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Study the Tribology Characteristics of HDPE Reinforced by Al_2O_3 and CNTs

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Abstract
The current work focuses on design pin-on-disc tribometer using stepper motors and linear actuator to achieve better accuracy of results. also focuses on improving the tribological properties of high-density polyethylene (HDPE) reinforced by 0.1– 0.5 wt. % of Al_2O_3, 0.1– 0.5 wt% SWCNTs and 0.1– 0.5 wt% MWCNTs nanoparticles. The nano-composite specimens were prepared to the cylindrical shape and subjected to friction and wear tests using pin on disc tribometer. The specimens were tested as counterpart and the disk which 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 very well noticed from the experiments that the HDPE nano-composite specimen of 0.2 wt% of Al_2O_3, 0.5wt% of SWCNTs and 0.2 wt% of MWCNTs gives the best tribological properties so that the friction coefficient is reduced also the wear rate.

***Keywords*:** HDPE; SWCNTs; MWCNTs; Al_2O_3 NPs.

1. Introduction

A renewed interest in nanocomposites using as frictional materials applications has been increased in recent years. The polymers are one of the most widely explored used for bearings materials, nowadays. High Density Polyethylene (HDPE) possesses many excellent material characteristics including good density, stiff plastic with a highly crystalline structure, high wear resistance and good abrasion resistance, [1]–[3]. The different nano-fillers have been used with polymers to enhance mechanical and tribological properties of the composite materials. Graphene oxide has been proved is a prefect filler material in HDPE matrix, which causes highly successful of improvement the mechanical, tribological and thermal properties, [4]–[6]. 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, [7], [8]. 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, [9], [10]. The synthesized MoS_2-containing micro-capsules were added to a HDPE matrix to improve the anti-friction and abrasion wear of composite stern bearings, [11], [12]. Thermal behavior of HDPE coated with 10% wt. $CaCO_3$ content were investigated, which causes a slightly rise in its melting point, [13], [14]. The tribological characteristics of HDPE containing bi-directional silk fiber with nano clay, 0.5 and 1.0% wt, are experimentally investigated. The wear resistance shows a positive trend due to add nano-clay to HDPE/silk fiber composites, [15], [16]. UHMWPE/HDPE nanocomposites reinforced with untreated and pretreated carbon nanofibers CNFs were prepared by a twin screw extrusion. However, UHMWPE/HDPE composite filled with pretreated CNFs caused a decrease crystallinity degree and enhancement in tensile strength compared to the specimens reinforced by untreated CNFs content, [17]–[19]. Treated Carbon nanotube CNTs with HCl and H_2SO_4/HNO_3 used as a filler material. The polymeric matrix reinforced by CNTs leads to improve the mechanical properties, [20]. UHMWPE/HDPE composite reinforced with 0.2 and 2.0% wt multi-wall carbon nanotubes MWCNTs filler content. The results showed that the wear rate reduced because of the presence of MWCNTs, [21]–[23]. 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%, [23]–[25].
Furthermore, the aluminum nanoparticles Al_2O_3 use 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

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and ZrO_2 nanoparticles, [26]–[31]. 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, [32]. Al_2O_3 particles and hydroxyapatite HAp 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, [25], [33].
The current work focuses on enhancement 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. % of Al_2O_3, 0.1– 0.5 wt% SWCNTs and 0.1– 0.5 wt% MWCNTs nanoparticles.

2. Experimental Procedures

2.1 Specimens' preparation

In current study, Al_2O_3 NPs, SWCNTs, MWCNTs nanoparticles reinforced high density polyethylene (HDPE) composites served as cylindrical samples. 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 Al-Joumhouria Co. Cairo, Egypt. Aluminum oxide nanoparticles were supplied by US Research Nanoparticles, Inc. 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 and Al_2O_3 nanoparticles mixed in a glass container for 90 seconds using a rotating mixer at about 300 rpm from 5 to 1 0min., to achieve a uniformly and complete dispersion. The mixture powder is poured into the cylindrical copper mold of 10 mm in diameter under pressure approximately of 15 MPa. The copper molds were heated in the furnace, at temperatures up to 200°C, for the duration of 40 minutes and under pressure of 25 MPa. The specimens were separated out and left to cool at room temperature.

Table 1. Technical Properties of nano additives.

Properties	SWCNTs	MWCNTs
Purity %	90	95
Color	black	black
Outside diameter **[nm]**	1-2	30-50
Inside diameter **[nm]**	0.8-1.6	5-12
Length **[μm]**	5-30	10-20
Specific Surface Area **[m^2/g]**	380	60
Tap Density **[gm/cm^3]**	0.14	0.22
True Density **[gm/cm^3]**	2.1	2.1

2.2 Friction and Wear Test

The specimens positioned within its holder normal to the stainless-steel disc. The counter-face disc of set up used was a stainless-steel alloy plate with 7 mm thickness and 150 mm diameter. Surface roughness tester utilized 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). Before start of the test, the disc was cleaned. The friction force can be measured through a load cell, as strain gauges are found. The software is provided to take the friction coefficient data and plot the charts of the tested specimens. Experiments were conducted under dry condition, with three different amounts of sliding velocity of 4.4, 5.9 and 7.4 m/s under normal load of 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.

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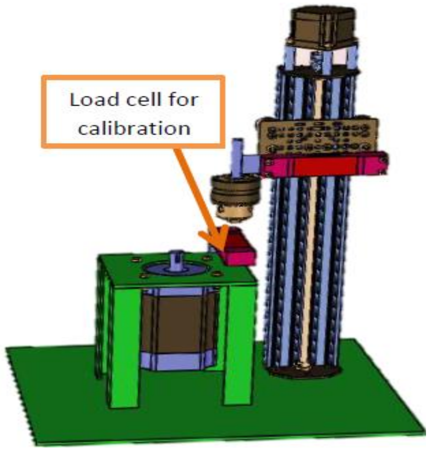

Figure 1 Schematic diagram of tribometer

3. Results and Discussion

In this experimental study the friction and wear rate were used to analyze the tribological behavior of HDPE/Al_2O_3, HDPE/SWCNTs and MWCNTs Nano-composites. Furthermore, to verify the best filler amount, the specimens with different filler content. 0.1– 0.2– 0.3 – 0.4– 0.5 wt% of Al_2O_3 nanoparticles, 0.1– 0.2– 0.3 – 0.4– 0.5 wt% SWCNTs nanoparticles and 0.1– 0.2– 0.3 – 0.4– 0.5 wt% MWCNTs nanoparticles were prepared. The friction coefficient of each specimen, which tested under dry condition was illustrated in Figures 2 - 10. The results show that the addition of Al_2O_3, SWCNTs and MWCNTs nanoparticles to the pure HDPE reduces its friction coefficient in dry condition.

The wear rate of each specimen, which tested under dry condition was illustrated in Figures 11-13. The results show that the addition of Al_2O_3, SWCNTs and MWCNTs nanoparticles to the pure HDPE reduces its wear rat in dry condition.

3.1 Effect of adding Al_2O_3 nanoparticles to HDPE

In case of dry contact, a maximum improvement is observed for specimen of 0.2 wt% of Al_2O_3 compared with HDPE base material. While the wear resistance of HDPE/Al_2O_3 specimens, which tested against stainless steel disc, also considerably was improved with adding Al_2O_3 nanoparticles as observed in Figure 2.

The wear rate reduces with adding of Al_2O_3 nanoparticles and it can notice that the 0.2 wt% of Al_2O_3 specimen exhibited an improvement in wear. The friction coefficient and wear rate values increase again in the nanocomposites with higher filler contents (0.3,0.4 and 0.5 wt% of Al2O3). Furthermore, the very fine Al_2O_3 particles embedded continuous matrix of a polymer composite reduces the pores. Consequently, the dispersion of Al_2O_3contentthrough the HDPE matrix is a key factor in the surface roughness smooth and in the effectiveness of the wear resistance ability. In the graph of Figure 3, the comparison of the effect of the Al_2O_3 nanoparticles amounts on the tribological characteristics, with respect to the characteristics of the reference specimen (HDPE base material). Finally, HDPE/0.2%Al_2O_3 specimen can be reported that, it would be ideal especially in bearing material applications for better field performance because of its lower wear loss and low friction.

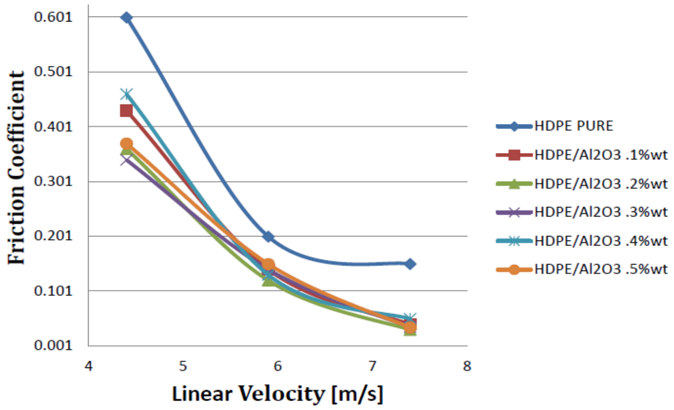

Figure 2 Friction coefficient HDPE/Al_2O_3 specimens

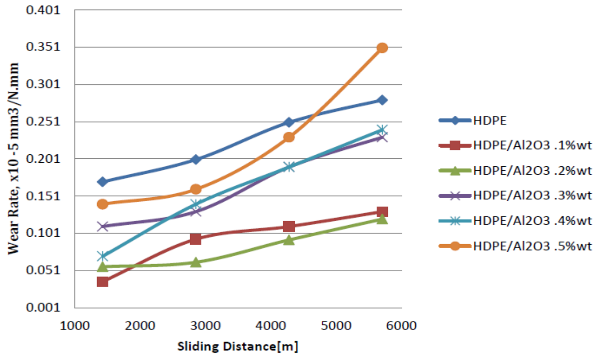

Figure 3 Wear rate HDPE/Al_2O_3 specimens

3.2 Effect of adding SWCNTs nanoparticles to HDPE

In case of adding SWCNTs at dry contact, a maximum improvement is observed for specimen of 0.5 wt% of SWCNTs compared with HDPE base material and HDPE/AL2O3.While, The wear resistance of HDPE/ SWCNTs specimens, which tested against stainless steel disc, also considerably was improved with adding SWCNTs nanoparticles. The wear rate reduces with adding of SWCNTs nanoparticles and it can notice that the 0.5 wt% of SWCNTs specimen exhibited an improvement in wear as observed in Figures 4 and 5. The friction coefficient and wear rate values decreasing with increasing filler contents (0.1,0.2,0.3,0.4 and 0.5 wt% of SWCNTs) compared to pure HDPE and HDPE/Al_2O_3. Furthermore, the very fine SWCNTs particles embedded continuous matrix of a polymer composite reduces the pores. Consequently, the dispersion of SWVNTs content through the HDPE matrix is a key factor in the surface roughness smooth and in the effectiveness of the wear resistance ability. In the graph of Figure 6, 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). Finally, HDPE/0.5%SWCNTs specimen can be reported that, it would be ideal especially in bearing material applications for better field performance because of its lower wear loss and low friction compared to pure HDPE and HDPE/Al_2O_3.

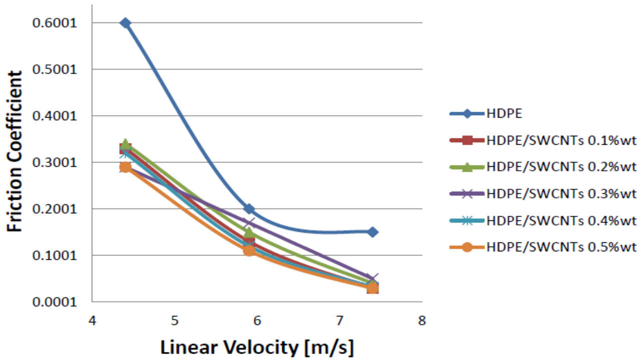

Figure 4 Friction coefficient HDPE/SWCNTs specimens

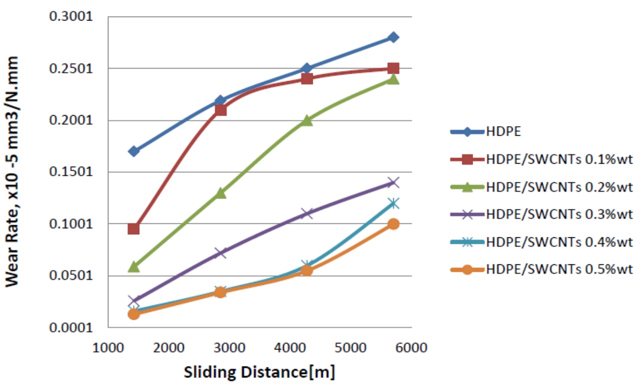

Figure 5 Wear rate HDPE/ SWCNTs specimens

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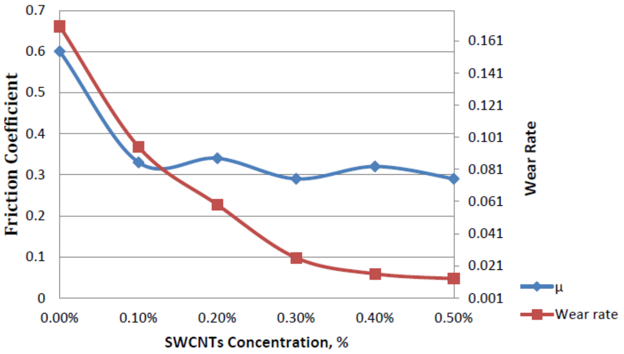

Figure 6 Tribological characteristics of HDPE/SWCNTs specimens.

3.3 Effect of adding MWCNTs nanoparticles to HDPE

In case of adding MWCNTs at dry contact, a maximum improvement is observed for specimen of 0.2 wt% of MWCNT compared with HDPE base material, HDPE/Al_2O_3 and HDPE/SWCNTs. While the wear resistance of HDPE/MWCNTs specimens, which tested against stainless steel disc, also considerably was improved with adding MWCNTs nanoparticles as observed in Figures 7 and 8. The wear rate reduces with adding of MWCNTs nanoparticles and it can notice that the 0.2 wt% of MWCNTs specimen exhibited an improvement in wear. The friction coefficient and wear rate values increase again in the nanocomposites with higher filler contents (0.3, 0.4 and 0.5 wt% of MWCNTs). Furthermore, the very fine MWCNTs particles embedded continuous matrix of a polymer composite reduces the pores. Consequently, the dispersion of MWCNTs content through the HDPE matrix is a key factor in the surface roughness smooth and in the effectiveness of the wear resistance ability. In the graph of Figure 9, the comparison of the effect of the MWCNTs nanoparticles amounts on the tribological characteristics, with respect to the characteristics of the reference specimen (HDPE base material). Finally, HDPE/0.2% MWCNTs specimen can be reported that, it would be ideal especially in bearing material applications for better field performance because of its lower wear loss and low friction.

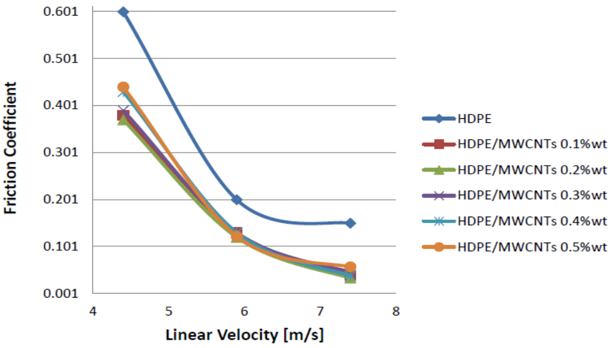

Figure 7 Friction coefficient HDPE/MWCNTs specimens.

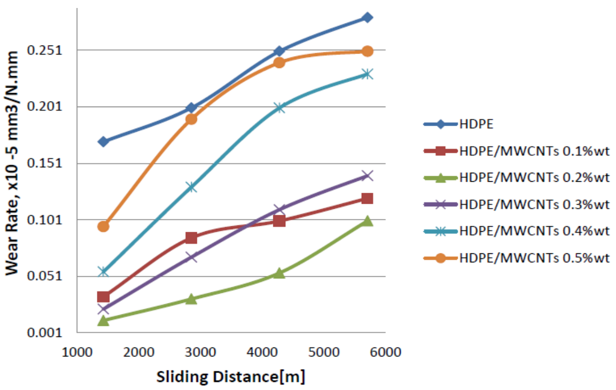

Figure 8 Wear rate HDPE/ MWCNTs specimens

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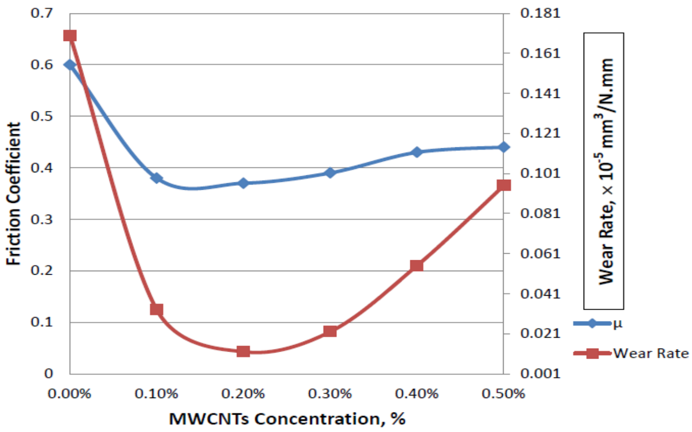

Figure 9 Tribological characteristics of HDPE/MWCNTs specimens.

4. Conclusion

As a result of the use of Al_2O_3, SWCNTs and MWCNTs 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:

- Al_2O_3 nanoparticles have shown the ability to improve the friction and wear resistance characteristics of HDPE without a layer of lubricant.
- HDPE nano-composite reinforced with 0.2 wt% of Al_2O_3 was caused a decrease in friction coefficient reached up 40% compared to conventional pure HDPE.
- HDPE/ 0.2 wt% of Al_2O_3 composites exhibited bring down in wear rate up to 47%.
- HDPE nano-composite reinforced with 0.5 wt% of SWCNTs was caused a decrease 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%.
- HDPE nano-composite reinforced with 0.2 wt% of MWCNTs was caused a decrease in friction coefficient reached up 38.3% compared to conventional pure HDPE.
- HDPE/ 0.2 wt% of MWCNTs composites exhibited bring down in wear rate up to 68%.

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