficient observed for virgin polymers might attributed to the adherence of polymer into the cutting edge of the insert.

Wear of the tested polymers increased with increasing load. The virgin coatings displayed higher wear than the recycled ones. It seems that the contaminants in recycled polymer decreases the plasticity of LDPE, Fig. 3. This performance could be explained on the basis that virgin polymer was more plastic than the recycled one, so that the LDPE removed from the groove of the wear track was higher for virgin LDPE. As a result of that, recycled LDPE can be used in such application where abrasive wear prevails. At 30 N load recycled LDPE displayed half the value of the wear observed for virgin LDPE.

The wear resistance of coatings containing recycled polymer is much better than that observed for virgin HDPE, Fig. 5. The improvement in wear resistance can be attributed to the influence of solid contaminants in the recycled polymer matrix on the degree of crystallization. It is well known that the physical and mechanical properties of polymers are affected by the degree of crystallization, which can be controlled by the production process. The presence of small spherulites, resulted from contaminated fine particles, causes an increase in the tensile strength; hardness and abrasion resistance accompanied by reduction in the ductility and impact strength.

The friction coefficient displayed by recycled PVC coatings increased up to maximum then decreased with increasing applied load, while virgin PVC coatings showed an increasing trend, Fig. 6. The lowest friction value (0.5) was observed for 100 % recycled PVC at 30 N load, while the lowest value displayed by Virgin PVC coatings was 0.8. It can be seen that the influence of both contaminants and previous forming and production process was to increase the plasticity of the recycled PVC.

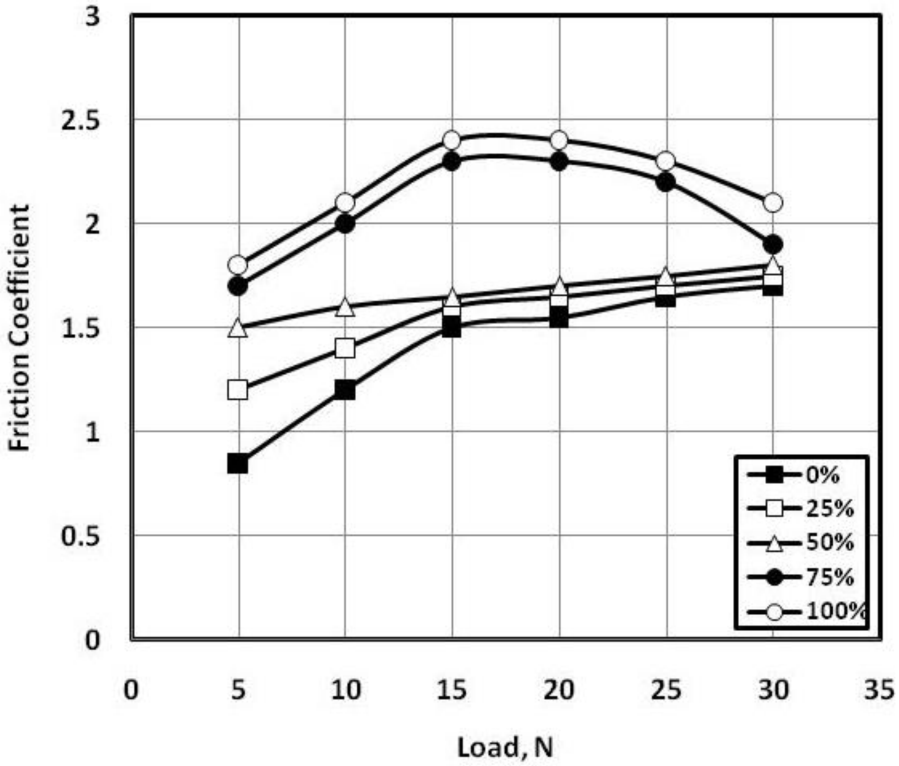

Fig. 2 Friction coefficient of virgin and recycled LDPE.

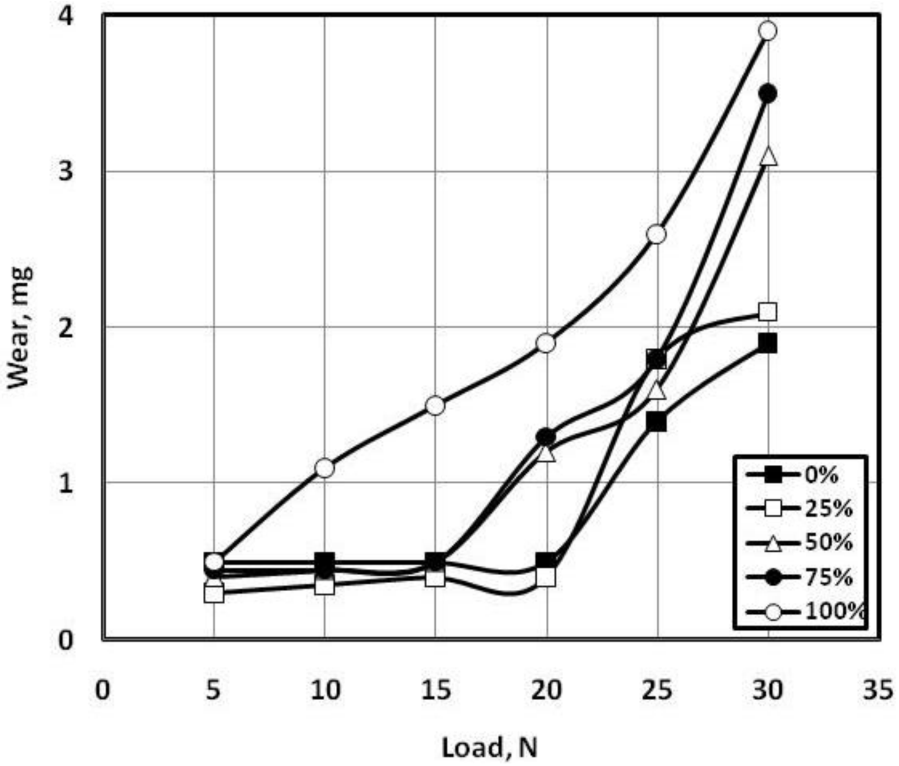

Fig. 3 Wear of virgin and recycled LDPE.

The friction coefficient of virgin HDPE increased as the load increased to 20 N. Further load increase showed consistent trend, Fig. 4. Generally, HDPE showed lower friction coefficient than LDPE due to the relatively higher strength compared to LDPE. 100 % recycled coatings still displayed the lowest friction.

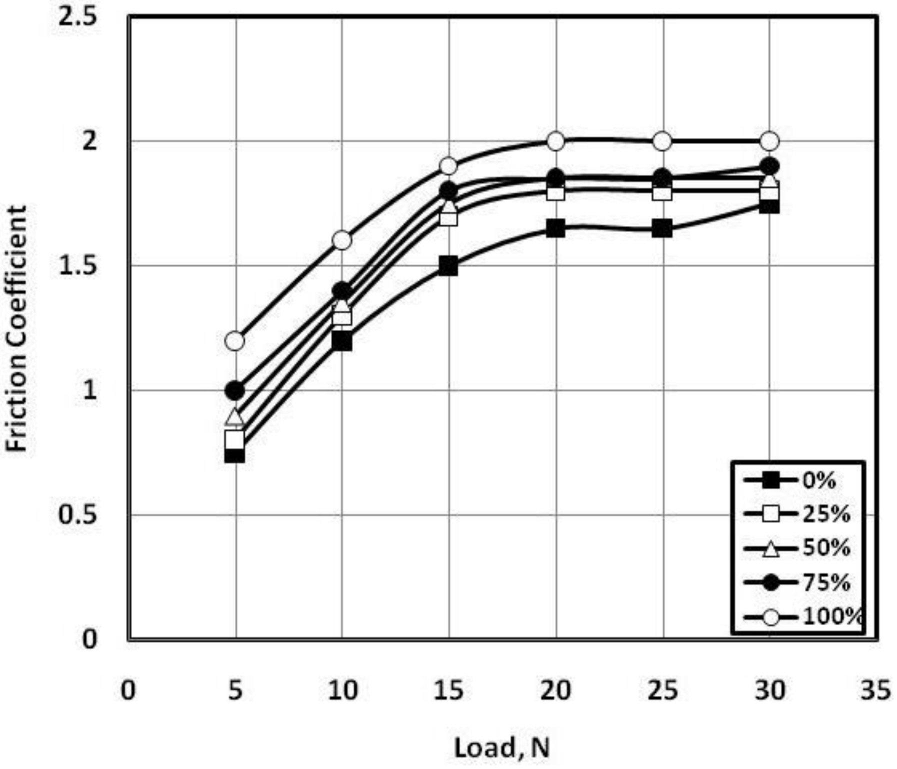

Fig. 4 Friction coefficient of virgin and recycled HDPE.

Wear of PVC coatings is shown in Fig. 7, where virgin PVC coatings experienced the lowest wear for load value of 30 N. Generally, The wear of PVC coating is much lower than the other tested polymers. This can be from the relative higher plasticity of PVC where the majority of the cutting energy would be consumed in plastic deformation.

Friction coefficient displayed by recycled PP displayed the lowest values, Fig. 8, while virgin PP showed the highest values. Generally, friction valued displayed by PP were much lower than the other tested polymers. Wear of PP showed relatively higher values than the tested polymers, Fig. 9. Recycled PP represented the lowest values at 30 N load.

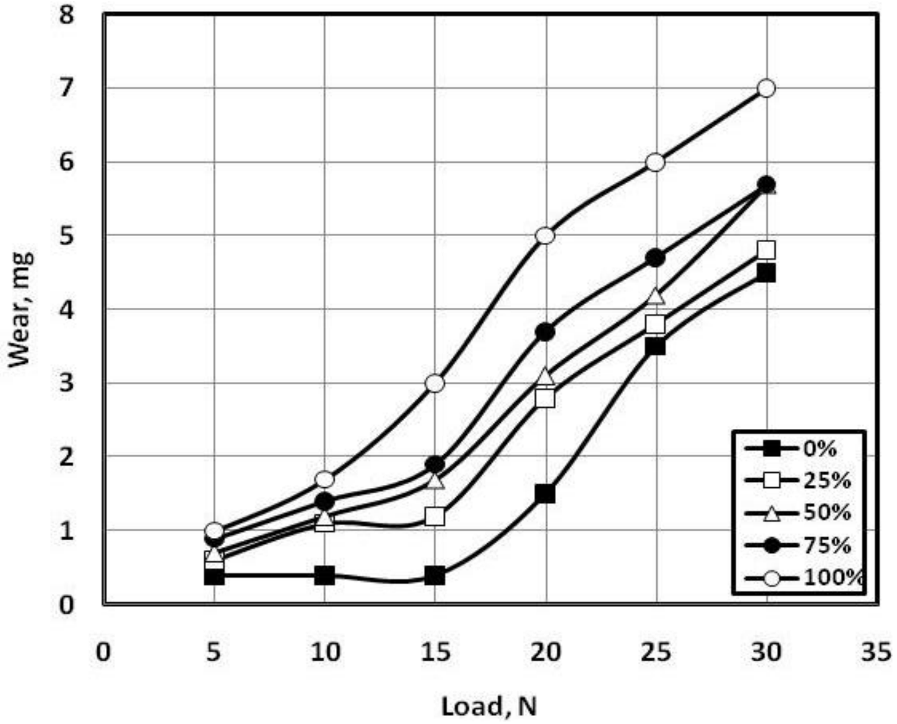

Fig. 5 Wear of virgin and recycled HDPE.

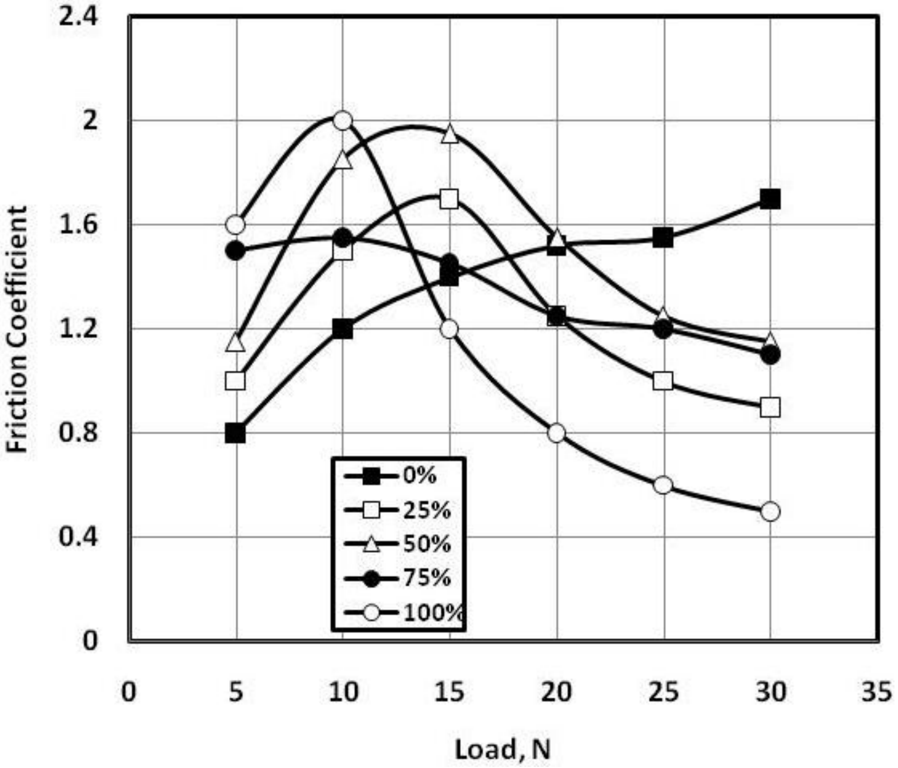

Fig. 6 Friction coefficient of virgin and recycled PVC.

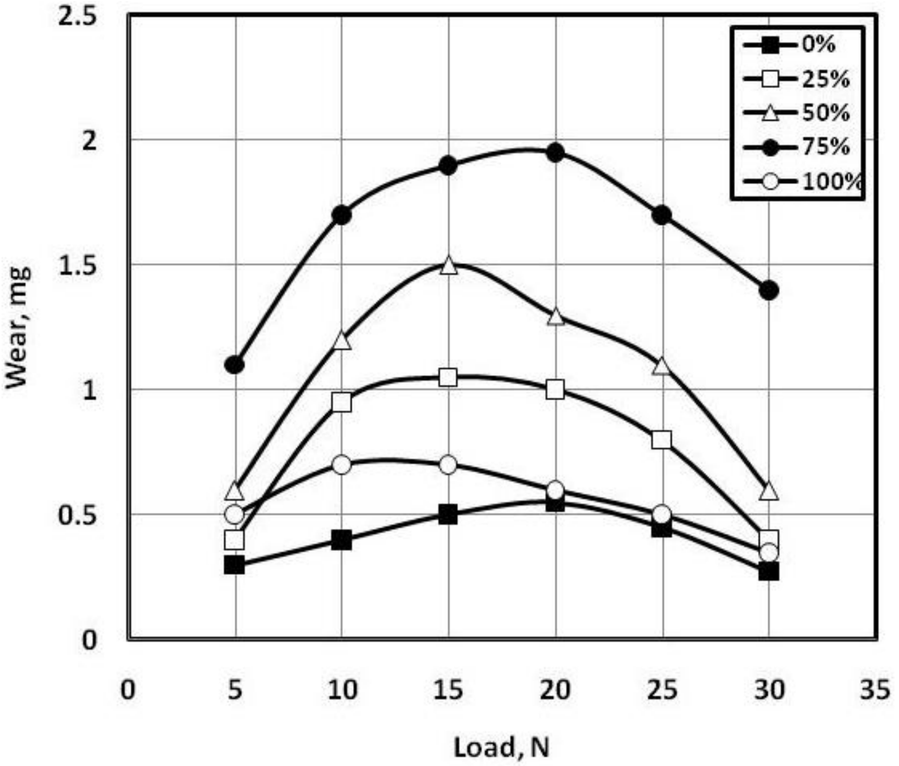

Fig. 7 Wear of virgin and recycled PVC.

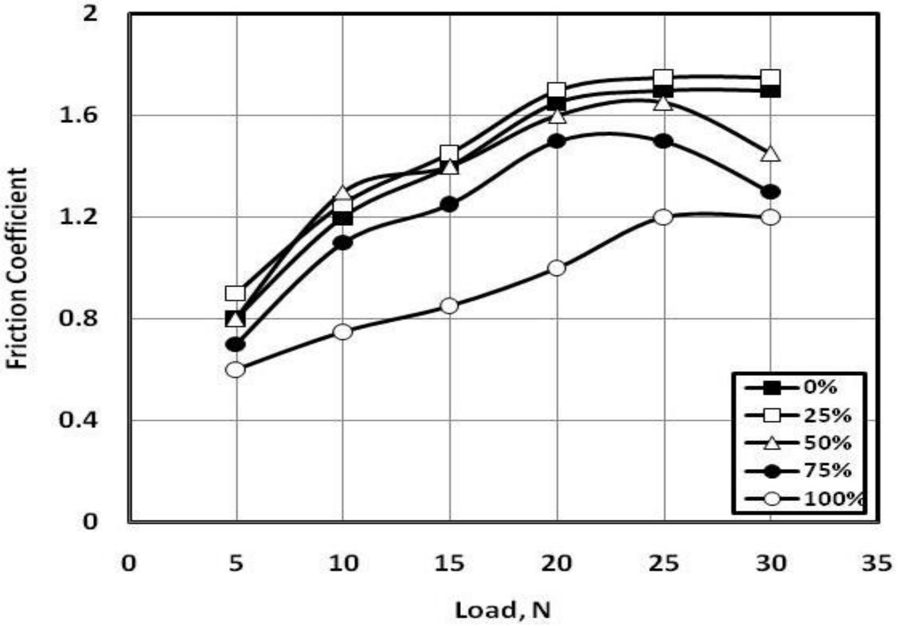

Fig. 8 Friction coefficient of virgin and recycled PP.

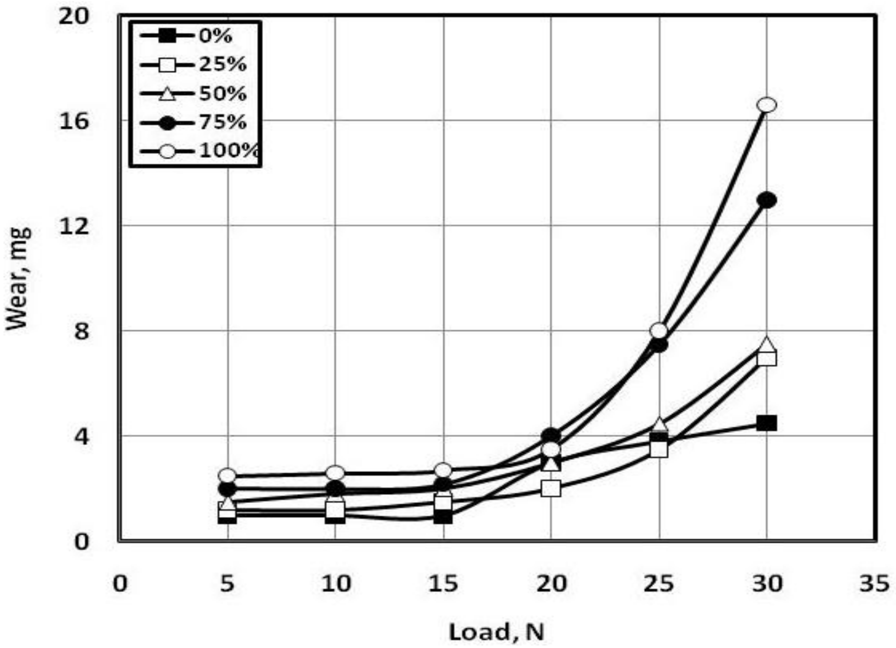

Fig. 9 Wear of virgin and recycled PP.

CONCLUSIONS

1. Friction coefficient, displayed by virgin LDPE coatings, increased up to maximum then decreased with increasing the load, while the friction coefficient caused by recycled coatings increased with load as a result of the loss of the elastic property and crystalline structure. The virgin LDPE coatings displayed higher wear than the recycled ones.
2. Friction coefficient of virgin HDPE increased as the load increased to 20 N. Further load increase showed consistent trend, while 100 % recycled coatings displayed the lowest friction. Wear resistance of coatings containing recycled polymer is much better than that observed for virgin HDPE.
3. Recycled PVC coatings showed the lowest friction values. Virgin PVC coatings experienced the lowest wear. Generally, the wear of PVC coatings was much lower than the other tested polymers.
4. Friction coefficient displayed by recycled PP showed lower values than virgin PP. Wear of PP showed relatively higher values than that observed for the other tested polymers. Recycled PP represented lower wear than the virgin one.

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