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The Effect of Acetone Dilution towards the Surface Topography and Morphology of Micro Bearing Concept for Epoxy Filled UHMWPE Composite

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ABSTRACT

Surface topography and morphological behaviours are the important aspects in the application of surface bearing as it deals with the contact area of objects upon motion. Improved surface bearing will be set as an indicator for tribology behaviour to reduce the possibility of wear rate and reduce the friction of objects, respectively. Thus, in this study, the fundamental of micro bearing concept was imparted as the Ultra High Molecular Weight Polyethylene (UHMWPE), which is a low density filler, will float onto the surface of the composite system to become a solid lubricant upon curing. UHMWPE filler, which is commonly known for its dominant properties of high tendency to resist wear and has low coefficient of friction were fabricated alongside epoxy resin in the composite system to achieve the desired strength and durability to perform over time. However, there are limitations of UHMWPE during processing upon the dispersion of the fillers with the matrix particles due to epoxy resin that has relatively high in viscosity. Therefore, acetone has been selected as a diluent with ratio of 1:1/4, 1:1/3, 1:1/2, 1:1 to dilute the high viscosity epoxy resin.

The surface profile measurement were examined using Alicona Infinite Focus and Polarised Optical Microscope. Based on the results observed, EpUPE3 (epoxy and UHMWPE with acetone ratio of 1:1/2) showed better surface distribution and morphology with relatively low value of surface roughness (Ra) which is 1.41 μm and low pseudocolour value of surface height which is around 6.76-6.77 cm compared to other formulation ratio. In near future, these surface topography and morphological analysis are important to relate with tribological, physical and mechanical properties of the micro bearing layers for bearing applications, specifically.

Keywords: *acetone dilution, micro bearing concept, morphological behaviours, UHMWPE filler, surface roughness (Ra), surface topography*

INTRODUCTION

Latest technology advancement on the application related to the surface bearing open up the study on improving the friction performance of materials, consecutively. Several of studies are conducted with the aim on providing less friction state upon movement to the plane of products. In conjunction with that, a good phase of tribological and morphological properties are needed for the bearing materials to function well for long-term performance. In recent years, many type of bearing materials which are usually made of steels, ceramics and polymers have been introduced to obtain the superior bearing properties depending on certain required applications. In the application that requires unique bearing properties, the choices of polymer as bearing materials are relatively significance which can be produced either independently or by using variation of materials combinations to form a composite material [1].

Recently, Ultra High Molecular Weight Polyethylene (UHMWPE) is the most dominant polymer material in the bearing applications due to its superior properties. It exhibits a distinctive physico-mechanico properties such as high wear resistance, low coefficient of friction, has chemical stability in corrosive state and high elasticity resistance which can allow to be used in extreme condition [2]. However, UHMWPE has some disadvantages in term of low hardness value, low Young's modulus, and easy to creep under load which restricts the capacity for load bearing and can cause long-term failure of materials. Based on study conducted by Wang *et al.* [3], the results showed that the ultimate tensile strength and elongation at break have significant effect on the wear rate of UHMWPE material over time. Through the findings, it can be seen that UHMWPE with relatively high in ultimate tensile strength and elongation at break will produce less wear rate of UHMWPE and vice versa. Hence, the main problem arise for the UHMWPE with relatively low tensile strength as it can yield significant large amount of wear debris due to potting and delamination of material after a while. This condition will eventually reduce the tribological functionality upon services which can lead to the failure of the products, respectively.

Therefore, in order to overcome the problems, the composition of UHMWPE is modified into micro bearing layer by imparting epoxy resin as a matrix phase to become a composite system. A recent study by Gahr [4] has mentioned that the ruptured particles from the surface of the bearing can be chemically adjusted through the replacement of the microstructure on the surface and mechanically by repeating the stress in cycle which can leads to fatigue. The epoxy resin has been chosen as the matrix constituents due to the fact that it is notable in form of balanced mechanical properties. Epoxy resin is widely used as an adhesives as well as matrix for fibre-reinforced composites. Upon curing, the microstructure yield many properties such as high in failure strength and Young's modulus, low tendency to creep upon loading and has good execution under elevated temperature [5]. Epoxy resins also possess high value of chemical and solvent resistance, excellent adhesion to many type of substrates, low degree of shrinkage on curing, high impact resistance, high flexibility as well as high electrical properties [6]. These properties of epoxy are needed for the UHMWPE to function well as a bearing surface through the formation of composite materials.

Indeed, the micro bearing concept of polymer composites requires the relation of fundamental of density and viscosity being interconnected with each other. In material science, viscosity can be considered as the basic elemental property that determine the characteristic of all liquids. It is a measurement of internal resistance of a liquid to flow during processing. The force being dragged and frictional property of the fluid can both be measured as they reflect on the characteristics of the liquid [7]. On the other hand, the density can be measured as the ratio of mass over volume.

Thus, the viscosity needs to be reduced in order for the low density filler to float in the composite system. In order to achieve the micro bearing layers, a solvent need to be introduced into the composite systems. Based on various studies conducted by Loos *et al*., Gong *et al*. and Dong *et al*. [8–10], acetone has been widely used as a solvent in the composite system to aid in the processing parameter. The solvent will be act as a diluent during fabrication process to reduce the viscosity of the epoxy matrix. This will somehow aid in the better filler dispersion especially for Nano-composite fillers. From all of these studies, it can be said that with the addition of diluent into thermoset resin will reduce the viscosity of resin, which then will allow better distribution of fillers, accordingly.

The aim of this work is to study the effect of acetone dilution towards the surface topography and morphology of micro bearing concept for Epoxy filled UHMWPE composite. The mixture of epoxy with UHMWPE fillers were successfully prepared whereas they have been diluted with acetone solvent with different concentrations ratio. The viscosity of the diluted epoxy filled UHMWPE were tested using viscosity test before being proceed on the physical observations of the micro bearing layers upon curing. The topography and morphological behaviours of the samples were observed and analysed using the surface profile measurement like Alicona Infinite Focus to measure the surface roughness (Ra) and pseudocolour behaviour of the samples. The samples also being observed under optical microscopy measurement using Polarised Optical Microscope to determine the surface morphology and distribution of the micro bearing layers in the composite system.

METHODOLOGY

Materials

The UHMWPE micro-filler with the trade name of GUR 4120 was supplied from Ticona Engineering Polymer, China in powdered form with molecular weight of $5x10^6$ $gmol^{-1}$ and density of 0.93 gcm^3. The size and shape of single UHMWPE filler and cluster formation of UHMWPE fillers were observed under Polarised Optical Microscopy in bright field mode under 5x and 50x magnification, as shown on Figure 1 a) and Figure 1 b). The Epoxy Resin, which consists of Epoxen CP362 'Part A' Resin (Epoxy DGEBA type) and Epoxen CP362 'Part B' hardener (modified aliphatic amine) were purchased from Oriental Option Sdn. Bhd. The acetone with trade name AR1003-P2.5L with molecular weight of 58.08 $gmol^{-1}$ and density of 0.79 gcm^3 at 25 °C which meet the A.C.S Specification was obtained by RCI Labscan Limited Company.

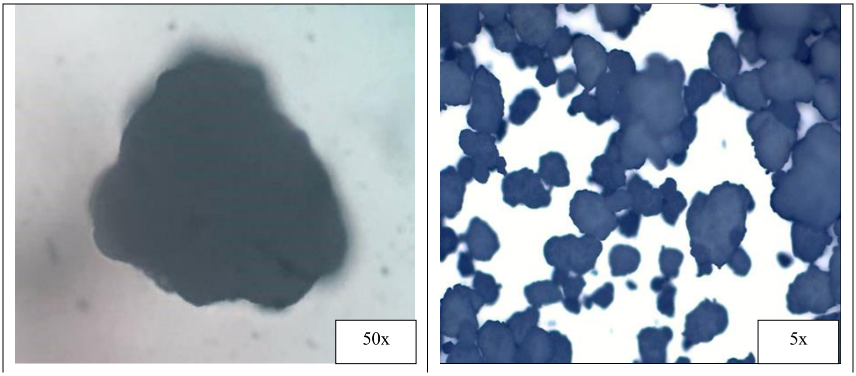

Figure 1: a) Optical Microscope of Single UHMWPE Filler with 50x Magnification b) The Cluster Formation of UHMWPE Fillers with 5x Magnification (Source by author)

Samples Preparation

Samples were prepared in line with the proposed formulation by using the mixing technique in composition of materials, as shown on Table 1. The fabrication process was a casting technique according to the study of Loos *et al.* [8]. The casting technique was modified to suit with the research aim and outcomes. First, the epoxy resin was stirred with UHMWPE using a mechanical stirrer at 650 rpm for ten minutes followed by mixing with hardener for five minutes. The ratio of epoxy to hardener is 2:1. Then, the mixture of epoxy with UHMWPE were diluted with acetone solvent with ratio of 1:0, 1:1/2, 1:1/3, 1:1/4 and 1:1 (epoxy to acetone ratio) and were mixed for two minutes. After that, the mixture were immersed in a water bath with 20 kHz frequency without heating element to sonicate the mixture for seven minutes. The diluted mixture were later being hold at ambient temperature for five minutes before being poured into an open mould. Later, the mixture was consistently observed for the formation of micro bearing layer upon reaching its gel time. Once reaching the respective gel time, the mould were cured at 40 °C in the oven for four hours before further undergo post-cure process at 50 °C for 24 hours.

Table 1: The Formulation of the Micro Bearing Layer Construction

Formulation Samples	Formulation Coding	Amount in wt%			
		Epoxy Resin	Hardener	UHMWPE	Acetone
		(2:1)			
Pure Epoxy	Ep	66.7	33.3	0	0
Pure Epoxy with UHMWPE filler	EpUPE	63.3	31.7	5.0	0
Epoxy, UHMWPE filler with acetone (ratio 1:1/4)	EpUPE1	50.7	25.3	5.0	19.0
Epoxy, UHMWPE filler with acetone (ratio 1:1/3)	EpUPE2	47.6	23.8	5.0	23.6
Epoxy, UHMWPE filler with acetone (ratio 1:1/2)	EpUPE3	42.2	21.1	5.0	31.7
Epoxy, UHMWPE filler with acetone (ratio 1:1)	EpUPE4	31.7	15.8	5.0	47.5

Viscosity Test

The viscosity test was conducted using a Brookfield DV-1 Prime Viscometer of spindle fibre number 0.2 with rotating speed of 20 rpm. The measured volume of 80 ml polymer resin in liquid form was placed in a cup and the viscosity reading was taken continuously every minute for a total of 20 minutes. The results were observed in viscosity unit (mPas) against time (seconds). The test procedure was conducted according to ASTM Standards D445-06 [11].

Surface Profile Measurements

The surface roughness (Ra) of the samples were measured using the 3D Infinite Focus optical measurement device by Alicona Infinite Element Machine. The parameters for the measurements are 5x magnification, 1.76 µm sampling distance and 1.00 µm of vertical resolution. A surface profile was drawn out from the surface and the parameters of the roughness were calculated from this profile. The results in the form of surface roughness (Ra), surface topography and surface distribution were determined. The surface height values were also determined by analysing the pseudocolour variation of each surface point. The test procedure was conducted according to ISO Standards 25178-6 [12].

Optical Microscopy Measurements

The optical microscopy measurements were taken on the surface of the samples using Olympus BX51 Polarised Reflected Microscope with U-TV1X-2 MoticamPro Camera Adapter under bright field mode. The observations were carried out under 50x magnification with controlled fluorescent ring illumination. The test procedure was conducted according to ASTM Standards E883-11 (2017) [13].

RESULT AND DISCUSSIONS

Viscosity Test

Based on Figure 2, it can be seen that viscosity of the pure epoxy resin is around 16000 mPas. The relatively high value of viscosity tend to make the UHMWPE filler to be randomly distributed and does not deposit onto the surface of the composite system upon curing, proven to the observation on Figure 3 for the EpUPE sample. This is due to the viscosity of the epoxy resin tend to hinder and restrict the movement of UHMWPE filler upwards when curing. Upon dilution with acetone at ratio of 1/4, 1/3, 1/2, and 1, the viscosity value drops significantly around 15-35 mPas indicating that the acetone reduce the viscosity value up to 99.91%. The drop in viscosity means it decreased the internal flow of fluid according to principle of viscosity [7]. With the relatively low density of UHMWPE filler which is 0.93 g/cm^3

compared to density of epoxy resin which is 1.24 g/cm^3, the filler distribution will generally float on the epoxy system upon processing and curing.

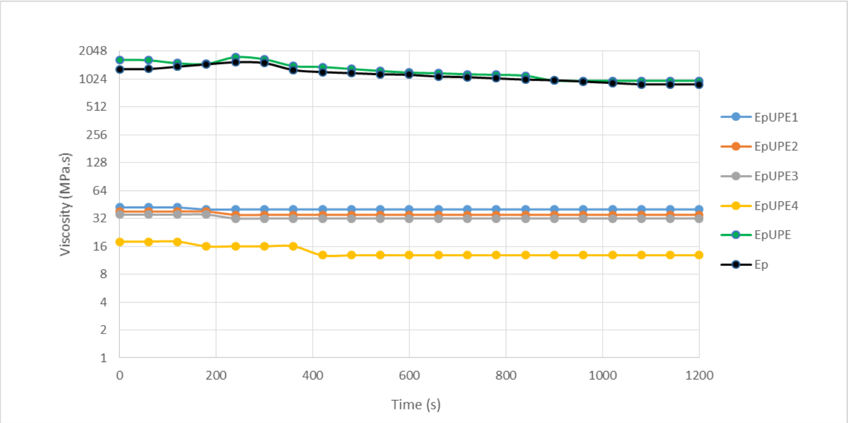

Figure 2: The Viscosity Value of Respective Formulation Coding Against Time

Therefore, based on the samples produced on Figure 3, it can be said that the micro bearing layer formation are only visible on EpUPE1, EpUPE2, EpUPE3 and EpUPE4, respectively, in agreement to the early hypothesis. From that, in term of the surface appearance, the ratio of acetone significantly play the role on the smoothness and waviness of the micro bearing layer produced. The EpUPE1 with relatively low amount of acetone will tend to form a crumple region on the surface indicates that UHMWPE filler does not fully float and to shift into the plastic region upon curing. While for the relatively high amount of acetone used which is EpUPE4 will tend to make the sample waviness upon curing indicates that high amount of acetone tend to interrupt the formation of micro bearing due to its high volatility that may altered the separation of the UHMWPE filler upon curing.

Apart from that, other physical observation on the samples is the colour of the epoxy layer which show relatively darker in yellowish colour with increasing the amount of acetone used. The observation can be supported by the study of Reed and Whale [14], whereas they discovered that high amount of acetone will discolour the clear epoxy resin to yellowish upon curing. Nonetheless, the exact surface characterisation and morphology will be further analysed using Optical Microscopy and Alicona Infinite Focus for the respective samples in order to determine and optimise better surface performance for solid lubricant applications.

Figure 3: Micro Bearing Layers Formation According to Respective Formulation Coding (Source by author)

Surface Profile Measurement

Based on Figure 4, the highest surface roughness (Ra) value shown is EpUPE2 with 2.22 µm while the lowest surface roughness (Ra) value is EpUpE4 with 1.16 µm. Overall analysis show an increasing trend with the increase in the ratio of acetone concentration until EpUPE2 and then decline afterwards until EpUPE4. For the comparison between the micro bearing layers ratio, EpUPE3 and EpUPE4 show relatively low in values which are 1.41 µm and 1.16 µm compared to EpUPE1 and EpUPE2 which are 1.92 µm and 2.22 µm.

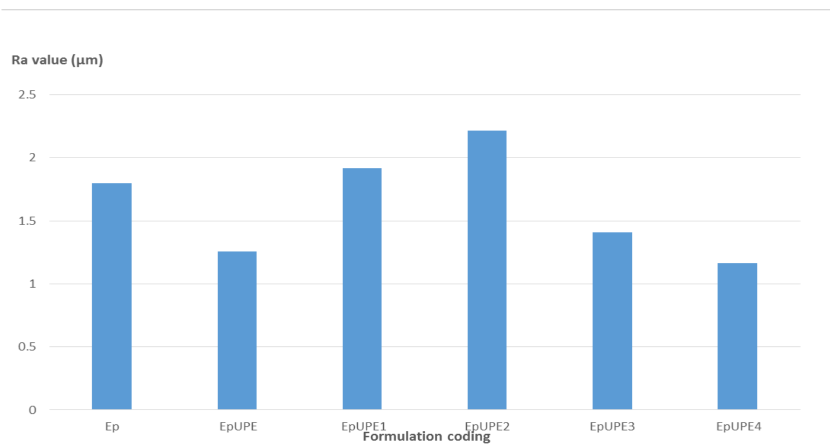

Figure 4: The Surface Roughness (Ra) for the Samples According to Formulation Coding

Generally, surface roughness (Ra) can be deduced as the mean height for the departure of profile from the reference line through sampling length [15]. From the definition, it can be said that the higher the surface roughness (Ra), the more depart of the profile height to the reference which then cause high irregularities of the surface. The high irregularities in surface means that the texture will not have a consistent baseline on the surface thus will reduce the performance upon contacting with other surface upon motion. From Figure 4, it can be seen that amount acetone dilution affects the surface roughness of the samples. Upon incorporating an increase in the ratio of acetone content, the surface roughness (Ra) is reduced. It may be due to the acetone is a solvent that have volatility which reduce the sagginess of relatively high viscosity of epoxy resin upon curing. The will evenly make the UHMWPE filler to be deposited evenly on top of the surface.

However, it can be observed that for EpUPE4, the pseudocolour of the surface height is relatively high which is around 7.025-7.026 cm compared to EpUPE3 compared to the EpUPE3 which is around 6.76-6.77 cm. This can be referred to the Figure 5 a) and b) whereas the reduce in the surface height indicates that the wavelength for surface profiler is relatively low which indicated that the surface is even smoother. Moreover, for the EpUPE4, there are some part of the surface region that is not in the irregular shape and may have grain surface which may affects the smoothness of the texture through the stylus reading of the surface profiler [15].

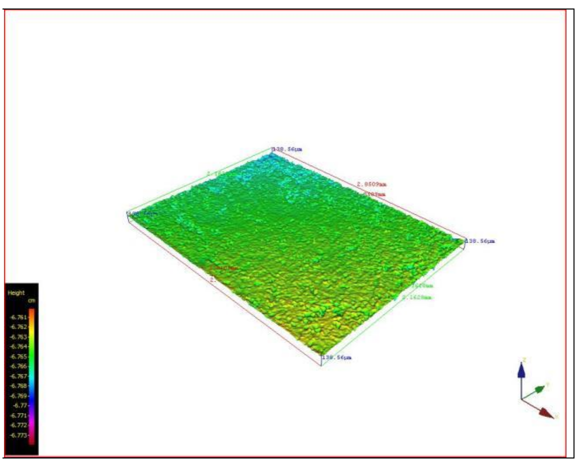

Figure 5: a) The Pseudocolour Surface Height Value for the EpUPE3 (Soure by author)

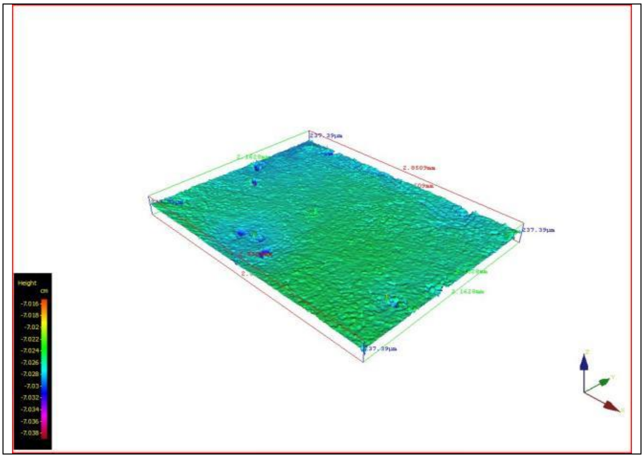

Figure 5: b) The Pseudocolour Surface Height Value for the EpUPE4 (Source by author)

Optical Microscopy Measurement

Based on the optical microscopy observation as shown on Figure 6, the surface morphology distribution of the micro bearing concept vary depending on the formulation. The control sample which is Ep (cured epoxy resin) shows the smoothness of the surface due the nature of epoxy which is a glassy-like structure when curing. However, upon incorporating with filler without acetone which is EpUPE, the surface tend to have waviness and uneven surface. This is may be due to the filler which does not deposit on the surface and being randomly distributed on the composite system. Other observations on the diluted samples show that the acetone dilution influence the surface distribution of the UHMWPE filler and also the waviness of the epoxy resin surface. This observations are eventually supporting the data collected from the Alicona Infinite Focus measurement.

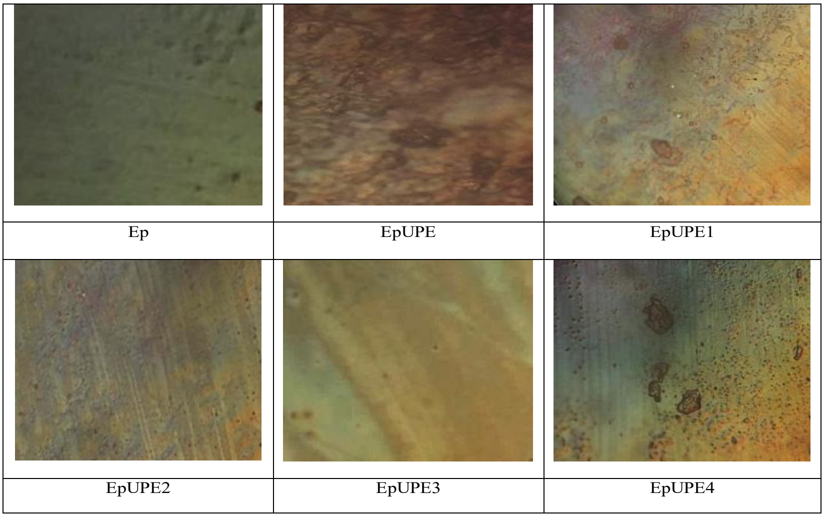

Figure 6: The Surface Morphology for Difference Formulation Coding Under Optical Microscopy (Source by author)

The surface for EpUPE, EpUPE1 and EpUPE4 show slightly grain in formation compared to EpUPE2 and EpUPe3 which is slightly smoother in surface measurement. It can be observed that relatively high amount of acetone will tend to make the epoxy resin to become smoothness of surface before it cures. The condition can be supported based on the common dominant property of acetone which is highly volatile and consist of volatility organic compound (VOC) content of 100%. This will tend to make acetone to evaporate fast to the air while processing and make the UHMWPE filler to be deposited on the surface. However, for the EpUPE4, the surface produce slightly grain surface in the middle which is slightly difference from the expected results. This is may be due to the amount of acetone that may be in access will disrupt the formation of micro bearing layer by increasing the gel time for the composite to cure. This will lead to the collision of the relatively low density filler with each other in the low viscosity liquid before curing.

CONCLUSION

The effect of acetone dilution towards the surface topography and morphology of micro bearing concept for Epoxy filled UHMWPE composite has been studied whereas the expected results shown that increase in the acetone ratio will reduce the surface roughness (Ra) of the surface and also will produce better surface distribution and morphology of the samples. Based on the results observed, EpUPE3 shows relatively low value of surface roughness (Ra) which is 1.41 μm and low pseuodocolour value of surface height which is around 6.76-6.77 cm which possessed better surface distribution and morphology compared to other formulation ratio. In near future, physical, mechanical and tribological properties need to be tested for the respective samples to determine the hardness value, Young's Modulus, creep value and wear rate in relation to the existing data. The improvements on all of these properties are expected to be the important parameters for the utilisation of micro bearing concept to counter the issues related to bearing applications.

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