Tribological and physical performance of micro bearing concept for diluted epoxy filled with UHMWPE composite

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Abstract. Short fillers have been widely used as reinforcing agents due to their successful effects on composite materials. However, studies for short fillers were mainly focusing on even dispersion of fillers in the composite system. As for the application related to bearing, the fillers needed to be deposited on the surface to improve the physical and tribological properties. Therefore, in this study, the fundamental of micro bearing concept was imparted by relating to the rheological study of polymer. These relations can be supported by the theory of particulate fillers in suspensions according to Modified Mooney-Einstein’s Theory of Viscosity. The Ultra High Molecular Weight Polyethylene (UHMWPE) fillers, which possess high wear resistance, were fabricated with epoxy resin. The mixture was prepared by diluting with acetone solvent and varying the filler loadings percentage for 1%, 3%, 5%, 7%, and 10%, accordingly. Based on the results observed, there were increment up to 41.7% for viscosity value. For the wear test, the results showed decrease in the wear rate up to 72.0%. For the hardness test, the results indicate increment in the hardness value up to 94% compared to UHMWPE alone. For the density test, the results showed decrease in the density value up to 3.8%.

Keywords: Diluted epoxy, Micro bearing concept, Modified Mooney-Einstein's Theory of Viscosity, UHMWPE, Wear rate

1. Introduction
In definition, bearing is a system of machine element that restrict correlative motion between operating parts by providing support upon an applied force through reducing friction between the relatively moving surfaces [1]. As for the bearing applications, the improvement in the bearing capacity are demanding which need to be optimized by enhancing the durability of the bearing properties upon movement on the plane of products. Normally, bearing products consist of single bearing material alone which can be made from metals, ceramics or polymer materials. Recently, since polymer materials possess addition unique properties which are corrosion and chemical resistant, they are widely being selected as bearing materials for various types of contact applications [2]. Another bearing products consist of secondary phase on top surface whether in form of protective layer, sheet and lubricant to function as noise reduction, shock absorber and improved the fatigue life of the product [3]. However, the challenges for the existing bearing products, whether they consist of a single phase or secondary phase are the durability to function over time. This is due to that bearing product that is relatively too
rigid which can break the load and cause high wear rate. For the bearing product that is too soft, it can cause potting and stress concentrator thus can disentangle the bearing surface upon creep and fatigue.

Therefore, in order to obtain the balanced tribological and physical properties for respective bearing surface, a study by Gahr [4] can be employed in this study whereas the findings show that the ruptured particles surface can be chemically modified by introducing a microstructure on the surface. The fundamental of polymer composite is being utilized whereas the bearing material which is Ultra High Molecular Weight Polyethylene (UHMWPE) polymer, in the form of micro-sized, has been chosen as the reinforcing fillers while epoxy resin has been selected as the matrix phase, consecutively. For UHMWPE, it is a semi-crystalline polymer with the dominant properties of high wear and abrasion resistance, chemical resistance and biocompatibility [5]. These properties makes it convenient for gears, liners and bearings application [6-7]. For epoxy resin, it consists of significant properties such as high solvent and chemical resistance, outstanding adhesion to substrates, low shrinkage upon curing, high flexibility and high impact resistance [7].

For the micro bearing concept, the fundamental study of material rheology which involves the Non-Newtonion fluid behaviour of polymer as relation to the viscosity and density study. In plastic material, when incorporating the short fillers, they will enhance the viscosity of the polymer mixture [8]. This will lead to the dilatant behaviour (shear thickening) of the Non-Newtonion fluid upon increase in the shear rate [9]. The theory that describe the behaviour of spherical fillers in polymers are first described by Einstein (1) for diluted solutions or dispersions. Einstein states that the viscosity of viscous fluid \( \eta_o \) increased when small, rigid and non-interacting spheres were suspended in the liquid [10]. According to the equation, the viscosity of the mixture (\( \eta \)) is directly proportional to the fractional volume (c) occupied by the particles which viscosity of the mixture does not depend on the polarity of the liquid and size of the spheres. The parameters are fractional volume (c) which is less than 0.1 and maximum packing of sphere is 90%. The introduction of a coefficient which is 2.5 indicates that it is for hard particle spheres. The equation has been modified by Mooney (2) by introducing hydrodynamics or crowding factor (\( \beta \)) which is equal to 1.35 and 1.91 for loosely and densely packed spheres. The modification can be similar to the original Einstein Equation when the crowding factor is equal to 0. The Einstein Equation and Modified Mooney-Einstein Equation can be deduced as follow.

\[
\eta = \eta_o (1+2.5c) \quad \text{and} \quad \eta_{sp}/c=2.5
\]
\[
\eta = \eta_o (2.5c/1-\beta c) \quad \text{and} \quad \eta_{rel}/c=2.5
\]

Since the increase in the filler loadings will contribute to the increase in the viscosity of the polymers, the need of diluent is significant to reduce the viscosity for the matrix. Hence, by introducing diluent, less dense filler can be deposited on the surface of composite upon curing. The methodology is different from the normal composite system which need the fillers to be evenly distributed inside the composite system. As for the diluent, acetone solvent has been widely used by various studies to improve the processing parameter and behaviour of respective fillers inside the matrix constituents. Based on various studies conducted by Gong et al., Loos et al. and Dong et al. [11-13], the outcomes show that acetone solvent reduce the viscosity of the resin, which then will allow a better dispersion and distribution of fillers upon curing.

The aim of this work is to study the effect of filler loadings on the tribological and physical performance of the micro bearing concept by fabricating the diluted epoxy filled with UHMWPE as a composite system. The mixture of epoxy resin were successfully prepared by diluting with acetone diluent and varying the UHMWPE filler loadings at different weight percentage. During processing, the viscosity of the mixtures were tested using viscosity test before being proceed on the tribological and physical tests upon curing. The tribological test, which is the wear test was conducted to determine the wear rate which can be deduced as [14],

\[
W = \Delta V/ F_{N} \times L
\]
whereas W is the specific wear rate, ΔV is the volume loss (mm³), \( F_N \) is the normal load (N), and L the sliding distance (m). The morphological analysis after wear was also conducted under optical microscopy measurement using Polarized Optical Microscope to observe the nature of sample after abrasion. For the physical tests, hardness test was conducted to determine the hardness value while density test was conducted to measure the density value of the respective samples.

2. Methodology

2.1. Materials

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 UHMWPE GUR 4120 fillers were supplied from Ticona Engineering Polymer, China in powdered form with molecular weight of 5 x 10⁶ g/mol and density of 0.93 g/cm³. The AR1003-P2.5L acetone, which meet the A.C.S Specification, with molecular weight of 58.08 g/mol and density of 0.79 g/cm³ at 25 °C was obtained by RCI Labscan Limited Company.

2.2. Samples Preparation

The micro bearing concept of Epoxy filled UHMWPE composites were mixed and fabricate using casting technique. The methodology of preparation the samples were based on study of Ariffin et. al. [15] with some modifications to obtain the micro bearing layers. First, the epoxy resin was stirred with UHMWPE fillers using a mechanical stirrer at 650 rpm for 10 minutes followed by sonication process at 20 kHz for 10 mins. Then, the mixture were diluted with acetone solvent for 5 minutes at 250 rpm. After that, the mixture were stirred with hardener for 5 mins at 250 rpm. The diluted mixture were later being hold at ambient temperature for 5 minutes before being poured into an open mould. Later, the samples were cured at room temperature for 24 hours before undergo post-cure process in the oven at 50 °C for 24 hours. Upon curing, the micro bearing layers can be observed with the distinction of the two phases on the composite sample. The deposition of fillers on the surface of composite can be illustrated based on Scanning Electron Microscopy analysis as shown on Figure 1. In this study, the research variables were the weight percentage of UHMWPE filler loadings in the composite system which are 1% (EpUPE1), 3% (EpUPE2), 5% (EpUPE3), 7% (EpUPE4) and 10% (EpUPE5), accordingly. While for the control sample, neat epoxy (Ep) was used as reference sample.

![Figure 1. The filler disposition on the surface of micro bearing layers under Scanning Electron Microscopy analysis (Source by author).](image)

2.3. Experimental Testing
2.3.1. Viscosity Test.
The viscosity test was conducted using a Brookfield DV-1 Prime Viscometer of spindle fiber number 0.2 with rotating speed of 2.5 rpm. The measured volume of 200 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 [16].

2.3.2. Wear Test.
The wear test was conducted using Sangyo Co. Ltd. AB-301 Color Fastness Rubbing Tester with 6 N load and 0.01m sliding distance. The pin configuration was a Pin-on-Table type with 5000 cycles in 3 hours. The results were measured in mm³/Nm. The test procedure was conducted according to ASTM Standards G132-96 [17].

2.3.3. Hardness Test.
The hardness test was examined using an Instron Wilson/Rockwell A654-R Digital Hardness Tester with 60N major load and 5 seconds delay time. The ball indenter diameter was 12.7 mm which is in the scale of 1:1/16. The results were measured in Rockwell Hardness Scale R (HRR). The test procedure was conducted according to ASTM Standards D-785 [18].

2.3.4. Density Test.
The density test was conducted using an Electronic Densimeter MD-300S with 0.001g/cm³ density resolution. The specimens were first weighed on top of the densimeter before being immersed in the densimeter water container to determine the apparent mass. After that, the specific gravity in term of relative density were calculated. The test procedure was conducted according to ASTM Standards D792-17 [19].

2.3.5. Optical Microscopy Measurements.
The optical microscopy measurements were taken by using Olympus BX51 Polarized Reflected Microscope under bright field mode with U-TV1X-2 MoticamPro Camera Adapter. The observations were carried out under 5x magnification with controlled fluorescent ring illumination. The test procedure was conducted according to ASTM Standards E883-11 (2017) [20].

3. Results and Discussions

3.1. Viscosity Test
For rheological study, the kinematic viscosities of the composite mixture with difference UHMWPE filler loadings can be seen on Figure 2. From the graph, the trend shows that incorporating filler loadings enhance the viscosity of the mixture. EpUPE5 shows the highest range of viscosity value which are around 17000 mPaS while EpUPE1 shows the lowest range of viscosity value which are around 12000 mPaS. This indicates that there is up to 41.7% viscosity increment from low filler loadings (1%) to high filler loadings (10%), respectively.
For the Ep mixture which act as reference sample, the range of viscosity of the neat epoxy resin is around 10000-11000 mPas indicates that the matrix is originally in high viscous flow behavior. Upon incorporating UHMWPE fillers into the mixture, the viscosity value increase significantly proved that it follows dilatant behaviour of polymer flow [9]. This is due to the UHMWPE particles tend to form agglomeration inside the matrix thus resulting restriction of material flow. The increase in the resistance of the flow makes more force needed to flow the mixture upon rotational motion as relation to the fundamental of viscosity [21]. Furthermore, since the fillers used are short fillers, they can penetrate randomly through the mixture of epoxy resin which provide the interfacial filler-matrix adhesion of the UHMWPE particles with the resin. The data obtained also had been proven based on the Modified Mooney-Einstein Theory of Viscosity whereas viscosity of the overall composite will be increased linearly upon increase in the filler loadings.

Hence, with the relatively high viscosity of composite mixture with increase in filler loadings, the micro bearing concept cannot be incorporated as the filler as they will randomly dispersed into the composite system upon curing. However, acetone diluent has been used to reduce the viscosity of the mixture so that the distinctive density of epoxy resin and UHMWPE filler can be separated into two phases to form the micro bearing layers. The micro bearing layers formation with acetone diluent and the epoxy filled with UHMWPE fillers without acetone can both be illustrated on Figure 3a and Figure 3b.

**Figure 2.** The kinematic viscosities of difference filler loadings against time.

![Figure 2](image-url)
Figure 3. a) The micro bearing layers formation with acetone diluent and, b) The epoxy filled UHMWPE fillers without acetone diluent (Source by author).

3.2. Wear Test

For wear test, the wear rate values of the composite with different filler loadings can be tabulated based on Figure 4. From the graph, the highest wear rate value is UHMWPE1 with $3.22 \times 10^{-5}$ mm$^3$/Nm while the lowest wear rate value is $0.9 \times 10^{-5}$ mm$^3$/Nm. The trend show a decline in wear rate with increase in the filler loadings. For the Ep sample, it can be said that it slightly increase the wear rate value due to the nature of epoxy which is brittle upon curing which is subject to catastrophic failure upon loading [7]. When incorporating filler from low to high loadings, the wear rate value decreases. This can be explained by the nature of the UHMWPE polymer which is commonly known for its dominant properties of improved the wear resistance and reducing the wear rate [22]. When incorporating an increase amount of UHMWPE filler, the surface of the bearing layers will be deposited by the aggregation of these fillers. The clump of fillers will somehow act as a cushion which reduce the brittleness of the matrix constituent. As a result, the stress loading behaviour can be transferred and distributed between the fillers thus reducing the friction and impact of load upon motion. Therefore, volumetric loss can be minimize when two surface being contacted with each other for period of time as referring to the wear rate equation [14].

![Figure 4. The wear rate values of the composite with different filler loadings.](image-url)
The morphological after wear for all of the respective samples were conducted as a relation to the data obtained from the study. The abrasive phase as well as the worn surface were analysed by using optical microscopy measurements on the surface of the micro bearing layers.

3.3. Hardness Test
The effect of UHMWPE filler loading on the hardness value of the composites were presented in column diagram as shown in Figure 5. As comparison, EUHMWPE5 yield the highest hardness value with 97 HRR while EUHMWPE10 yield the least hardness 88 HRR. The trend of the graph show that increasing in the filler loading concentrations will tend to increase the hardness value until EUHMWPE5 and significantly drop the value from EUHMWPE 7 to EUHMWPE10. Based on the data observed, it can be said that incorporation of fillers give significant effect depending on several factors like density, distribution and dispersion of the fillers themselves inside the composite matrix.

![Figure 5](image_url). The hardness value of the composite different filler concentrations.

Generally, for Ep sample tend to generate high hardness value which is 110 HRR. Upon mixing with acetone and UHMWPE fillers, the values drop indicates that acetone reduce the brittleness of the epoxy matrix and provide slightly elastic behaviour of the composite [23]. The slightly decrease in the hardness value with filler loadings are tolerable since the range hardness values, which are between 88 to 97 HRR, are way more harder and stronger than typical hardness value of UHMWPE alone which is 50 HRR [24]. As referring to the trend on the graph, for low filler loadings (EUHMWPE1, EUHMWPE3 and EUHMWPE5), it can be said that upon increase the aggregation of UHMWPE fillers into the epoxy matrix, they will provide a relatively packed region on the surface thus providing stronger phase to resist deformation. However, starting on high filler loadings (EUHMWPE7 and EUHMWPE10) onwards, the hardness values are slightly decline. The reason may be due that the filler-filler interaction which has reach the threshold value and being saturate on the surface. With the filler-filler interaction being the dominant phase compared to filler-matrix interaction, there might be lack of adhesion between fillers thus soften the surface when being clump together on a large scale. The data can be further supported by the relation with the density test and optical microscopy measurements of the filler loadings distribution on the surface of the micro bearing layers.
3.4. Density Test
For density test, the relationship between density value with filler loadings can be shown on Figure 6. From the graph, EUHMWPE1 yield higher density value with 1.137 g/cm³ while EUHMWPE5 yield the least density value with 1.095 g/cm³. For Ep sample, the density of the epoxy resin is relatively higher due to nature of epoxy resin that possess high viscosity and has low shrinkage upon cure [7]. This will lead to reduce in the void formation inside the matrix when curing. For the sample with filler loadings, the trend show that the density value of the composite decrease with increase in the filler loadings.

![Figure 6](image)

**Figure 6.** The density test for the respective formulation coding with difference filler loadings.

Based on the study conducted by Sudheer et al, hardness test is directly proportional to the density value [25]. The outcomes showed that the filler being used which is PTW fillers is harder and denser than the matrix which yield the dominant density and hardness properties upon increase in the filler loadings, respectively. However, the correlation are difference for this study whereas the UHMWPE filler being used are less dense filler with density of 0.96 g/cm³. Comparatively, when imparting a large amount of these fillers with specific amount of acetone, it will slightly reduce the overall viscosity of the composite which make the fillers to be the dominant phase on the surface of the micro bearing layers. The fillers that being clumped together on the surface will somehow make the composite to yield the density value closing to the dominant phase, which are the fillers as compared to the matrix phase.

3.5. Optical Microscopy Measurements
3.5.1. Wear Test.
For the wear test, the morphological analysis of the worn surface of Ep sample, EpUPE sample with low filler loadings and high filler loadings can be illustrated on Figure 7. Based on the optical microscopy measurements, all of the respective samples possess abrasion pattern perpendicular to the sliding direction of the pin with the same load cycles. The abrasion pattern can be represented on the circle of the respective samples. For Ep sample, in Figure 7a, the surface possess a high worn and abrasion upon contacting with the load. Upon the lateral direction of the sliding load, Ep sample show a wear debris in the form of black particles indicates that the surface has been worn out and the surface undergo plastic deformation. For low filler loadings, in Figure 7b, it shows that the abrasion pattern is reducing indicates
that UHMWPE filler provide slightly abrasion resistance by reducing the load friction thus restrict the high impact cycle load upon motion. For high filler loadings, in Figure 6c, the abrasion pattern show the least pattern due to the crumple formation of UHMWPE fillers on the surface. They will tend to form the surface cushion that which act as ‘roller’ that absorb and transfer the load between fillers into the micro bearing layers surface.

![Figure 7](image_url)

**Figure 7.** The optical microscopy of worn surface of a) Ep sample, b) EpUPE sample (low filler loadings) and, c) (high filler loadings) (Source by author).

### 3.5.2. Hardness Test

Hardness test can be supported by the morphological analysis of Ep sample, EpUPE sample with low filler loadings and high filler loadings, as shown on Figure 8. From the optical measurements, the figures show that UHMWPE fillers are generally being deposited on the surface of the composite as a clump of micro bearing layers. For Ep sample, in Figure 8a, the surface of the neat epoxy is shiny and tend to become glassy-like surface. This is due to the nature of epoxy which is hard but brittle in structure. For low filler loadings, in Figure 8b, it shows that epoxy resin fills the space between UHMWPE fillers which act as adhesion to strengthen the filler-matrix interaction on the surface. For high filler loadings, in Figure 8c, the crumple of fillers form filler-filler interaction which dominate the epoxy on the surface encapsulation layer thus represent the medium to resist deformation.
Figure 8. The optical microscopy for micro bearing layers surface of a) Ep sample b), EpUPE sample (low filler loadings) and, c) (high filler loadings) (Source by author).

4. Conclusion
The effect of filler loadings on the tribological and physical performance of the micro bearing concept by fabricating the diluted epoxy filled with UHMWPE has been studied. The mixture of epoxy resin were successfully prepared by diluting with acetone diluent and varying the UHMWPE filler loadings at different weight percentage. Based on the results observed, EpUPE5 shows the highest range of viscosity value which are around 17000 mPAs while EpUPE1 shows the lowest range of viscosity value which are around 12000 mPAs. This indicates that there is up to 41.7% viscosity increment. For the wear test, the highest wear rate value is UHMWPE1 with $3.22 \times 10^{-5}$ mm³/Nm while the lowest wear rate value is $0.9 \times 10^{-5}$ mm³/Nm which indicates that it decreases the wear rate up to 72.0%. For the hardness test, EUHMWPE5 yield the highest hardness value with 97 HRR while EUHMWPE10 yield the least hardness 88 HRR, indicates that increment in the hardness value compared to UHMWPE alone up to 94%. For the density test, EUHMWPE1 yield higher density value with 1.137 g/cm³ while EUHMWPE5 yield the least density value with 1.095 g/cm³. The overall value shows that filler loadings decreases the density value up to 3.8%. The improvements on all of these properties are expected to be the important parameters for the utilization of micro bearing concept to counter the issues related to bearing applications especially on tribological and physical properties of the micro bearing layers of the composite.

5. References
[1] Majumdar B C 2008 Introduction to Tribology of Bearings (New Delhi: S. Chand & Company Ltd.) p 298
[2] Rubens N J, Seshagiri R S and Harihara S S P 2013 A review on the materials used for bearing and failure behavior Int. J. of Stud. Res. in Technol. & Mgmt. 1 431-443
[3] Qiu M, Chen L, Li Y and Yan J 2017 Bearing Tribology: Principles and Applications (Berlin/Heidelberg: Springer-Verlag) p 333
[4] Gahr K H Z 1987 Microstructure and Wear of Materials (Amsterdam: Elsevier) p 560
[5] Rocha L F M, Cordeiro S B, Ferreira L C, Ramos F J H and Marques M F 2016 Effect of carbon fillers in ultrahigh molecular weight polyethylene matrix prepared by twin-screw extrusion Mater. Sci. Appl. 7 863-880
[6] Puértolas J A and Kurtz S M 2016 UHMWPE matrix composites UHMWPE Biomaterials Handbook (Third Edition) ed S M Kurtz (Amsterdam: Elsevier) pp 369-397
[7] Massingill Jr J L and Bauer R S 2000 Epoxy resins Applied Polymer Science: 21st Century
ed C D Craver and C E Carraher Jr (Amsterdam: Elsevier) pp 393-424
[8] George K E 2009 Non-Newtonian fluid mechanics and polymer rheology Advances in Polymer Processing: From Macro To Nano Scales ed S Thomas and Y Weimin (Cambridge: Woodhead Publishing) pp 13–46
[9] Silberberg A 1977 Basic rheological concepts Mucus in Health and Disease (Advances in Experimental Medicine and Biology vol 89) ed M Elstein and D V Parke (Boston: Springer) pp 181-190
[10] Carraher J C E 2003 Seymour/Carraher's Polymer Chemistry: Sixth Edition (New York: Marcel Dekker, Inc.) p 960
[11] Gong X, Liu J, Baskaran S, Voise R D and Young J S 2000 Surfactant-assisted processing of carbon nanotube/polymer composites Chem. of Mater. 21 1049-1052
[12] Loos M R, Coelho L A F, Pezzin S H and Amico S C 2008 The effect of acetone addition on the properties of epoxy Polímeros: Ciência e Tecnol. 18 76-80
[13] Dong B, Yang Z and Li H L 2005 Study on tribological properties of multi-walled carbon nanotubes/epoxy resin nanocomposites Tribol. Lett. 20 251-254
[14] Wang Y, Yin Z, Li H, Gao G and Zhang X 2017 Friction and wear characteristics of ultrahigh molecular weight polyethylene (UHMWPE) composites containing glass fibers and carbon fibers under dry and water-lubricated conditions Wear 380–381 42–51
[15] Ariffin A A, Ibrahim N N I N, Shuib S, Romli A Z and Ismail N F 2019 The effect of acetone dilution towards the surface topography and morphology of micro bearing concept for epoxy filled UHMWPE composite Sci. Res. J. 16(2) 27–42
[16] ASTM D445-06 2006 Standard test method for kinematic viscosity of transparent and opaque liquids (and calculation of dynamic viscosity) ASTM International
[17] ASTM G132-96 2018 Standard test method for pin abrasion testing ASTM International
[18] ASTM D785-08 2015 Standard test method for rockwell hardness of plastics and electrical insulating materials ASTM International
[19] ASTM D792-13 2013 Standard test methods for density and specific gravity (relative density) of plastics by displacement ASTM International
[20] ASTM E883-11 2017 Standard guide for reflected-light photomicrography ASTM International
[21] Viswanath D S, Ghosh T K, Prasad D H L, Dutt N V K and Rani K Y 2007 Viscosity of Liquids: Theory, Estimation, Experiment, and Data (Netherlands: Springer) p 662
[22] Selyutin G E, Gavrilov Y Y, Voskresenskaya E N, Zakhrov V A, Nikitin V E and Poluboyarov V A 2010 Composite materials based on ultra high molecular polyethylene: properties, application prospects Chem. Sustain Dev. 18 301-314
[23] Abbas L K 2011 Study of the effect of acetone dilution percentage on mechanical properties of epoxy-acetone system Iraq j. Mech. Mater. Eng. 11 371-379
[24] Tiwari A, Murugan N A and Ahuja R 2016 Advanced Engineering Materials and Modeling (USA: Wiley-Scrivener Publishing) p 528
[25] Sudheer M, Prabhu R, Raju K and Bhat T 2014 Effect of filler content on the performance of epoxy/PTW composites Adv. Mater. Sci. Eng. 2014 1-11

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