DOI: 10.5604/01.3001.0014.6775
Volume 102 • Issue 2 • October 2020
Journal of Achievements in Materials and Manufacturing Engineering
International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Enhancement of tribological properties and characteristic of polymer matrix composite (UHMWPE reinforced with short fibres of polyester) for Total Disc Replacement (TDR)

M.N. Obaid [a,*], S.H. Radhi [b]
[a] Department of Polymer and Petrochemical Industries,
College of Materials Engineering – University of Babylon, Hilla, Iraq
[b] Department of Materials Engineering, College of Engineering, University of Kufa, Najaf, Iraq
* Corresponding e-mail address: mat.massar.najim@uobabylon.edu.iq
ORCID identifier: https://orcid.org/0000-0002-3836-4665 (M.N.O.); https://orcid.org/0000-0002-2933-5280 (S.H.R)

ABSTRACT

Purpose: The number of people suffering from Degenerative Disc Disease (DDD) is increasing. The disease causes heavy pain and restrict a number of day-to-day life activities. In extreme cases, the degraded disc is removed under total disc replacement which is usually made up of Ultra-High Molecular Weight Polyethylene (UHMWPE). The material has astounding biocompatible characteristics mechanical properties and wear resistance. However, these characteristics are insufficient in arthroplasty application. Therefore, research investigations are ongoing to improve tribological properties through reinforcement that may result in a composite material of UHMWPE. Thus the current study is aimed at reinforcing UHMWPE with short fibres of polyesters to enhance the tribological properties and surface characteristic so as to improve wear resistance and nourish the fibroblast cells on synthetic disc.

Design/methodology/approach: The researcher prepared UHMWPE composite material, reinforced with different weight fractions of short polyester fibres (2, 4, 6, 8 and 10% following hot press method. Further pin-on-disc device was used to study the tribological properties (coefficient of friction and volume of wear). The study tested surface roughness and surface characteristics by atomic force microscopy (AFM) device, hardness by shore D device, contact angle to study the effect of polyester short fibres on wettability of UHMWPE surface and tested the thermal properties and crystalline degree using Differential Scanning Calorimetry measurement (DSC) device.

Findings: The results infer that the wear resistance got improved when using 2% w.t polyester though it got decreased initially. However, the value was still more than neat UHMWPE. There was a decrease observed in coefficient of friction, but after 4 w.t% polyester, the coefficient of friction got increased due to increasing percentage of fibres which make it harder and stiff compared to UHMWPE. There was a decline observed in surface roughness due to alignment of the fibres with smooth surface. The contact angle got increased in a moderate range while the roughness enhanced the growth of fibroblast cell. The hardness of composite material got increased, because the fibres turned stiffer and harder than the matrix. DSC results infer the improvements in thermal stability due to high thermal properties of polyester fibres compared to UHMWPE. The degree of crystallinity got increased which in turn enhanced wear resistance, especially at 6 w.t % polyester fibres. There was a mild increase observed in density since the density of polyester is higher than polymer.

Research limitations/implications: The major challenge was the dispersion of fibres. Uniform distribution of fibres within the matrix (UHMWPE) was achieved through two steps of mixing processes such as mechanical mixture and twin extruder. In future studies, fatigue tests must be conducted to study the behaviour of prepared composite materials under fatigue cycle.

Practical implications: A significant objective is how to connect among different properties to obtain good improvement in tribological and surface properties so as to enhance wear resistance and growth of fibrolase cells.

Originality/value: In this study, polymeric short fibres were used as reinforcement with polymeric matrix to enhance the wettability of fibres with matrix. In this way, the bonding among them got increased which supports the tribological, surface, and crystalline behaviour.

Keywords: Total Disc Replacement, UHMWPE, Polyester fibres, Tribological, Contact angle, Crystalline degree, Roughness, Melting temperature, Volume loss

Reference to this paper should be given in the following way:

M.N. Obaid, S.H. Radhi, Enhancement of tribological properties and characteristic of polymer matrix composite (UHMWPE reinforced with short fibres of polyester) for Total Disc Replacement (TDR), Journal of Achievements in Materials and Manufacturing Engineering 102/2 (2020) 55-65. DOI: https://doi.org/10.5604/01.3001.0014.6775

BIOMEDICAL AND DENTAL ENGINEERING AND MATERIALS

1. Introduction

Degenerative Disc Disease (DDD) is a predominant clinical state observed among 40% of people aged less than 30 and 90% of the people aged more than 50. In this disease, the nerves get compressed with continuing ache. Though pharmacological and physiotherapy treatments alleviate primary symptoms, surgical procedure is required among more than 500 patients in the US yearly [1]. In the present surgical method that treats DDD, the whole IVD is removed and the vertebrae are either merged or mediated with a disc prosthesis to maintain motion. Between these two procedures, merging poses high risks such as pseudarthrosis and disease to the adjacent part which may result in repetitive surgeries in such patients. As a suitable alternative, synthetic total disc replacement devices are developed which are advanced enough to preserve the motion of segments [1,2].

The most successful orthopaedic procedure is total joint replacement such as spinal discs which comprise of cervical and lumbar discs. But, the wear which arise in service could cause osteolysis and settlement of longstanding performance of orthopaedic implants. As per the observations, an implant contains dissimilar bearing materials such as sliding of metal-on-polymer. Therefore, the selection of bearing materials and the development of their tribological performances are critical in making successful implants for a long time [3]. Amid these situations, the substitute polymer i.e., Ultra-High Molecular Weight Polyethylene (UHMWPE) is the broadly used bearing material and has been in use for more than 40 years. The UHMWPE material generally slides with rigid materials such as metal and ceramic materials in prostheses. While many such materials lose shapes and get delaminated, altered crystallinity and pitting of the polymer. This results in the creation of billions of polyethylene debris on the sliding surface [3,4].

To overcome these challenges, researchers made several attempts in the past few decades to improve virgin UHMWPE using different methods, few of which are crosslinking by radiation, ion implantation [5,6], addition of upper coverings of Diamond-Like Carbon (DLC), and carbon-based, metallic, ceramic, and mineral fillers into UHMWPE matrix to yield composite materials that possess enhanced tribological and mechanical properties [7-9].

A number of studies conducted earlier considered UHMWPE- polymer composites because of its mechanical and tribological features since the material is reinforced with glass fibres treated with conservative silane link agents [4].

It has been exposed that 'KH-550' silane link agent pose the highest impact upon the material. The last portion has considerably enhanced the tribological properties of UHMWPE-based composites over a varied range of loads and sliding speeds. These researches which used UHMWPE-polymer composites were made up of 'GUR-2122' fine powder. At present, different studies are ongoing about the preparation of UHMWPE-based composites reinforced with nano- and micro-fillers [5,10].

In the present work, the authors prepared UHMWPE polymer composite material, reinforced with different weight fractions of polyester fibres i.e., 2,4,6,8 and 10 w.t%. A polymer fibre has enhanced wettability between fibres and matrix, thus it supports the mechanical and tribological properties to be used in disc replacement of the spine.

2. Experimental work

2.1. Materials and methods

Ultra-High Molecular Weight Polyethylene (UHMWPE) petite was procured from Luoyang Max Pipe Industry. The composite had a density of (0.93-0.94) g/cm^3 with molecular weight 550600(10^4g/mol.). The measurements were made according to the percentage of addition and short fibres of polyester which were obtained from TENGZHOU TUOLDUO INDUSTRIAL &TRADE CO., LTD. Each individual composite had a length of (2-3) mm and diameter (13±2) µm with density 1.36±0.01 g/cm^3 were also determined according to of percentage of addition i.e., 2, 4, 6, 8, and 10%. After this step, the fibres are dispersed using a mechanical mixer and the petites of UHMWPE were added gradually. After continuously mixing the blend for 20 minutes, the mixture was then extruded by twin extrude with three-heated reigns i.e., 140, 150 and 155°C to melt the matrix and obtain a homogenous distribution of fibers within UHMWPE. Further, the sheet of composite material was compressed by hot press at a temperature of 160°C and pressure at 16 MPa for 5 mins using steel mould. The mould is then cooled to room temperature. Out of the composite material sheet, the standard samples were cute for each test.

2.2. Properties measurement

Volumetric wear rate

A pin-on-disc machine was used to conduct friction and wear test according to ASTM G99-05 [11]. The sample had a diameter of 40 mm and a thickness of 4 mm sliding against a steel pin which had a diameter of 6 mm. Its surface roughness was 3.2 µm whereas the hardness of sphere was HRC 56. The researchers applied a vertical load of 50 N [12]. The pin slid track at 30 mm with a speed of 0.35 m/sec and 2000 m sliding distance. The volume wear was calculated as a function of volume loss in cubic millimetre, according to the equation (1) [11]. The relation between the coefficient of friction and adverse sliding distance is drawn from the device.

$$\text{Volume loss } (\text{mm}^3) = \left(\frac{\Delta w}{\rho}\right) \times 1000 \quad (1)$$

where volume loss: volume of wear (mm$^{3)}$, Δw: Weight loss (g), ρ: Density of specimen (g/cm^3)

Hardness test

Shore D was used to measure the hardness of papered composite materials, according to ASTM (D2240) [13]. Hardness value is the average of five values of hardness in different positions.

Roughness Surface Topography Test (AFM Test)

Being measured in nonmetric, Atomic Force Microscopy (AFM) can be used to analyse the surface of samples by making the probe interact, with the surface of sample. Further, the imagining can be achieved by recording the height of probe according to the surface of specimen, which formed three-dimension image (topography) with high resolution for sample surface.

DSC analysis

Differential Scanning Calorimetry measurements (DSC) were carried out, according to ASTM D3418-03, under nitrogen gas atmosphere. The prepared samples with a weight of (8-10) ± 0.5 mg, were mounted in aluminium pans and heated from -50°C to 220°C at a heating rate of 10 °C/min.

Contact Angle Test

Contact angle test was carried out using the device, SL 200C – Optical Dynamic I Static Interfacial Tensiometer & Contact Angle Meter. The purpose of this test is to study the effect of polyester fibres on the wettability of polymer which impose an effect on the growth of living cells and create blood clots. The left and right contact angles of the water drop are measured at two time intervals i.e., 0, 60 and 180 seconds.

Density test

Density test was performed according to ASTM D-792 using high precision density tester, (digital accuracy = ±0.0001 g/cm^3; type GP-120 S). The weight of the samples was measured according to Archimedes method using accurate balance and following displacement method.

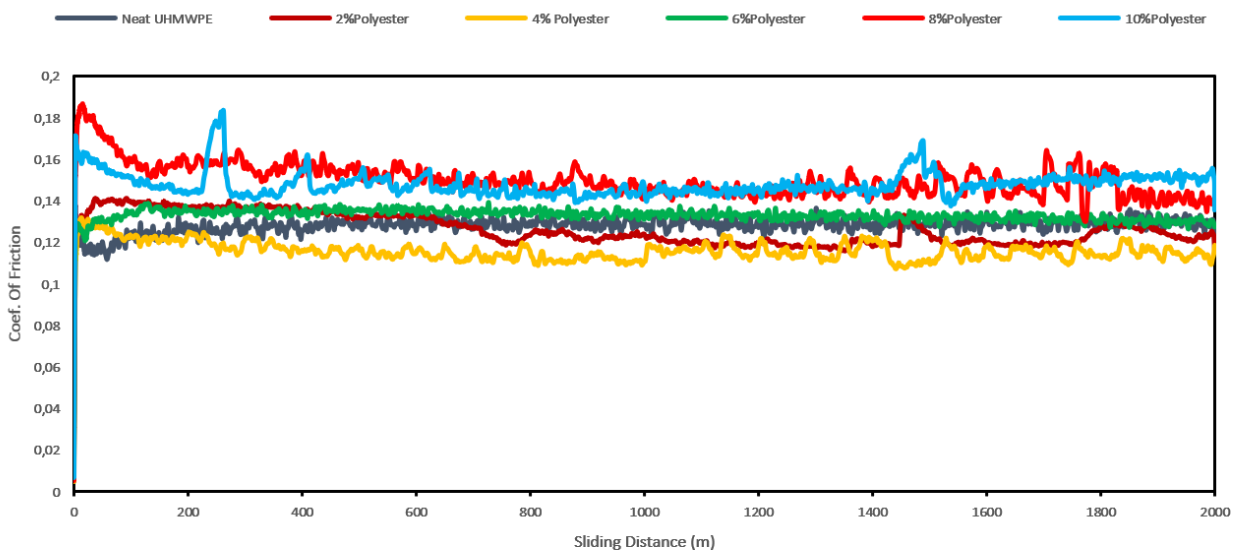

Fig. 1. Coefficient of friction as a function for percent of polyester fibres and sliding distance

3. Results and discussions

3.1. Volumetric wear rate and coefficient of friction

The authors used pin on disc apparatus to determine the effect of adding polyester fibres on coefficient of friction and loss in the volume of prepared samples of UHMWPE reinforced with different weight fractions of polyester such as 2, 4, 6, 8 and 10 w.t%. In general, the rate of friction can be calculated by measuring the coefficient of friction and wear volume. Figure 1 illustrates that the coefficient of friction got decreased with increased weight fraction of polyester. This might be attributed to the creation of protective transfer on counterface that dilutes the intensity of friction between pin and samples. This scenario would've facilitated the sliding on the surface of samples. But after 4% w.t polyester fibres, the coefficient of friction got increased due to increase in the percentage of fibres that were rigid in nature. This rigidity restricted the sliding force and caused higher friction [14].

In Figure (2), the authors inferred that there was a decrease in the volume loss of wear with the addition of 2% polyester fibres. This is due to good distribution and adhesion of fibres with polymer matrix UHMWPE [15]. However, when the weight fraction wt.% of fibres got increased, the volume loss also increased which attributed to the brittle nature of fibre compared to the polymer. This resulted in slight decrease in the ability of polymer composite material to resist the sliding force. Therefore, the internal slippage of chain molecules got increased which in turn reduced the wear resistance [15]. Hence, there was an increase in volume loss in comparison to 2 w.t% fibres composites. However, the volume loss of composite material was very low than neat UHMWPE [14].

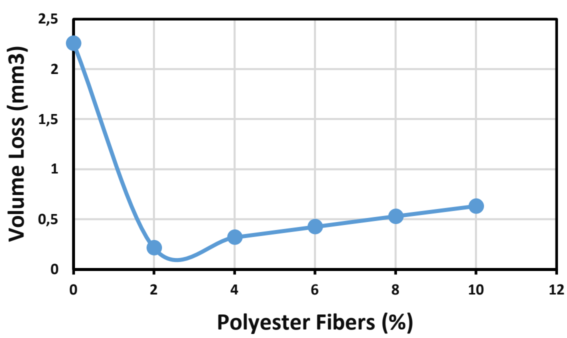

Fig. 2. Volume loss as a function for percent of polyester fibres

3.2. Hardness

The hardness illustrated in Figure 3 got increased when the percentage of polyester fibres got increased. This is because the fibres inhibit the motion of molecular chains, thus experienced an increase in the resistance to penetrate and hardness. Moreover, the fibre was stiffer and highly rigid than the polymer matrix UHMWPE [16]. The results inferred that the increase in hardness, in the presence of polyester fibre, was higher than pure UHMWPE. The highest values of hardness were observed for (UHMWPE/ 10% polyester fibre) equal to (65 Shore D), followed by (64.4shore D) for (UHMWPE/8%polyester fibre), when compared with hardness of pure UHMWPE (59 Shore D) [17,18].

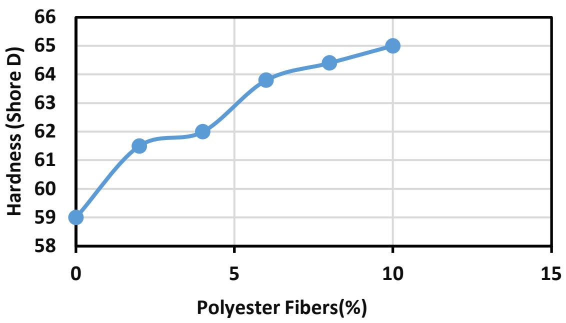

Fig. 3. Hardness as a function for percent of polyester fibres

3.3. Surface roughness

AFM test was employed to characterize the surface of prepared composite materials. From Table 1, it can be understood that the Root Mean square (Rq) and Roughness average (Ra) got decreased when the weight fraction of polyesters got increased. This is due to smooth nature of the fibre surface, increased huddle and alignment of fibres. This clearly concludes that the reinforcement with filler materials results in a narrow reduction of surface roughness, since it fills the voids and helps in achieving a smooth surface with fewer defects. This reduction is visibly higher when the weight fraction of additives [19] was increased. Figure 4 shows the 3D topography of surface of the composite materials modified with different weight fractions of polyester fibres. The results indicate the homogenous distribution of polyester short fibre. When the polyester w.t% was increased, the hills or highs got smoothened and uniform distribution was achieved on the surface of polymer composite materials (UHMWPE reinforced with polyester fibres). This infers the impact of polyester fibres on the roughness of surface [20]. But at 10% polyester composition, the roughness got slightly increased due to some crowded fibres which results in mean high percentage from weight fraction.

Table 1.
Surface roughness of polymer composite material as function of polyester fibres wt.% content in composite

Composite material	Ra (Roughness Average) nm	Rq (Root Mean Square) nm
Neat UHMWPE	24.1	28.7
UHMWPE+2%Polyester	18	23.5
UHMWPE+4% Polyester	14.3	18
UHMWPE+6%Polyester	13.5	17.6
UHMWPE+8%Polyester	12.8	16.9
UHMWPE+10%Polyester	16.3	20.5

3.4. Differential Scanning Calorimetry (DSC) analysis

Differential Scanning Calorimetry (DSC) is used to study the thermal properties of materials such as melting temperature, crystalline temperature, and crystalline degree of the prepared composite materials. Table 2 contains the

a) b)

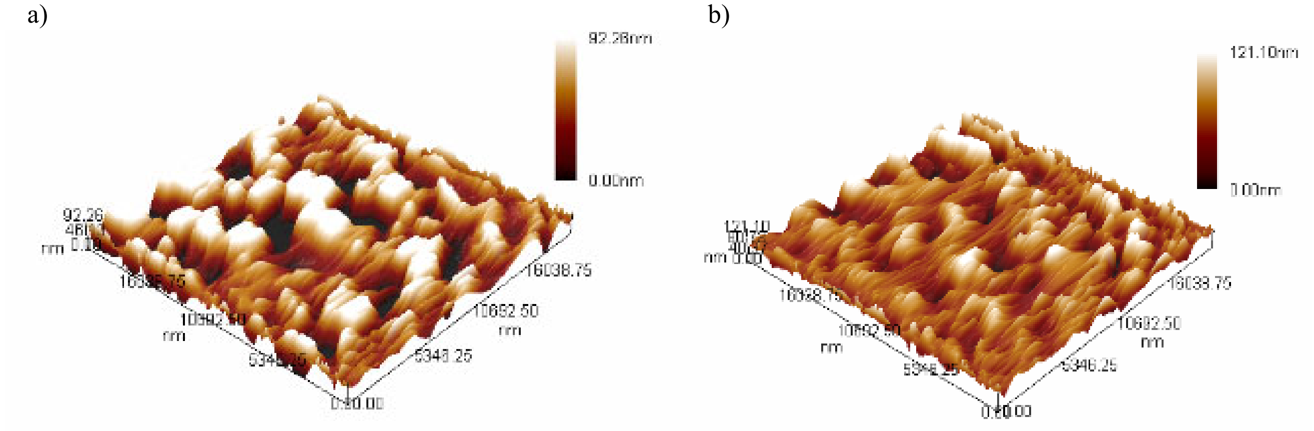

Fig. 4 a),b). 3-D topography of composite material reinforced with different percent of polyester fibres: a) neat UHMWPE, b) UHMWPE + 2% polyester

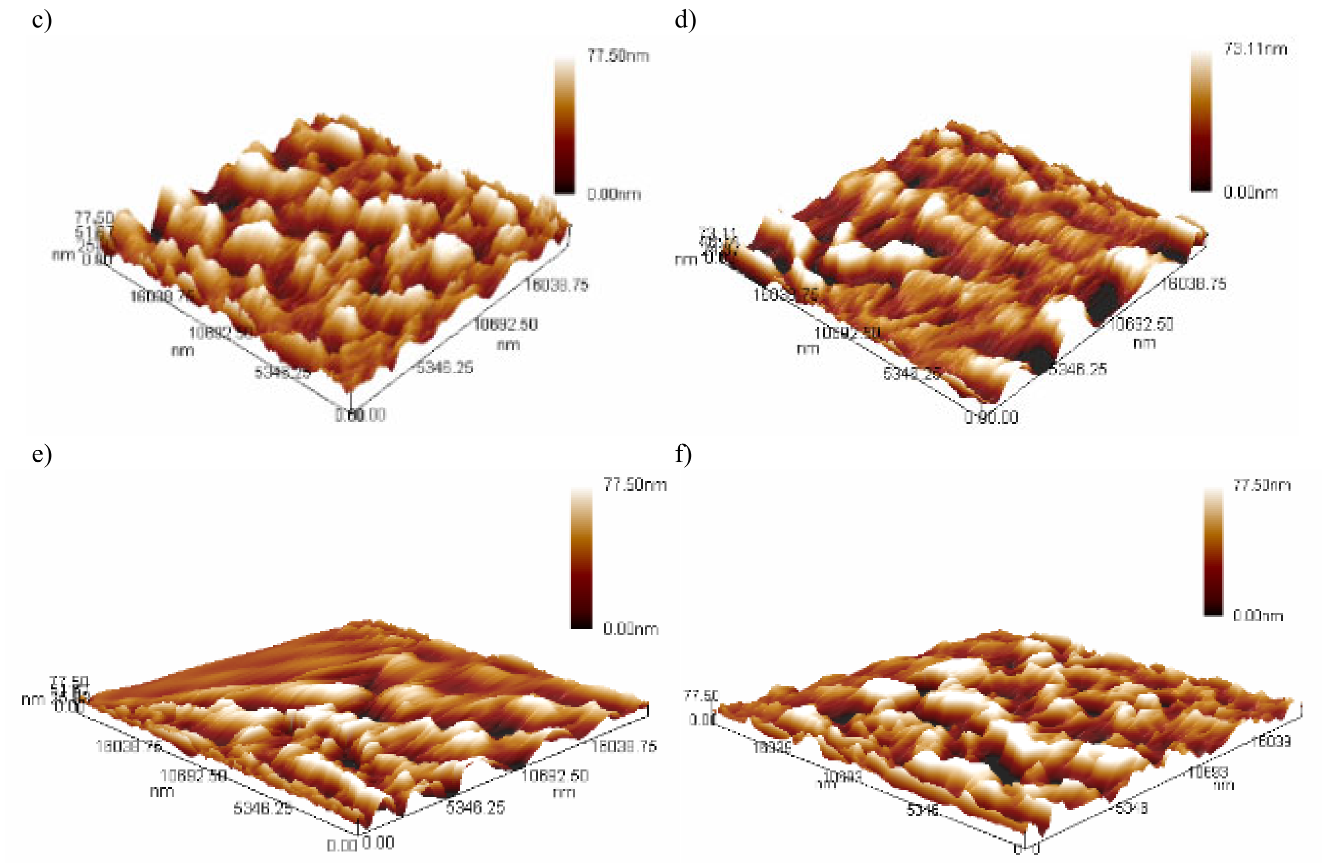

Fig. 4 c)-f). 3-D topography of composite material reinforced with different percent of polyester fibres: c) UHMWPE + 4% polyester, d) UHMWPE + 6% polyester, e) UHMWPE + 8% polyester, f) UHMWPE + 10% polyester

Table 2.
DSC data for composite material during heating and cooling scans

Composite Material	T_c, °C	T_m, °C	H_c, J/g	X_c, %
Neat UHMWPE	112.8	136.43	134.51	45.908
UHMWPE+2% Polyester	111.61	143.03	148.26	51.633
UHMWPE+4%Polyester	115.70	139.39	139.60	49.630
UHMWPE+6%Polyester	113.53	140.11	152.65	56.663
UHMWPE+8%Polyester	112.20	140.23	141.98	51.550
UHMWPE+10%Polyester	114.45	139.10	136.10	51.612

information on melting temperature, crystalline temperature, crystalline degree, and enthalpy as per the Figures 5 and 6. The melting temperature got increased with increasing weight fraction of polyester fibres. This is due to high thermal properties of polyester than the polymer and uniform distribution of fibres within the matrix [21]. Generally, the reinforcement with different materials as filler (i.e., particles, fibres, powder) provided high melting temperature to UHMWPE composite materials [19]. The highest melting temperature (T_m) was observed for UHMWPE composite materials, reinforced with 2% w.t short polyester fibre. This is due to good entanglement between the filler and UHMWPE polymer matrix materials [19]. The degree of crystalline (X_c) was calculated from equation (2) [22]:

$$Xc = \Delta H / (1-Ø)\ \Delta H° \qquad (2)$$

where ΔH is the apparent enthalpy of fusion per gram of composite, ΔH° is the heat of fusion of 100% crystalline UHMWPE i.e., 293 Jg-1 [20] and Ø is the weight fraction of filler in the composites.

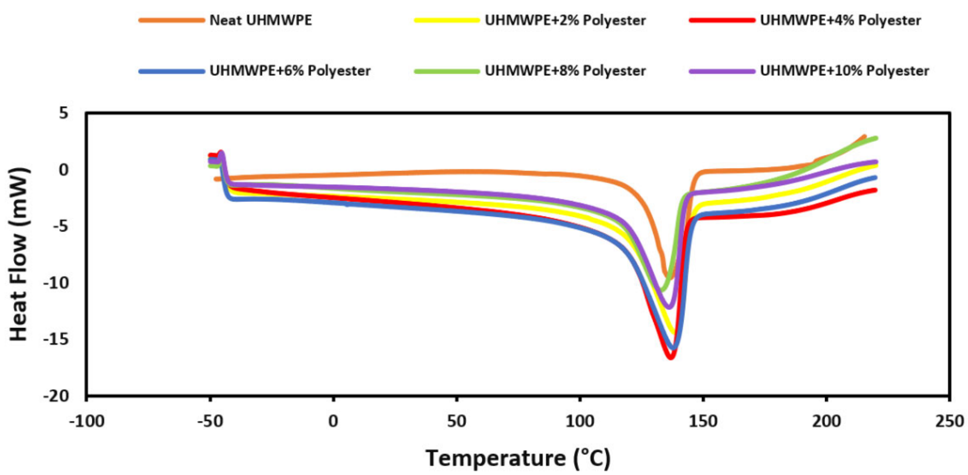

Fig. 5. DSC for melting endotherm in nitrogen atmosphere of composite materials as function of polyester fibres content

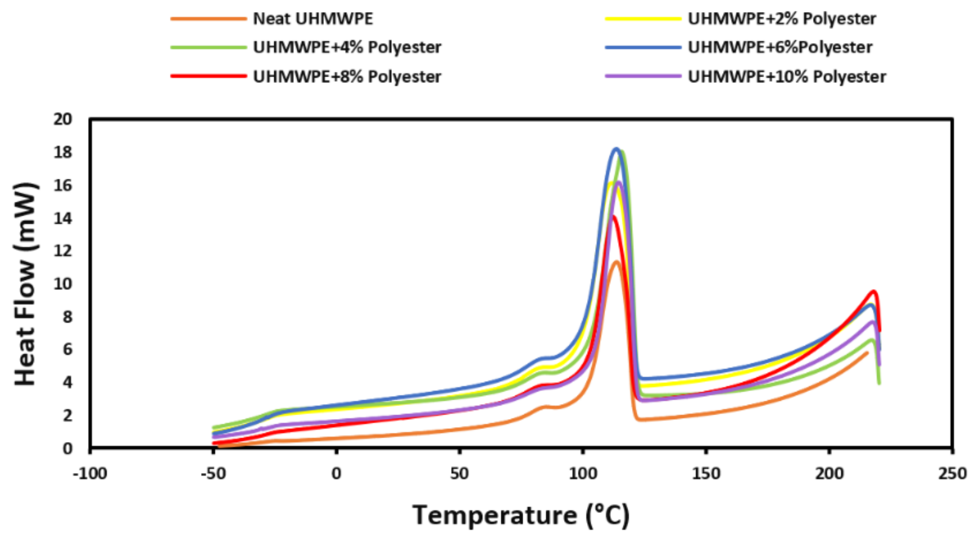

Fig. 6. DSC cooling exothermic in nitrogen atmosphere of composite materials as function of polyester fibres content

From DSC cooling curve, Figure 6 and Table 2, it can be inferred that crystalline temperature (T_C) and degree of crystalline (Xc) got increased when the weight fraction of polyester fibres was increased. The highest value at 6% polyester fibres might be due to homogenous dispersion of fibres within the matrix. This phenomenon would've restricted the intermolecular motion and acted as nucleation sites for polymeric chain segments [12,21].

3.5. Contact angle

Figures 7-12 shows the water contact angle detected as a function of percent of polyester fibres. There was a decrease observed in Contact Angle (CA) with increased ratio of fibres. This indicates that the behaviour got changed from hydrophilic, in case of pure UHMWPE (CA <35°) [23], to hydrophobic which decreased the adhesion and wettability by blood. Further, this scenario prevented coagulation, clotting and other aspects. It enhances the growth of human fibroblast cells on the surface of prepared composite materials spatially. The best growth of human fibroblast cells can be observed at moderate hydrophilic, when the contact angle is between 35° and 80° [23]. The contact angle is generally measured after 60 sec and 180 sec in Table 3. The results showcase that the contact angle got decreased. But within the range of moderate hydrophobic, it enhances the growth of fibroblast cell.

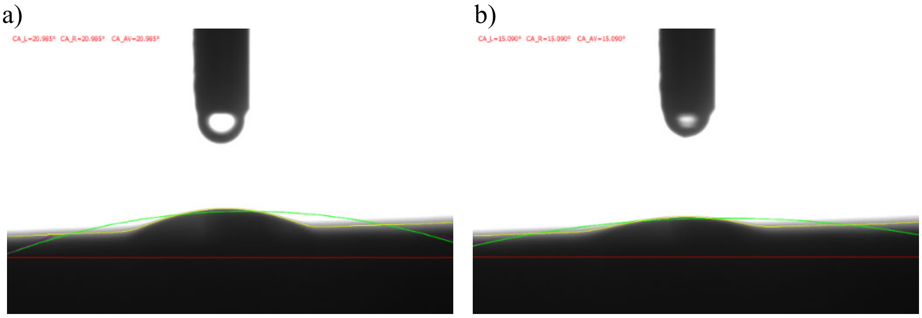

Fig. 7. Contact angle for composite material as function for polyester fibres. Neat UHMWPE: a) at time zero sec, b) at time 60 sec

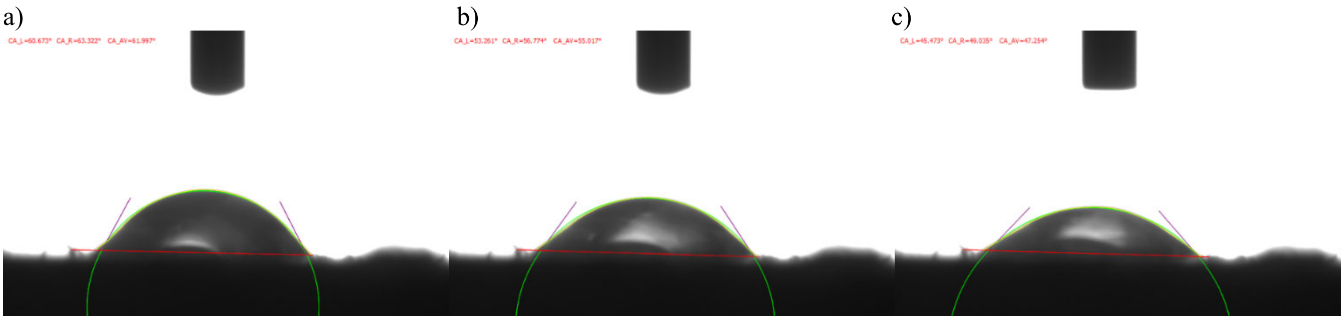

Fig. 8. Contact angle for composite material as function for polyester fibres. UHMWPE + 2% polyester: a) at time zero sec, b) at time 60 sec, c) at time 180 sec

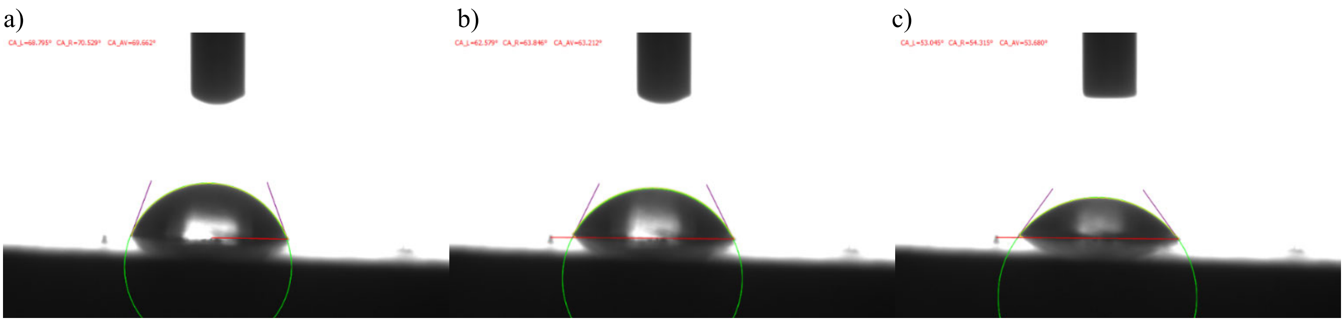

Fig. 9. Contact angle for composite material as function for polyester fibres. UHMWPE + 4% polyester: a) at time zero sec, b) at time 60 sec, c) at time 180 sec

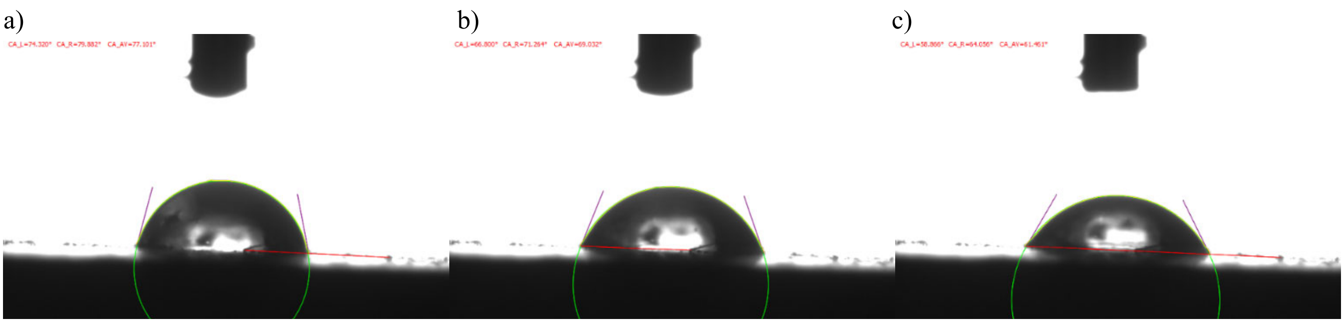

Fig. 10. Contact angle for composite material as function for polyester fibres. UHMWPE + 6% polyester: a) at time zero sec, b) at time 60 sec, c) at time 180 sec

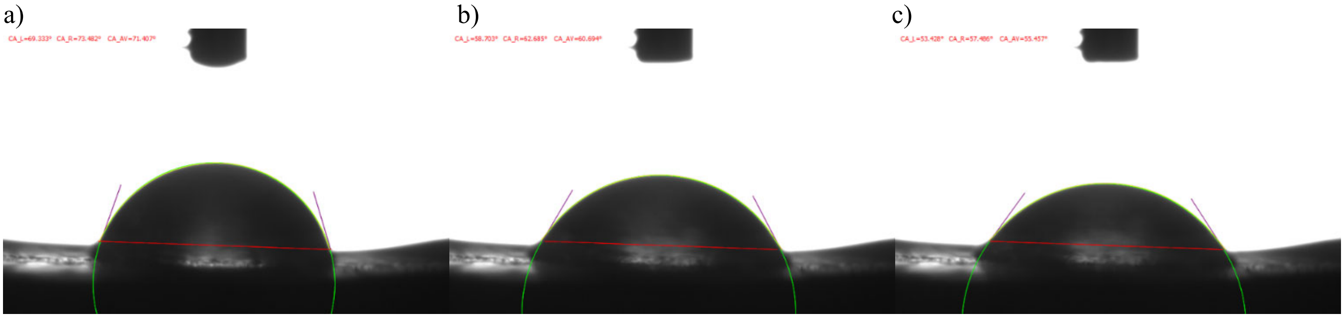

Fig. 11. Contact angle for composite material as function for polyester fibres. UHMWPE + 8% polyester: a) at time zero sec, b) at time 60 sec, c) at time 180 sec

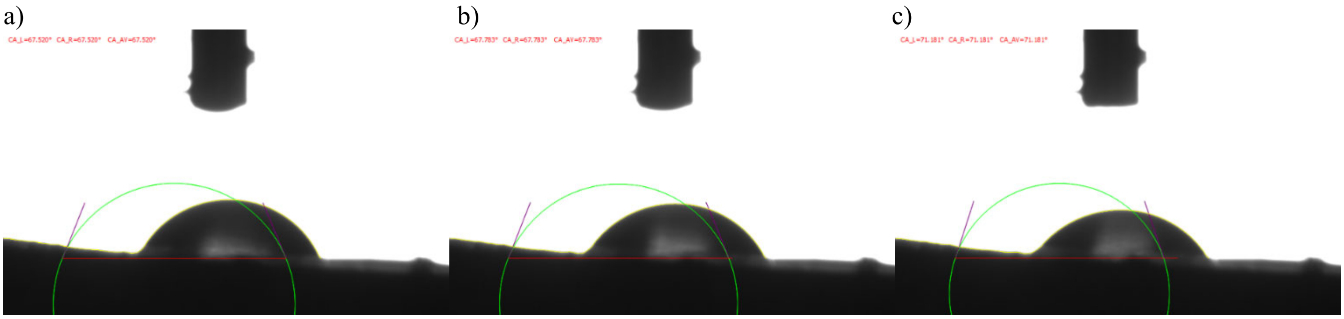

Fig. 12. Contact angle for composite material as function for polyester fibres. UHMWPE + 10% polyester: a) at time zero sec, b) at time 60 sec, c) at time 180 sec

Table 3.
Contact angle for composite materials at different time

Composite material	Contact angle by circle fitting, °	Time, sec
Neat UHMWPE	20.985	0
	15.09	60
	0	180
UHMWPE/ 2%polyester	61.997	0
	55.017	60
	47.254	180
UHMWPE/ 4%polyester	69.662	0
	63.212	60
	53.680	180
UHMWPE/ 6%polyester	77.101	0
	69.032	60
	61.461	180
UHMWPE/ 8%polyester	71.407	0
	60.694	60
	55.457	180
UHMWPE/ 10%polyester	67.520	0
	67.783	60
	71.181	180

3.6. Density of UHMWPE polymer composites

The density of composite materials, as shown in Figure 13, got increased with increasing weight fraction of polyester fibres (1.36 g/cm^3). This is because the density of fibre was higher than UHMWPE. The figure indicates that the density of UHMWPE polymer composite materials got increased after reinforcing with filler additives (short fibre polyester). The true density of UHMWPE was (0.93-0.94 g/cm^3). Besides, these reinforcement material additives can be made to diminish, fill the spaces and voids within UHMWPE polymer matrix [19].

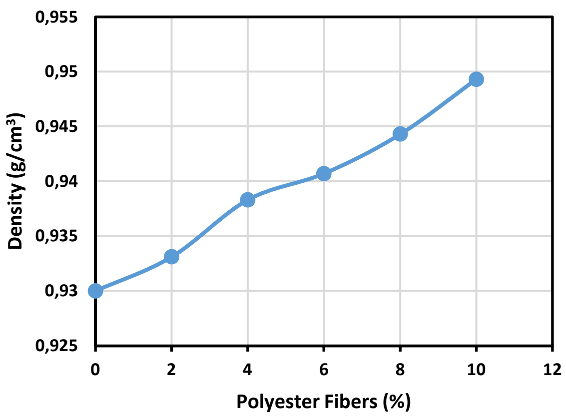

Fig. 13. Density of composite materials as a function of polyester fibres

4. Conclusions

The objective of this research is to improve the tribological properties of UHMWPE to enhance their performance in total disc replacement, spatially, for lumbar disc used to fix accident high wears. The prepared composite material exhibited good contact angle and permitted the growth of fibrous cell on it. At the same time, it prevented the created clots. The polyester fibres enhanced the thermal properties and improved the crystalline degree which in turn incremented both wear resistance and toughness. The crystalline temperature and degree got increased with increasing weight fraction of polyester fibres and the highest value was observed at 6% polyester fibres. The AFM results concluded that the roughness got decreased with increasing percentage of fibres. This enhanced the wear resistance and growth of fibroblast cells on the disc.

References

[1] Y. Moriguchi, J. Mojica-Santiago, P. Grunert, B. Pennicooke, C. Berlin, T. Khair, R. Navarro-Ramirez, R.J. Ricart Arbona, J. Nguyen, R. Härtl, L.J. Bonassar, Total disc replacement using tissue-engineered intervertebral discs in the canine cervical spine, Plos One 12/10 (2017) e0185716.
DOI: https://doi.org/10.1371/journal.pone.0185716

[2] C.V. Maldonado, R.D. Paz, C.B. Martin, Adjacent-level degeneration after cervical disc arthroplasty versus fusion, European Spine Journal 20 (2011) 403.
DOI: https://doi.org/10.1007/s00586-011-1916-1

[3] S. Wang, J. Song, Z. Liao, Y. Liu, C. Zhang, W. Liu, Study on the Wettability and Tribological Behavior of Different Polymers as Bearing Materials for Cervical Prosthesis, Journal of Materials Engineering and Performance 24 (2015) 2481-2493.
DOI: https://doi.org/10.1007/s11665-015-1529-7

[4] A. Bistolfi, A. Bellare, The Relative Effects of Radiation Crosslinking and Type of Counterface on the Wear Resistance of Ultra high-Molecular-Weight Polyethylene, Acta Biomaterialia 7/9 (2011) 3398-3403. DOI: https://doi.org/10.1016/j.actbio.2011.05.018

[5] A.S. Mohammed, UHMWPE Nanocomposite Coatings Reinforced with Alumina (Al_2O_3) Nanoparticles for Tribological Applications, Coatings 8/8 (2018) 280.
DOI: https://doi.org/10.3390/coatings8080280

[6] L. Zhang, Y. Sawae, T. Yamaguchi, T. Murakami, H. Yang, Effect of radiation dose on depth-dependent oxidation and wear of shelf-aged gamma-irradiated ultra-high molecular weight polyethylene (UHMWPE), Tribology International 89 (2015) 78-85. DOI: https://doi.org/10.1016/j.triboint.2014.12.011

[7] A. Arun, V. Sathiyamoorthy, S.M.K. Vivek Anand, V. Ganesh Boopathy, R. Prasanth, Tribological studies on properties of Al_2O_3 reinforced ultra-high molecular weight polyethylene, Journal of Chemical and Pharmaceutical Sciences 2/Special Issue (2017) 186-189.

[8] N. Naresh Kumar, S.L. Yap, M.Z. Khan, R.S. Pattela Srinivasa, Effect of argon plasma treatment on tribological properties of UHMWPE/MWCNT nanocomposites, Polymers 8/8 (2016) 295. DOI: https://doi.org/10.3390/polym8080295

[9] A.A. Ezzat, M.O. Mousa, W.Y. Ali, Influence of aluminum oxide nanofibers reinforcing polyethylene coating on the abrasive wear, Friction and Wear Research 4 (2016) 1-13.
DOI: https://doi.org/10.14355/fwr.2016.04.001

[10] S. Cao, H. Liu, S. Ge, G. Wu, Mechanical and tribological behaviors of UHMWPE composites filled

with basalt fibers, Journal of Reinforced Plastics and Composites 30/4 (2011) 347-355. DOI: https://doi.org/10.1177%2F0731684410394698

[11] ASTM G99-05, Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus, 2010.

[12] A.A. Hussein, Fabrication and Characterization of Advanced Blend Polymer Nanocomposites for Human Bone Structural Applications, Ph.D. Thesis, 2017.

[13] Annual Book of ASTM Standard, Standard Test Method for Plastics Properties-Durometer Hardness, D 2240-03, 2003, 1-12.

[14] N.A. Saad, M.N. Obaid, The synergetic Effect of Short Fibers of PAN and Nanoparticles (GNP/HAp) on Tribological Behavior and Surface Roughness of UHMWPE, Test Engineering and Management 83 (2020) 22000-22012.

[15] A. Shalwan, B.F. Yousif, In State of Art: Mechanical and tribological behaviour of polymeric composites based on natural fibres, Materials and Design 48 (2013) 14-24.
DOI: https://doi.org/10.1016/j.matdes.2012.07.014

[16] N.A. Saad, M.N. Obaid, Enhanced the Antibacterial and Mechanical properties of UHMWPE by Addition Sort Fibers of Polyacrylonitraile (PAN), Graphene Nanoplate (GNP) and Hydroxyapatite (HAp), Indian Journal of Forensic Medicine and Toxicology 14/2 (2020) 1370-1376.
DOI: https://doi.org/10.37506/ijfmt.v14i2.3103

[17] J.K. Oleiwi, R.A. Anaee, S.H. Radhi, Compression and Hardness with FTIR Characterization of UHMWPE Nanocomposites as Acetabular Cup in Hip Joint Replacement, International Journal of Plastic and Polymer Technology 8/1 (2019) 1-10.

[18] J.K. Oleiwi, Q.A. Hamad, Studying the Mechanical Properties of Denture Base Materials Fabricated from Polymer Composite Materials, Al-Khwarizmi Engineering Journal 14/3 (2018) 100-111.

[19] J.K. Oleiwi, R.A. Anaee, S.H. Radhi, Roughness, Wear and Thermal Analysis of UHMWPE Nanocomposites Asacetabular Cup in Hip Joint Replacement, International Journal of Mechanical and Production Engineering Research and Development 8/6 (2018) 855-864.

[20] A.A. Hussein, O.H. Sabr, Preparation and facilitation of antibacterial activity, hydrophilicity of piezo–pvdf/n-MgO film by electro-spinning and spin coated for wound dressing: a comparative study, Journal of Mechanical Engineering Research & Developments 42/4 (2019) 23-31.
DOI: http://doi.org/10.26480/jmerd.04.2019.23.31

[21] L. Zhu, D. Wu, B. Wang, J. Zhao, Z. Jin, K. Zhao, Reinforcing High-density Polyethylene By Polyacrylonitrile Fibers, Pigment & Resin Technology 47/1 (2018) 86-94. DOI: https://doi.org/10.1108/PRT-03-2017-0030

[22] M. Salari, S. Mohseni Taromsari, R. Bagheri, M.A. Faghihi Sani, Improved wear, mechanical, and biological behavior of UHMWPE-HAp-zirconia hybrid nanocomposites with a prospective application in total hip joint replacement, Journal of Materials Science 54 (2019) 4259-4276.
DOI: https://doi.org/10.1007/s10853-018-3146-y

[23] K.L. Menzies, L. Jones, The Impact of Contact Angle on the Biocompatibility of Biomaterials, Optometry and Vision Science 87/6 (2010) 387-399. DOI: https://doi.org/1040-5488/10/8706-0387/0