

MECHANICAL 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

The effect of GO nanoparticles and natural oils on the mechanical properties of high-density polyethylene (HDPE) was investigated experimentally in this study. Melt compounding was used to create HDPE-GO- (Olive/Corn oils) nanocomposites, and the molded nanocomposites were shaped for compression and bending tests. The results showed that the addition of GO improved the mechanical properties of the composites. With GO loading fractions of 0, 0.06, 0.12, 0.25, 0.5, and 1 wt. %, the compressive and bending strength values were significantly increased. Corn and olive oils were added to composites at a 10% weight ratio.

KEYWORDS

High density polyethylene (HDPE), graphene oxide (GO), mechanical properties, compressive strength, bending strength.

INTRODUCTION

The concept of synergistically mixing several materials of very diverse nature is one of the most successful techniques to obtaining multifunctionality at the cutting edge of materials technology. In this regard, the appropriate assembly of graphene and polyolefins offers a path to the development of versatile materials with a wide range of applications. This is because it involves more than just the combination of two compounds. Due to their excellent chemical and physical qualities, low production costs, simple processing, remarkable adaptability, potential for recycling, and use as sustainable materials, polyolefins are one of the most commonly used families of polymers on earth, [1].

This family of polymers is mostly used in home cleaners, automobile parts, cosmetics, health care goods, and food packaging. However, due to its wide range of extraordinary properties, such as flexibility with superior mechanical properties, [2], high thermal conductivity, [3], high electrical conductivity, [4], high specific surface area, [5], optical transparency, [6], as well as several non-conventional electronic properties like the anomalous quantum Hall effect and massless Dirac ferromagnetism, graphene should not be regarded as a single material, [7].

In this regard, the effective coupling of graphene with polyolefins represents a potent path for the development of novel materials with superior properties, [8]. The homogeneous

dispersion of graphene and the effective load transfer between components via strong filler/polymer interfacial interactions, [9] are the keys to success in this regard.

Like other polymer matrices, graphene and polyolefins together typically produce physically stronger nanocomposites with increased heat stability, [10–16]. The former is ascribed to the barrier effect of the nanomaterial, which successfully prevents the passage of volatile breakdown products from the bulk of the polymer to the gas phase, delaying the degradation process, [13]. Inherent characteristics of the nanomaterial, such as its high Young's modulus and intrinsic strength that is significantly greater than that of any polymer, are principally responsible for mechanical improvements, [17].

Other characteristics, like electrical conductivity, gas barrier, and electromagnetic interference (EMI) shielding, are of special interest, as they depend significantly more on the distribution of graphene and the strength of the interface. Field effect transistors, solar cells, energy storage devices, anti-static coatings, and EMI shielding are just a few of the many uses for conductive nanocomposites, but their lack of electrical conductivity is a severe limitation, [18].

Only a small number of research have, however, produced polyolefin-based nanocomposites with adequate electrical conductivity. The creation of nanocomposites of high-density polyethylene (HDPE) with ad hoc covalently modified graphene was documented in early research on such materials, [19, 20]. In order to create electrically conductive graphene/polyethylene nanocomposites, a novel chemical method based on the covalent modification of graphene oxide with vinylsilane groups and in situ polymerization of ethylene has recently been published, [21]. In the present research, the mechanical properties of high density polyethylene filled by graphene oxide nanoparticles are investigated.

EXPERIMENTAL WORK

Materials

Commercial high density polyethylene (HDPE) with a mass flow rate (MFR) of 1.5×10^{-5} m³/10 min and a density of 945 kg/m³ was used as the polymer matrix. From Angstrom Materials, graphene oxide (GO) powder was purchased (USA). The manufacturer's specs state that the product had a specific surface area of >400 m²/g, a thickness of 2-3 nm, and lateral dimensions of 6-8 μm for the GO sheets.

Preparation of Nanocomposites

Figure 1 displays the molds used in the fabrication process of compression and bending test specimens. The compression specimen mold, as shown in the figure, is made up of a cylindrical barrel containing 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. The rectangular mold shown on the right was used to create rectangular specimens for bending strength testing.

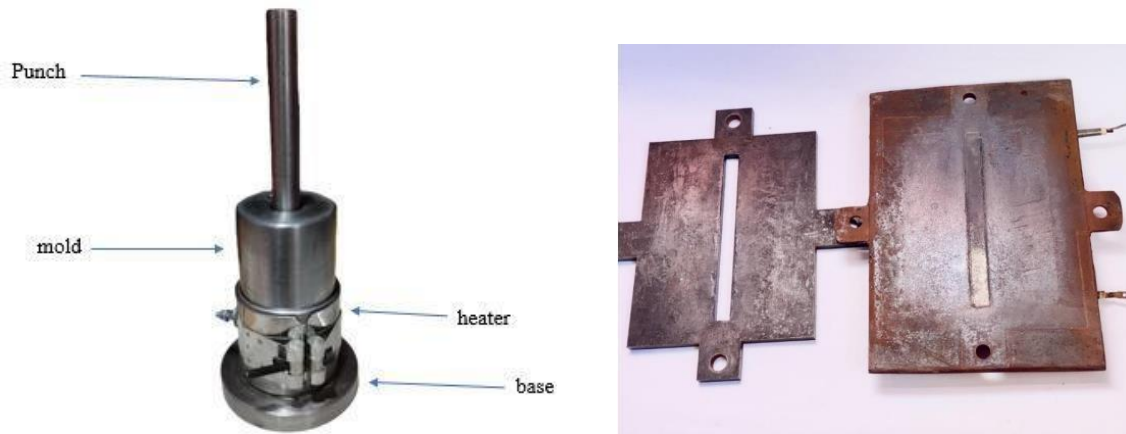


Fig. 1 Compression and Bending specimens molds.

As depicted in Fig. 2, the heater was constructed from a steel casing encircled by a coil of nickel chrome. The mold was heated to a maximum temperature of 165 degrees Celsius using a heating band sleeve coupled to a thermocouple controller. A programmable PID controller, relay, and type J thermocouple were used to control the temperature, as illustrated in Fig. 3.



Fig. 2 Heaters for the compression and bending specimen's molds.



Fig. 3 Thermocouple used for controlling the temperature.

As seen in Fig. 4, the composites were compacted using a hydraulic press. The specimens were pressed under a three tons pressure to eliminate any air bubbles or voids that may have developed during the production process.



Fig.4 Hydraulic press

By dispersing GO Nano particles into an HDPE matrix over the period of ten minutes while the mixer rotated at a speed of roughly 300 rpm, the specimens were mechanically mixed at room temperature in a glass container. After that, the mixture was sent to the mold. Furthermore, HDPE/GO/Oils composites with various compositions were created, as shown in Table 1, in order to assess the ideal filler weight fraction. Figure 5 displays the test specimens for compression and bending. Its measurements are displayed in Fig. 6.

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 specimens for compression and bending tests.



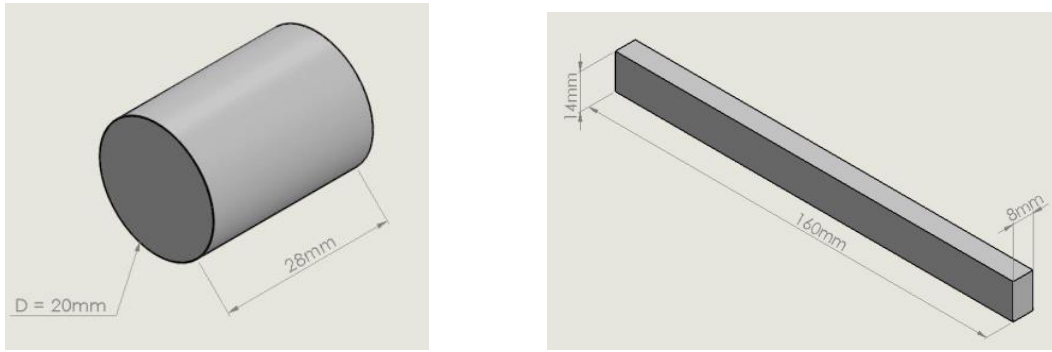


Fig. 6 Test specimens dimensions.

Testing and Characterization

Through bending and compression testing, the composites mechanical characteristics were evaluated. The compression and bending tests were carried out using a United High Capacity Smart Universal Hydraulic (DFM-300KN), Fig. 7, in line with ASTM standard D1621. System has an encoder resolution of 0.0005 mm and a load accuracy of $\pm 0.5\%$ for a 300 KN capacity. To assess their compressive and bending characteristics, the three test specimens are made from each composition. The device automatically measured the stress-strain curves.



Fig. 7 Universal Testing Machine

RESULTS AND DISCUSSION

Compression Test Results

Figure 8 illustrates how GO concentrations affect the mechanical performance of HDPE composites. Analyzing the figure makes it obvious to see that the compressive strength improves as the GO concentration rises. This might be explained by high modulus of GO and extremely its high aspect ratio. Since GO is one of the stiffest materials and has a high strength and modulus, it is desirable to add this filler to HDPE to enhance the mechanical properties of composites. At strain value 0.7, HDPE composites containing 1.0 wt. % GO had the highest compressive strength, 110 MPa. This result is remarkable because it improved by 360 % when compared to a pure specimen at the same strain, which was around 30 MPa.

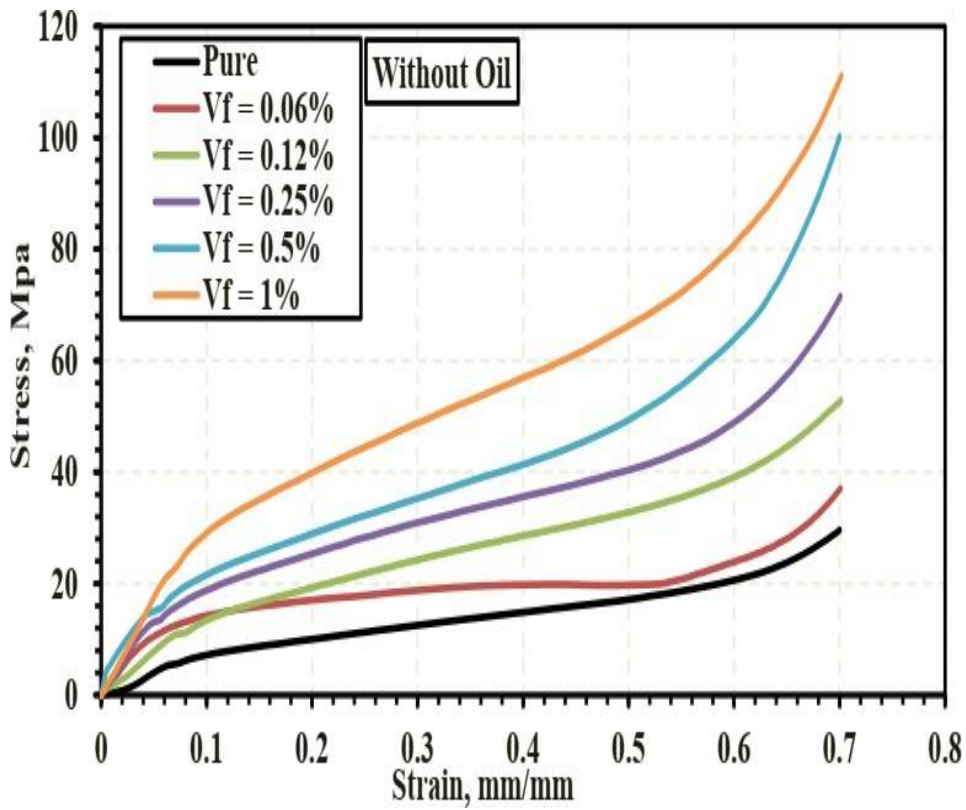


Fig. 8 Stress – Strain diagram of (HDPE / GO) composites with different volume fraction contents.

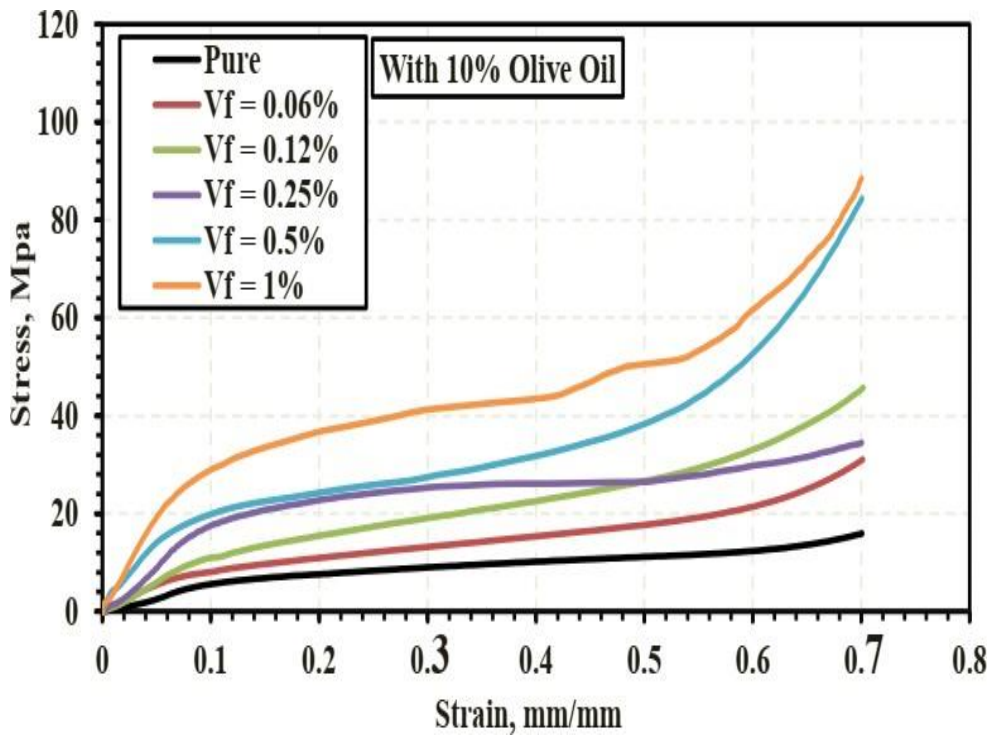


Fig. 9 Stress – Strain diagram of (HDPE / GO) composites with different volume fraction contents with Addition of 10 wt. % olive oil.

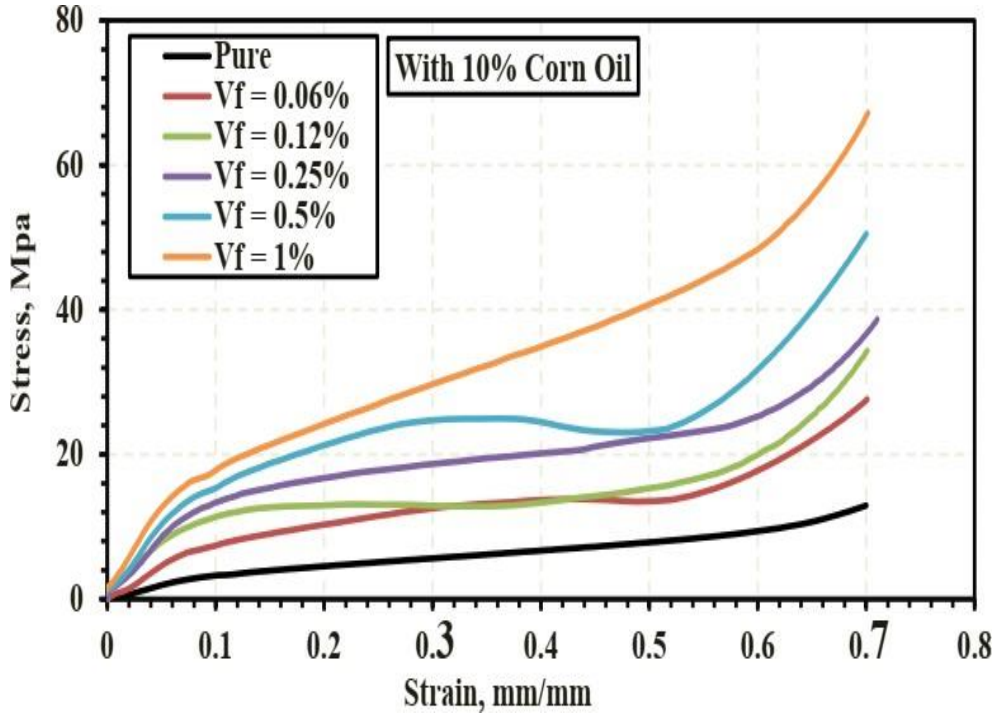


Fig. 10 Stress – Strain diagram (HDPE / GO) composites with different volume fraction contents with Addition of 10% corn oil.

The effect of filling composites by corn and olive oils on compressive strength are shown in Figs. 9 and 10 respectively. It is clear that oils decreased the composites strength. This result is explained by the fact that oil interaction and diffusion with HDPE chains produce a decrease in the bonding force between HDPE molecules. Unfortunately, this reduces the mechanical properties of the composites; however, the oils are beneficial in tribological properties since they reduce the coefficient of friction and weight loss.

The strength value of composites containing olive oil was around 90 MPa at strain 0.7 and 1.0 wt. % GO, but the strength value of composites containing corn oil was around 70 MPa under the same conditions. As a result, composites containing olive oil have superior mechanical characteristics versus composites using corn oil, which may be attributed to the lower viscosity of corn oil.

Bending Test Results

Figure 11 demonstrates the relationship between stress and deflection for composites filled with GO. It was noted that as the GO concentration increased, the bending stress increased as well. The pure sample had a bending stress of 40 MPa at a deflection of 25 mm, whereas the sample with the highest % of GO reinforcement had a bending stress of approximately 120 MPa at the same deflection. This is an interesting outcome because the improvement is about 300% of the bending stress.

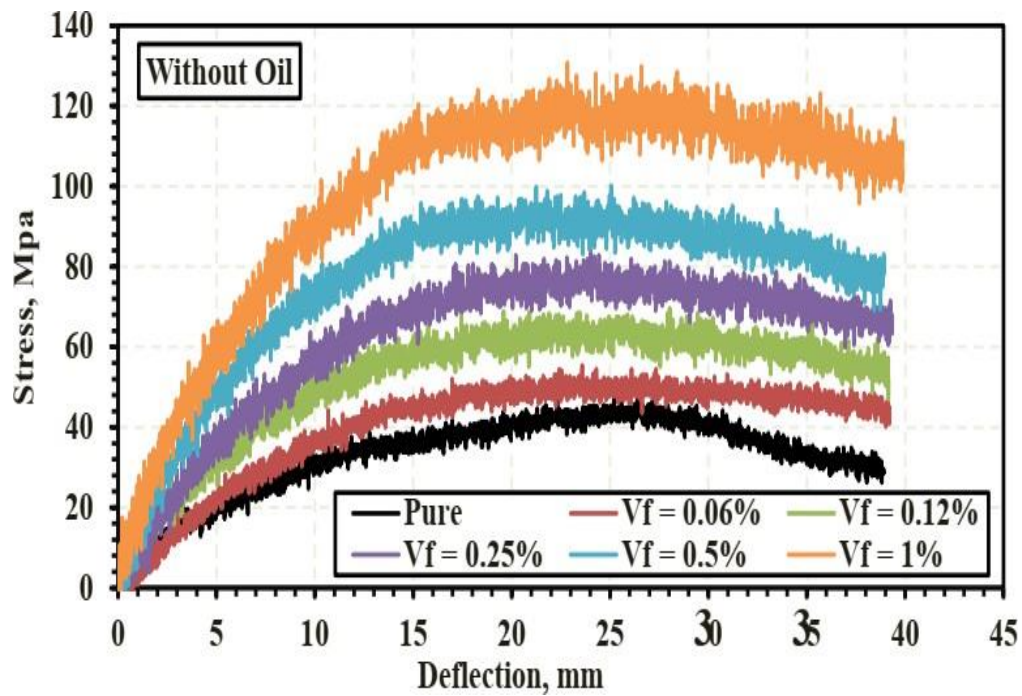


Fig. 11 Stress – Deflection diagram for (HDPE / GO) composites with different volume fraction contents.

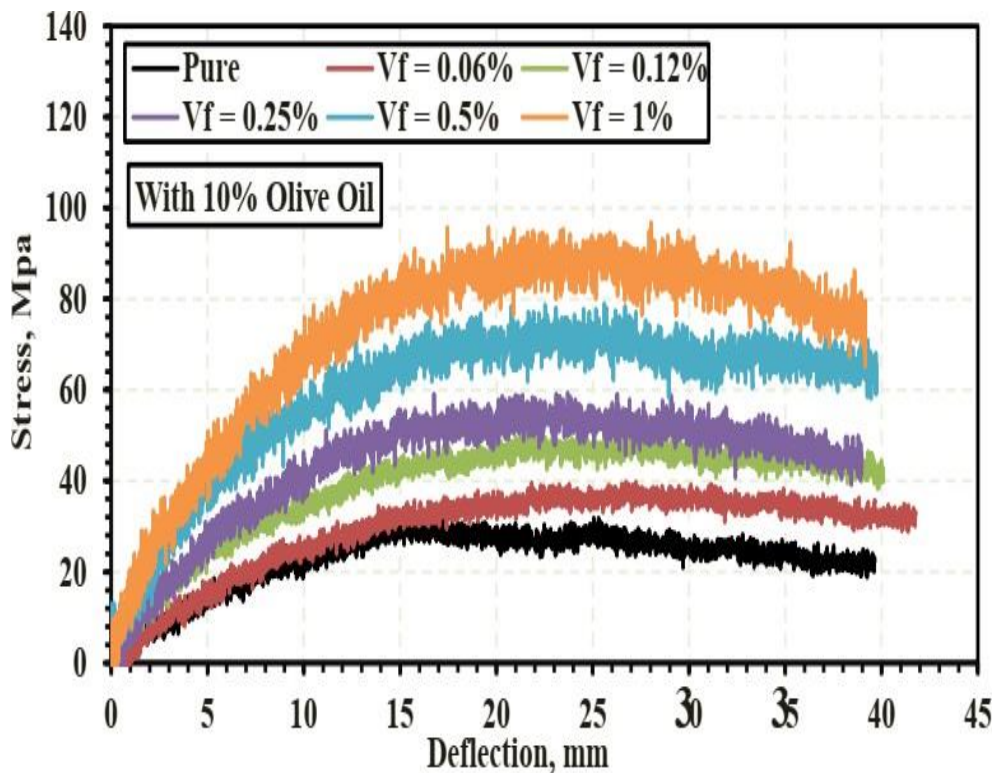


Fig. 12 Stress – Deflection diagram for (HDPE / GO) composites with different volume fraction contents with Addition of 10% olive oil.

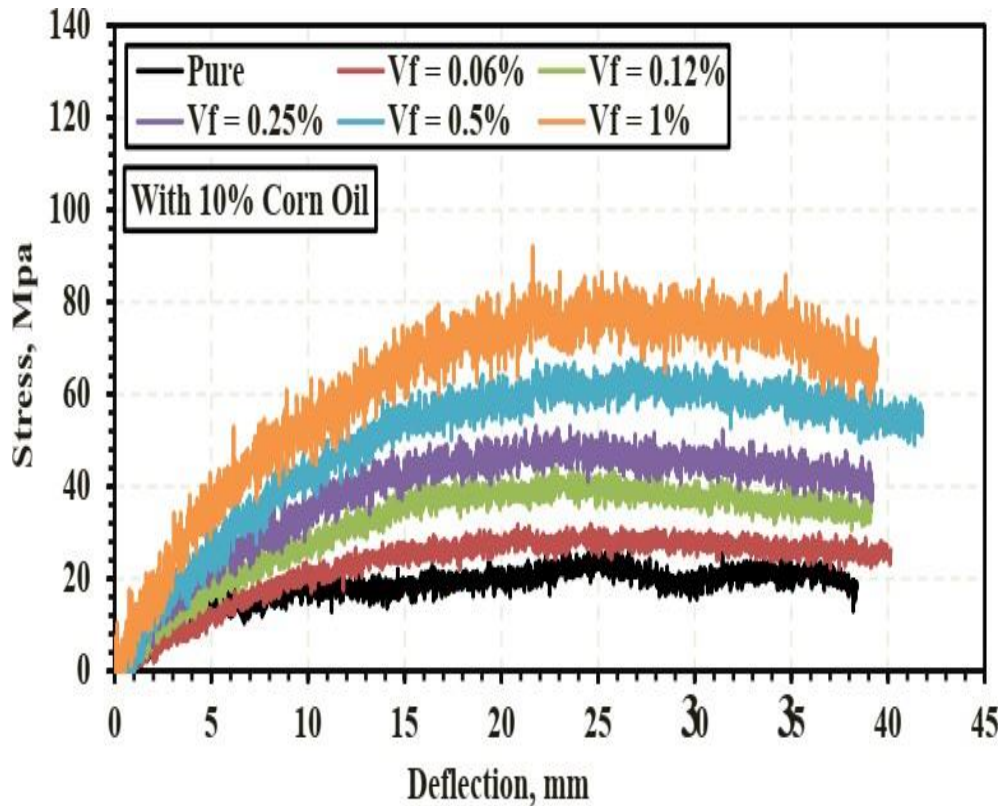


Fig. 13 Stress – Deflection diagram for (HDPE / GO) composites with different volume fraction contents with Addition of 10% corn oil.

The relationship between stress and deflection for composites filled with olive and corn oil, respectively, was shown in Figures 12 and 13. According to these figures, adding 10% oil, whether olive oil or corn oil, results in a decrease in bending stress. These findings appear to be the result of the oil forming internal pores within the HDPE matrix.

It is also worth noting that composites including olive oil outperform those containing corn oil at 1.0 wt.% GO and a deflection of 25 mm. Under this condition, the bending stress of the olive oil sample was around 90 MPa, while the bending stress of the corn oil sample was lower, reaching 80 MPa.

CONCLUSIONS

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

1. As the GO concentration increases, the compressive and bending strength improves.
2. It was observed that oils reduce the compressive and bending strength of composites.
3. Composites involving olive oil have better mechanical properties over composites including corn oil.

REFERENCES

1. Geyer R., Jambeck J. R., Law K. L., “Production, use, and fate of all plastics ever made”, *Science Advances*, Vol. 3 , pp. 1 - 5, (2017) .
2. Lee C., Wei X., Kysar J.W., Hone J., “Measurement of the Elastic Properties and Intrinsic Strength of Monolayer Graphene”, *Science*, Vol. 321, pp. 385 – 388, (2008).
3. Balandin A.A., Ghosh S., Bao W., Calizo I., Teweldebrhan D., Miao F., Lau C.N.,

“Superior Thermal Conductivity of Single-Layer Graphene”, *Nano Letters*, Vol. 8, pp. 902–907, (2008).

4. Du X., Skachko I., Barker A., Andrei E.Y., “Approaching ballistic transport in suspended graphene”, *Nature Nanotechnology*, Vol. 3, pp. 491 – 495, (2008).

5. Stankovich S., Dikin D.A., Dommett G.H.B., Kohlhaas K.M., Zimney E.J., Stach E.A., Piner R.D., Nguyen S.T., Ruoff R.S., “Graphene-based composite materials”, *Nature*, Vol. 442, pp. 282 – 286, (2006).

6. Nair R. R., Blake P., Grigorenko A. N., Novoselov K. S., Booth T. J., Stauber T., Peres N. M. R., Geim A. K., “Fine Structure Constant Defines Visual Transparency of Graphene”, *Science*, Vol. 320, pp. 1308, (2008)

7. Net, A.H.C., Guinea F., Peres N.M.R., Novoselov K.S., Geim A.K., “The electronic properties of graphene”, *Reviews of Modern Physics*, Vol.81, pp.109–162, (2009).

8. Tripathi S.N., Rao G.S.S., Mathur A.B., Jasra R., “Polyolefin/graphene nanocomposites: A review”, *RSC Advances*, Vol. 7, pp. 23615–23632, (2017).

9. Salavagione H.J., “Covalent Graphene-Polymer Nanocomposites”, In *Graphene Materials. Fundamentals and Emerging Applications*, 1st ed., Tiwari A., Syväjärvi M. Eds., Scrivener Publishing: Beverly, MA, USA, pp. 101 – 149, (2015).

10. Toh G. Y., Ong H. L., Bindumadhavan K., Doong R. A., “Physicochemical properties of reduced graphite oxide conglomerated polyethylene nanocomposites”, *Polymer International*, pp. 1638 – 1647, Vol. 67, (2018).

11. Ren P. G., Wang H., Huang H. D., Yan D. X., Li Z. M., “Characterization and performance of dodecyl amine functionalized graphene oxide and dodecyl amine functionalized graphene/high-density polyethylene nanocomposites: A comparative study”, *Journal of Applied Polymer Science*, Vol. 131, pp. 39 - 48, (2013).

12. Kuila T., Bose S., Mishra A.K., Khanra P., Kim N.H., Lee J.H., “Effect of functionalized graphene on the physical properties of linear low density polyethylene nanocomposites”, *Polymer Testing*, Vol.31, pp. 31 – 38, (2012).

13. Quiles-Díaz S., Enrique-Jimenez P., Papageorgiou D.G., Ania F., Flores A., Kinloch I., Gómez-Fatou M., Young R., Salavagione H., “Influence of the chemical functionalization of graphene on the properties of polypropylene-based nanocomposites”, *Composites Part A: Applied Science and Manufacturing*, Vol. 100, pp. 31 – 39, (2017).

14. Tayebi M., Ramazani S. A. A., Mosavian M. T. H., Tayyebi A., “LDPE/EVA/graphene nanocomposites with enhanced mechanical and gas permeability properties”, *Polymers for Advanced Technologies*, Vol. 26, pp. 1083 – 1090, (2015).

15. Honaker K., Vautard F., Drzal L., “Investigating the mechanical and barrier properties to oxygen and fuel of high density polyethylene–graphene nanoplatelet composites”, *Materials Science and Engineering B*, Vol. 216, pp. 23 – 30, (2017).

16. Gaska K., Kádár R., Rybak A., Siwek A., Gubanski S.M., “Gas Barrier, Thermal, Mechanical and Rheological Properties of Highly Aligned Graphene-LDPE Nanocomposites”, *Polymers*, Vol. 9, pp. 294, (2017).

17. Papageorgiou D.G., Kinloch I.A., Young R.J., “Mechanical properties of graphene and graphene-based nanocomposites”, *Progress in Materials Science*, Vol. 90, pp. 75 – 127, (2017).

18. Potts J. R., Dreyer D. R., Bielawski C. W., Ruoff R. S., “Graphene-based polymer nanocomposites”, *Polymers*, Vol. 52, pp. 5 – 25, (2011).

19. Castelaín M., Martínez G., Ellis G. J., Salavagione H. J., “A versatile chemical tool for the preparation of conductive graphene-based polymer nanocomposites”, *Chemical Communications*, Vol. 49, pp. 8 - 17, (2013).

20. Castelaín M., Martínez G., Marco C., Ellis G.J., Salavagione H.J., “Effect of Click-Chemistry Approaches for Graphene Modification on the Electrical, Thermal, and

Mechanical Properties of Polyethylene/Graphene Nanocomposites”, *Macromolecules*, Vol. 46, pp. 8980 – 8987, (2013).

21. Cruz Aguilar A., Navarro Rodriguez D., Pérez Camacho O., Fernández Tavizón S., Gallardo Vega C. A., García Zamora M., Barriga Castro E. D., “High-density polyethylene/graphene oxide nanocomposites prepared via in situ polymerization: morphology, thermal, and electrical properties”, *Materials Today Communications*, Vol. 16, pp. 232 – 241, (2018).