TRIBOLOGICAL PROPERTIES OF HIGH DENSITY POLYETHYLENE FILLED BY GRAPHENE OXIDE NANO PARTICLES

Atia K. M., Esayed A. A., Ali W. Y. and Badran A. H.

**Department of Production Engineering and Mechanical Design, Faculty of Engineering,
Minia University, El-Minia, EGYPT.**

ABSTRACT
Graphene oxide (GO) is favored as a filler material in polymer matrix composites becauseit has higher aspect ratios than many nanosize fillers, such as carbon nanotubes, in addition to having better mechanical qualities than many polymers. In this study, the tribological properties of high density polyethylene (HDPE) were experimentally studiedin relation to the effects of GO nanoparticles and vegetables oils. By using the melt compounding process, the nanocomposites (HDPE – GO - vegetables oils) were manufactured. The molded nanocomposite were then tested for friction and wear tests. According to the findings, the addition of GO improved the friction and wear behavior of the composites. With GO loading fractions of 0, 0.06, 0.12, 0.25, 0.5, and 1.0 wt. %, the wear and coefficient of friction values were drastically reduced. The corn and olive oils were added by 10 wt. % to the composites.

INTRODUCTION
A continuous material that serves as the matrix and a reinforcing scattered material are the two or more different materials that make up a composite. A continuous polymeric matrix and fillers acting as reinforcements make up polymer matrix composite materials. Because of this, polymer composites provide a superior mix of mechanical qualities not seen in pure polymers, [1] Due to polymer composites' exceptional qualities, which include their ability to be molded into complicated geometries, low manufacturing costs, high production rates, and noticeably low weight to strength ratios, large-scale industrial applications are quickly expanding, [2, 3].

As a result of the vast range of qualities displayed by polymer composites and their high processing ability, polymer composites have seen a wide variety of uses in daily life and industry during the last several decades. [4, 5] Linear low-density polyethylene (LLDPE),a kind of polyethylene (PE), with a density that falls between 0.915 and 0.940 g/cm3. Short, uniform branches attached to the main backbone of the linear carbon chain in LLDPE hinder the linear carbon chain from forming organized crystal formations. Superior stiffness, strength, and ductile characteristics are the outcome of this feature, [3, 6, and 7].

HDPE is one of the most commonly used plastic products in the world because of its great combination of flexibility and stiffness in a wide range of industrial applications, including packaging film, agricultural mulch, lay flat pipe, water tubing, and low temperature food containers, [8].

At room temperature, graphene is a stable two-dimensional (2D) crystalline substance. Graphene is a new material, but because of its excellent mechanical, thermal, and electrical properties, it has many promising uses. As a result, numerous investigations have been carried out with the goal of improving the mechanical properties of polymers with graphene. [9] Kuila et al., [10] examined the mechanical characteristics of LDPE nanocomposites reinforced with graphene that had undergone dodecyl amine modification (DA-G). According to their research, adding more DA-G to nanocomposites significantly increased their thermal stability and storage moduli, [11].

As a result of its promise for the efficient large-scale manufacture of graphene-based products, graphene oxide (GO), a graphene derivative that is produced through oxidation by potent oxidizing acids, has successfully received substantial study interest. GO has two key advantages: (1) it can be produced in vast numbers chemically from cheap graphite; and (2) the covalent attachment of functionalized groups to the plane of carbon atoms in GO increases the interlayer distance of GO, [12], Liang et al. conducted research on the PVA graphene composites' mechanical characteristics. The samples were also made via polymerization of solution-mixed materials. It was discovered that the composite containing 0.7 weight percent of GO has increased tensile strength and Young's modulus by 76% and 62%, respectively, [13].

A comparable improvement was seen, [14] for polylactic acid (PLLA)/GO composites produced by solution mixing. The tensile strength and Young's modulus of PLLA were found to be improved by 28 % and 59 %, respectively, with the addition of 2.0 wt. % of GO Nano platelets into the matrix. In addition, a study by Wan et al., [15] found that the tensile strength and Young's modulus of the epoxy were improved by 10% and 48%, respectively, with 0.25 wt. % of silane-functionalized-GO. They also mixed solutions to prepare their samples in a similar manner.

Additionally, Suner et al., [16] found that GO nanoparticles added to an ultra-high molecular weight polyethylene (UHMWPE) matrix could significantly improve the material's thermal stability, oxidative resistance, and mechanical properties. According to their research, adding GO to the UHMWPE matrix boosted the material's Young's modulus, yield strength, and fracture strength by about 15% and 25%, respectively. These findings demonstrate that GO has enormous promise for designing and producing GO-based polymer nanocomposites with exceptional integrated performance for industrial applications.

When comparing the impact of organic fillers like carbon black, calcium carbonate, graphite, and graphene with GO on the properties of polymeric materials, especially GO is preferred to use as active filler in many applications due to its lower cost than graphene, higher range of reactive oxygen functional groups, and higher UV stability than Ca. However, the research on improving fatigue properties of polymers by melting GO with polymers is still limited, [17]. In the present work, the tribological properties of high density polyethylene filled by graphene oxide nanoparticles are investigated.

EXPERIMENTAL

Materials

The polymer matrix was a commercial high density polyethylene (HDPE) with a mass flow rate (MFR) of $1.5 \ 10^{-5} \ m^3$/10 min and a density of 945 kg/m^3. The graphene oxide (GO) powder was obtained from Angstrom Materials (USA). According to the manufacturer's specifications, the GO sheets had a specific surface area of $> 400 \ m^2$/g, a thickness of 2 - 3 nm, and lateral dimensions of 6 - 8 μm.

Preparation of Composites

Figure 1 shows the mold used to create test spacemen. As shown in the figure, the mold is made up of a cylindrical barrel that contains the polymer for the composites. A vertical punch used to press the polymer during the heating process. To accommodate the thermocouple temperature sensor, a hole was drilled. As a gasket between the die body and the base, a heat resistant sheet was used.
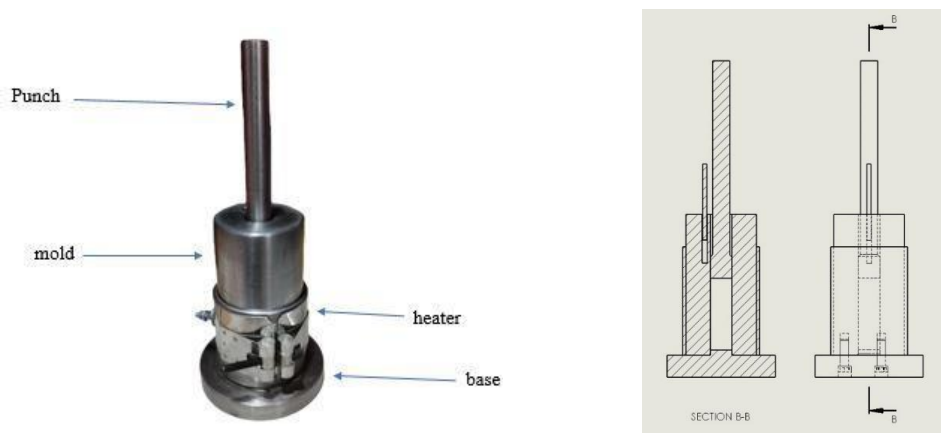

Fig. 1 Cylindrical mold.

As shown in Fig. 2, the heater was made of a steel case surrounded by a nickel chrome coil. The mold was heated to up to 165 degrees Celsius using a heating band sleeve connected to a thermocouple controller. A programmable PID controller, relay, and type J thermocouple were used to control the temperature, as shown in Fig. 3.

Fig. 2 Heater for the mold.

Fig. 3 Thermocouple controller.

Fig. 4 Hydraulic Press.

The composites were compacted using a hydraulic press, as shown in Fig.4. During the manufacturing process, the specimens were pressed with a three-ton pressure to remove any cavities and air bubbles. The specimens were mechanically mixed in a glass container at room temperature by dispersing GO Nano particles into an HDPE matrix with a rotating mixer at about 300 rpm for 10 minutes. The mixture was then transferred to the mold. Furthermore, to determine the optimal filler weight fraction, HDPE/GO/Oils composites with various compositions were prepared, as shown in Table 1. The specimen and its dimensions are illustrated in Fig. 5.

Table 1. Variation of HDPE/GO/Oils percentages (%)

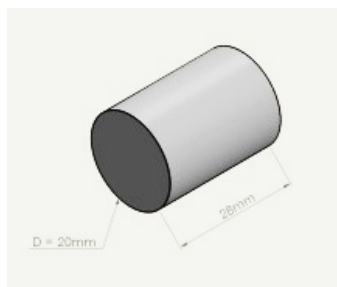| HDPE %	GO %	Corn oil %	Olive oil %
100	-	-	-
rest	0.06	10	-
rest	0.12	10	-
rest	0.25	10	-
rest	0.5	10	-
rest	1	10	-
rest		-	10
rest		-	10
rest		-	10
rest		-	10
rest		-	10

Fig. 5 Test specimen.

Testing and Characterization
As shown in Fig. 6, a reciprocating pin-on-disk tribometer with a stroke of 50 mm was used to test the tribological behavior of composites specimens under dry contact conditions at 28°C and 50% relative humidity.

The cylindrical specimens were tested, and the disc was a rectangular P600 Sandpaper. The tests were carried out with different normal loads of 2, 4, 6, 8, and 10 N. Wear tests were carried out by calculating the weight difference between the initial and final weights of samples. The experiment was repeated three times for each specimen under the same conditions, and the average values were recorded. An optical microscope was used to examine the worn surfaces (OLYMPUS BX53M, USA). The wear tracks and pits on the sliding surfaces were assessed using 3D and 2D images.
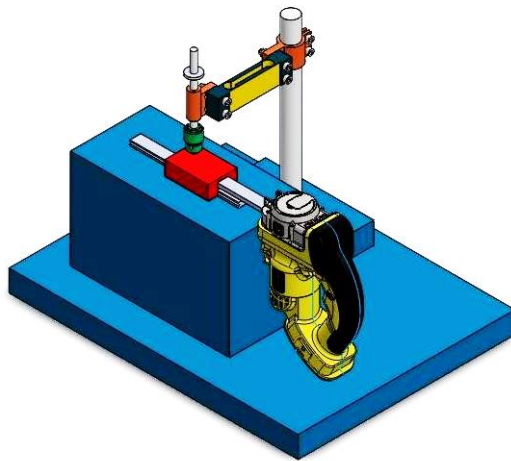

Fig. 6 The used reciprocating tribometer.

RESULTS AND DISCUSSION
Frictional behavior for composites
Friction is typically characterized by a friction coefficient which is the ratio of the frictional resistance force to the normal force which presses the surfaces together. In this case the normal force is the weight of the blocks. Normal load was applied by weights of 2, 4, 6, 8 and 10 N. Friction force was measured using load cell mounted to the loading lever and connected into digital monitor display.

Figure 7 depicts the relationship between the friction coefficient and the normal load for composites filled with GO. The friction coefficient reduces with increasing GO content, as can be observed in the image. At a normal load of 10 N, it can be shown from curves that composites reinforced with 1% GO performed 70% better in terms of coefficient of friction than pure composites.

The GO self-lubricating mechanism during wear may be responsible for this. It is also possible to see that as the normal load increases, the friction coefficient falls. This may be attributed to more heat produced when sliding. When the temperature is high, a layer of material with low shear strength is anticipated to form at the contact, providing low values of the coefficient of friction.

In Figs. 8 and 9, respectively, the effect of filling composites with corn and olive oils on

friction coefficient is displayed. Oils obviously reduced the friction coefficient. The oil in the many pores of the composite, which act as oil reservoirs and leak oil up to the sliding surface, is what reduces friction. Due to the layer that forms on the sliding surface when oil is present, friction coefficient is reduced. The friction coefficient is significantly reduced by the addition of GO. Additionally, composites loaded with olive oil displayed a lower friction coefficient than composites loaded with corn oils.

This could be attributed to olive oil molecules having a higher degree of polarity than corn oil molecules, which makes it easier for olive oil molecules to attach to the friction surface and reduce friction coefficient. The composites loaded with corn oil showed a 49% improvement in coefficient of friction under a normal load of 10 N compared to the same ratio with no oil, while the composites loaded with 1% GO and 10% olive oil showed a 54% improvement.
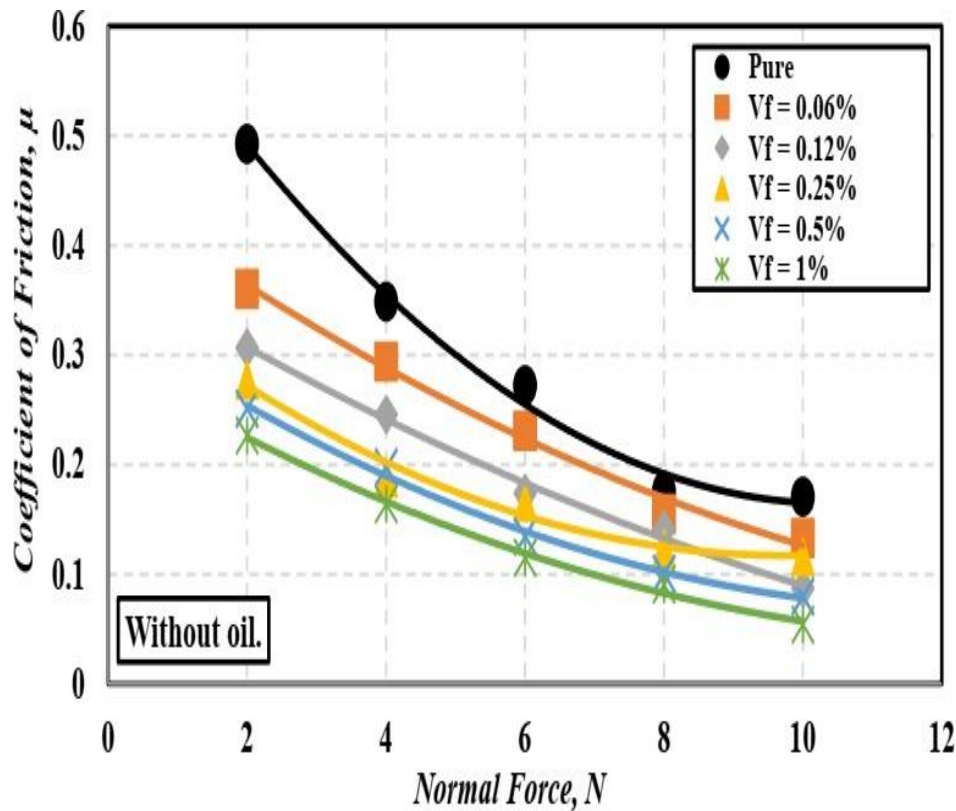

Fig. 7 Coefficient of Friction – Normal Force diagram for (HDPE / GO) composites with different volume fraction contents.
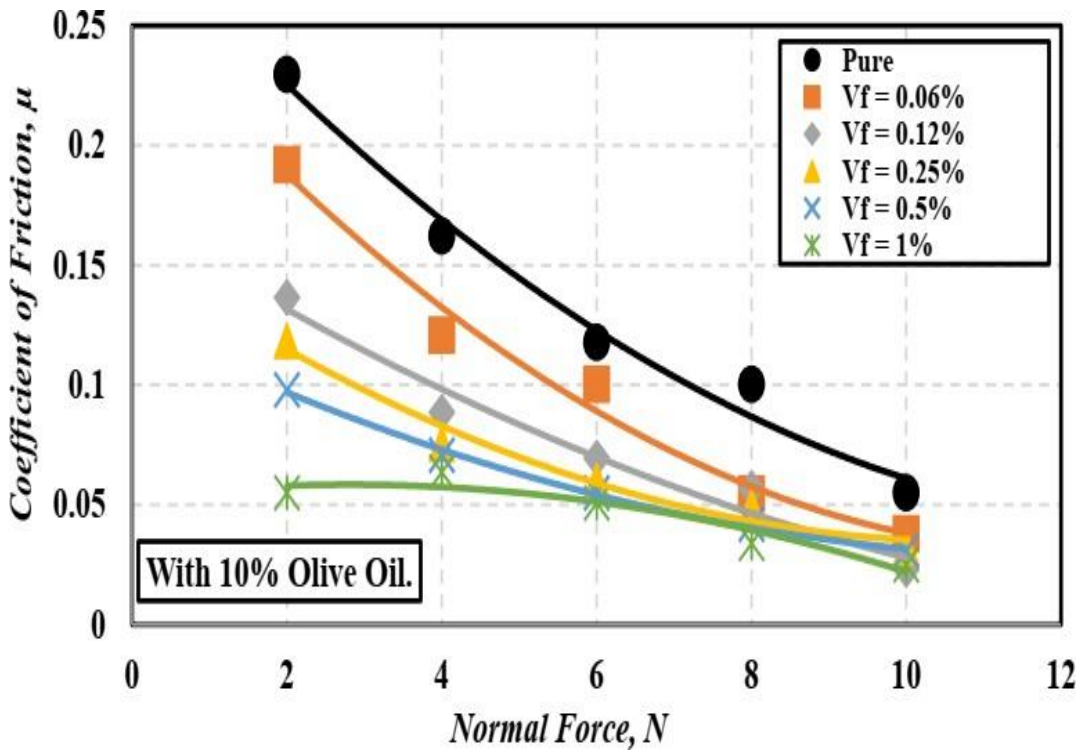
Fig. 8 Coefficient of Friction – Normal Force diagram for (HDPE / GO) composites with different volume fraction contents with Addition of 10% olive oil.
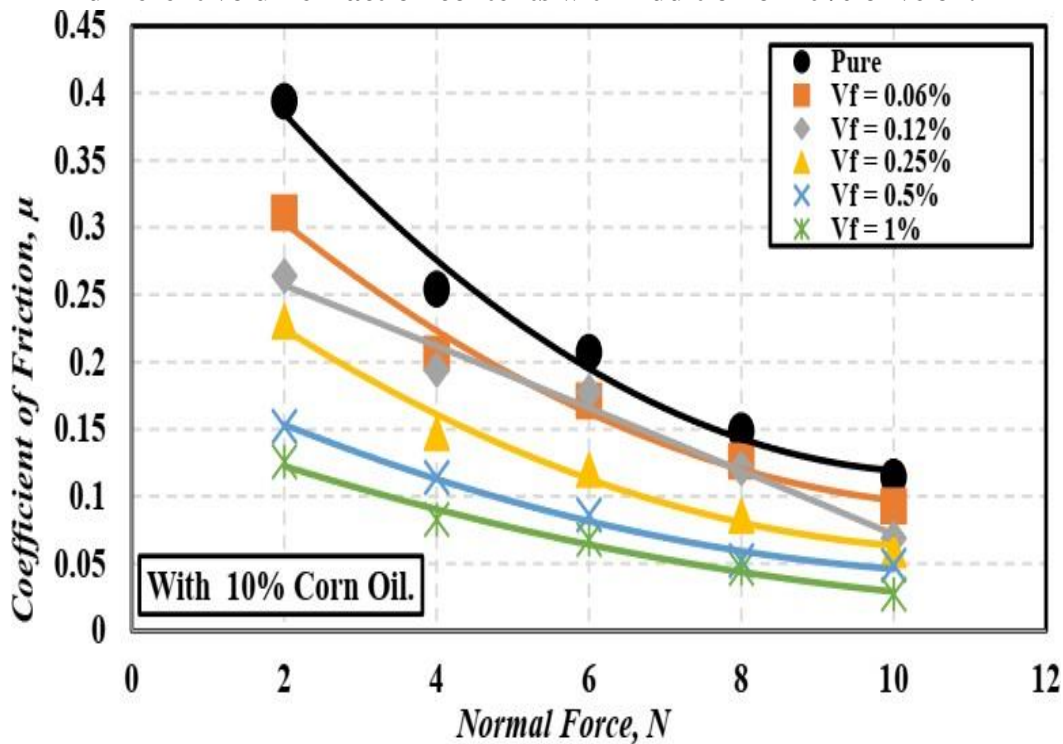

Fig. 9 Coefficient of Friction – Normal Force diagram for (HDPE / GO) composites with different volume fraction contents with Addition of 10% corn oil.

Wear results for composites
Figure 10 shows the relationship between wear loss and normal load for composites filled with GO. It was revealed that increasing the GO content resulted in a decrease in wear

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loss. In comparison to the pure specimen, the specimen containing 1% GO reduces wear loss by 54% for a normal load of 10 N. This behavior is attributed to GO increasing the wear resistance of composites. During the wear process, the two mating wear surfaces were filled with the dispersed GO, and the GO on the wear surface could then serve as spacers, preventing rough contact between the two mating wear surfaces and significantly reducing wear loss.
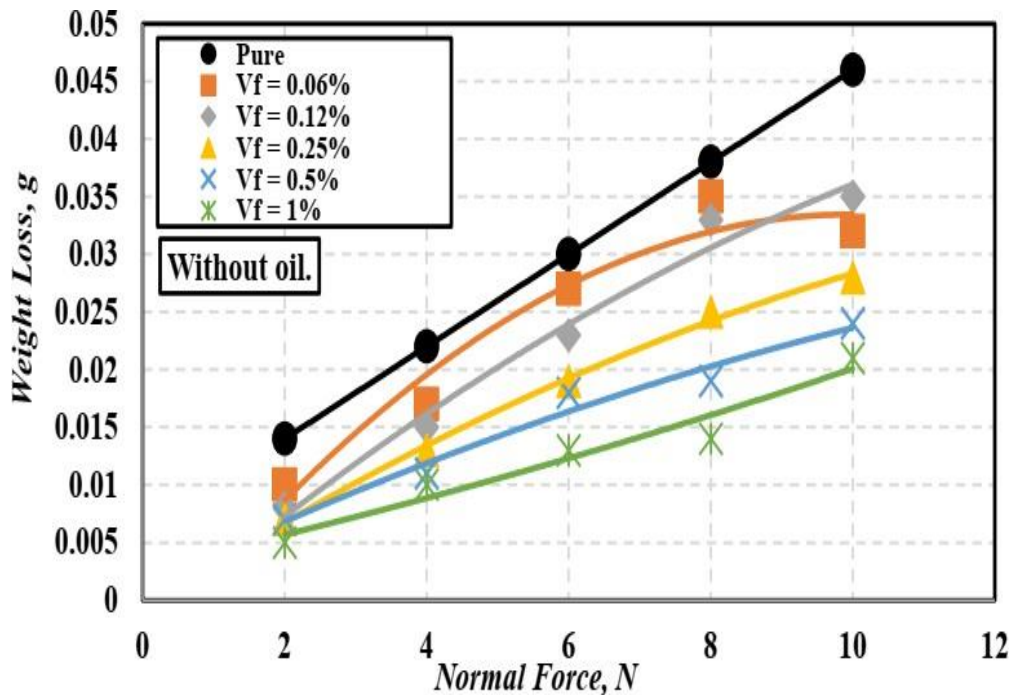

Fig. 10 Weight Loss – Normal Force diagram for (HDPE / GO) composites with different volume fraction contents.
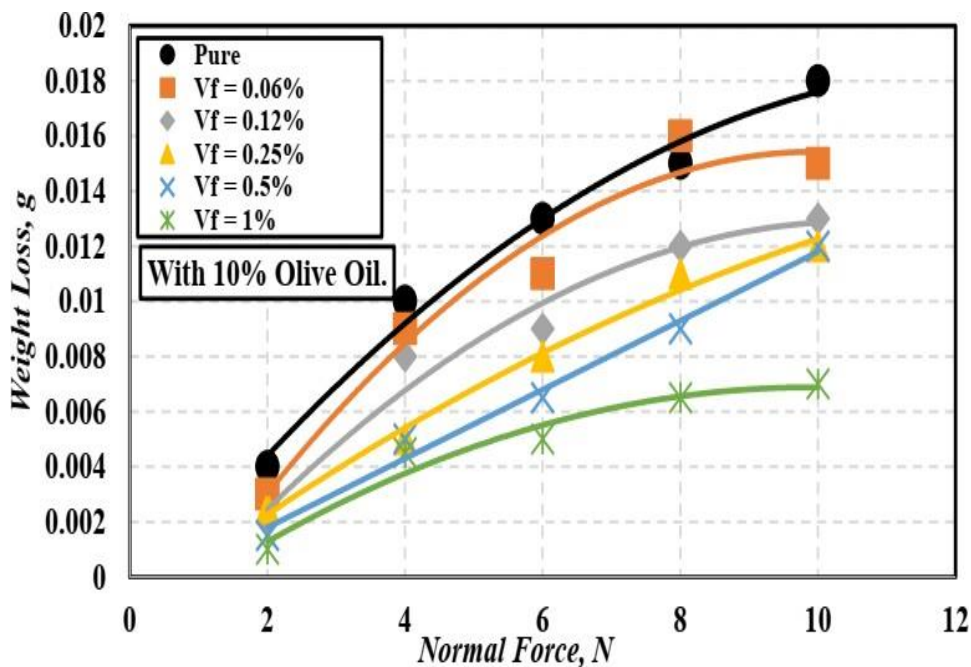

Fig. 11 Weight Loss – Normal Force diagram for (HDPE / GO) composites with different volume fraction contents with Addition of 10% olive oil.
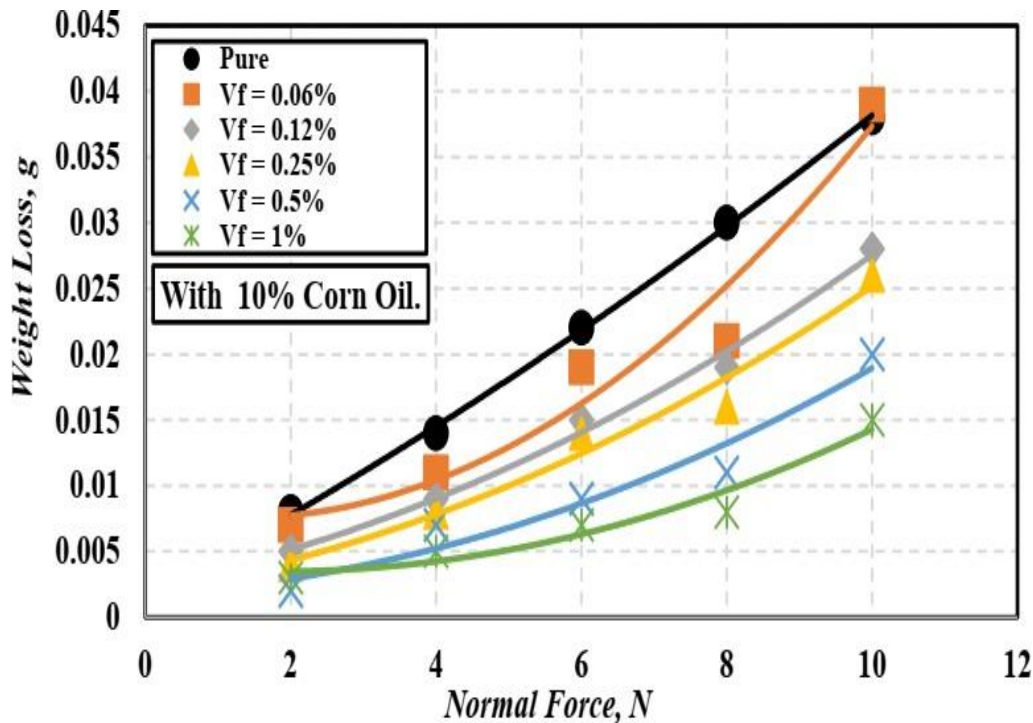
Fig. 12 Weight Loss – Normal Force diagram for (HDPE / GO) composites with different volume fraction contents with Addition of 10% corn oil.

Figures 11 and 12 represented the relationship between wear loss weight and normal load for olive and corn oil-filled composites, respectively. The presence of oil reduces wear due to the formation of an oil film on the sliding surface between the two mating surfaces. It should be noted that GO has a significant impact on decreasing wear values. This could be because the GO was exposed to the sliding interface, which effectively protected the polymer. The graph shows that wear increases as the normal load increases. This is due to the fact that as the normal load increases, frictional heat is generated at the contact surface, resulting in a decrease in material strength.

For a normal load of 10 N, the composites reinforced with 1% GO and 10% olive oil reduced wear loss by 67% when compared to the same ratio without oil, while the composite materials incorporating corn oil reduced wear loss by 28%.

CONCLUSIONS
From the present work, the following points can be concluded:

1. By increasing the GO content, the friction coefficient and wear are drastically reduced.

2. Compared to pure specimens, the addition of olive oil reduced coefficient of friction by 70%.

3. Corn oil reduced the coefficient of friction by 40% when compared to pure one.

4. Applying corn oil reduced wear loss by 28% while using olive oil reduced wear loss by 67%.

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