EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
*VOLUME 16, No. 3, July 2019, pp. 1 - 14* ISSN 2090 - 5882
(Received March 11. 2019, Accepted in final form May 05. 2019) www.egtribjournal.com

# INFLUENCE OF FILLING MEDIUM DENSITY POLYETHYLENE BY ALMOND OIL AND TALC ON FRICTION AND WEAR

**Mahmoud K. H.[1] and Khashaba M. I.[2]**

[1]Mechanical department, Al-Ameeria Integrated Technical Education Cluster, Cairo, Egypt.
[2]Production Engineering and Mechanical design department, Faculty of Engineering, Minia University, Minia, Egypt.

## ABSTRACT
**The present study aims to investigate wear and friction properties of composite of medium density polyethylene MDPE, 15 wt. % almond oil, and talc powder. Also, to investigate wear and friction properties of composite of MDPE filled by talc powder. First, MDPE was filled with talc powder at contents of 5, 10, 15, and 20 wt. % and then results were recorded. After that MDPE was blended with 15 wt. % almond oil and different weight contents of Talc powder: 5, 10, 15, and 20 wt. %. All composites were tested using pin-on-disc. Five loads were applied during test: 12 N, 14 N, 16 N, 18 N, and 20 N.**

**It was observed that filling MDPE with talc showed improvement of wear resistance. It showed also less friction at loads of 14 N, 16 N, 18 N, and 20 N. Talc increased MDPE hardness slightly. Addition of 15 wt. % almond oil to talc improved wear resistance of MDPE. However, an increasing in friction was observed. This composite showed hardness lower than unfilled MDPE and higher than MDPE filled with almond oil. Almond oil of 15 wt. % content achieved the best result of wear resistance. This composite achieved the lowest wear. Scanning electron microscope SEM micrographs showed formation of transfer films on specimens' surfaces. These transfer films interpreted the results of wear and friction obtained.**

## KEYWORDS
**Polyethylene, almond oil, talc, pin-on-disc, and scanning electron microscope (SEM).**

## INTRODUCTION
**Polyethylene (PE) is polarized Ethylene (CH2=CH2). Ethylene is the simplest olefin that may be polymerized through the action of initiators and catalysts, [1]. Polyethylene PE is widely used in many different industrial and medical applications. PE exhibits good resistance against biological attack [2]. For example, Ultra-high Molecular Weight Polyethylene UHMWPE is used for manufacturing of components of artificial replacement joints "prosthesis joints". Low Density Polyethylene LDPE is used for manufacturing of some types of cable insulations and pipes. High (HDPE) and Medium (MDPE) Density Polyethylene are used for manufacturing of bottles of domestic applications, grocery sacks, cable insulations, pipes etc. UHMWPE, HDPE, and MDPE have long linear molecular chains, but UHMWPE have chains longer than HDPE and MDPE. So the molecular weight of UHMWPE is greater than molecular weight of HDPE**

**AND MDPE. The molecular weight affects the degree of crystallinity which can be achieved within a material, [3].**

**Enhancing polymers with talc powder was a successful choice by many authors. Talc is an industrial raw material used in many industrial applications because of its unique physical and chemical features. It is a layered, hydrous magnesium silicate with the chemical formula of $Mg_3(Si_2O_5)_2(OH)_2$ and the theoretical chemical composition of 63.5 wt.% of $SiO_2$, 31.7 wt.% of MgO, and 4.8 wt.% of $H_2O$, [4]. Nasrin Parvin et al. [5] investigated the properties of PE after blending fillers with it. They reported that filling of HDPE with Talc and carbon black, at certain extent, increase both Young's modulus and microhardness. Boon Peng Chang et al. [6] reported that wear rate and friction coefficient decreased as talc content in UHMWPE increases. They also found that the hardness of composite increased slightly at certain extent.**

**The blends of polyphenylene oxide/ultrahigh molecular weight polyethylene and polystyrene/ultrahigh molecular weight polyethylene were prepared, [7]. The wear test was conducted then they found that blend of 90/10/0, compared with other ratios, was the optimum ratio which achieved the lowest wear rate and friction coefficient. One of attempts, to improve tribological behaviors, was by lubricating the surface of test with paraffin and vegetable oils such as almond, castor, corn, glycerine, jasmine, olive and sun flower oils were used as lubricants in presence of magnetic field and then pin-on-disc test has been applied. The test using lubricated disc resulted wear and friction lower than this dry one, [8]. Reinforcing UHMWPE, used for artificial human joints, with hydroxyapatite (HA) enhanced both mechanical and tribological properties. HA facilitated biological fixation between the implant and the human cells, [9].**

**Improving of the frictional properties of injection moulded thermoplastics using tribological additives were studied by J. L.Laursen et al. They studied influence of tribological additives, polydimethylsiloxane and polytetrafluoroethylene (PTFE), on friction and impact properties of polyacetal (polyoxymethylene). The test were conducted through ring-on-disc testing against polypropylene (PP) to simulate use-conditions in a particular medical device. It was found that additives effectively reduced the friction, [10]. Blending of 10 wt. % of carbon nano-fibres (CNF) with UHMWPE revealed the significant potential of dispersed carbon nano-fibres to reduce the wear rate of this polymer. The wear test was against a disc of 100Cr6 steel, [11]. Blending some types of polymers with each other may achieve good mechanical and tribological behaviors. M. Palabiyik and S. Bahadur studied the mechanical and tribological behaviors of polyamide 6 (PA6) and HDPE polyblends made using maleic anhyride polypropylene PP as the compatibilizing agent. The compositions investigated for tribological behavior were 80 wt. % PA6–20 wt.% HDPE and 60 wt.% PA6–40 wt.% HDPE. They reinforced polyblends with glass fiber (GF) and filled with PTFE and copper oxide (CuO) The minimum wear and friction coefficient were obtained at blending of 10% wt. PTFE, [12].**

**Michel Wathier et al. created a polymer acts as a lubricant in the human joints. The polyanion, sodium poly (7-oxanorbornene-2-carboxylate), is synthesized by ring-opening metathesis polymerization of methyl 5-oxanorbornene-2-carboxylate. When dissolved in aqueous solution and applied to the surface of human cartilage it reduces the friction at the interface and acts as a lubricant. The advantage of this polymer created remains in the joint for more than two weeks whereas leading synovial fluid supplement may last one or two days, [13]. Some additives can resist both wear and corrosion. Wenchao Pang**

**et al. investigated tribological properties of graphene oxide GO reinforced UHMWPE under artificial seawater lubricating condition. They found that wear rate decreased with increasing of GO addition, [14]. Tribological behaviour of nanodiamond reinforced UHMWPE in water-lubricated contacts was studied by Arash Golchin et al. Incorporation of 1 wt% nanodiamond in the polymer matrix achieved a significant reduction of 72% in wear and 24% in friction of UHMWPE, [15]. A study by M. J. Sheykh et al. evaluated the effect of nano-SiO2 (at 2 and 3 wt. %), rice husk and bagasse ash (at 5 and 10 wt.%) on the wear resistance and friction coefficient of HDPE (high-density polyethylene)/lignocellulosic fiber composites. This study found that the fillers improved the wear resistance noticing that the nano-SiO2 possess more effect, [16]. An old attempt to reduce the wear of UHMWPE in total joint replacements was through Crosslinking of UHMWPE by ionizing radiation. This attempt was based upon the theory of orientation softening, [17].**

**The previous results reveal that: polymers reinforced with organic or inorganic materials, e.g. talc, improved both mechanical and tribological behaviors. Furthermore, in presence of oil as a lubricant, the tribological behaviors can be enhanced. As a result, blending some oils with a polymer can produce a self-lubricating bearing material. Vegetable oils are much recommended for this purpose. Vegetable oils are good lubricants due to its amphiphilic properties. The amphiphilic properties resulted from the fatty acid composition of vegetable oils contribute to a better lubricity and effectiveness as anti-wear compounds than mineral or synthetic lubricant oils. However, limited viscosities of these oils constrain the use of them in many industrial application [18]. So the addition of some chemical additions (like ethylene–vinyl acetate copolymer (EVA)) to vegetable oils (like Soy oil) can increase their viscosities and improve their tribological properties, L. Quinchia et al. reported [18], or blending these oils with bearing materials to be self-lubricated "as discused in this search".**

**A. E. Delgado-Tobón et al. The search compared two mineral oils, have contrasting viscosity and no additives, with Almond oil. The instrument test was four-ball tribometer. It was found Almond oil has greater lubricity than the two mineral oils. Almond oil showed better performance under extreme pressure conditions and a greater weld point than mineral oils. An FTIR spectroscopic analysis determined that, under the conditions of the current tests, Almond oil does not oxidize, [19]. Vegetable-oil-based polymers, like polyurethane, have excellent biocompatibilities with unique properties, [20]. Based on another searching paper, by the same authors of this paper, Almond oil (at 15% and 20% weight content) achieved noticeable and important results concerning of resisting wear.**

**This study aims to fill MDPE with different weight contents of talc powder and almond oil to investigate wear and friction properties of MDPE. Almond oil content will be kept 15 wt. % for all composites.**

## EXPERIMENTAL

### Materials and Compositions

**Materials used are Medium Density Polyethylene (MDPE) with almond oil and talc commercial (see Table1 and Table 2). MDPE (supplied by Ethydco Egypt, code: EM-3405-UVH) has the following characteristics: density 0.934 g/cm3, melt index (190 ˚C / 2.16 Kg) 5.0 g /10 min, yield strength 14 MPa. The composites of MDPE with Talc powder were as shown in Table 1. The composites of MDPE with Almond oil and Talc were as shown in Table 2.**

Table 1: composition of MDPE with different contents of Talc.

| Polyethylene PE% | Talc % |
|---|---|
| 100 | - |
| 95 | 5 |
| 90 | 10 |
| 85 | 15 |
| 80 | 20 |

Table 2: Composition of MDPE with the Almond oil and different contents of Talc.

| Polyethylene PE% | Almond Oil % | Talc % |
|---|---|---|
| 100 | - | - |
| 80 | 15 | 5 |
| 75 | 15 | 10 |
| 70 | 15 | 15 |
| 65 | 15 | 20 |

## Composites Preparation

**Composites were produced using a hot mold as shown in Fig. 2.1. A pressure of about 2 MPa was applied (see fig. 2.1). Different loadings of oil, for each oil, were mixed homogeneously with MDPE using a turbine mixer. Specimen were heated up to 180~190 ˚C for 8 min with continuous pressing. The mold was cooled in water at about 18 ˚C. Fig 2.2 shows specimens after getting out of the mold.**

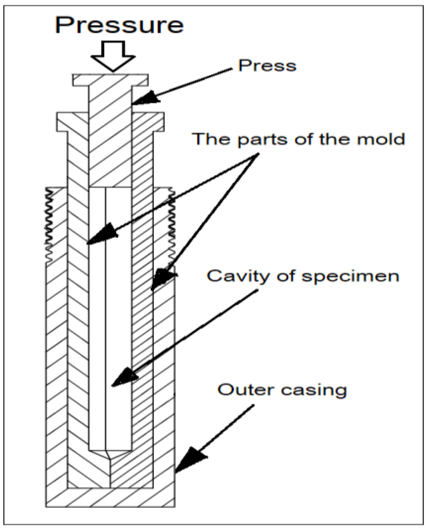



Fig. 2.1 Hot compressed mold.

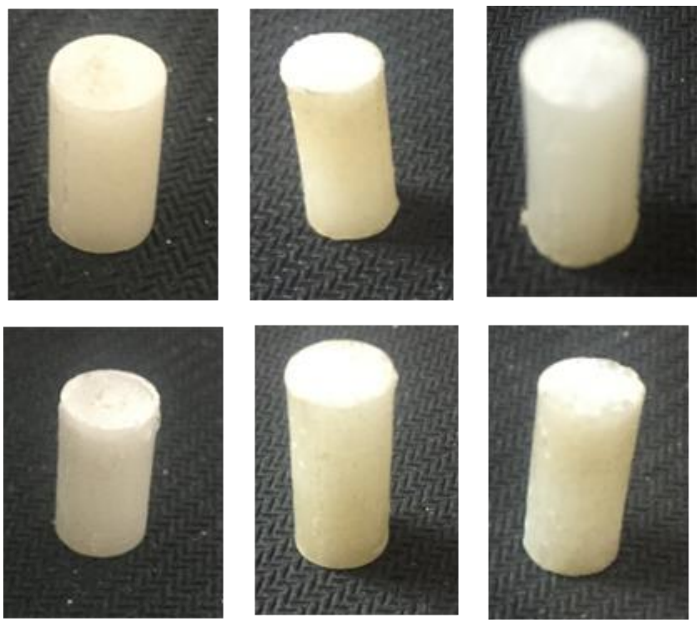


Fig. 2.2 Test specimens after molding.

## EXPERIMENTAL

### Tribological Test

**Tribological Test was done according to ASTM G99 method using pin -on-disc tester (Fig. 2.4). The disc dimensions are, 4 mm thickness and 150 mm outer diameter. The track diameter is 75 mm. As mentioned, dimensions of pin (polymer specimen) are, 30mm length and 8 mm diameter. The material of disc is a polished stainless steel 316. The rotation speed disc was 250 rpm. Each test was carried out for 7 minutes under laboratory conditions of (~22˚C and ~ 10% humidity).**

**The weight loss "wear" was determined by the following equation:**

$$wear = m_b - m_a$$

**where $m_b$ is mass of specimen before test and $m_a$ is mass of specimen after test. The mass was weighed by a sensitive balance (readability: 0.1 mg, capacity 200g, supplied by YMC Co., Ltd, Japan) show in Fig. 2.4.**

**The dynamic friction coefficient $\mu_d$ was determined using the following equation:**

$$\mu_d = \frac{F_d}{F_n}$$

**where, $F_d$ is the frictional dynamic force, and $F_n$ is the normal force. There was five loads used as a normal force: 12, 14, 16, 18, and 20 N. These loads were applied with each oil weight content.**

**Fig. 2.3 Electronic balance.**

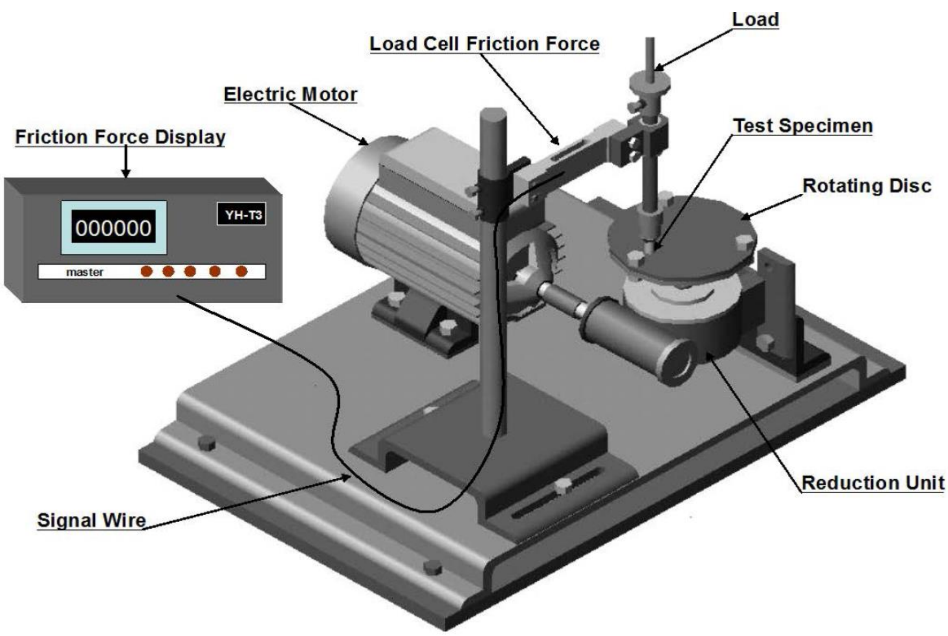



**Fig. 2.4 Pin-on-disc instrument tester.**

**Test specimens**

**Specimens of each composition were prepared in dimension of 30cm length and 8mm diameter. For every composition, three specimens were tested and the average of the three were reported. The hardness test was conducted according to the ASTM D2240 method with shore D hardness tester (fig. 2.5). The hardness test were conducted on three different positions on specimen worn surface. (See Fig. 2.6).**


**Fig. 2.5 Shore D hardness tester.**

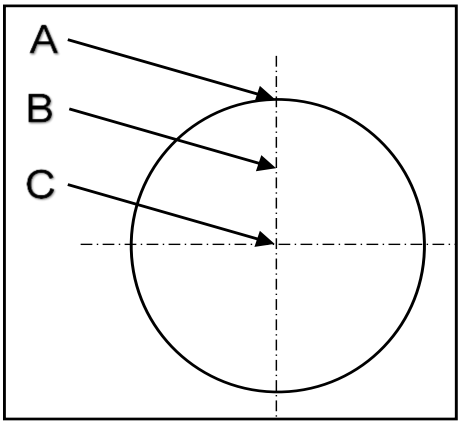



**Fig. 2.6 The positions where hardness was measured.**

**SEM Microscopy**

**The worn surface was coated by a very thin layer of gold using Magnetron Sputtering Coater instrument. This is called "sputtering process". This process aims to prevent electrical charging on the surface of specimen. After that, the surface was scanned by a Scanning Electron Microscope SEM (JSM-IT200, Japan) at acceleration voltage of 5.0 kVolts.**

**RESULTS AND DISCUSSION**

**The effect of filling MDPE with dry talc compared to the pure one and that is filled with almond oil is shown in Fig. 3.1. The results show a significant improvement of friction. The friction trend tends to decrease as Talc content increases at all different loads. Comparing pure MDPE to this enhanced with dry talc, the results show that wear resulted from MDPE enhanced with dry talc is lower than that resulted from pure MDPE at all different loads. The friction decreased obviously at all loads compared to its value for MDPE-almond oil composites.**

**MDPE filled with 15 wt. % Almond oil content achieved the lowest wear and the highest friction. However, it can be observed that at some loads MDPE-talc composite can be a suitable replacement for MDPE-almond oil composite to reduce the friction with preserving the wear amount at the same level or nearby. For example, 10% Talc content can be a good alternative for 15% Almond oil at 12 N with the same wear value "0.23 mg".**

**The effect of filling MDPE with almond oil and talc compared to the pure one and that is filled with almond oil is shown in Fig. 3.2. When looking at wear results for composite of MDPE-almond oil-Talc, it can be found that composite of 75%-15%-10% achieved lower wear at most of loads.**

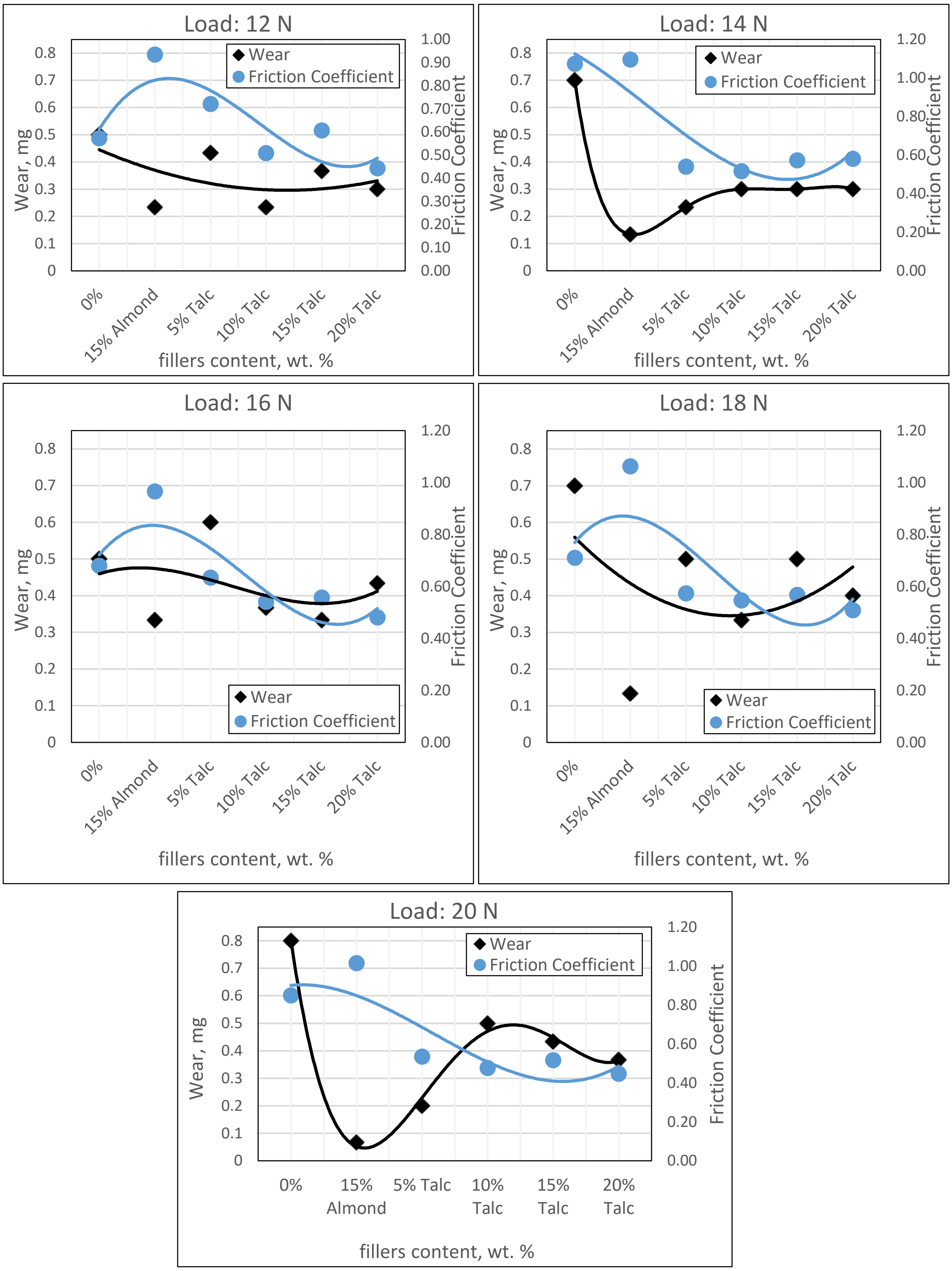



**Fig. 3.1 wear and friction coefficient against Almond oil and powder Talc content.**

**That composite displayed friction lower than observed for MDPE-15% almond oil composites. When looking at wear results for composite of MDPE-Almond oil-Talc, it can be found that composite of 75 wt. %-15 wt. %-10 wt. % achieved lower wear. MDPE-**

**15% Almond oil composite still generally shows wear resistance better than other composites.**

**As shown in Fig. 3.3.a, the hardness slightly increases as talc content increases. Fig. 3.3.b shows that increasing almond oil and Talc content in MDPE slightly raises the hardness value. But at all filler contents the hardness values are still lower than the hardness of pure MDPE. The hardness trend of MDPE filled with almond oil tends to decrease as the oil content in this polymer increases, see Fig. 3.3.c. This is because presence of oil inside the polymer matrix makes the polymer matrix less homogeneous. Also a new compound of polymer and oil that may have introduced during preparation can affect bonding of polymer matrix. However, presence of talc adds a simple enhancement for MDPE matrix raising its hardness as shown in Fig. 3.3.b.**

**It is thought that non regular behaving may be attributed to two key reasons. First, non-homogeneity of composites. There is great gap between melting point of PE and decomposition temperature of Talc. Talc's decomposition temperature is about 800˚C [21]. Second, PE is classified as a semi-crystalline polymer. PE is sensitive to heat treatment. It plays a key role in crystallinity degree of PE, [22]. The approach of mixing it with other material fillers can affect its crystallinity, [23]. So even preparing approach and heat resulted from test can affects the results.**

**Micrographical Properties**

**Investigation of topography of composite material can interpret its behavior. It also provides the desired mechanical properties. SEM micrographs showed the morphology of worn surface of tested specimens.**

**Oluyemi O. Daramola et al. [24] reported that composites change the morphology of PE and consequently change the surface properties. SEM micrographs reported that the surface of pure MDPE (fig. 3.4) seems relatively smoother than MDPE filled with different oils.**

**The transfer film produced due to wear plays a key role in wear resistance. SEM micrographs show the shape of worn particles which are forming a part of the transfer film produced.**

**Fig 3.5 indicates the worn surface of MDPE filled with talc powder. In this figures arrows point to the regions rich with talc. The image can interpret decreasing the wear resulted from MDPE filled with talc. Talc formed what can called a cushion layer acted as a lubricant that helped more to reduce both wear and friction. Image shows that Talc is distributed in somewhat non exemplary way. However, just its presence improved wear resistance and friction behavior of MDPE. Image indicates a worn surface with little dislocated rubbed particles from the surface in presence of Talc.**

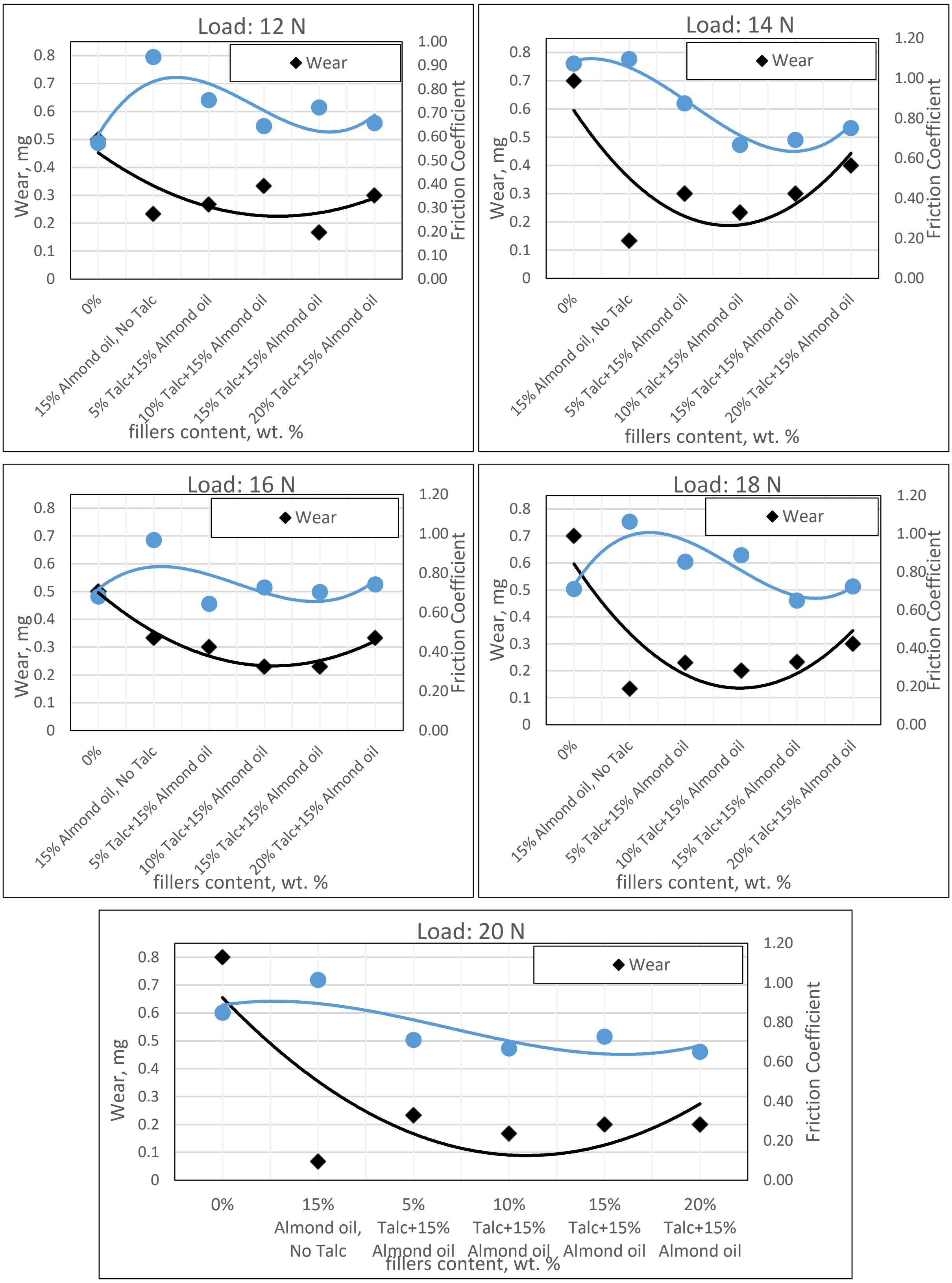
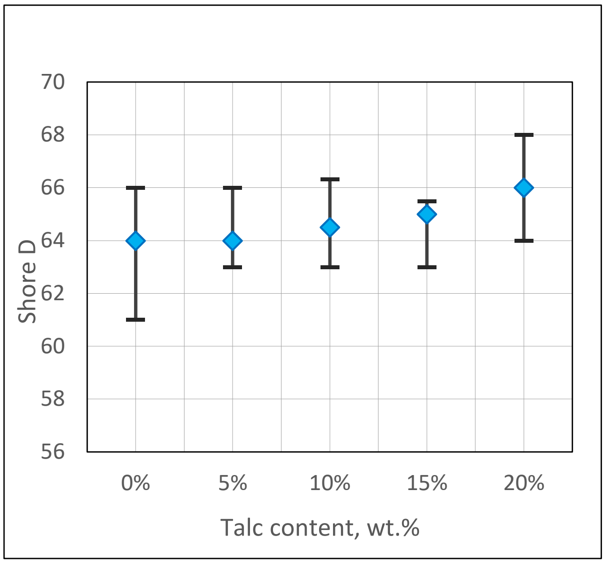
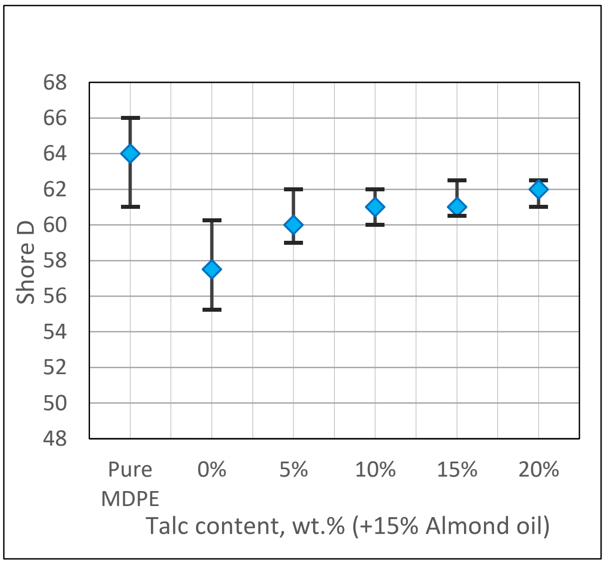


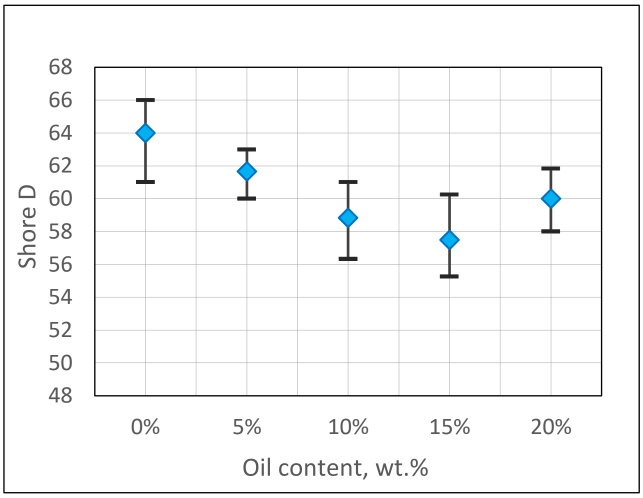

**Fig. 3.2 wear and friction coefficient against Almond oil and Talc with Almond oil content.**




(a)




(b)




(c)

**Fig. 3.3 The hardness shore D of (a) MDPE filled with dry Talc powder (b) MDPE filled with Talc powder and Almond oil (c) MDPE filled with Almond oil.**

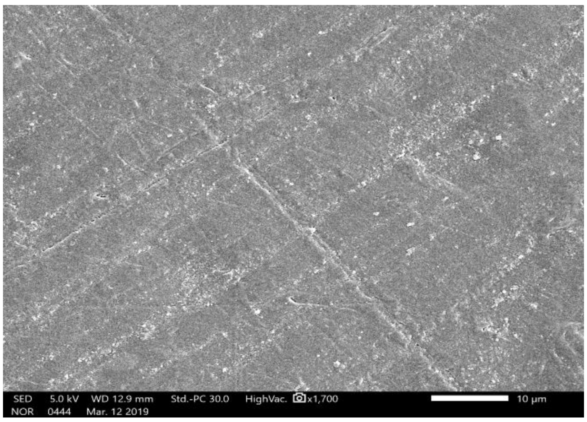



**Fig. 3.4 SEM micrograph of pure MDPE.**

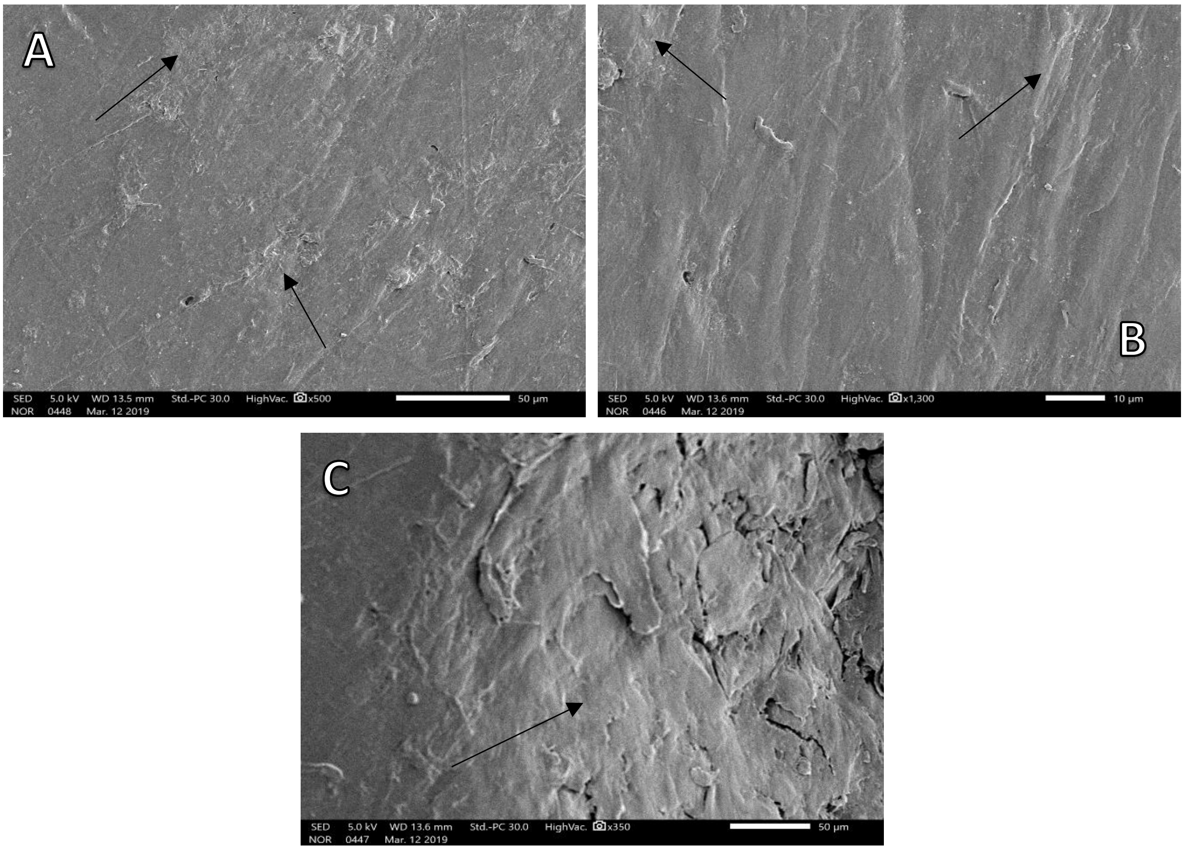



**Fig. 3.5 SEM micrograph of MDPE filled with dry powder talc.**

**Comparing surface of MDPE filled with Talc and that filled with Talc and Almond oil (fig. 3.6), it can be found that both surfaces are relatively similar. The different seems in transfer film. It seems that oil helped in improving distribution of Talc in polymer matrix. A new compound may have created of Talc, MDPE, and Almond oil. This compound has good wear resistance properties with higher friction. This may interpret the friction and wear results.**

**R. H. Ewell et al., [21] found that Talc loses more than 1 molecule when exposing to temperature equal to or more than 380˚C without any change in crystal structure or optical properties up to 500 ˚C. The authors concluded that their data support the hypothesis of Foshag and Wherry that water in talc in excess of 1 molecule is not constitutional and may be held' electrostatically between basal cleavage planes.**

**The temperature of test and the thermal conductivity of oil, which is great, may have resulted in domination of a weld mechanism between some of Talc particles and the polymer in presence of the water driven off the Talc. This weld may have restricted a part of ability of Talc to reduce the friction.**

**All SEM micrograph (Fig. 3.6 and Fig. 3.7) show obviously cavities on the surface (circled on the figures). These cavities can interpret indicating oil film on the friction disc during test. The scenario supposed may be that: pressure on the specimen resulted adsorbing oil preserved in cavities through the polymer matrix. The worn surface of pure MDPE**

**produced due to friction seem different from this of MDPE oil filled. The worn surface of pure MDPE produced due to friction seems different from this of MDPE oil filled. Comparing SEM micrograph of pure MDPE (Fig. 3.4) to micrographs of MDPE oil blended would show that plastic deformation of MDPE oil filled is higher than pure MDPE. However, MDPE oil filled showed wear resistance more than other composites at most of loads.**

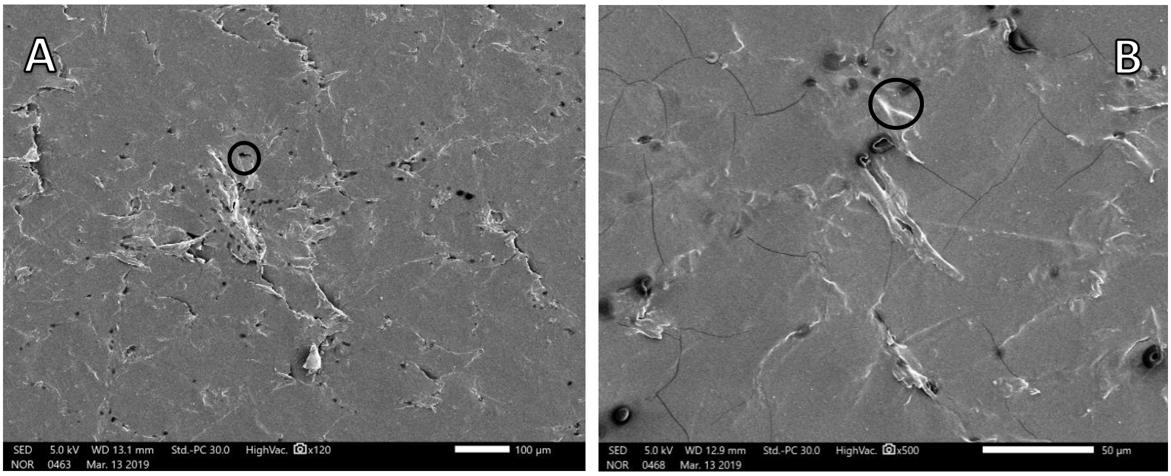



**Fig. 3.6 SEM micrograph of MDPE filled with powder Talc and Almond oil**

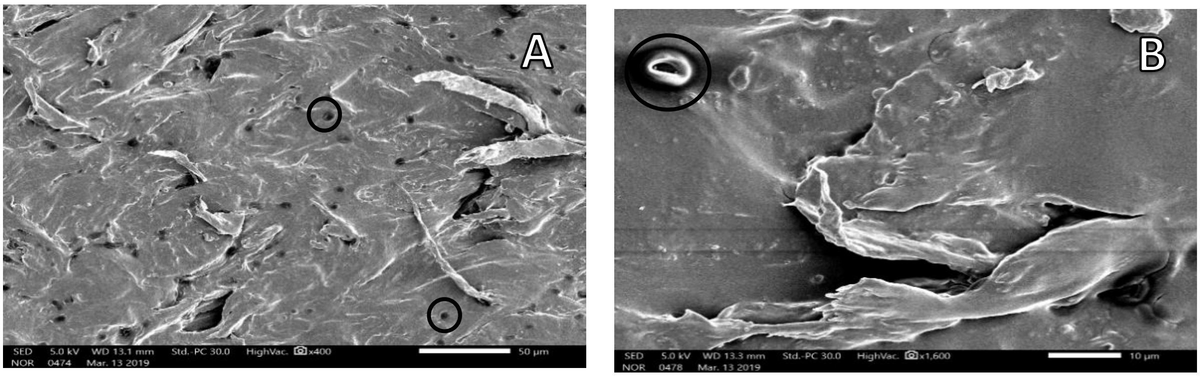



**Fig. 3.7 SEM micrograph of MDPE filled with Almond oil**

**CONCLUSIONS**

**1. Enhancing MDPE with talc improves its wear resistance.**
**2. Talc powder filler can slightly raise the hardness of MDPE.**
**3. Talc powder filler helps to reduce the friction at medium and high loads.**
**4. MDPE filled with both talc and almond oil achieved wear resistance more than this filled with talc only.**
**5. The results showed that composite of MDPE-almond oil-talc: 75 wt. %-15 wt. %-10 wt. % can be suitable for medium loads whereas 85 wt. %-15 wt. %-0 wt. % can be suitable for high loads.**
**6. MDPE filled with talc and 15% almond oil showed improving of hardness at all talc contents.**

**REFERENCES**


**1. Malpass D. B., "Introduction to Industrial Polyethylene ", Canada, Scrivener Wiley, (2010).**

**2. Chanda M. and Roy S. K., "Plastics Fundamentals Properties, and Testing", USA, Taylor & Francis group, (2009).**

**3. Visakh P. M. and Morlanes M. J. M., "Polyethylene-Based Blends, Composites and Nanocomposites", USA, Scrivener Publishing, (2015).**

**4. Bahri Ersoy, Sedef Dikmen, Ahmet Yildiz, Remzi Gören, and Elitok Ö., "Mineralogical and Physicochemical Properties of Talc From Emirdağ, Afyonkarahisar, Turkey", Turkish Journal of Earth Sciences, pp. 632-644, (2013).**

**5. Parvin N., Samir-Ullah M., Mina M. F., and Abdul-Gafur M., "Structures and Mechanical Properties of Talc and Carbon Black Reinforced High Density Polyethylene Composites : Effects of Organic and Inorganic Fillers", Journal of Bangladesh Academy of Sciences, Vol. 37, pp. 11-20, (2013).**

**6. Chang B. P., Akil H. M., and Nasir R. B. M., "Dry Sliding Wear Behaviour of Talc-Reinforced UHMWPE Composite for Implant Application", Sains Malaysiana, Vol. 6, pp. 819-825, (2015).**

**7. Wu Q., Li W., Zhang J., and Yao Z., "Tribological, Mechanical Properties, and Morphology of Polyphenylene Oxide/Ultrahigh Molecular Weight Polyethylene Blends", Polymer-Plastics Technology and Engineering, Vol. 56, pp. 535-542, 2017/03/24 (2017).**

**8. Abdel-Jaber G., Mohamed M., and Ali W. Y., "Effect of Magnetic Field on The Friction and Wear of Polyamide Sliding Against Steel", Materials Sciences and Applications, Vol. 5, p. 46, (2014).**

**9. Macuvele D. L. P., Nones J., Matsinhe J. V., Lima M. M., Soares C., Fiori M. A., et al., "Advances in Ultra High Molecular Weight Polyethylene/Hydroxyapatite Composites for Biomedical Applications: A Brief Review", Materials Science and Engineering: C, Vol. 76, pp. 1248-1262, (2017).**

**10. Laursen J. L., Sivebæk I. M., Christoffersen L., Papsøe M., Vigild M. E., Brondsted P., et al., "Influence of Tribological Additives on Friction and Impact Performance of Injection Moulded Polyacetal", Wear, Vol. 267, pp. 2294-2302, (2009).**

**11. Galetz M. C., Blaβ T., Ruckdäschel H., Sandler J. K. W., Altstädt V., and Glatzel U., "Carbon Nanofibre-Reinforced Ultrahigh Molecular Weight Polyethylene for Tribological Applications", Applied Polymer Science, Vol. 104, pp. 4173-4181, (15 June 2007).**

**12. Palabiyik M. and Bahadur S., "Tribological Studies of Polyamide 6 and High-density Polyethylene Blends Filled with PTFE and Copper Oxide and Reinforced with Short Glass Fibers", Wear, Vol. 253, pp. 369-376, (2002).**

**13. Wathier M., Lakin B. A., Bansal P. N., Stoddart S. S., Snyder B. D., and Grinstaff M. W., "A Large-Molecular-Weight Polyanion, Synthesized via Ring-Opening Metathesis Polymerization, as a Lubricant for Human Articular Cartilage", Journal of the American Chemical Society, Vol. 135, pp. 4930-4933, 2013/04/03 (2013).**

**14. Pang W., Ni Z., Wu J., and Zhao Y., "Investigation of Tribological Properties of Graphene Oxide Reinforced Ultrahigh Molecular Weight Polyethylene Under Artificial Seawater Lubricating Condition", Applied Surface Science, Vol. 434, pp. 273-282, (2018).**

**15. Golchin A., Villain A., and Emami N., "Tribological Behaviour of Nanodiamond Reinforced UHMWPE in Water-Lubricated Contacts", Tribology International, Vol. 110, pp. 195-200, (2017).**

**16. Sheykh M. J., Tarmian A., and Doosthoseini K., "Wear Resistance and Friction Coefficient of Nano-SiO 2 and Ash-filled HDPE/Lignocellulosic Fiber Composites", Polymer Bulletin, Vol. 74, pp. 4537-4547, (2017).**

**17. Wang A., Essner A., Polineni V., Stark C., and Dumbleton J., "Lubrication and Wear of Ultra-high Molecular Weight Polyethylene in Total Joint Replacements", Tribology International, Vol. 31, pp. 17-33, (1998).**
**18. Quinchia L., Delgado M., Reddyhoff T., Gallegos C., and Spikes H., "Tribological Studies of Potential Vegetable Oil-based Lubricants Containing Environmentally Friendly Viscosity Modifiers", Tribology International, Vol. 69, pp. 110-117, (2014).**
**19. Delgado-Tobón A. E., Aperador-Chaparro W. A., and García-Cáceres R. G., "Evaluation of The Lubricating Power of Sweet Almond Oil Without Additives", Evaluación del poder lubricante de aceite de almendras dulces sin aditivos., Vol. 85, pp. 179-183, (2018).**
**20. Miao S., Wang P., Su Z., and Zhang S., "Vegetable-oil-based Polymers as Future Polymeric Biomaterials", Acta biomaterialia, Vol. 10, pp. 1692-1704, (2014).**
**21. R. H. Ewell, E. N. Bunting, and Geller R. F., "Thermal Decomposition of Talc", Journal of Research of the N.ational Bureau of Standards, Vol. 15, (1935).**
**22. Aly A. A., "Heat Treatment of Polymers: A Review", International Journal of Materials Chemistry and Physics, Vol. 1, pp. 132-140, (2015).**
**23. Lu D. and Pan S., "Effects of Ball Milling Dispersion of Nano-SiOx Particles on Impact Strength and Crystallization Behavior of Nano-SiOx–Poly (Phenylene Sulfide) Nanocomposites", Polymer Engineering & Science, Vol. 46, pp. 820-825, (2006).**
**24. Oluyemi O. D., Okikiola G. A., Isiaka O. O., and Marindoti D. M., "Influence of Silica Sand Particles on The Tensile Properties and Water Absorption Behaviour of High Density Polyethylene Matrix Composites", ANNALS of Faculty Engineering Hunedoara - International Journal of Engineering, Vol. 14, (2016).**