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WEAR OF HIGH DENSITY POLYETHYLENE REINFORCED BY SINGLE WALL CARBON NANOTUBES AND ALUMINIUM OXIDE NANOPARTICLES FOR BEARING MATERIALS APPLICATIONS

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ABSTRACT

Bearing materials must withstand the extremely hard operations affairs through unique tribological and mechanical properties. Various types of polymers exhibit acceptable solutions as bearing materials because of their high weight ratio and self-lubrication materials. In the current work, tribological properties of bearing material high-density polyethylene (HDPE) reinforced by 0.1 aluminium oxide (Al_2O_3) nanoparticles and 0.1– 0.5 wt. % single wall carbon nanotubes (SWCNTs) were investigated in order to enhance the tribological and mechanical properties The Nano-composite specimens were prepared in cylindrical shape and they were subjected to friction and wear tests using pin on disc tribometer. The specimens were tested as counterparts and the disk was made from stainless steel. Wear tests were done each exactly 120 sec., and the weight losses calculated by weighing the specimens before and after the test. It is noticed that the HDPE nano-composite specimen with additives of SWCNTs 0.5 wt. % gives the specific optimum tribological properties and the coefficient of friction was reduced by 30% in comparing with pure HDPE material.

KEYWORDS

High-density polyethylene (HDPE), SWCNTs, Al_2O_3 nanoparticles.

INTRODUCTION

Nowadays, an increasing interest in nanocomposites applications especially that were used as frictional materials products and that field attention has been increased in recent years. Bearing materials must withstand operations difficult substances with presence of absence of lubrication thus the polymers are considered one of the most widely bearings materials applications. High density polyethylene (HDPE) exhibits

outstanding unique properties such as high wear resistance, good density, stiff plastic with a highly crystalline structure, and good abrasion resistance, [1 – 4]. To improve the tribological and mechanical properties, nanofillers different materials are being supported of composite materials. Graphene is one of the significant filler materials in HDPE matrix, because of its ability in enhancing the thermal, mechanical and tribological properties, [5 – 8]. The polyolefin-functionalized graphene oxide shows homogeneous dispersion in HDPE matrix, therefore the enhancement of the stress and strain at break point reach up to 28.7% and 130% respectively with only 0.2%wt functionalized graphene oxide content, [9 – 12]. However, 0.8% wt. of molybdenum disulfide MoS_2 added to HDPE/graphene oxide composite caused a positive response of the friction behavior and wear resistant, [13, 14]. In order to support the composite stern bearing materials, the synthesized MoS_2-containing micro-capsules were added to a HDPE matrix, [15, 16]. Adding HDPE coating with 10% wt. $CaCO_3$ content rises the melting point and enhance the thermal property, [17, 18]. Whereas HDPE composite material containing bi-directional silk fiber with nano clay, 0.5 and 1.0 wt. %, are experimentally investigated and it is found that the wear resistance was enhanced with a positive trend because of adding nano-clay to HDPE/silk fiber composites, [19, 20].

Ultra high molecular weight polyethylene (UHMWPE) was reinforced with pretreated and untreated carbon nanofibers CNFs and prepared by technique of a twin screw extrusion. However, UHMWPE/HDPE composite filled with pretreated CNFs caused a reducing in crystallinity degree beside enhancing in the tensile strength when it was compared to the specimens that reinforced by untreated CNFs content, [21 – 24]. Treated Carbon nanotube CNTs with contents HCl and H_2SO_4/HNO_3 were used as a filler material. Mechanical properties of the polymeric matrix were enhanced by means of reinforcing by CNTs, [25]. UHMWPE/HDPE composites were reinforced with 0.2 to 2.0 wt. % multi-wall carbon nanotubes MWCNTs filler content and that reduced wear rate due to the presence of MWCNTs, [26 – 29]. HDPE/TiO_2 nanocomposites were fabricated through injection molding under process parameters of the barrel temperature and the residence time. The degradation temperature decreased with an increase in the injection parameters, however, the rate of crystallization exhibited a rise to 75 %, [30 – 33].

Furthermore, the aluminum nanoparticles Al_2O_3 are used as a filler material for different polymers, which can be alone or as a hybrid with other additives. Polymer mortars PMs enhanced mechanical characteristics are improved through polymer reinforced by Al_2O_3 and ZrO_2 nanoparticles, [34 – 36]. Influence of size and content of Al_2O_3 filler on the thermal conductivity, impact strength and tensile strength was investigated. HDPE composite filled with 25% wt. Al_2O_3 content with filler size of 0.5 µm has best properties, [37 , 38]. Al_2O_3 particles and hydroxyapatite (HA) were added to HDPE to enhance physical properties of biopolymers, elastic modulus, and hardness. HDPE composites with filler up to 40% wt. were fabricated under the optimal compression molding conditions, and the friction and wear resistance were improved at fretting surfaces, [39].

The current work focuses on enhancement of the tribological (Friction and wear rate) and mechanical properties (hardness and material strength) of high-density polyethylene (HDPE) reinforced by 0.1– 0.5 wt. % SWCNTs.

EXPERIMENTAL

In this experimental study the friction and wear rate were used to analyze the tribological behavior of HDPE/SWCNTs nanocomposites. Furthermore, to verify the best filler amount, the specimens with different filler content of 0.1, 0.2, 0.3, 0.4, and 0.5 wt. % were prepared.

HDPE matrix is a white powder color, particle size of 50 to 105 µm, density of 0.94 gm/cm^3 and was purchased from Sigma Aldrich Co. Single walled carbon nanotubes SWCNTs were used to be reinforced into high density polyethylene (HDPE) matrix. HDPE composites were formed as cylindrical samples.

Aluminum oxide nanoparticles and SWCNTs were supplied by US Research Nanoparticles, Inc. SWCNTs has specifications were listed as the following: black color, purity 90%, 1-2 nm outer diameter, 0.8-1.6 nm inside diameter, length of 5-30 µm, specific surface area of 380 m^2/g, tap density of 0.14 gm/cm3 and true density of 2.1 gm/cm^3. Al_2O_3 nanoparticles (80% alpha - 20% gamma), of purity 99.9%, particles size of 40-50 nm, specific surface area of 35 m^2/g, nearly spherical morphology, bulk density of 0.18 g/ml and true density of 3890 kg/m^3 were used.

Specimens are prepared from a dry powder of HDPE, Al_2O_3 Nanoparticles and SWCNTs were mixed in a glass container for 90 sec. using a rotating mixer at about 300 rpm from 5 to 10 min., to achieve a homogenous and complete dispersion. The mixture powder was exposed to 15 MPa into cylindrical copper mold of 10 mm in diameter. Then the mixture with mold was heated into furnace up to 200°C, for 40 minutes duration and 25 MPa pressure. The specimens were separated out and left to cool at room temperature. Specimens loading content of hybrid nanofillers of Al_2O_3 nanoparticles and were displayed in Table 1.

The specimens were fastened within its holder in which the axe of the specimen is perpendicular on the stainless-steel disc level. The counter-face disc used was a stainless-steel alloy plate with 7 mm thickness and 150 mm diameter. Surface roughness tester was used to precisely gauge accurate roughness of the stainless-steel plate (Surface roughness of Ra = 0.023 µm, Rq = 0.029 µm, and Rz = 0.179 µm). The disc was cleaned before the initiation of the experiment. The friction force can be measured through a load cell, as strain gauges are found. Figure 1 shows the tribometer device set up.

Experiments were conducted under dry conditions. 31.4, 47.1, 62.8, 94.2 and 125.6 m/s sliding velocities were utilized under normal load of 2, 4, 6, 8 and 10 N. Wear tests were done, each exactly 120sec. The final and initial weights of specimens are measured with the help of an electronic balance with an accuracy of 0.0001 g. to determine the weight loss.

Table 1. Various samples compositions of HDPE/Hybrid nanocomposites.

Sample No	HDPE	Al_2O_3 Nanoparticles	SWCNTs
Sample O	100%	-	-
Sample A	99.8%	0.1%	0.1%
Sample B	99.7%	0.1%	0.2%
Sample C	99.6%	0.1%	0.3%
Sample D	99.5%	0.1%	0.4%
Sample E	99.4%	0.1%	0.5%

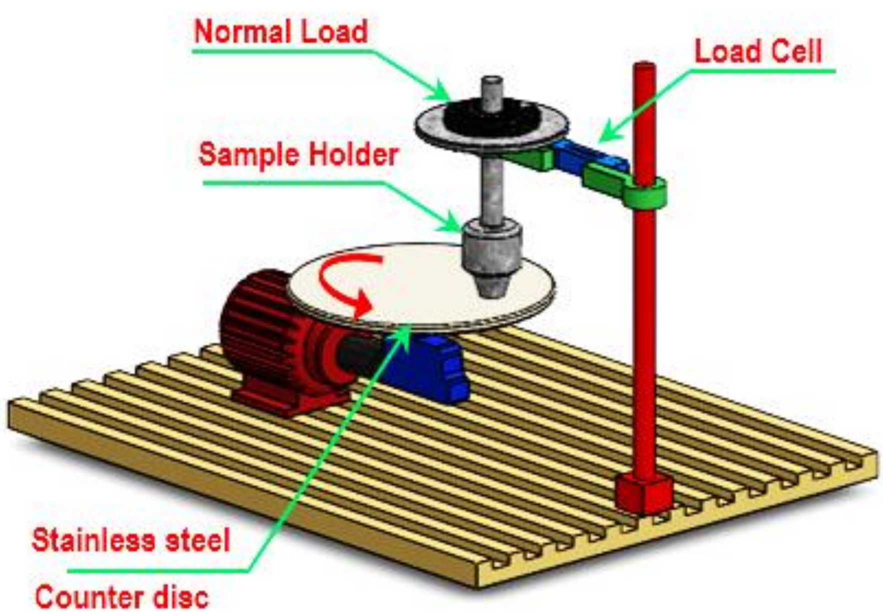

Figure 1 Schematic diagram of tribometer.

RESULTS AND DISCUSSION

Figures 2 shows the relationship between the coefficient of friction (COF) and normal load. It is demonstrated that the relation trend is proportional, when normal load is increased for all samples, the coefficient of friction is increased of each one. That is logic because increasing normal load causes more penetration hence more resistance and friction were produced. It is noteworthy that the increasing of SWCNTs wt. % contents to 0.5 wt. % showed lower specific coefficient of friction and 30% nearby reduction in the COF with higher additives 0.5wt.% SWNCTS in comparing with the other lower wt. % contents. The higher percentage 0.5 wt. % exhibits higher volume percentage thus higher contact area is offered for the SWCNTs, and that high percentage acts as self-lubrication in the composite material. SWCNTs with homogenous dispersion and good tribological properties are the main factor in decreasing the COF of the composite material.

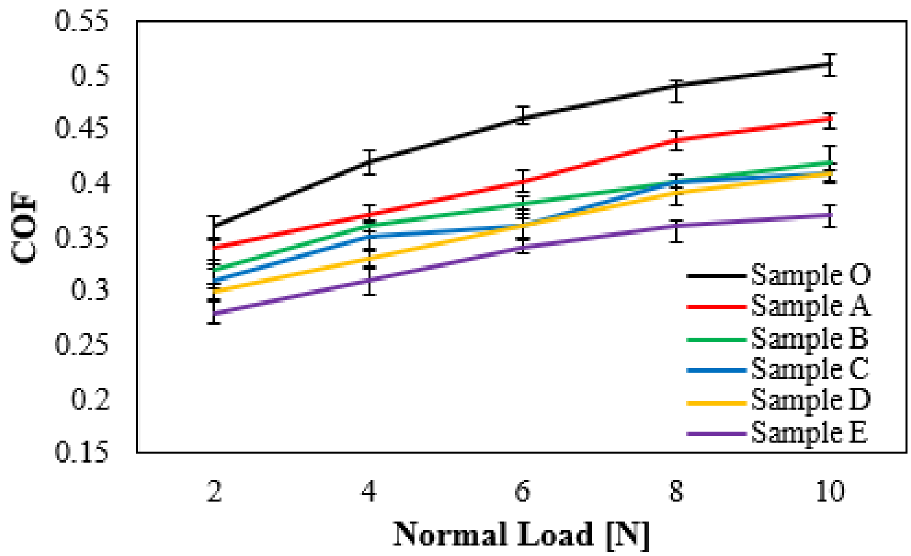

Fig. 2 Friction coefficient HDPE/SWCNTs specimens.

Figure 3 shows the relation between the wear rate and sliding distance for all samples. With increasing sliding distance, the wear resistance of each sample was decreased. It is concluded that the adding of 0.5 wt. % of filler amount of SWCNTs is the main reason wear rate reduction with about 30 %. The samples with no additives were exposed to high temperature due to friction then the temperature decrease the elastic modulus. Deeper indentation of steel stylus into HDPE increases the real contact area between them. More HDPE deformation produces higher COF and hence higher wear rate. As monitoring in the Fig. 5, increasing additives till 0.5 wt. % increases the trend of tensile strength and elastic modulus thus that tend to decrease the wear rate because of the softer material has low shear strength making the sliding between the HDPE and the counterpart surfaces easier.

It is monitored that adding SWCNTs at dry contact, 0.5 wt. % additives percentage viewed maximum improvement HDPE base material in tribological properties. While the wear resistance of HDPE/ SWCNTs specimens tested against stainless steel disc, was significantly improved with adding SWCNTs nanoparticles weight percentages.

The wear rate was reduced with the adding of SWCNTs nanoparticles. The adding of SWCNTs 0.5 wt. % into specimen exhibited an improvement in wear as shown in Figures 2 and 3. The friction coefficient and wear rate values decreased with increasing filler contents (0.1, 0.2, 0.3, 0.4 and 0.5 wt. % of SWCNTs) compared to pure HDPE.

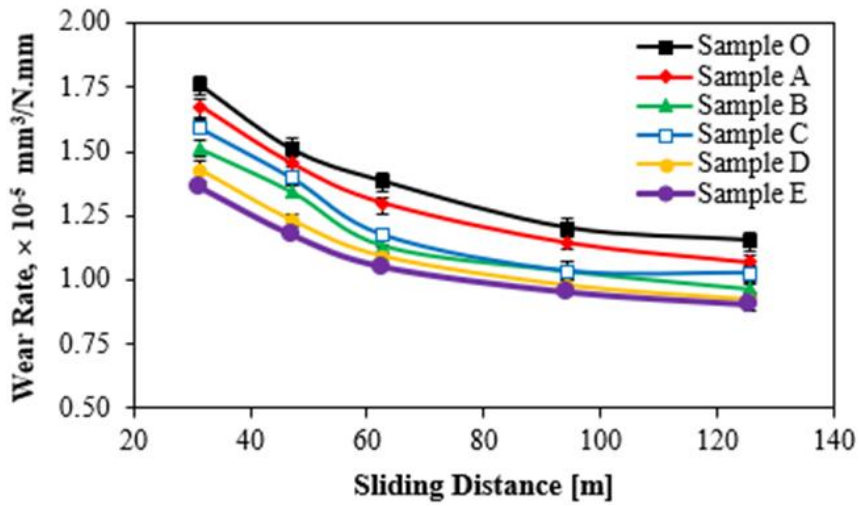

Fig. 3 Wear rate HDPE/ SWCNTs specimens.

Figure 4 showed optical images of samples surfaces in shape of 2D and 3D worn scans. The very fine SWCNTs particles embedded in a continuous matrix of a polymer composite reduces the pores. Consequently, the dispersion of SWCNTs content through the HDPE matrix is a key factor in the surface roughness smooth and in the effectiveness of the wear resistance ability. The comparison of the effect of the SWCNTs nanoparticles amounts on the tribological characteristics, with respect to the characteristics of the reference specimen (HDPE base material).

Figure 5 showed the stress strain curve of samples with pure and different percentages of SCWNTs percentages. Figure 6 displays the hardness and tensile strength of specimens. Tensile strength was evaluated from the stress strain curve. The increasing of SWCNTs percentages enhance the tensile strength and hardness along with filler amount. Sample with 0.5 wt. % amount of SWCNTs showed the maximum improvement of the hardness 79 (D index) with nearly 18.5 % enhancement from the pure HDPE. It is significant that the SWCNTs play a vital role in enhancing the mechanical properties of HDPE. The presence of filler composition in the matrix microstructure embeds the dislocation movement during loading that improves the mechanical properties.

Finally, HDPE / 0.5 wt. %SWCNTs specimen can be recommended especially in bearing material applications for better field performance because of its lower wear loss and low friction compared to pure HDPE.

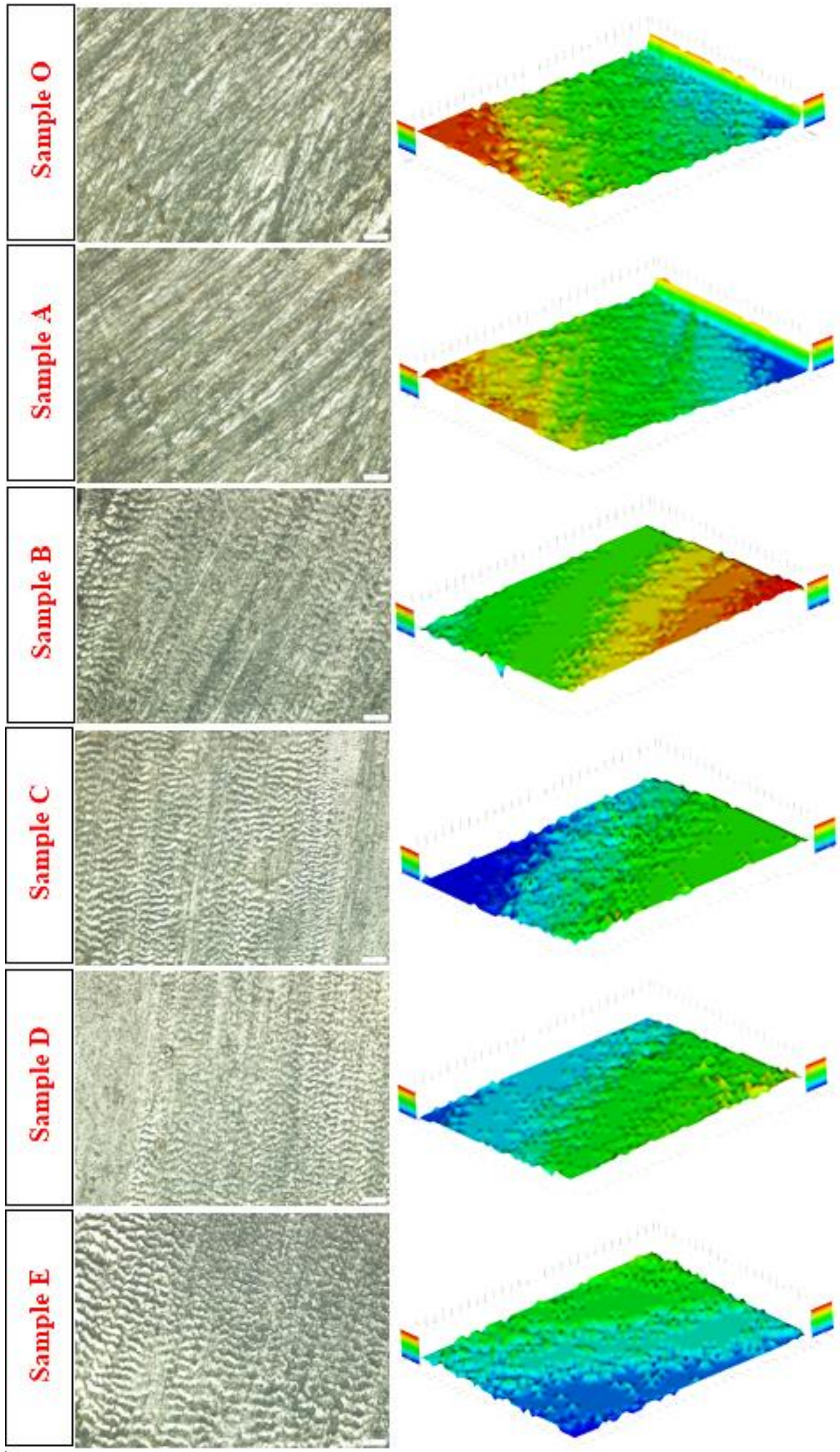

Fig. 4 Optical images 2D and 3D scan of worn surfaces of HDPE nanocomposites.

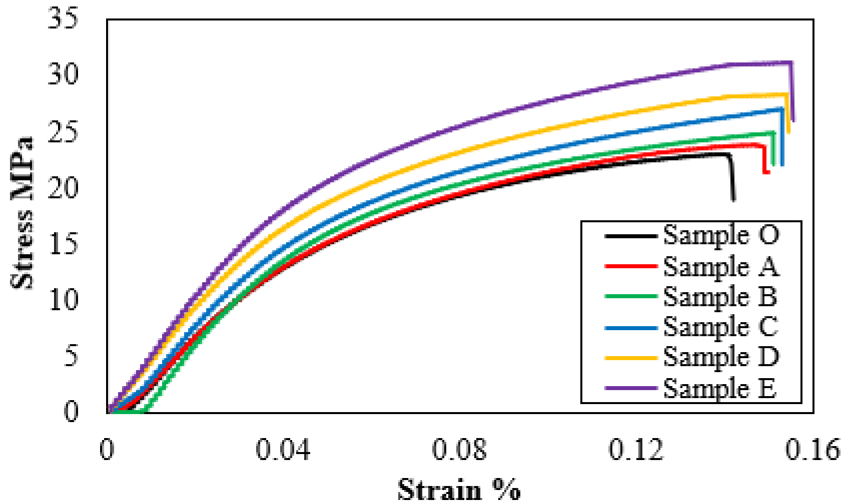

Fig. 5 Stress-strain curve of HDPE nanocomposite samples.

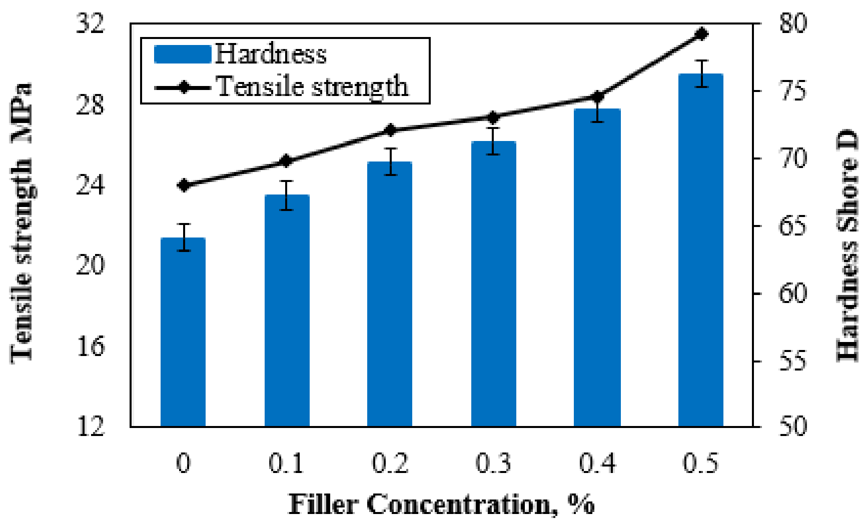

Fig. 6 Tensile strength and hardness Shore D of HDPE nanocomposite samples.

CONCLUSIONS

The current work focuses on improving the tribological properties of high-density polyethylene (HDPE) reinforced by 0.1 Al_2O_3 Nanoparticles and 0.1 – 0.5 wt. % SWCNTs. The friction and wear test were achieved using tribometer beside the mechanical properties were investigated. As a result of the use of Al_2O_3, and SWCNTs as a reinforced material, HDPE nanocomposites have shown the ability to improve the tribological properties compared to pure HDPE. Clearly, the following conclusions can be made:

- **Hybrid SWCNTs and Al_2O_3 nanoparticles have shown the ability to improve the friction and wear resistance characteristics of HDPE without a layer of lubricant with 30% nearby enhancing percentage.**

- **HDPE nano-composite reinforced with 0.5 wt. % of SWCNTs was caused a decreasing in friction coefficient reached up 52 % compared to conventional pure HDPE.**
- **HDPE/ 0.5 wt. % of SWCNTs composites exhibited bring down in wear rate up to 65.4 %.**

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