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Effects of Dispersion of Multiwalled Carbon Nanotubes (MWCNT's) on Wear Resistance of Polytetrafluoroethylene (PTFE)

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Abstract— Multi walled carbon nanotubes (MWCNT's) were added as reinforcement in different proportions into the polymer matrix of polytetrafluoroethylene (PTFE) to study the wear and friction properties of PTFE. Cylindrical specimens of dimensions ϕ 12 mm and length 30mm of pure PTFE and PTFE/MWCNT nanocomposites were prepared by compression moulding technique followed by sintering at fixed temperature. Pin-On-Disc type tribometer was used to investigate and compare the wear rate and frictional coefficient of pure PTFE and PTFE/MWCNT nanocomposites under dry sliding conditions. Experiments were carried out by considering parameters for low load (10N, 20N) and for high load (100N) applications, under sliding speed of 500 r.p.m for 10 minutes. From results, it was observed that the addition of carbon nanotubes as filler material maintained low values of coefficient of friction as pure PTFE with an appreciable increase in the wear resistance. Worn surfaces of samples were analyzed through optical microscope and obtained images were used to discuss the abrasion mechanism of PTFE nanocomposites.

Index Terms - Carbon Nanotubes, Polytetrafluoroethylene, Nanocomposite, Wear Resistance, Coefficient of Friction.

1. INTRODUCTION

Teflon (Poly-Tetra-Fluoro-Ethylene, PTFE) is an important thermoplastic fluoropolymer that exhibits lowest value of coefficient of friction and because of this property it can also be used as solid lubricant [1]. PTFE is one such polymer which has widely been used in industry as replacement to metal in manufacturing of various engineering products, especially for tribological applications. Due to its unique properties like high temerature stability, high chemical resistivity and low coefficient of friction, PTFE is utilized for making high performance mechanical seals [2]-[4]. But the problem associated with Teflon is its high wear rate resulting in frequent replacement of parts which limits its application area upto low load conditions only. Various approaches considering micro and nano-fillers (in form of nano-clay and nanoparticles) in the polymer matrix conclude the enhancement in wear resistance [5]-[6]. The shape and size of filler material added also plays an important role to effect the wear rate of composite subjected to abrasion [7]. PTFE fabricated bearings can also be used as replacement to gun metal and brass bears used in sugar industeries [8]. Moreover, extremely less attention is given towards incursion of Multiwalled Carbon Nanotubes (MWCNTs) as a nano-filler in Teflon matrix. So the present idea is based on the need that an engineer should develop a good quality wear resistance composite material for various industrial applications by incorporating the MWCNTs in PTFE polymer matrix by low cost dispersion technique. The resulting composite will be tested for wear rate and coefficient of friction under dry conditions varying the following factors like applied load, rotational/sliding speed etc. Carbon nanotubes showing outstanding mechanical properties have been the subject of many investigations as reinforcement for several composite applications.

Various research groups have studied the effect of fillers on the tribological & mechanical properties of PTFE [1]–[17]. However, dispersion of CNTs in the polymer matrix possesses the major problem when dealing with high performance polymer nanocomposites. The strong Vander Waals forces make it difficult to achieve desired level of dispersion as CNT's are highly flexible and capable of bending in circles and forming knots.

The behavior of PTFE alloy steel composite and PTFE bronze composite was under look by *Dinghan Xiang et al.* [9]. Furthermore *Arash Golchin et al.* [10] proposed that addition of MoS2, fiber glass, black glass, bronze and carbon as filler materials in PTFE matrix can improve the wear resistance and other mechanical properties. PTFE filled with PEEK as filler material was investigated by *David L. Burris* [11] that reveals ultra low wear rate and low frictions in composite. *Brian B. Johnson* [12] introduces untreated MWCNT's in high density polyethylene matrix and predicted that addition of CNT can decrease the wear rate as well as coefficient of friction. The introduction of very small amount of CNT of 0.5 wt. % in ultra high molecular weight polyethylene matrix could decrease wear rate to great extent was studied by *Yeong-Seok Zoo* [13]. *Deepak Bagale* [14] discusses the effects of applied load, velocity of sliding and sliding distance on friction and wear behavior of polymer material made of polytetrafluoroethylene (PTFE) and its composites prepared by using filler materials such as 40% bronze and 40% carbon. He concluded that The highest wear resistance was observed for 40% carbon filled PTFE followed by 40% bronze filled PTFE and then virgin PTFE. *N V Klass* [15] discloses the wear and friction behavior of polytetrafluoroethylene (PTFE) filled with glass as filler material. In his results, glass fibres showed the lowest wear as compared to glass bead filled PTFE because in case of glass beds thicker films were formed on counterface. *H. Unal* [16] investigated the influence of test speed and load values on the friction and wear behaviour of PTFE and its composites filled with glass fiber, carbon and bronze in different proportions and concluded that wear rate shows very little sensitivity to test speed and large sensitivity to the applied load for the range of load. *W. Gregory Sawyer* [17] represented PTFE filled alumina nanocomposite for tribological behavior and concluded that alumina nanoparticles could effectively decrease the wear rate as compared to pure PTFE. In present work, there is comparative investigation on both pure PTFE and varying proportions of PTFE-MWCNT nano composites so as to determine the effect of CNT's inclusion in PTFE matrix and its further effect on wear rate and friction coefficient of material.

2. EXPERIMENTAL PROCEDURE

2.1 *Material used*

Pure polytetrafluoroethylene (PTFE) in powder form (HIFLON MM2) was used as the source material for all specimens was purchased from Hindustan Fluorocarbons Limited, Hyderabad, India. MWCNTs of 99% purity having outer diameter 10-20 nm and length of 3-8 µm was purchased in 10gm quantity from Intteligent materials pvt. Ltd., Dera Bassi, Punjab, India.

3. MIXING PROCEDURE

3.1 *Aqueous Mixing Method*

In previous experimental trails PTFE aqueous solution (HIFLON 603) shown in figure 1, was used for the preparation of bare Teflon (PTFE) and PTFE/MWCNT cylindrical specimens with a consideration that MWCNT would effectively dispersed in polymer using aqueous solution. The amount of MWCNT by weight percentage added to the HIFLON 603 aqueous solution and stirred for 10-15 minutes with the help of magnetic stirrer. Then solution in beaker heated in Muffle furnace at temperature of 200^0 for 20 minutes so that moisture can be removed. The resulting dry mix is shown in figure 2.

In the next step, the dry form of PTFE was poured in the mould and compressed under load of 10 KN to prepare required cylindrical specimen of dimensions (Dia = 12mm and Legth = 32mm) by assistance of compression moulding.

Fig. 1 - PTFE aqueous Solution

Fig. 2- Dry mixture of PTFE

It was found that the resulting specimens were not of adequate strength and surface finish. This was due to the presence of moisture and surfactant particles in PTFE aqueous solution that leads to improper sintering at high temperatures. So, PTFE powder (HIFLON MM2) was decided to be used instead of aqueous solution.

3.2 *Powder Mixing Method*

Two types of specimens were fabricated using PTFE powder. First samples of pure PTFE were prepared and then afterwards CNT reinforced nanocomposites with composition of 0.1, 0.5, 1, 5% by wt. were produced. Pure PTFE powder was converted into standard pin type samples of diameter 15 mm and length 30mm using hot pressing (Compression Moulding) technique followed by sintering at 320°C for 30 minutes, particularly for tribological test. Afterwards MWCNTs were added into the PTFE in such way that the resulted specimens were contain 0.1, 0.5, 1, 5 wt% of MWCNT's in PTFE. For this, MWCNTs were dispersed in volatile organic solvent, Acetone. After this PTFE powder was added. In Next step, the mixture was ultrasonicated by using ultrasonicator (shown in fig. 3) as well as stirred using magnetic stirrered (Shown in fig. 4) for 2 hrs at 90^0C temperature.

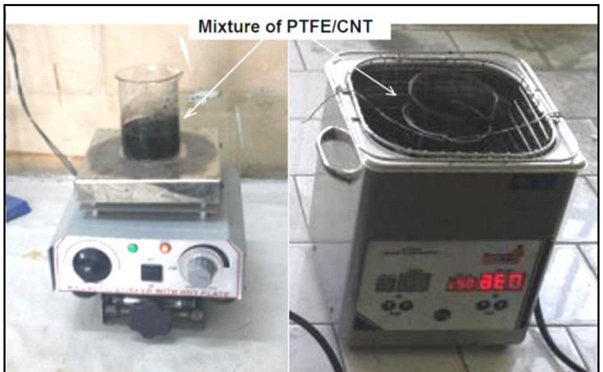

Fig. 3 - Magnetic Stirrer   Fig. 4 - Ultrasonic Cleaner

After the removal of acetone the resulted dry mixture was poured into the mould (shown in fig. 5) and thereafter, the mould assembly was placed in the hot press table and hydraulic actuator lever was activated to raise the hot press table and apply the force on the mould plate assembly.

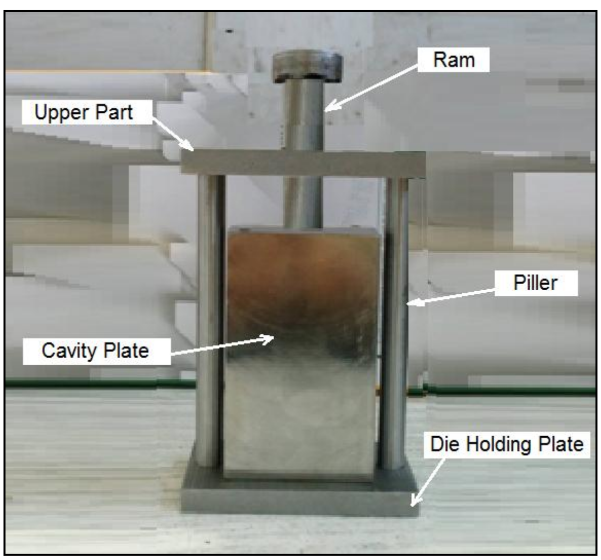

Fig. 5 – Mould for Specimen Preparation

The pressure force 10 KN was applied on the mould assembly to produce the cylindrical pin type specimens of diameter 15mm and length 40mm. A standard conventional lathe machine was used to machine samples so that desired dimensions of ϕ 12 mm and length 30mm would be attained. Resulting machined specimens are shown in fig. 6

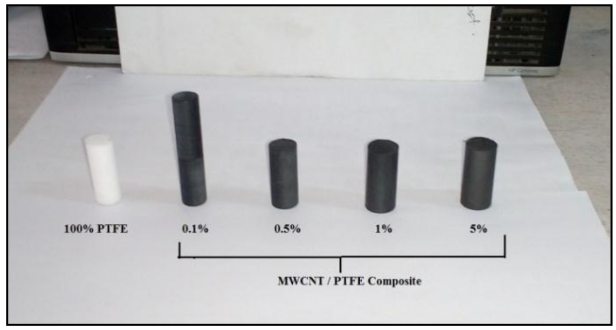

Fig. 6 – cylindrical specimens for tribological testing

3.3 *Testing of Specimens*

Pin-on-Disc type Tribometer (DuCom, TR-20-M26), was utilized to evaluate wear rate and friction coefficient of the pure PTFE and PTFE/MWCNT nano composite material by selecting parameters like load, sliding speed, time and sliding distance. The specimens were tested for both low load (10-20N) and high load (100N) application under sliding speed of 500 r.p.m and time 10 minutes for comparative investigation. Tribological testing is as shown in fig. 7 below.

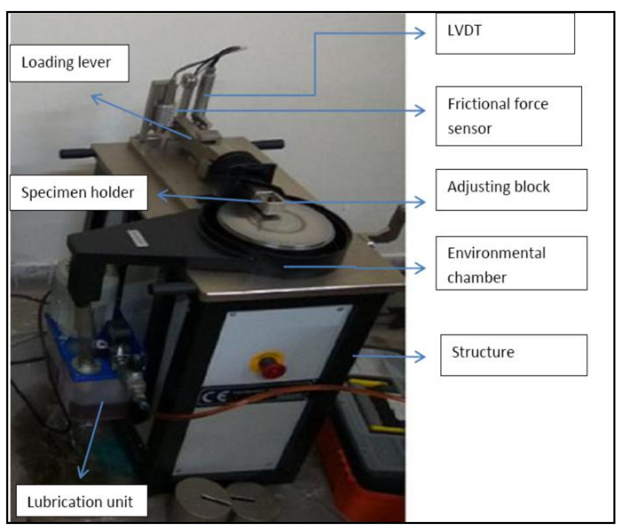

Fig. 7 – Tribological testing of PTFE and PTFE/MWCNT nano composites

4. RESULTS AND DISCUSSIONS

The uniform dispersion of MWCNT's in PTFE polymer matrix plays an important role to achieve the desired level of reinforcement within the composite. Mixing of MWCNT's with aqueous form of PTFE was not found to be suitable to give adequate strength to specimen as compared to powder mixing technique. Various experiments were conducted for comparative investigation of tribological behavior of pure PTFE and PTFE/MWCNT nano composites and obtained results are critically analyzed. The results from tribological analysis regarding wear and friction coefficient of specimens are obtained and are presented in a detailed manner in form of graphs shown in fig. 8-10 and table 1.

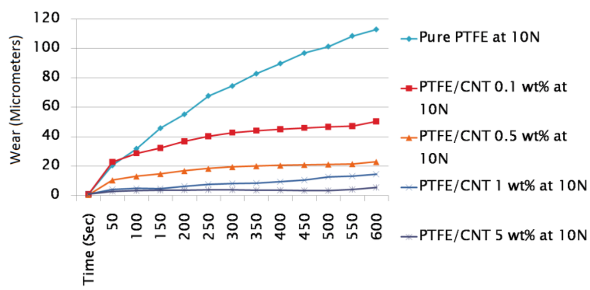

Fig. 8- Wear of PTFE/MWCNT nano composites at load 10N, Speed 500 r.p.m for 10 Minutes

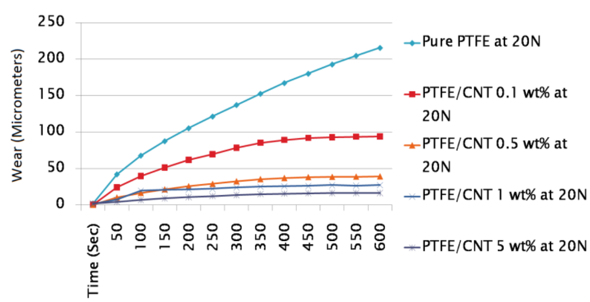

Fig. 9 - Wear of PTFE/MWCNT nano composites at load 20N, Speed 500 r.p.m for 10 Minutes

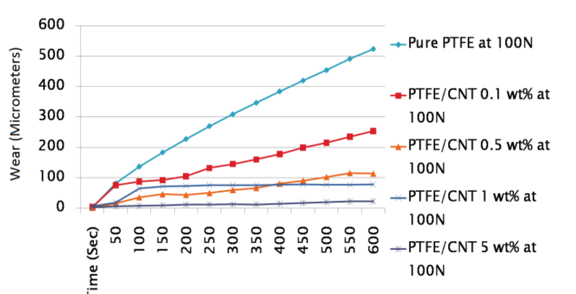

Fig. 10 - Wear of PTFE/MWCNT nano composites at load 100N, Speed 500 r.p.m for 10 Minutes

S.No.	Specimen Composition	COF
1	Pure PTFE	0.019
2	PTFE/CNT 0.1 wt.%	0.019
3	PTFE/CNT 0.5 wt.%	0.019
4	PTFE/CNT 1.0 wt.%	0.019
5	PTFE/CNT 5.0 wt.%	0.019

Table 1 – Coefficient of friction of pure PTFE and PTFE/CNT nanocomposites

The wear rate of 0.1% CNT/PTFE nanocomposite specimen was found to be reduced by 45% as compared to pure PTFE sample for both low load and high load applications with negligible increase of coefficient of friction. An increase in wear resistance upto 5 times compared to pure PTFE was observed for 0.5% CNT/PTFE nanocomposite. Spectacular results of decreased wear rate were observed for both 1% CNT/PTFE and 5% CNT/PTFE compositions that demonstrated tremendous reduction in wear rate of 8 times and 22 times compared to pure PTFE. Table 1 shows experimentally observed values of coefficient of frictions of all specimens. In comparison, it was found that the coefficient of friction of PTFE samples without CNT and with CNT remains similar for both low load and high load applications. This is due to the deposition of thin layer of CNT/PTFE sample on steel counterpart that makes CNT acts as self lubricator to reduce wear rate of specimen and to maintain low values of coefficient of fiction. Optical Microscopy of worn surfaces of specimens were investigated and images were comparatively analyzed with the assistance of optical microscope. Figure 11-13 shows microscopy pictures of worn surfaces of specimens. The worn surfaces of pure PTFE samples were smooth with broader and deeper wear tracks. On the other hand, CNT reinforced PTFE samples had polished worn surfaces along with narrow wear tracks. These clearly conclude self lubricating action and wear resisting mechanism of CNT as an effective filler material.

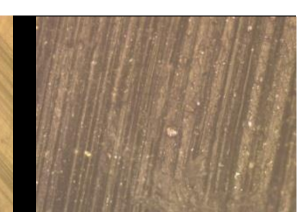

Figure 11- Pure PTFE **Figure 12- PTFE/CNT 0.1 wt.%**

Figure 13- PTFE/CNT 5 wt.%

5. CONCLUSIONS

I. The addition of carbon nanotubes as filler in PTFE not only reduced the wear rate but also provided resistance to abrasion without affecting its friction coefficient.

II. Incorporation of small amount of CNT (0.1 wt.%) particulates into PTFE can significantly double the wear resistance of PTFE fabricated material subjected to sliding wear or abrasion. Minimum wear rate was observed for filler percentages of 1% and 5%.

III. The effective dispersion of CNT in PTFE polymer matrix predicted as key factor to provide adequate strength and to reduce wear rate of specimen.

IV. Self lubricating protective action of CNT on sliding counter surfaces leads to unaltered values of friction coefficients for all specimens thus making CNT as unique and highly recommended filler material to increase durability of PTFE fabricated parts.

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