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WEAR OF BIOCOMPATIBLE POLYMERIC COMPOSITES

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ABSTRACT
The main objective of this work is to study the effect of vegetables oils contents on the wear of high density polyethylene (HDPE) by adding 2.0, 4.0, 6.0, 8.0 and 10.0 wt. % of vegetables oils such as mint, avocado, watercress, castor, camphor, mustard, almond, clove, coconut and black seed oil to HDPE matrix before molding. The proposed composites can be used in hip joint or knee joint to reduce the friction and wear. After adding the oil, mixing with HDPE and molding then the test specimens were heated to 145 °C and quenched water.

It was found that wear decreased with increasing oil content down to minimum then increased with further oil content increase. The optimum oil content was 6.0 wt. %. The lowest wear values were observed for the composites filled by watercress and black seed oils. Those observations recommend the composites to be used as bearing materials at dry sliding applications such hip joints. While the highest wear was observed for composites filled by coconut oil.

KEYWORDS
High density polyethylene (HDPE), vegetables oils, wear.

INTRODUCTION
Total hip replacement has been widely acclaimed as the "Operation of the century", [1, 2]. Although multiple treatment modalities have been tried for treatment of hip arthritis, surgical treatment has been tried only in last 150 years. Total hip replacement (THR) is a surgical procedure in which a patient's vegetables hip joint is replaced with a prosthetic hip implant. Approximately 300,000THR surgeries are performed annually in the United States (2015 data [3]), and this number is projected to grow due to the increased prevalence of degenerative joint diseases such as arthritis, and the success of prosthetic hip implants in improving a patient's quality of life, [4]. A prosthetic hip implant typically comprises a femoral head component that is attached to a metal alloy stem fixated in the patient's femur, and articulates with an acetabular liner that is secured in an acetabular shell anchored in the pelvis, thus replacing the vegetables hip

joint function. Several material combinations are currently used in prosthetic hip implant bearings, including metal-on-polyethylene (Mop), ceramic-on-polyethylene (CoP), and ceramic-on-ceramic (CoC). In 2012, 56% of all prosthetic hip implants consisted of Mop and 35% of CoP bearings, [5]. This work specifically focuses on Mop Prosthetic hip implant bearings.

Implant is replaced with a new one, accounts for approximately 10% of all THR surgeries, has a higher number of complications for the patient than primary THR surgery, and is costly for the healthcare system, [6]. Therefore, reducing the number of revision surgeries is of critical importance. The most common causes of revision surgery are instability and dislocation of the prosthetic implant (22.5%), mechanical loosening (19.7%), and Infection (14.8%), [7]. It is well-documented that per prosthetic osteolysis attributed to polyethylene wear debris, among other things, can play a crucial role in each of these failure modes. Hence, polyethylene wear remains an important problem that must be addressed to further improve the longevity of Mop prosthetic hip implants.

Many researchers have attempted to increase the longevity of Mop prosthetic hip implants by improving the mechanical properties and wear resistance of the polyethylene acetabular liner or, alternatively, by changing the design of the prosthetic hip implant components. For example, highly cross-linking ultra-high molecular weight polyethylene (UHMWPE), and subsequently blending or infusing it with anti-oxidant materials such as vitamin E, has significantly reduced polyethylene wear and successfully increased the longevity of MoP prosthetic implants, [8–12]. Using new materials such as titanium and zirconia, [13–16], and manufacturing ultra-smooth bearing surfaces have also been implemented successfully, as indicated by the increased interest in CoP and CoC prosthetic hip implants [17–19].

In total hip replacement surgery, both the acetabular and femoral bearing surfaces are replaced with artificial material like metal, ceramic and/or polymeric components. Wiles performed first total hip replacement in 1938 in United Kingdom using a metal on metal combination, [20]. This was further developed by surgeons like Ring & McKee during the 1950s & 1960s. During the same period, Dr Ban Saw of erstwhile Burma replaced femoral heads of patients with femoral neck fractures with handmade ivory components achieving excellent results, [21]. The most significant development in evolution of THR bearing surfaces was the introduction of concept of low friction arthroplasty by Sir John Charnley in 1958, using metal on high-density polyethylene as bearing surface, [22]. The principles proposed by him remain relatively unchallenged till today despite rapid evolution of multiple facets of hip replacement surgery. In 1970, Boutin introduced the ceramic on ceramic articulation in THR for the first time, [23].

In the current work, the effect of vegetables oils contents on the wear of HDPE is studied. Vegetables oils such as mint, avocado, watercress, castor, camphor, mustard, almond, clove, coconut and black seed oil were added to HDPE matrix before molding.

EXPERIMENTAL

The material used in this study is HDPE that added to vegetables oils such as mint, avocado, watercress, castor, camphor, mustard, almond, clove, coconut and black seed oil. The test specimen were in cylindrical form of 8.0 mm and 20 mm length, while the oil content was 2.0, 4.0, 6.0, 8.0 and 10.0 wt. %, Figs. 1 and 2.

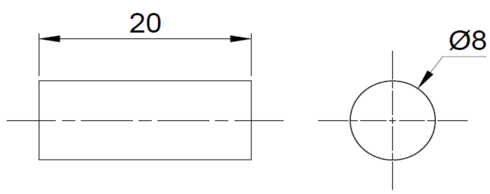

Fig. 1 shows specimen dimensions.

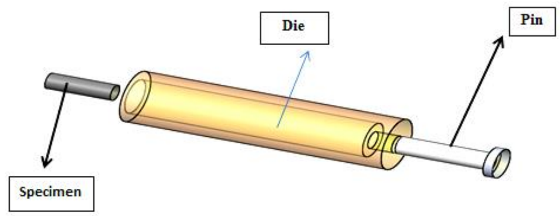

Fig. 2 Molding the test specimen.

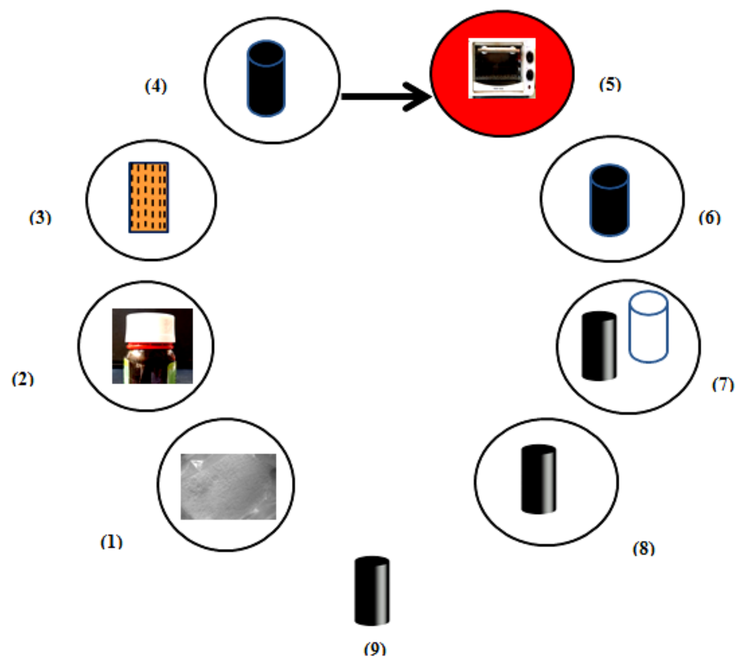

Fig. 3 Steps of preparing the tested composites.
1. Polyethylene, 2. Oil content 3. Mixing, 4. Packing, 5. Heating 6. Quenching, 7. Removing, 8. Grinding, 9. Final Specimen.

Wear tests were done by weighing the specimens before and after the test to measure the weight loss by digital balance, where the specimens were tested by making friction between specimens and stainless steel pin on disk test rig, Fig. 7. The sliding velocity was 0.5 m/s, while the load was 10 and 16 N for 300 seconds.

Fig. 4 Test specimen free of oil.

Fig. 5 test specimen filled by vegetables oil.

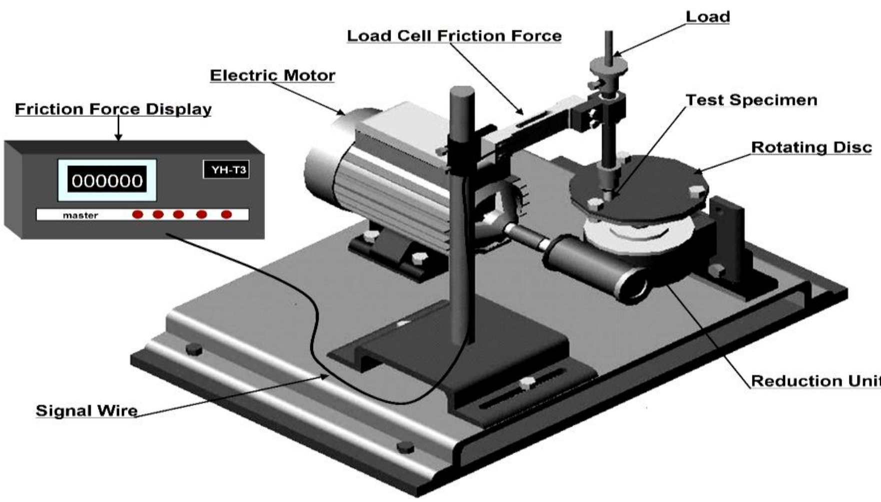

Fig. 6 Pin on disk test rig.

RESULTS AND DISCUSSION

Figure 7 shows the relationship between wear and mint oil content at 10 and 16 N. It can be noticed that wear decreased with increasing oil content. Wear at 16 N was higher than that observed for 10 N. Wear showed consistent trend with increasing oil content At 16 N. When the tested composites slid on steel surface, the contact area was divided into two parts. The first was the contact between polymer and steel, while second was covered by the oil film that separated the two sliding surfaces. As the oil content increased, wear due to the presence of oil film covering the contact area decreased. Adhesion of polymer into steel surface decreased with increasing oil content. Increase of wear may be attributed to the low compressive strength of the matrix due to the presence of oil.

Wear of composites filled by avocado oil showed lower values than that observed for HDPE filled by mint oil. It can be noticed that wear decreased with increasing oil content down to minimum at 6.0 wt. % oil content then increased with further oil increase, Fig. 8. It seems that oil increase made the bond between the HDPE grains

weaker. It seems that wear decrease was displayed due to oil transfer from the pores of the specimen to the counterface forming a thin layer, which was responsible for the wear decrease.

The lowest wear values were observed for the composites filled by watercress oil, Fig. 9. It is clear from the figure that the optimum oil content was 6.0 wt. %. This behavior may be attributed to increase of oil squeezed from surface of the test specimens. The adhesive force of oil molecules into the sliding surfaces depends on the polarity of oil molecules, where vegetables oils have polar molecules. Polar molecules will form multilayers, which strengthen the adhesion of oil into the solid surface. Polarity of oil influences the thickness of oil film. Further increase in oil content caused slight wear increase.

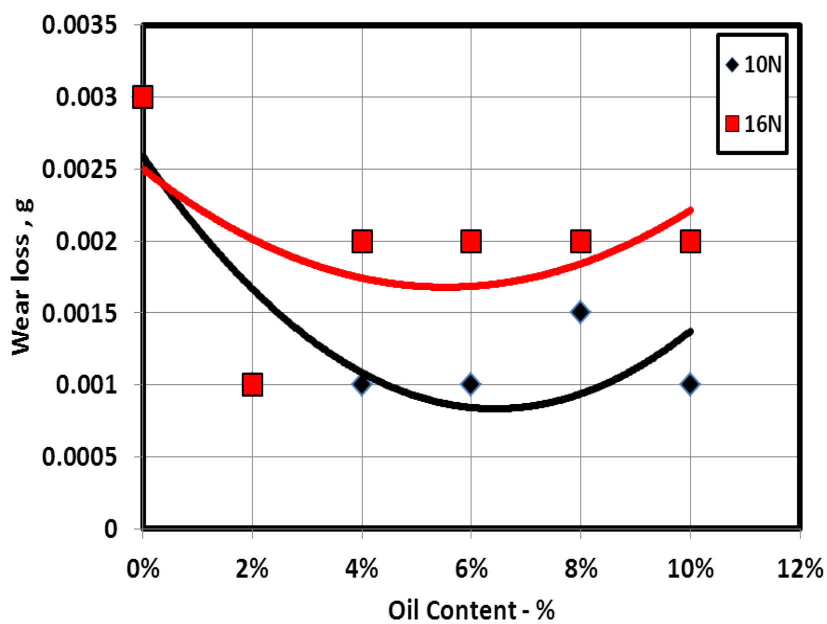

Fig. 7 Effect of mint oil content on wear of the composites.

Wear behavior of HDPE composites filled by castor oil and camphor showed the same trend observed for mint, avocado and camphor oils, Figs. 10 and 11 respectively. Wear values were higher than that observed for watercress oil filled composites. This may be referred to the presence of oil in multipores inside the polymer matrix, where they work as reservoirs of oil from which it leaks up to the sliding surface and causes wear decrease. Presence of oil decreases wear due to the film formed on sliding surface, where the contact will be between partially polymer composites/steel and oil/steel due to the mixed lubrication regime offered by the oil film.

The relationship between wear and mustard oil content is shown in Fig. 12. As shown, slight decrease in wear was observed with increasing oil content down to minimum. This may be attributed to the lubricating mechanism provided by oil during sliding. Also, it can be noticed that wear displayed lower values than that presented by composites free of oil. This observation can confirm that oil can decrease wear. The lowest wear value was observed at nearly 6.0 wt. % oil content.

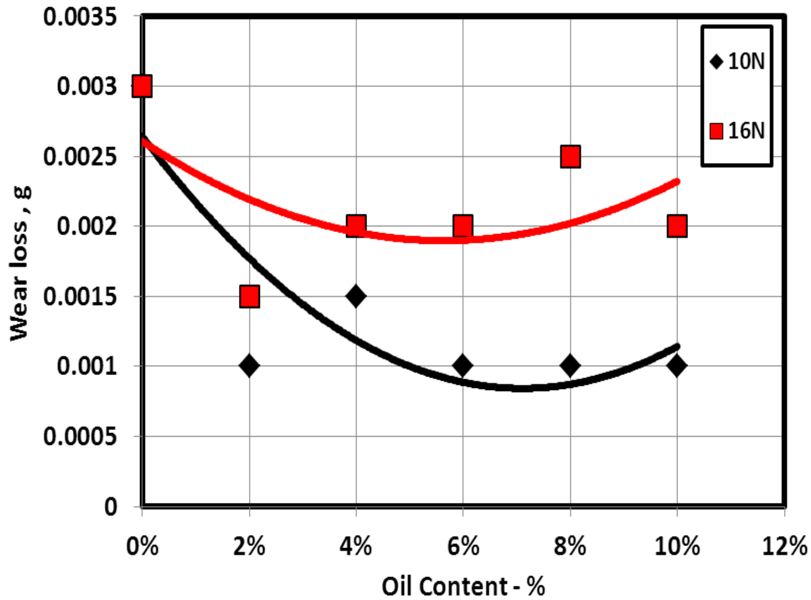

Fig. 8 Effect of avocado oil content on wear of the composites.

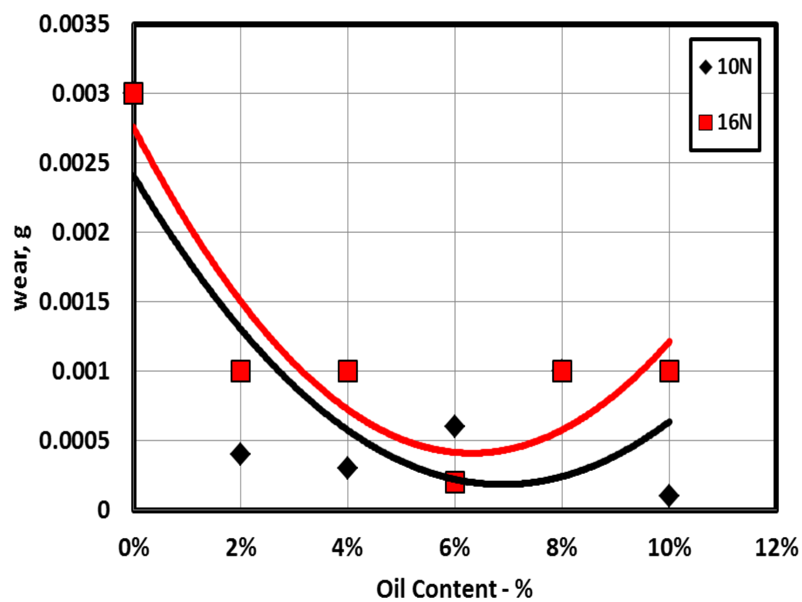

Fig. 9 Effect of watercress oil content on wear of the composites.

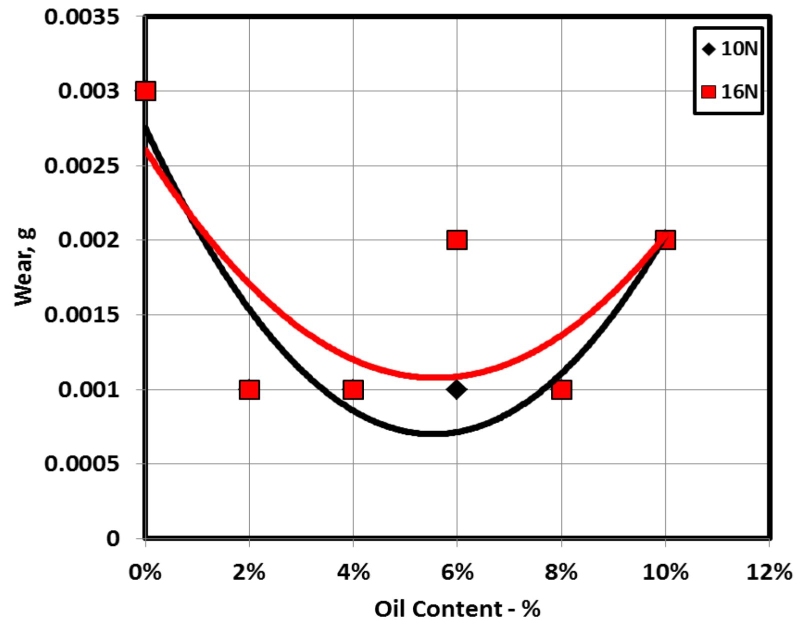

Fig. 10 Effect of castor oil content on wear of the composites.

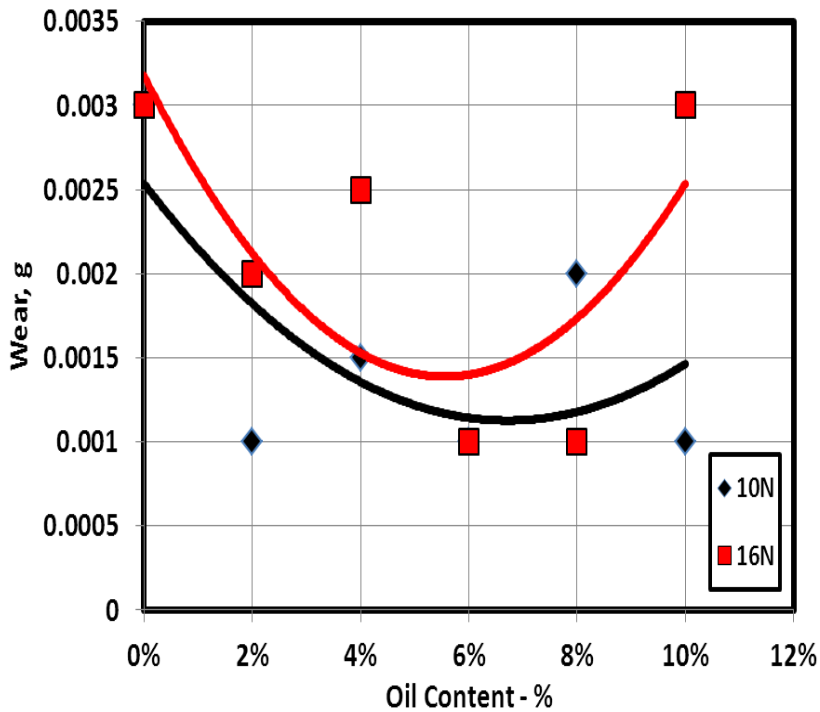

Fig. 11 Effect of camphor oil content on wear of the composites.

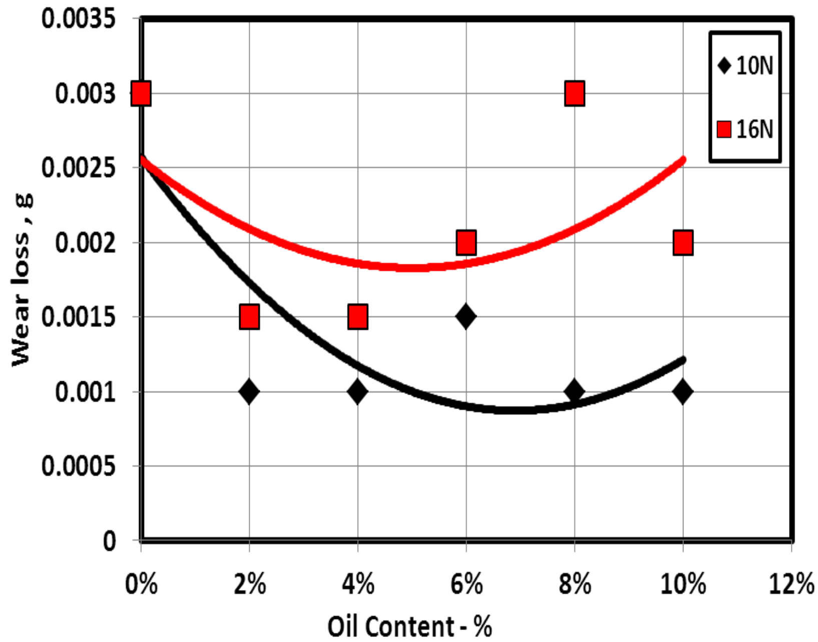

Fig. 12 Effect of mustard oil content on wear of the composites.

Based on the findings in the present work, it can be noticed that the presence of oil provided the sliding surface by a uniform oil film that isolated the contacting asperities of the sliding surfaces from excessive wear. Besides, high shear tearing and transfer of polymer to the steel surface were diminished due to the oil film. Wear decrease may be attributed to oil transfer from polymer matrix to the sliding surface forming a thin layer that decreases the shear force exerted at the sliding surfaces. The results of wear values recommend the proposed composites to be used as bearing materials at dry sliding applications such hip joints. The effect of almond oil content on wear of the composites is illustrated in Fig. 14, where higher load (16 N) revealed the proper oil content than the lower load.

Filling the polymer by cloves oil displayed drastic decrease in wear that was attributed to the adhesion of oil molecules into the sliding surfaces, Fig. 15. It was proved that the oil is trapped in pores after solidification of the polymer, [24 - 30]. Those pores are working as reservoirs feeding the oil into the sliding surfaces and forming oil film on the contact surfaces. The film was fed by the oil stored inside the pores in the polymer matrix. The strong adhesion of the oil molecules experienced boundary lubricating film in which a low shear interfacial layer was formed on the sliding surfaces and easily removed by the shear instead of the contacting asperities. It is worthy to mention that due to the polarity of vegetables oils, the adhesion of their molecules into the sliding surfaces will be relatively stronger, where polar molecules will form multilayers, which strengthen the adhesion of oil into the sliding surfaces.

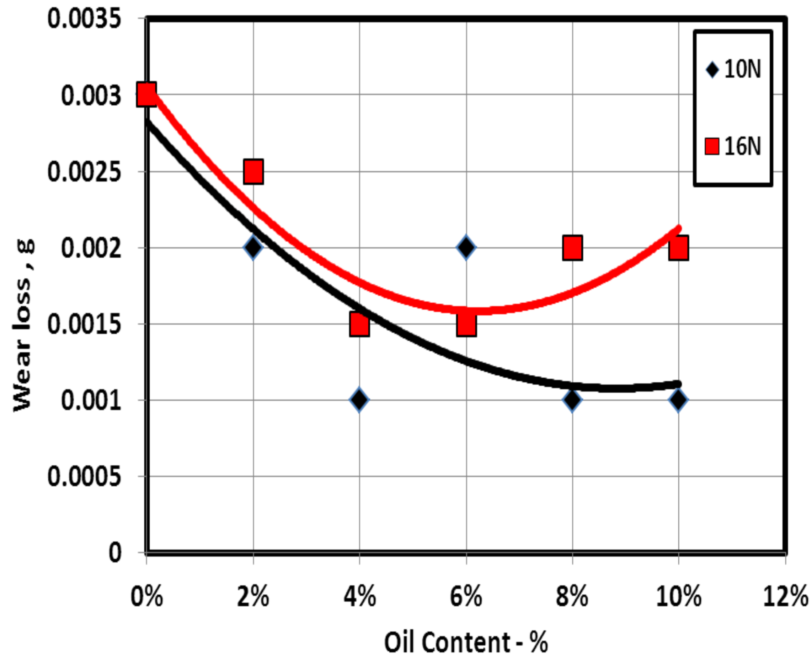

Fig.14 Effect of almond oil content on wear of the composites.

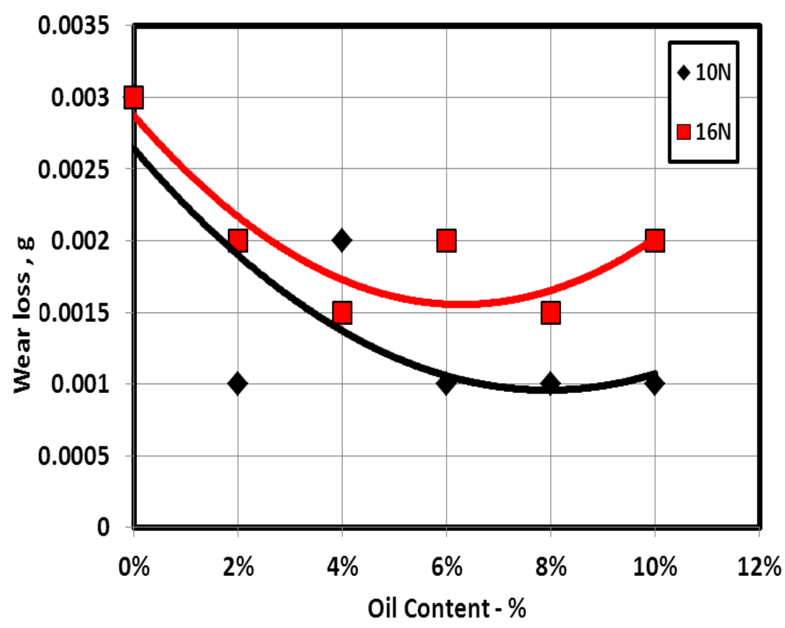

Fig. 15 Effect of cloves oil content on wear of the composites.

Filling the matrix by coconut oil displayed the highest wear values, Fig. 16. This may be referred to that the polarity of coconut oil was not enough strong to enable the molecules to be adhered into the sliding surfaces.

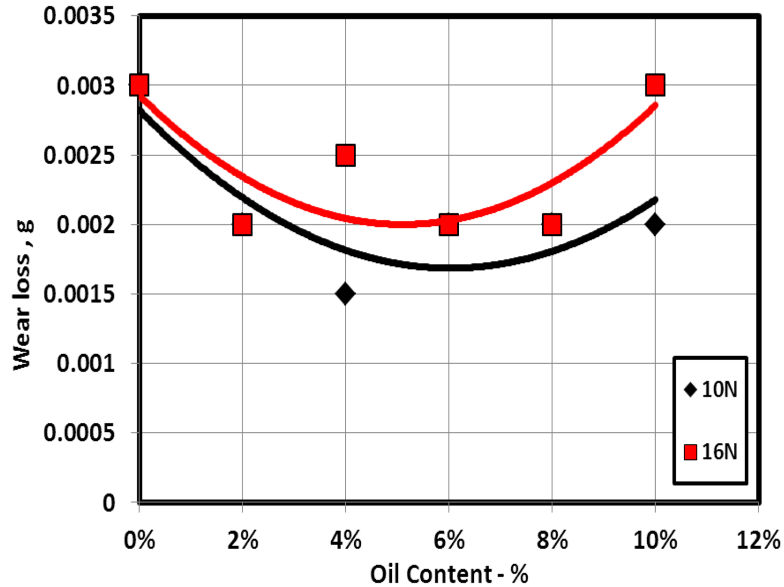

Fig. 16 Effect of coconut oil content on wear of the composites.

The relationship between wear and black seed oil content for composites reinforced by oil is shown in Fig. 17. It is noticed that a drastic decrease in wear was observed with increasing oil content. This behavior is attributed to the increase of wear resistance of composites because of oil. The improvement of the wear resistance of composites was due to the oil reinforcing polymer matrix. Besides, presence of oil decreased wear due to the film formed on sliding surface. As shown from figure that the lowest value of wear was observed at 6.0 wt. % oil content. It is noticed that wear values were lower than that observed for composites filled by coconut oil. The self-lubricating mechanism of the proposed composites during sliding depends on the oil adhesion on the steel surface.

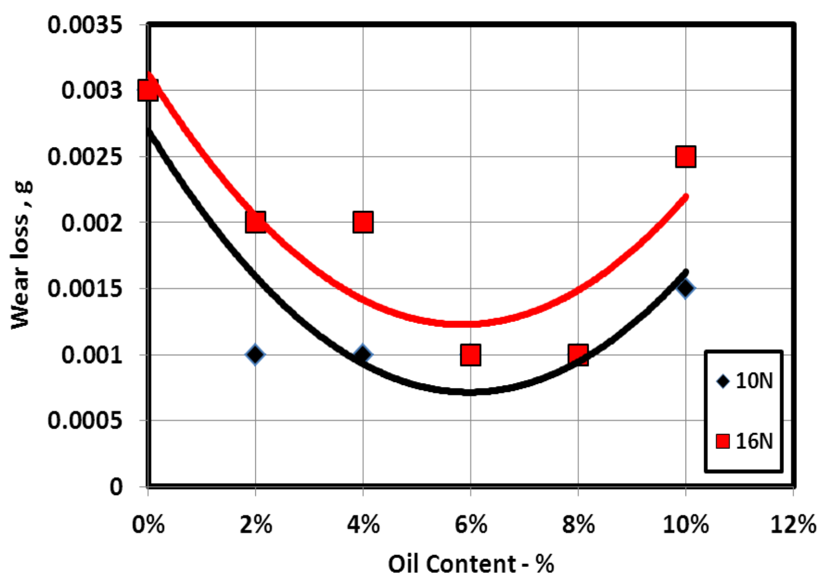

Fig. 17 Effect of black seed oil content on wear of the composites.

CONCLUSIONS

Wear decreased with increasing oil content down to minimum then increased with further oil content increase. The optimum oil content was 6.0 wt. %. The lowest wear values were observed for the composites filled by watercress and black seed oils, while the highest wear was observed for composites filled by coconut oil.

The mechanism of action of the oil that was trapped in pores after solidification of the polymer is adhered into the sliding steel counterface. Those pores are working as reservoirs feeding the oil into the sliding surfaces and forming oil film on the contact surfaces. The film was fed by the oil stored inside the pores in the polymer matrix. The strong adhesion of the oil molecules experienced boundary lubricating film in which a low shear interfacial layer was formed on the sliding surfaces and easily removed by the shear instead of the contacting asperities. It is worthy to mention that due to the polarity of vegetables oils, the adhesion of their molecules into the sliding surfaces will be relatively stronger, where polar molecules will form multilayers, which strengthen the adhesion of oil into the sliding surfaces.

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