Thesis for the Degree of Master of Engineering

Tribological Behavior of Cu Nano-Particles Impregnated PTFE

by

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February 2009

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by

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A thesis submitted in partial fulfillment of the requirements
Master of Engineering

in Department of Control and Mechanical Engineering
Graduate School
Pukyong National University

February 2009

이 논문을 **Nguyen Tuyen Quang** 의 공학석사

학위으로 인준함

2008 년 12 월 16 일

주	심	공학박사	장지성	(인)
위	원	공학박사	한규일	(인)
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February 25th, 2009

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Tribological Behavior of Cu Nano-Particles Impregnated PTFE

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Abstract

Polytetrafluoroethylene (PTFE) impregnated with Cu nano-particles (CuN-PTFE) and Virgin PTFE slided against a brass disc under the various condition of loads, lubricating oil temperatures and sliding speeds. They were investigated on the Pin-On-Disc friction and wear tester (P.O.D).

Experiment results showed that the friction coefficients of CuN-PTFE at the low condition of sliding speed and oil temperature (0.44mm/s and 40°C) were higher than Virgin PTFE (0.024 - 0.020 for CuN-PTFE; 0.023 - 0.018 for Virgin PTFE). Fortunately, that changed as specimens worked in the high condition of load and oil temperature, the friction coefficient of CuN-PTFE was lower than that of Virgin PTFE. In addition, the experiment indicated also, if as under the load condition of 20N, their wear volume loss difference was $2x10^{-3}$ gram, then at 80N that was 0.024 gram. This evidenced the load carrying capacity of CuN-PTFE was much better than that of Virgin PTFE, under high load condition specially.

On the other hand, on graphs showed that the viscosity of the lubricating oil influenced not much to the wear rate as well as the friction coefficient of CuN-PTFE. Further, it was demonstrated that the wear properties of PTFE materials could be greatly improved by a layer of lubricating oil film.

Therefore, it can be concluded that, the friction coefficient variation of CuN-PTFE is very small but its wear rate decreases greatly with increase in sliding speed.

Cu Nano-Particles 이 함침된 PTFE 마모 거동

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제어 기 계 공 학 과

요 약

구리 나노 입자가 함침된 PTFE의 소재에 대하여 윤활하중, 온도변화, 미끄럼속도등의 다양한 실험 조건으로 연구되었다.

실험결과 CN/PTFE는 0.44mm/s, 40℃ 조건에서 마찰계수가 순수한 PTFE보다 높게 나타났다. 0.024~0.020, CuN-PTFE, 0.023~0.018및 순수한 PTFE에서는 대조적으로 고부하(80N)와 100℃상태에서는 낮게 나타났으며 0.024~0.023;CN/PTFE, 0.020~0.026;순수한 PTFE에서는 CuN-PTFE가 고부하조건에서 순수한 PTFE보다도, 그리고 두 종류의 순수한 PTFE와 Cu nano-particles이 함침된 PTFE (이하 CuN-PTFE)를 마찰 황동판의 마찰을 P.O.D. 타입의 시험장치에서 부하, 윤활온도에서 훨씬 높게 나타났다. 만약 20N이하의 저부하라면 마모율 손실차이는 0.002g이고 80N일때는 0.024g으로 낮아졌다.

또한 윤활유의 점도영향은 CuN-PTFE 마찰계수뿐만 아니라 마모율도 낮게 그래프에 나타났다. 반면, 순수한 PTFE 점도영향은 오일온도를 증가시키며 윤활 오일 필름층은 미끄럼 속도 증가로 경계면이 보다 쉽게 형성된다는 것을 실험결과를 통해 알 수 있다.

따라서 마모를 줄이는데 주도적인 역할을 하는 마찰표면 윤활상태는 크게 향상될 수 있으며 CuN-PTFE 미끄럼 속도의 마찰계수의 값은 작게 나타났다. 그러나 CuN-PTFE 마모율은 미끄럼 속도를 높여도 크게 감소하지 않는 경향이 있다.

1. Introduction

With outstanding thermal stability, good resistance to many chemicals, non stick, having exceptional dielectric properties and the low coefficient of friction in range of 0.09 to 0.05 generally [2], polytetrafluoroethylene(PTFE) has been used widely as an engineering plastic.

However, the wear rate of PTFE was high relatively, about of 7.36×10^{-4} to 7.41×10^{-4} mm^3/Nm in normal friction condition [3]. For this reason, there were many researchers, who have tried to find out methods to improve the wear resistance ability of PTFE by mean of inorganic or organic compound inclusion [4-7]. Sawyer et al [4] investigated that PTFE after filled with 10wt.% of Al_2O_3 nano-particles could greatly reduce the mass loss of this polymer, but it indicated also the friction coefficient of the composite increased slightly in comparison with that of unfilled one. The wear rate considerably decreased and the friction coefficient lightly increased after PTFE was filled with 15 vol.% nanometer ZnO also showed by Li et al [5]. And Larsen et al [6] reported that the best results of the wear and friction behavior was seen at a CuO content in the range of 0.1 to 0.4 vol.% incorporate with PTFE. In addition, the substances such as carbon fibers, lead or alumina ...etc has been used for this purpose [7-9]. However, most of them were investigated under dry sliding condition.

Besides, there are also several reports on tribological properties of polymers that were investigated under lubricated condition [11-16]. In there, Briscoetal et al [11-13] studied the lubricated friction and wear of some polymers. They found that the absorption of fluid into the surface layers of polymers could change the mechanical properties of the polymers, and so, in turn, influence the friction and wear of the polymers. Watanabe et al. [14-16] investigated the friction and wear behavior of polymer composites in aqueous environments (water). They pointed out that many polymers wear much more in water than in air, and the wear of PTFE composites filled with only glass fibers is much greater than that of other composites in water. However, with enlargement of the application fields of FTFE based composites in practice, it is essential to study the friction and wear behavior of PTFE-based composites under oil-lubricated conditions. Until now, much less information has been available on the friction and wear behavior of PTFE composites under oil-lubricated conditions.

The purpose of this study is to investigate the friction, wear behavior of Cu nano-particles impregnated PTFE, under the refrigerator oil lubricated condition to give some insight about it. Moreover, it is expected that this study may be useful to the application of CuN-PTFE in practice.

2. Preparation of Experiment

2.1 Teflon

Teflon is polytetrafluoroethylene(PTFE). This is a polymer with repeating chains of - (CF2-CF2) - in it. The molecular structure of Teflon is based on a chain of carbon atoms, the same as all polymers (Fig. 2.1 and 2.2). Unlike some other fluoropolymers, in Teflon this chain is surrounded by fluorine atoms. The bond between carbon and fluorine is very strong, and the fluorine atoms shield the vulnerable carbon chain. This unusual structure gives Teflon its unique properties. In addition to its extreme slipperiness, it is inert to almost every known chemical.

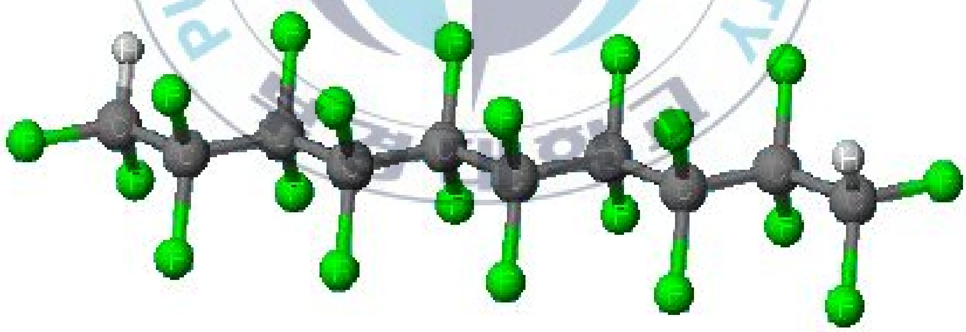

Fig. 2.1 PTFE structure

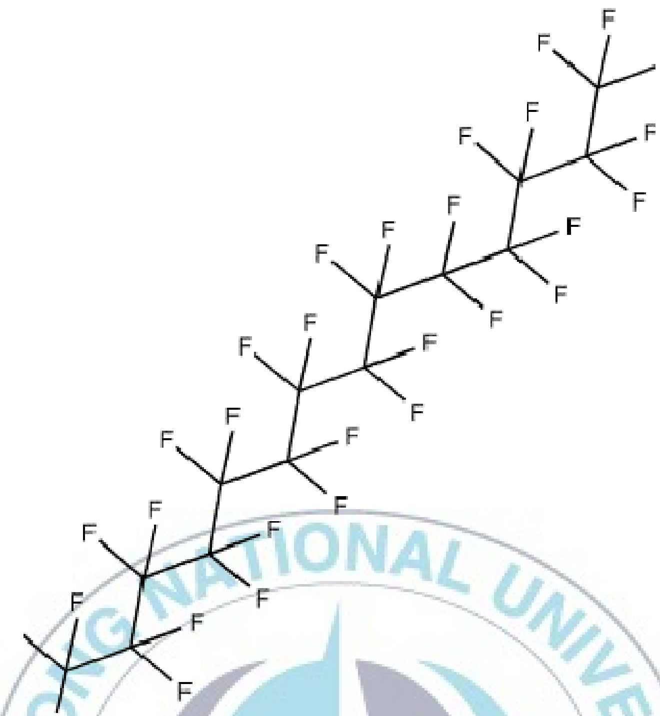

Fig. 2.2 Repeat chain of -(CF2-CF2)-

PTFE was accidentally invented by Roy Plunkett of Kinetic Chemicals in 1938. It is a white solid at room temperature, with a density of about 2.2g/cm³. The melting point is 327°C (620.6°F), but its properties degrade above 260°C (500°F) [1].

Hereunder being the properties of PTFE, with noting that the values shown represent average experiences from numerous testing sources, these values will vary depending upon the individual compositions of the primers and topcoats and the systems used.

Table 2.1 Mechanical Properties

Properties	Unit	PTFE
Specific Gravity	--	2.15
Tensile Strength	MPa	21-34
Elongation	MPa	300-500
Hardness	Hv(N/mm^2)	27-32
Coefficient of Friction, Dynamic	--	0.05-0.10

Table 2.2 Thermal Properties

Properties	Unit	PTFE
Melting point	^{o}C	327
Cure temperature	^{o}C	379-429
Heat of combustion	MJ/kg	5.1

Table 2.3 Electrical Properties

Properties	Unit	PTFE
Dielectric Constant	1 MHz	2.1
Dielectric Strength*	V/µm	18
Dissipation Factor	1 MHz	< 0.0001
Arc Resistance	sec	>300
Volume Resistivity	ohm·cm	>10^{18}
Surface Resistivity	ohm/sq	>10^{18}

Table 2.4 Chemical Properties

Properties	Unit	PTFE
Chemical/Solvent Resistance	--	Excellent
Water Absorption, 24 h	%	< 0.01
Salt Spray Resistance -on aluminum -on steel	Hours Hours	744+ 192
Weather Resistance	Years Unaffected	20

To spend many years for study and experiment, PTFE has been well known as a special material with the preponderant features and applied widely in various fields. Such as in the electric – electronic field, PTFE has excellent dielectric properties. This is especially true at high radio frequencies, making it suitable for use as an insulator in cables and connector assemblies and as a material for printed circuit boards used at microwave frequencies. Combined with its high melting temperature, this makes it the material of choice as a high-performance substitute for the weaker and lower melting point polyethylene that is commonly used in low-cost applications. Its extremely high bulk resistivity makes it an ideal material for fabricating long life electrets, useful devices that are the electrostatic analogues of magnets.

In optical radiometry, sheets made from PTFE are used as measuring heads in spectroradiometers and broadband radiometers (e.g. il-luminance meter and UV radiometer) due to its capability to diffuse a transmitting light nearly perfectly. Moreover, optical properties of PTFE stay constant over a wide range of wavelengths, from UV up to near infrared. In this region, the relation of its regular transmittance to diffuse transmittance is negligibly small so light transmitted through a diffuser (PTFE sheet) radiates like Lambert's cosine law. Thus, PTFE enables co-sinusoidal angular response for a detector measuring the power of optical radiation at a surface, e.g., in solar irradiance measurements.

Moreover, powdered PTFE is used in pyrotechnic compositions as oxidizer together with powdered metals such as aluminum and magnesium. Upon ignition, these mixtures form carbonaceous soot and the corresponding metal fluoride and release large amounts of heat. Hence, they are used as infrared decoy flares and igniters for solid-fuel rocket propellants. PTFE is also used to coat certain types of hardened, armor-piercing bullets, so as to reduce the amount of wear on the firearm's rifling. PTFE's high corrosion resistance makes it ideal for laboratory environments as containers, magnetic stirrers and tubing for highly corrosive chemicals such as hydrofluoric acid, which will dissolve glass containers. In the daily life, we often see PTFE be used as a thread seal tape in plumbing applications. Sometimes PTFE is used to prevent insects climbing up surfaces painted with the material. PTFE is so slippery that insects cannot get a grip and tend to fall off. Moreover, due to its low friction, it is used for applications where sliding action of parts is needed: bearings, bushings, gears, slide plates, etc.

2.2 Specimens

There are two kinds of specimens of Virgin PTFE and CuN-PTFE with the mechanical properties shown in Table 2.5. The specimens are manufactured as pins to investigate on P.O.D tester. It has the dimension of Φ10 x 30 mm (Fig. 2.3-a) and supplied by the chemical faculty of Pukyong National University. The pin-samples slide against Brass disc (40% Zn), that has the diameter of Φ300mm and thickness of 10mm (Fig. 2.3-b). The experiment was carried out under lubricated condition by Refrigerator Oil (VG 56).

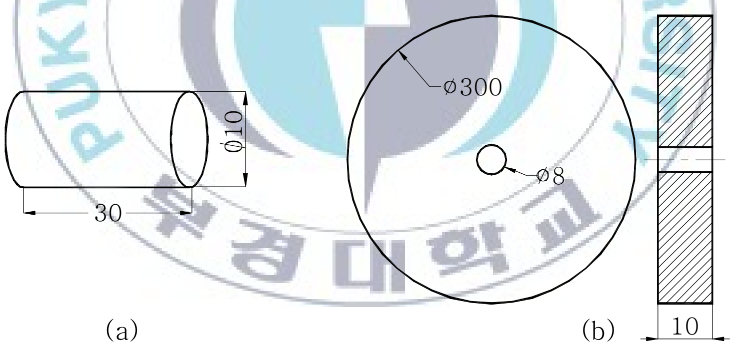

Fig. 2.3 Dimension of specimens - (a) pin-sample; (b) brass disc

Table 2.5 Mechanical Properties of Specimens

Properties (Unit) \ Specimens	PTFE	CN/PTFE	BRASS
Roughness Ra (μm)	0.04	0.06	0.8
Hardness Hv (N/mm^2)	27-32	55-60	118-196
Density g/cm^3	2.15	2.52	8.4
Tensile Strength/Yield MPa	21-34	40-42	124-310
Melting point ^oC	327-340	327-340	900-940

2.3 Cu Nano-Particles Impregnation Procedure

The supercritical carbon dioxide method was applied for Cu nano-particles impregnation to PTFE and carried out as schematic diagram in Fig.2.4.

The Virgin PTFE specimens and the nanometer copper powder were putted in the chamber 6 and chamber 5, respectively. CO2 gas was supplied to two chambers by pump 2 through A, C valves (at that time, opening). Adjusting temperature and pressure of two cylinders to a desired one (T = 40^{o}C; P = 138 bar), then closing A,C valves and opening H,E,I valves to purge to eliminate air for period of twenty minutes with flow rate of 2 l/min. At last, closing H, E, I valves and keep such as for 24 hour, then release CO_2 gas to obtain the desirous samples.

The copper powder was impregnated into Virgin PTFE with 0.924 wt%.

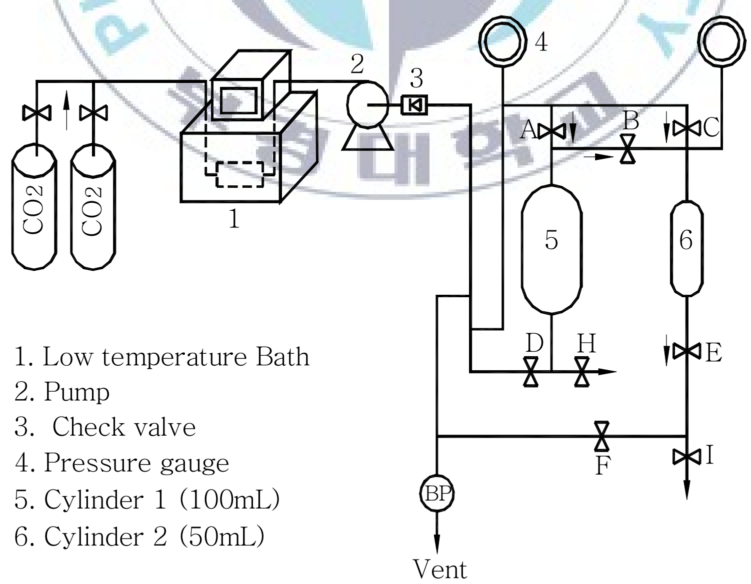

Fig. 2.4 Schematic diagrams of Cu nano-particle impregnation procedure

3. Experiment

3.1 Experimental Apparatus

Investigation was conducted on P.O.D test apparatus (see Photo3.2 and Fig.3.3).

The system consist of the brass disc (3) join to the shaft (2) that is driven by motor (1). The rotating speed of motor can be adjusted from zero to 160 r.p.m by control volume (14). The brass disc rotates against the specimen (4) that clamped in the pin holder (5), under the various condition of load, sliding speed and lubricating oil temperature.

The lubricating process is carried out by oil pump (7); pump oil from tank (10) through valve (15), then through nozzle to the interface, dropping down to basin and return to tank (10).

In each concrete experimental case, the lubricating oil temperature can be changed by the setting volume on control box (13) and heated by heater (12). The temperature sensor (11) feedbacks always the temperature signal to control box. In there the temperature signal will be handled to give the connecting or disconnecting status of current to heater. Thus, the oil temperature is stable always as desire.

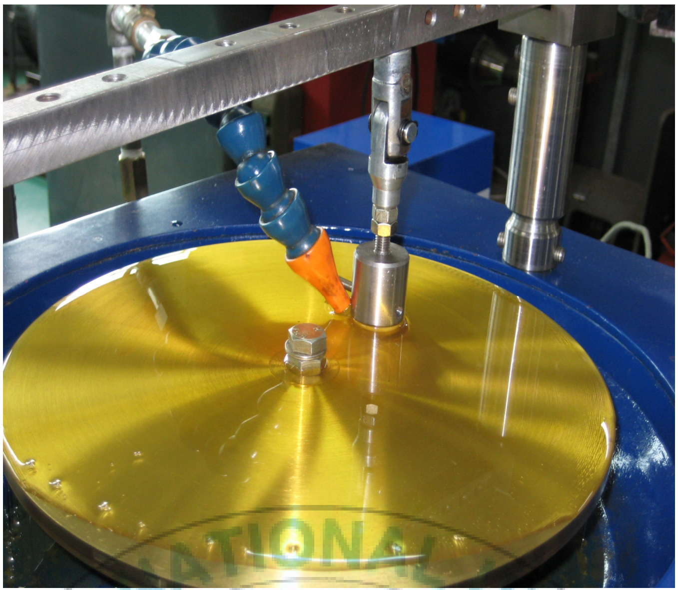

Photo 3.1 Experimental set up

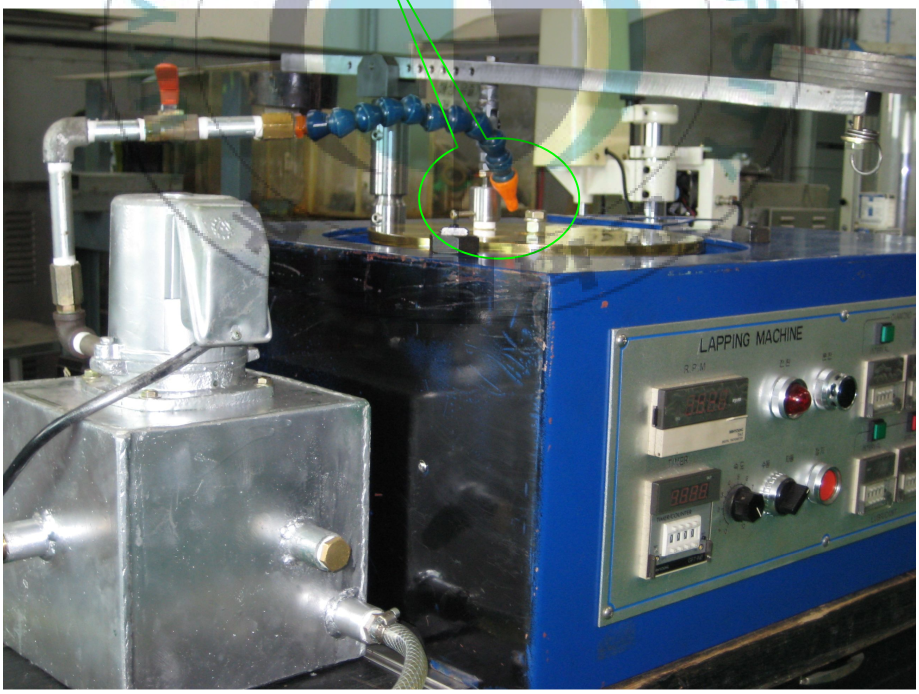

Photo 3.2 Experimental apparatus

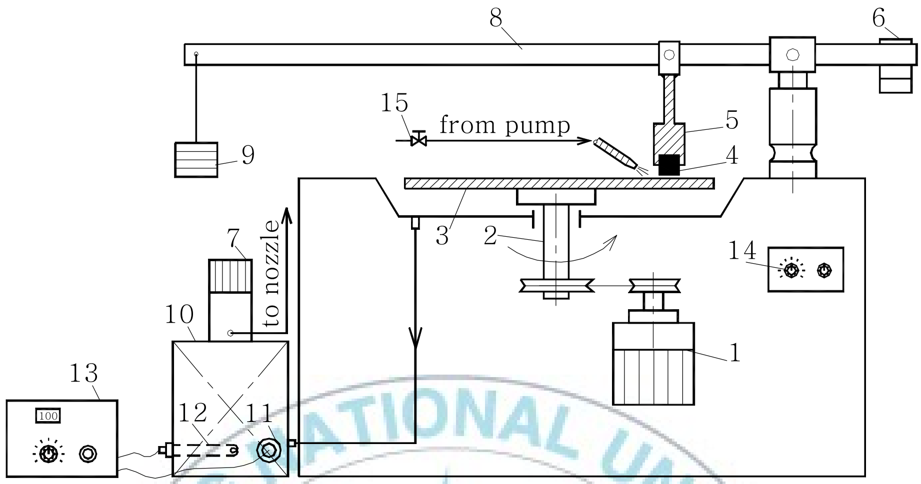

Fig. 3.1 Schematic diagram of experimental apparatus

1) Drive motor
2) Shaft
3) Disc
4) Pin-specimen
5) Specimen holder
6) Counter load
7) Oil pump
8) Load level
9) Load
10) Oil tank
11) Temperature sensor
12) Heater
13) Control box (for heater)
14) Speed control volume
15) Valve

3.2 Calculation Theory

As known, the coefficient of friction μ was defined as the ratio of the friction force F between the surfaces in contact to the normal force:

$$\mu_i = \frac{F_i}{N_i} \tag{1}$$

From the experiment had the calculating diagram as Fig. 3.4

Initially, as without load, the system balanced at pivoted support O and the specimen nearly contacted with the disc surface. When the load W was applied into system, the specimen exerted on disc a force correspond with the normal force N (N)

$$N_i = \frac{W_i . l_1}{l_2} \tag{2}$$

With l_1 = 544mm is distance calculated from the abutment O to the load position, l_2 = 152mm is distance calculated from the center of specimen to the abutment O

On the other hand, the torque of disc determined by following formulae:

$$T_i = 97400 \frac{H_i}{n} \tag{3}$$

Where:

T_i (kg.mm) is torque on disc in proportion with each type of test load

H_i (KW) is power of current that measured by indicator during testing

n (r.p.m) is rotational speed of disc

From (3) the friction force is determined as following:

$$F_i = \frac{T_i - T_{i-1}}{r} \tag{4}$$

With F_i (N) is friction force in proportion with each type of test load and r (r = 60mm) is radial distance calculated from the center of disc to specimen center.

Substituting (4) and (2) into (1) is to obtain the coefficient of friction in correspond with supplied load.

The mass loss of specimens were measured by a precision balance with the accuracy of 1/10000 gram. In addition, after each test time, the disc surface was polished with 800-grit paper.

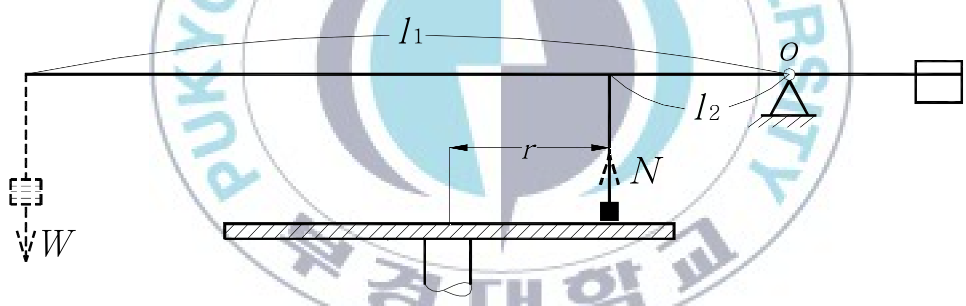

Fig. 3.2 Calculating diagram

3.3 Test and Results

The friction and wear properties of Virgin PTFE and CuN-PTFE would be investigated under the various condition of the load, sliding speed and lubricating oil temperature.

Step 1: Firstly, experiment was investigated at the rotational speed of disc of 70 r.p.m (0.44 m/s), the lubricating oil temperature of 40°C, and the various load of 20, 40, 60 and 80 N, respectively. Then, with speed and load as above also, but under the various temperature of 60, 80 and 100°C.

Experimental results was recorded as in table 3.1 and table 3.2

Step 2: Conducted as step 1 but with the rotation speed of 140 r.p.m (0.88m/s) and results recorded in table 3.3 and table 3.4

Table 3.1 Experimental results of Virgin PTFE at velocity of 0.44mm/s

Load (N)	Distance (m)	Output (KW)	Friction coefficient	Wear volume loss (g)
Oil temperature t = 40°C				
20	1000	0.2552	0.023	0.0135
40	-	0.2932	0.022	0.022
60	-	0.3423	0.019	0.0275
80	-	0.4096	0.0195	0.043
Oil temperature t = 60°C				
20	1000	0.2548	0.0225	0.009
40	-	0.2893	0.02	0.019
60	-	0.3397	0.0195	0.0275
80	-	0.4087	0.02	0.04
Oil temperature t = 80°C				
20	1000	0.2587	0.027	0.0245
40	-	0.2983	0.023	0.031
60	-	0.3578	0.023	0.0485
80	-	0.4389	0.0235	0.066
Oil temperature t = 100°C				
20	1000	0.263	0.032	0.0254
40	-	0.3078	0.026	0.035
60	-	0.4669	0.0255	0.0525
80	-	0.4669	0.027	0.068

Table 3.2 Experimental results of CuN-PTFE at velocity of 0.44mm/s

Load (N)	Distance (m)	Output (KW)	Friction coefficient	Wear volume loss (g)
Oil temperature t = 40°C				
20	1000	0.2567	0.024	0.012
40	-	0.2972	0.0235	0.0175
60	-	0.3515	0.021	0.019
80	-	0.4205	0.02	0.02
Oil temperature t = 60°C				
20	1000	0.2562	0.0235	0.0115
40	-	0.2993	0.025	0.0175
60	-	0.3511	0.02	0.018
80	-	0.4166	0.019	0.0185
Oil temperature t = 80°C				
20	1000	0.2601	0.028	0.011
40	-	0.3024	0.0245	0.0165
60	-	0.3593	0.022	0.0174
80	-	0.4283	0.02	0.02
Oil temperature t = 100°C				
20	1000	0.2627	0.031	0.0146
40	-	0.3058	0.025	0.016
60	-	0.3653	0.023	0.02
80	-	0.4429	0.0225	0.02

Table 3.3 Experimental results of Virgin PTFE at velocity of 0.88mm/s

Oil temperature t = 40°C				
Load (N)	Distance (m)	Output (KW)	Friction coefficient	Wear volume loss (g)
20	1000	0.2552	0.023	0.01
40	-	0.2931	0.022	0.019
60	-	0.3449	0.02	0.0225
80	-	0.4173	0.021	0.0412
Oil temperature t = 60°C				
20	1000	0.2578	0.026	0.01
40	-	0.3009	0.025	0.0224
60	-	0.3604	0.023	0.035
80	-	0.4432	0.024	0.049
Oil temperature t = 80°C				
20	1000	0.2612	0.03	0.0173
40	-	0.3069	0.0265	0.0245
60	-	0.369	0.024	0.0422
80	-	0.4587	0.026	0.0615
Oil temperature t = 100°C				
20	1000	0.2647	0.034	0.0214
40	-	0.3131	0.028	0.0285
60	-	0.3815	0.0265	0.04
80	-	0.4764	0.0275	0.065

Table 3.4 Experimental results of CuN-PTFE at velocity of 0.88mm/s

Load (N)	Distance (m)	Output (KW)	Friction coefficient	Wear volume loss (g)
Oil temperature t = 40°C				
20	1000	0.2566	0.024	0.0092
40	-	0.2963	0.023	0.0125
60	-	0.3494	0.0205	0.013
80	-	0.4184	0.02	0.0135
Oil temperature t = 60°C				
20	1000	0.2592	0.027	0.0085
40	-	0.3041	0.026	0.01
60	-	0.3611	0.022	0.0125
80	-	0.4334	0.021	0.0144
Oil temperature t = 80°C				
20	1000	0.2635	0.032	0.0116
40	-	0.3111	0.0275	0.0124
60	-	0.3713	0.0233	0.0115
80	-	0.4575	0.025	0.0136
Oil temperature t = 100°C				
20	1000	0.2635	0.032	0.0134
40	-	0.3118	0.028	0.0135
60	-	0.3739	0.024	0.0162
80	-	0.4947	0.035	0.0185

4. Discussions

4.1 Friction characteristic

The variation of friction coefficient, as well as the effect of the Cu nano-particle impregnating to Virgin PTFE under the various conditions of load, sliding speed and lubricating oil temperature, showed in the figures from Fig.4.1 to Fig. 4.8 hereunder.

In comparison the friction coefficient charts between Virgin PTFE and CuN-PTFE, it was seen that, the friction coefficient of Virgin PTFE was usually lower than that of CuN-PTFE. The friction coefficient of both of specimens decreased with the increase in load firstly. The Fig. 4.1 showed that at the sliding speed of 0.44mm/s and the lubricating oil temperature of 40°C, the friction coefficients of both of Virgin PTFE and CuN-PTFE were lowest (0.024-0.020 for CuN-PTFE; 0.023 – 0.018 for Virgin PTFE). However, it was noteworthy, when increase to 60N, the friction coefficient of Virgin PTFE began increase sharply while that of CuN-PTFE decreased continuously. This was indicated clearly on the graphs that had the higher sliding speed and lubricating oil temperature as on Fig. 4.2 to Fig. 4.8. At the loads of 80N, the friction coefficient of Virgin PTFE was always higher than that of CuN-PTFE.

For the above matter, as well known in [10], since Virgin PTFE is viscoelastic material, its deformation under load is viscoelastic. For this reason, the variation of friction coefficient according to load can apply with follows equation $\mu = KN^{(n-1)}$, where μ is the friction coefficient, N is the applied load, K and n is also a constants, with value between 2/3 and 1 ($2/3 < n < 1$). From this equation, the friction coefficient of PTFE decreases with the increase in load. However, when the load and temperature increase to the certain limit, the viscoelastic deformation of Virgin PTFE will sharply increase, so the load carrying capacity will reduce, result in increase of friction coefficient.

While comparing the friction coefficient charts of Virgin PTFE and CuN-PTFE on the figures from Fig. 4.1 to Fig. 4.8, it was recognized that at the same condition of sliding speed and load condition, the friction coefficient of specimens would increase with increase in the lubricating oil temperature. In here, it should be analyzed with the sliding speed of 0.44mm/s as shown on Fig. 4.1, Fig. 4.3, Fig. 4.5 and Fig. 4.7. It was seen that when the oil temperature of 60^{o}C (Fig. 4.3) the friction coefficients of Virgin PTFE and CuN-PTFE decrease simultaneously until the oil temperature increase to 80^{o}C. It would be clearer, when compared the friction coefficient of Virgin PTFE and CuN-PTFE at the load of 20N with the lubricating oil temperature of 60^{o}C and 100^{o}C. From Fig. 4.3 saw that, at the load of 20N the friction coefficient was about 0.022 for Virgin PTFE and about 0.023 for CuN-PTFE. While on Fig. 4.7 indicated that the friction coefficient of Virgin PTFE was 0.032 and 0.031 for CuN-PTFE. In comparison of the above results demonstrated that, the friction coefficient of both of specimens decreased with the increase in oil temperature firstly and then increase with the increase in temperature. Besides, from the result analysis on Fig.4.7 showed also that under the high oil temperature condition, the friction coefficient of CuN-PTFE was lower than that of Virgin PTFE. Therefore, it may be deduced that after impregnated with Cu nano-particles, Virgin PTFE has working capacity better than original one.

The influence of the lubricating oil temperature to the friction characteristic of PTFE composite may be explained by the oil viscosity. At 60^{o}C, the viscosity of oil was best for the lubricating process until the oil temperature reached to 80^{o}C. With this temperature the viscosity of oil was very low, so the tribological pair might work in the unperfected lubricated condition or under dry friction condition. For this reason, the friction coefficient of PTFE was higher than that at the low temperature.

Comparing the figure pairs of as Fig.4.1 and Fig.4.2, Fig.4.3 and Fig.4.4, Fig.4.5 and Fig.4.6, Fig.4.7 and Fig.4.8, it was seen that at the similar temperature, when the sliding speed of disc increase twice but the friction coefficient variation of PTFE was very small. Hence, it can be concluded that the sliding speed not influenced to the friction coefficient of CuN-PTFE.

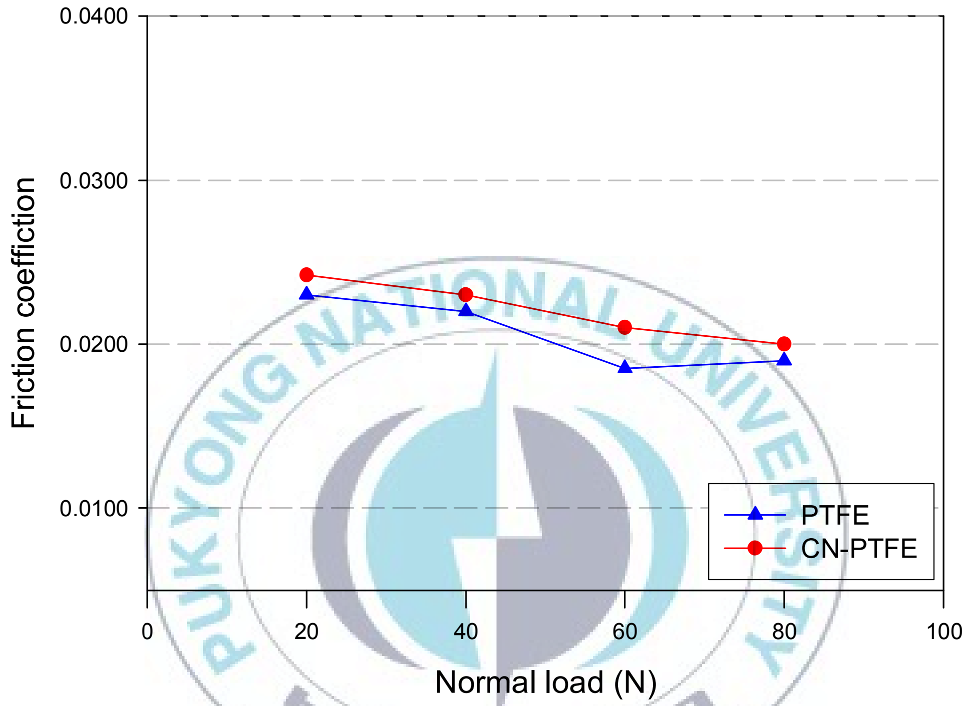

Fig. 4.1 Variations of friction coefficient with load at sliding speed of 0.44 m/s and 40°C of oil temperature

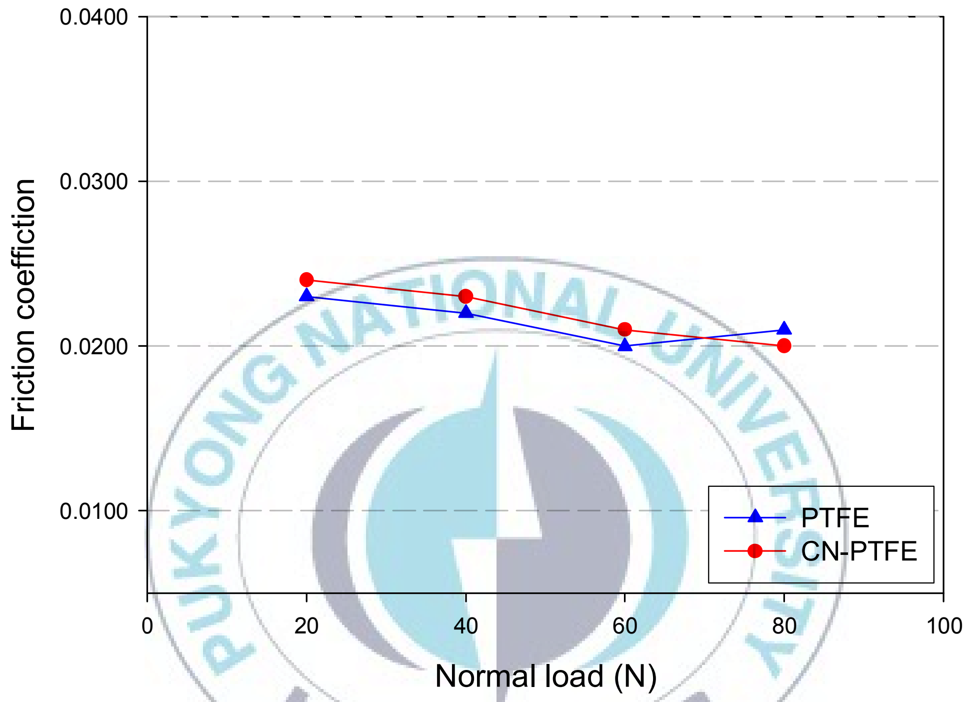

Fig. 4.2 Variations of friction coefficient with load at sliding speed of 0.88 m/s and 40^{o}C of oil temperature

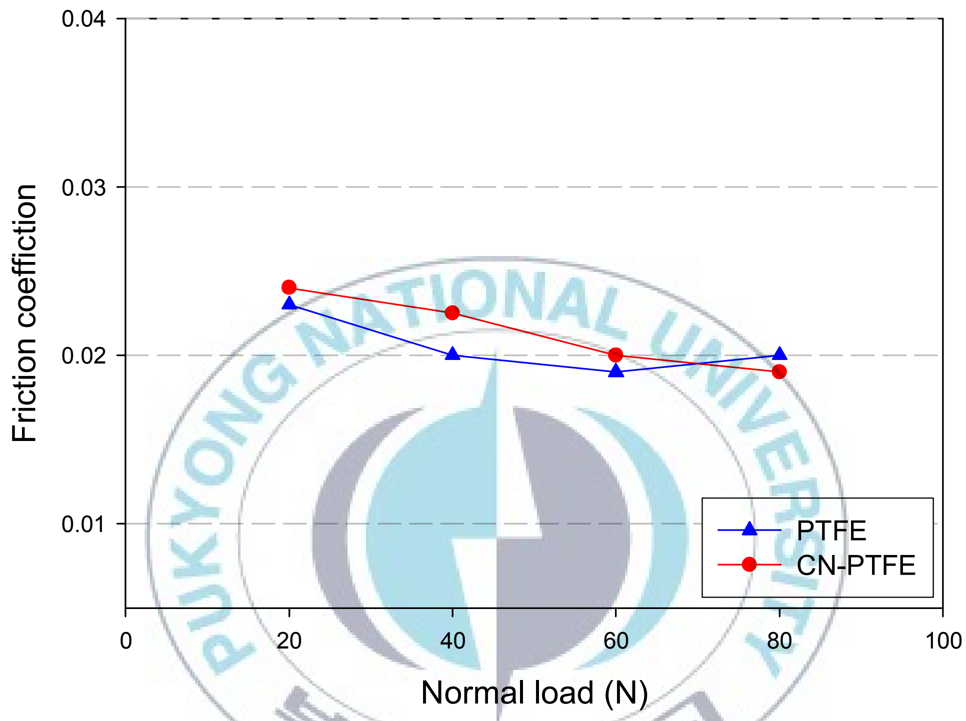

Fig. 4.3 Variations of friction coefficient with load at sliding speed of 0.44 m/s and 60°C of oil temperature

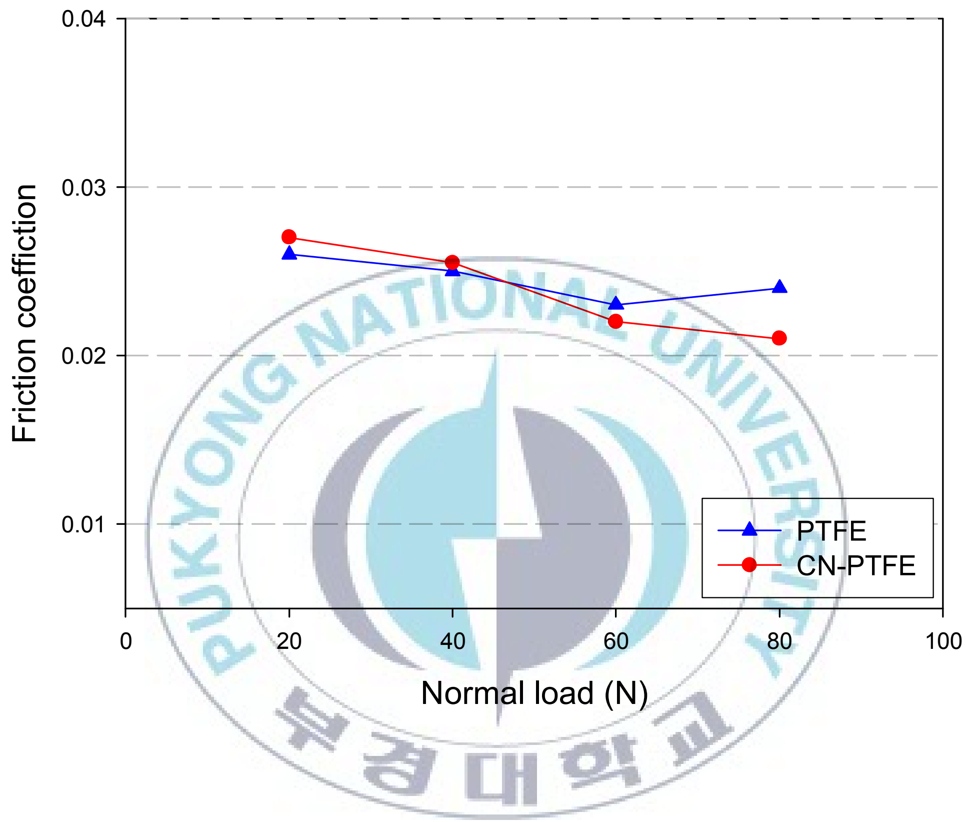

Fig. 4.4 Variations of friction coefficient with load at sliding speed of 0.88 m/s and 60°C of oil temperature

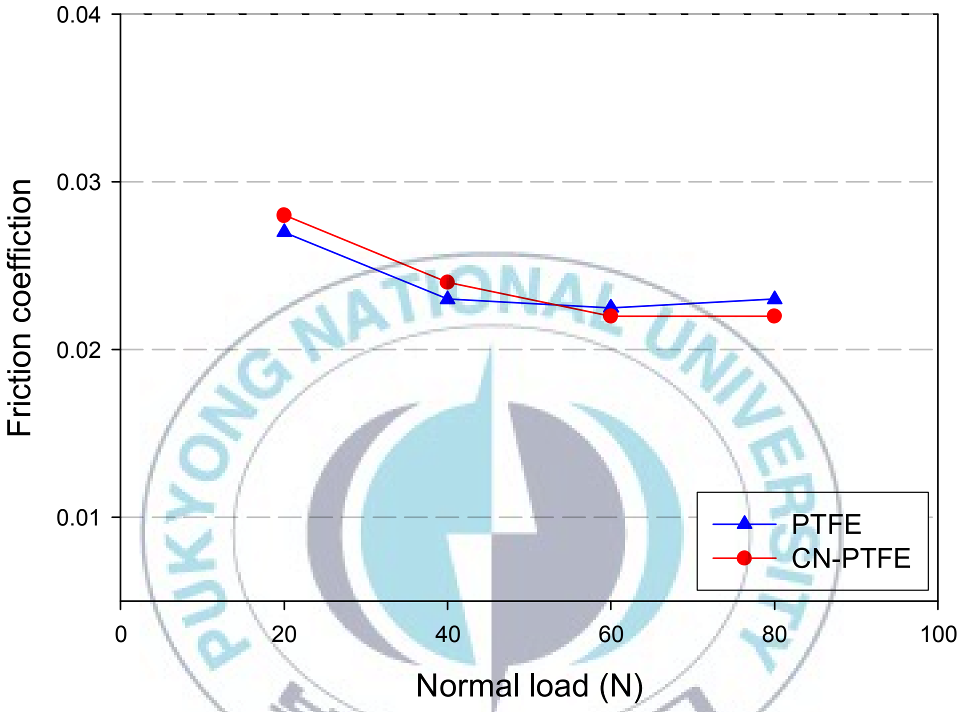

Fig. 4.5 Variations of friction coefficient with load at sliding speed of 0.44 m/s and 80°C of oil temperature

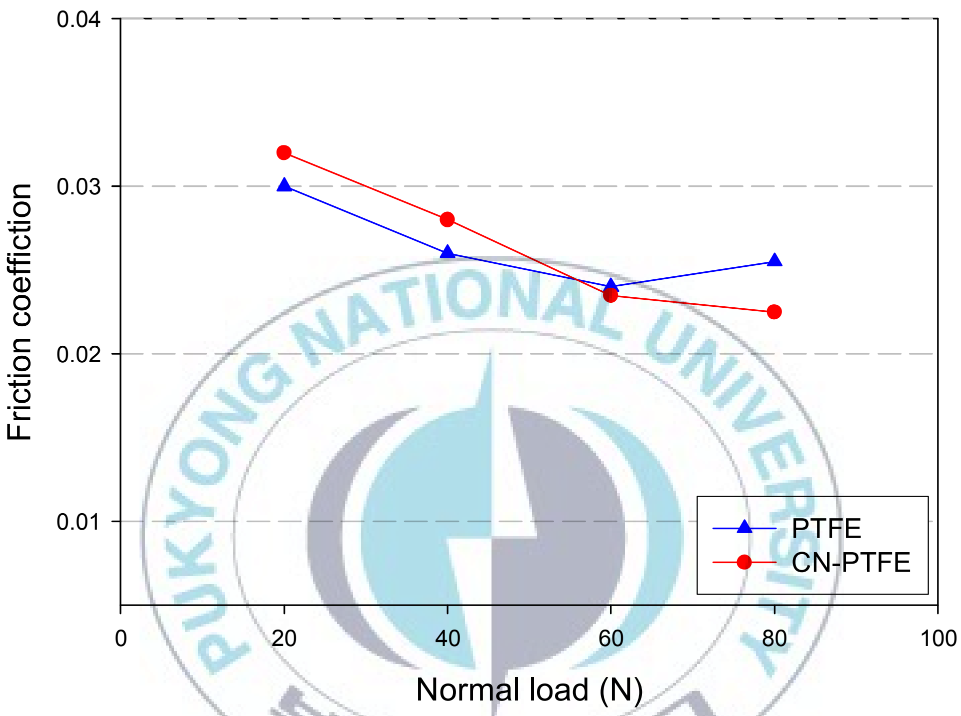

Fig. 4.6 Variations of friction coefficient with load at sliding speed of 0.88 m/s and 80^{o}C of oil temperature

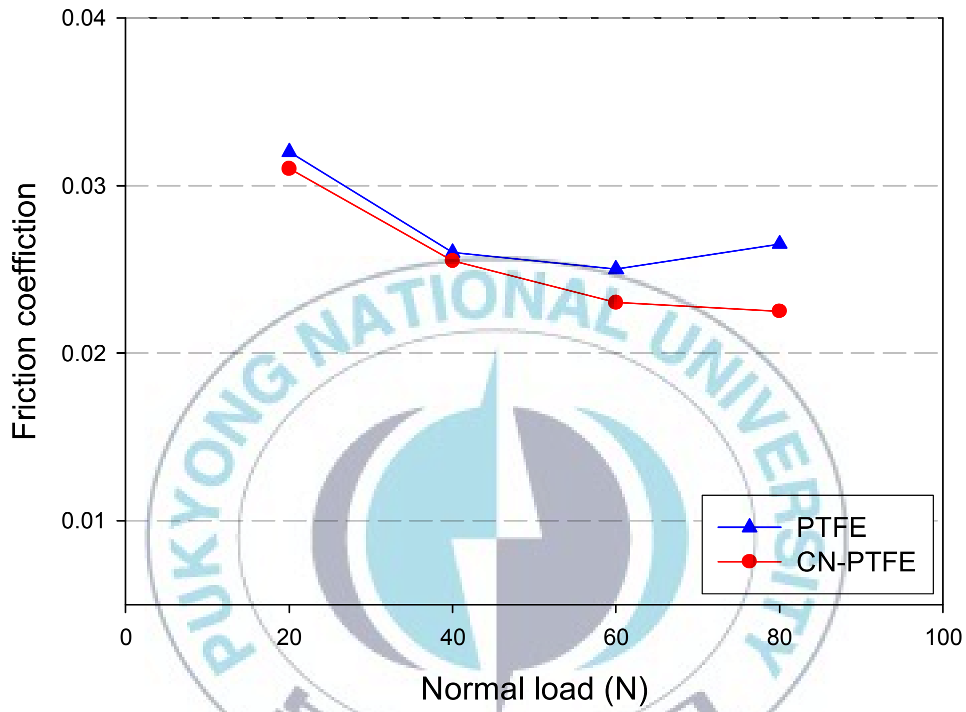

Fig. 4.7 Variations of friction coefficient with load at sliding speed of 0.44 m/s and 100^{o}C of oil temperature

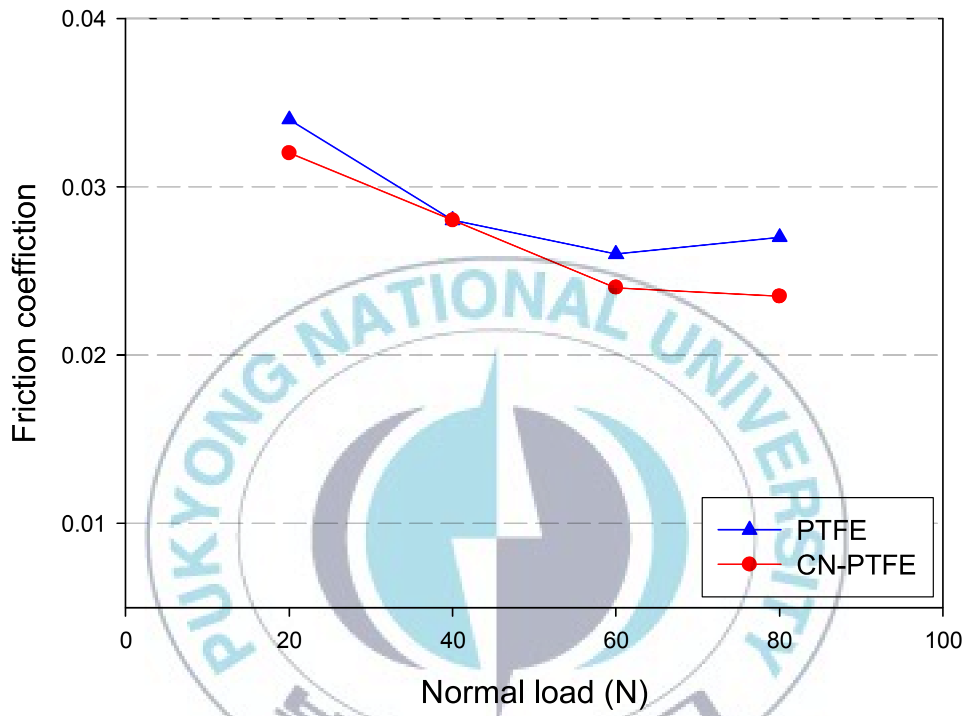

Fig. 4.8 Variations of friction coefficient with load at sliding speed of 0.88 m/s and 100°C of oil temperature

4.2 Wear characteristic

The wear rate of Virgin PTFE and CuN-PTFE slide against the brass disc in the various condition of load, sliding speed and lubricating oil temperature was presented in figures from Fig. 4.9 to Fig.4. 16.

On Fig. 4.9 showed that in the low sliding speed and oil temperature condition, the wear volume loss of Virgin PTFE was always higher than that of CuN-PTFE. That was seen clearer during the tribological pair worked with the high load. Specially, the wear rate of Virgin PTFE increased sharply when reach to the load level of 80N (the wear volume loss about 0.043 gram) while that of CuN-PTFE increased gradually in the narrow range of 0.012 – 0.020 gram.

During experimental process indicated also, in the other conditions of the oil temperature and the sliding speed, the wear volume loss of Virgin PTFE and CuN-PTFE raised together as increase in load. Nevertheless, in comparison with the wear rate of Virgin PTFE, that of CuN-PTFE was much lower, at high load especially.

As presented in preceding part, Virgin PTFE was viscoelastic material. Therefore, with increase in load over the load limit of PTFE would result in the increase in deformation, cause the reduction of the mechanical strength and load carrying capacity of PTFE composite. This leaded to the increase in the friction coefficient and wear, as presented on graphs. From the experimental results and above analysis, it can be concluded that after impregnated with Cu nano-particles, the anti-wear capacity of Virgin PTFE improved greatly.

Because of worked in the lubricated condition, the oil viscosity was one of factors that effected to the wear rate of materials. Seen on graphs, at a similar sliding speed, the wear volume loss would vary differently depend on the lubricating oil temperature. On Fig.4.9 and Fig.4.11, when the oil temperature changed from 40oC to 60oC, the wear rate of both of specimens reduced together. When the oil temperature reach to $80^{o}C$ and $100^{o}C$ (Fig.4.13 and Fig. 4.15), the wear rate of Virgin PTFE increased greatly, while that of CuN-PTFE increased in little.

In addition, to appreciate the effect of the Cu nano-particles impregnating, on Fig.4.9 and Fig.4.11 at load of 20N. It can be seen, the difference of the wear volume loss between Virgin PTFE and CuN-PTFE was very low, even the wear volume loss of Virgin PTFE was lower than that of CuN-PTFE ($9x10^{-3}$ – $13.5x10^{-3}$ for Virgin PTFE and $11.5x10^{-3}$ – $12x10^{-3}$ for CuN-PTFE). In contrast, at temperature of $80^{o}C$ and $100^{o}C$ with the load of 20N (see Fig.4.13 and Fig.4.15), that difference was very clear ($24.5x10^{-3}$ – $25.4x10^{-3}$ for Virgin PTFE and $11x10^{-3}$ – $14.6x10^{-3}$ for CuN-PTFE). That evidenced that the anti-wear capacity of Virgin PTFE was greatly improved by the Cu nano-particles impregnation technology.

On the other hand, the influence of the sliding speed to the wear rate of specimens was seen by comparison between the pairs of Fig. 4.9 and Fig.4.10, Fig. 4.11 and Fig. 4.12, Fig. 4.13 and Fig. 4.14, Fig. 4.15 and Fig. 4.16. It was obvious that the wear rate of Virgin PTFE and CuN-PTFE decrease with increase in sliding speed. It was believed that, with the increased in sliding speed, a layer of lubricating oil film could be more easily formed on the friction surface, thus the lubrication condition of the frictional surface can be greatly improved, leading to the decrease in the wear rate.

Therefore, it can be concluded that the CuN-PTFE can be used in practice as a kind of material which has excellent friction and wear reducing properties under oil lubricated condition.

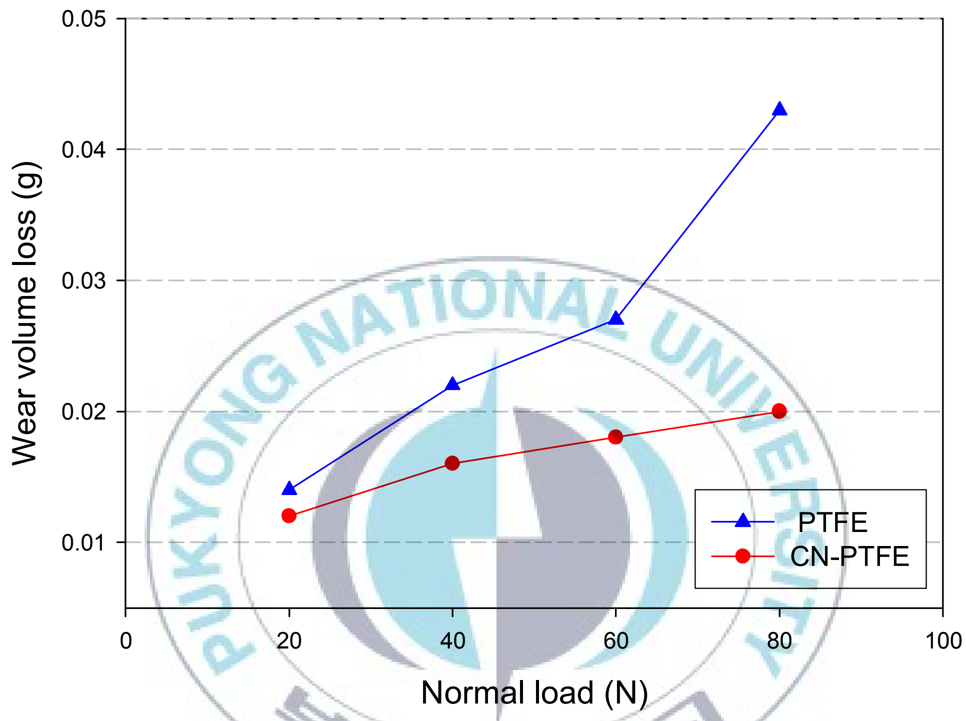

Fig. 4.9 Variations of wear with load at sliding speed of 0.44 m/s and 40^{o}C of oil temperature

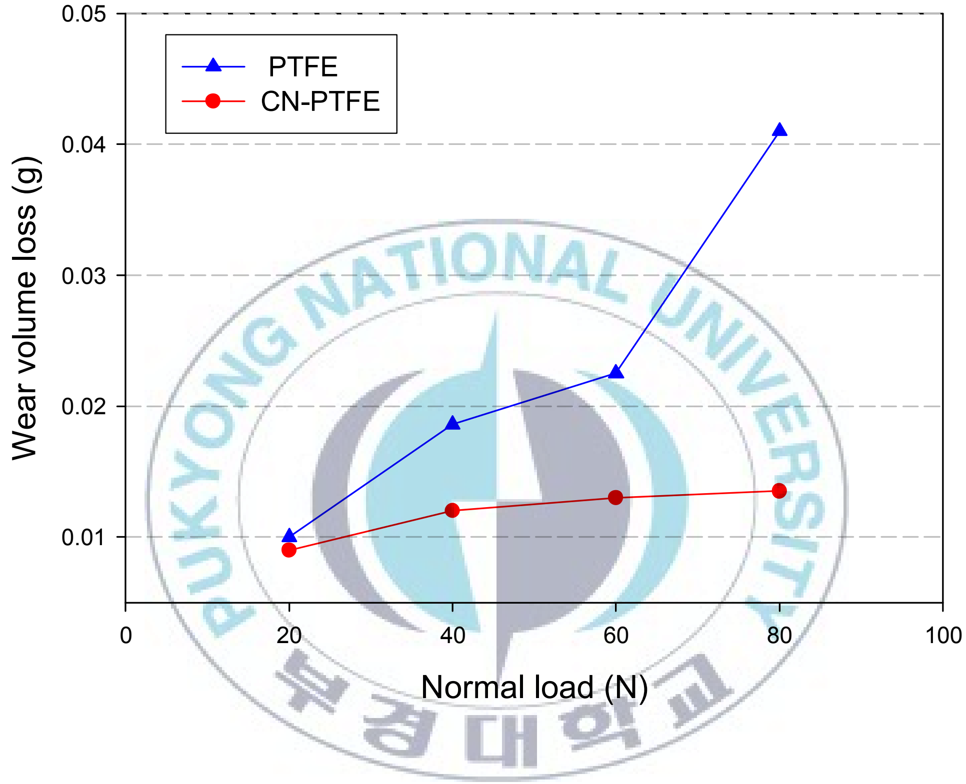

Fig. 4.10 Variations of wear with load at sliding speed of 0.88 m/s and 40°C of oil temperature

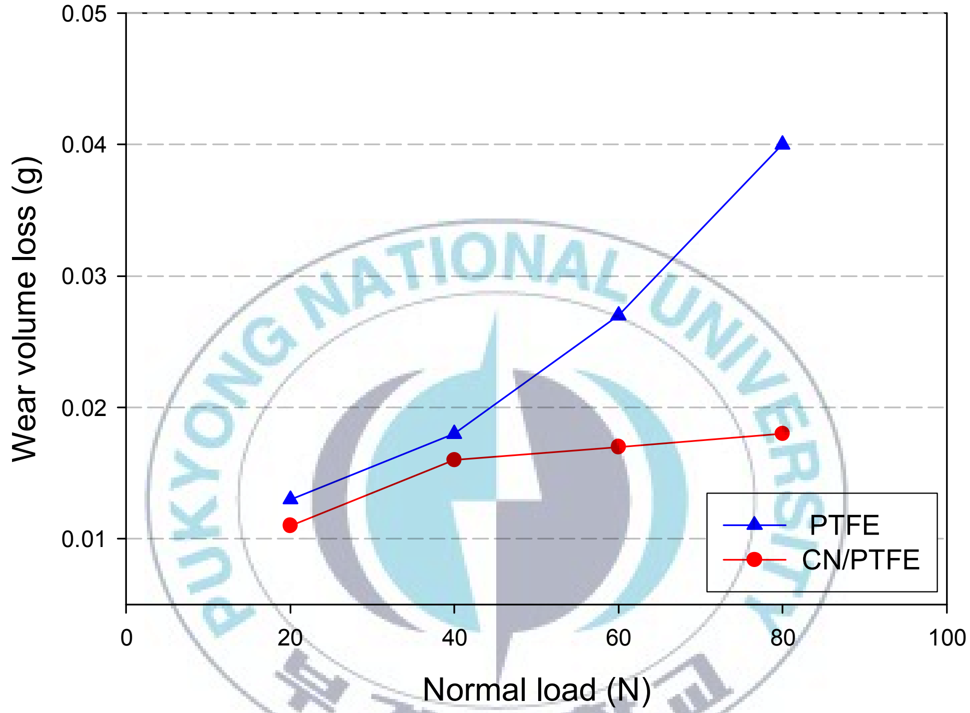

Fig. 4.11 Variations of wear with load at sliding speed of 0.44 m/s and 60^{o}C of oil temperature

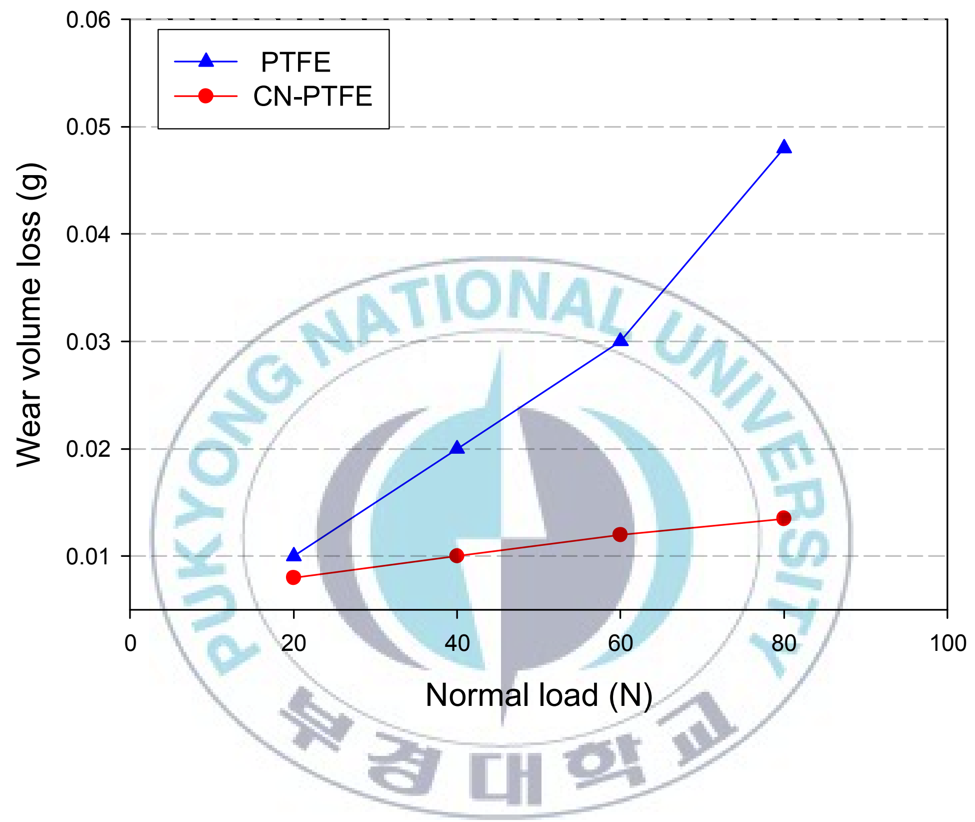

Fig. 4.12 Variations wear with load at sliding speed of 0.88 m/s and 60°C of oil temperature

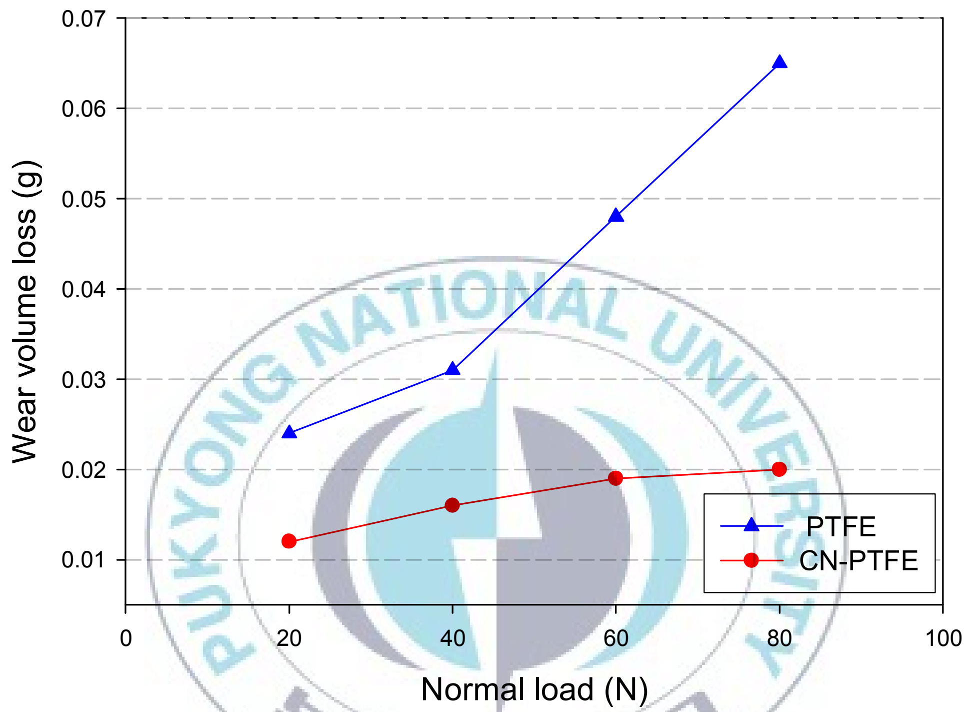

Fig. 4.13 Variations of wear with load at sliding speed of 0.44 m/s and 80°C of oil temperature

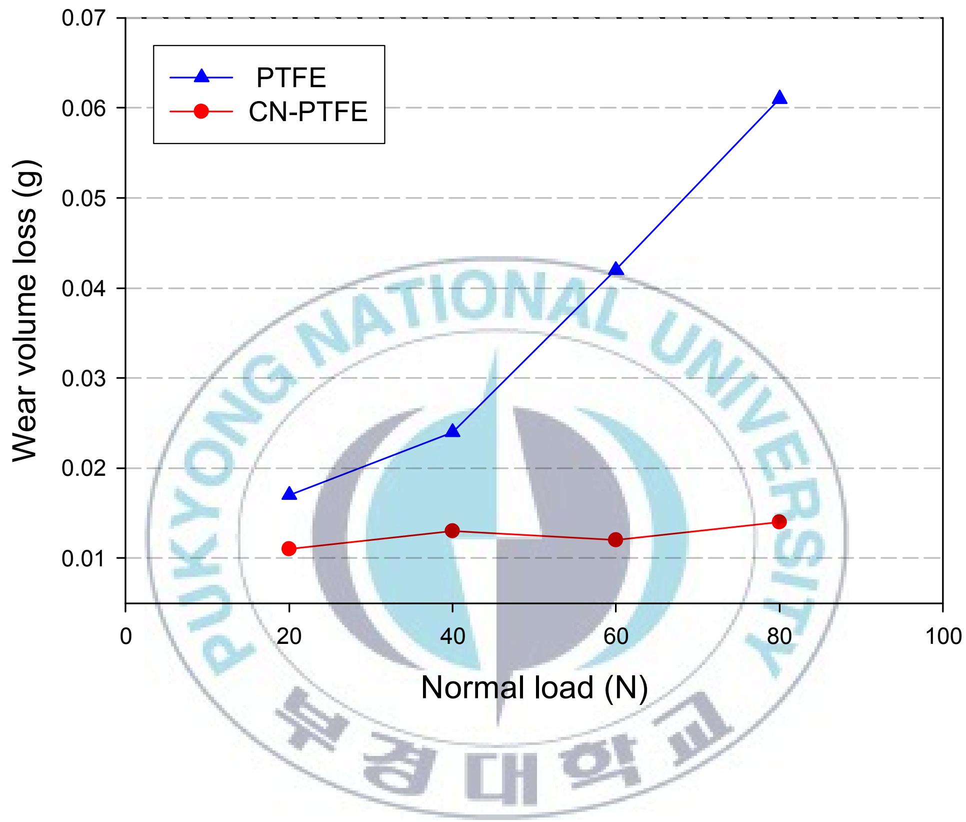

Fig. 4.14 Variations of wear with load at sliding speed of 0.88 m/s and 80°C of oil temperature

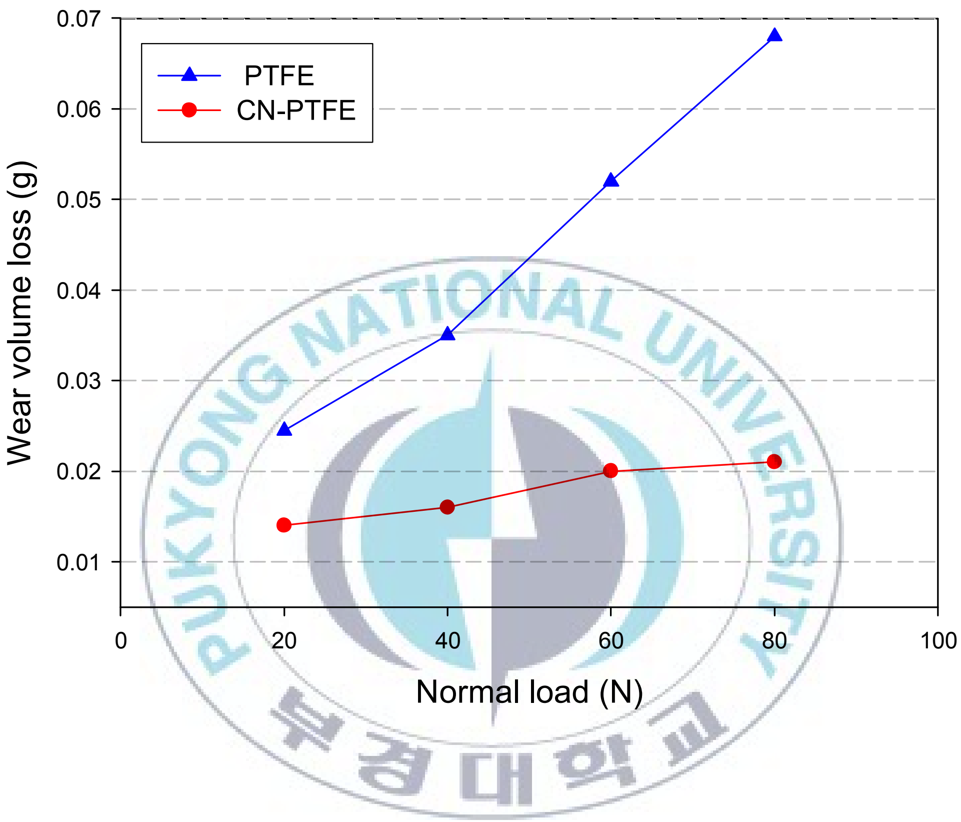

Fig. 4.15 Variations of wear with load at sliding speed of 0.44 m/s and 100°C of oil temperature

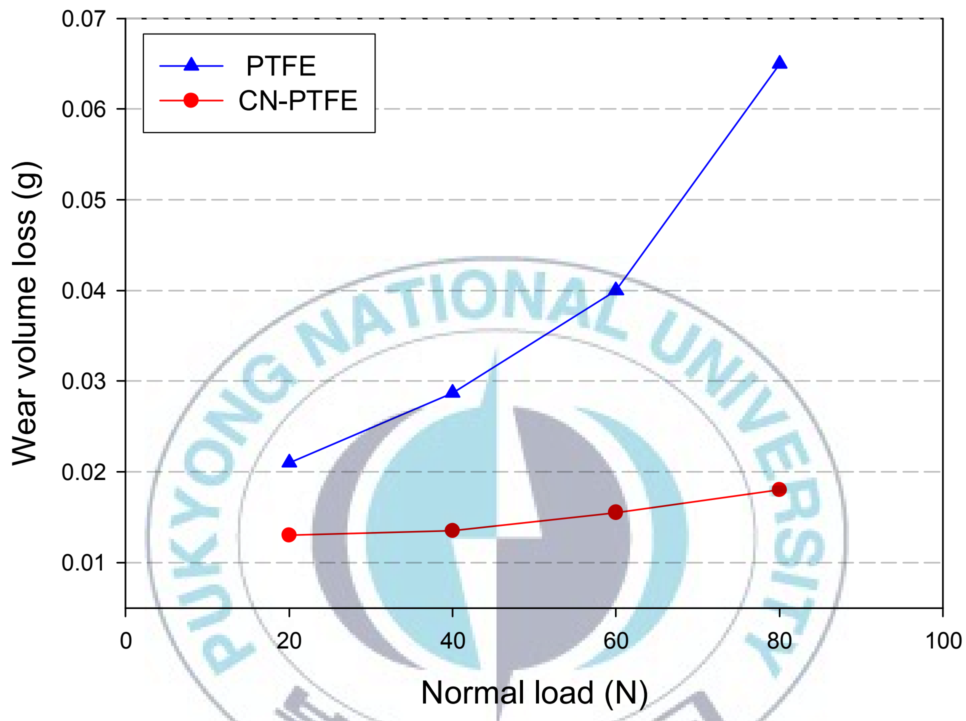

Fig. 4.16 Variations of wear with load at sliding speed of 0.88 m/s and 100^{o}C of oil temperature

5. Conclusions

PTFE composites have been well known as a special material with the preponderant features and applied widely in various fields. To improve those characteristics of PTFE-base, in this study, the Cu nano-particles impregnating method applied to Virgin PTFE that would be investigated under Refrigerator Oil-lubricated condition and drew the following conclusions:

1) After impregnated with Cu nano-particles, at the low sliding speed and oil temperature, the friction coefficient of CuN-PTFE is higher than original one but it is lower in the high load condition. In addition, the load carrying capacity of CuN-PTFE is much better than that of Virgin PTFE. Therefore, it can be said that with Cu nano-particles impregnating, the friction and wear properties of PTFE were improved greatly.

2) The viscosity of the lubricating oil influence not much to the wear rate as well as the friction coefficient of CuN-PTFE, while that of Virgin PTFE increase with increase in the oil temperature.

3) The influence of sliding speed to the friction coefficient of CuN-PTFE is very small, but it improved greatly the anti-wear capacity of PTFE.

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ACKNOWLEDGEMENTS

The help and continuous support from professors, colleagues, friends, and family to whom I am most grateful, will never be forgotten. Without you, all of you, I would not be what I am today. I would like to thank each of you individually by word, but I do so in my heart.

At first, I would like to express my deepest gratitude to my supervisor, Professor Kim Si Young (김시영 교수님), with a spirit of enterprise for his strong support and patient guidance, encouragement and advice in this study. I appreciate the time spent with him in the numerous discussions in this research. His rich knowledge and practical experience in the tribological field has been also most helpful in guiding this study. I have learned a lot from his thorough and insightful review of this research and his dedication to producing high quality and practical research. Financial supports from the Professor during Master studying period are also gratefully acknowledged.

I would like to recognize the contributions and helpful suggestions provided by my thesis advisory committee members Professor Han Kyu Il (한규일 교수님) and Professor Jang Jea Seong (장지성 교수님). These two Professors have given me their valuable comments, feedback and great suggestions based on their work, thus greatly contribution to the improvement, refinement and completion of my thesis.

Sincere gratitude is extended to Professor Ju Young Suk (주영석 교수님) and Teacher Hoang il Ho (황일호 선생님) of the Department of Mechanical Engineering in Pukyong National University, who provided many engineering tools and helped me during the experimental period.

In addition, I would like to thank my managers also, Professor Pham Ngoc Tiep and Professor Tran Van Hanh of the Maritime Research Institute in Viet Nam Maritime University, who gave me the opportunity to have been studying here.

I show great appreciation to members of Fluid Machinery Lab. for giving me a comfortable and active environment as well as enthusiastic and invaluable help during the periods of time spent working with them. They all, in this way or another, have helped me a lot from the time of my first step here to the time of my graduation.

I am very happy to know all Vietnamese students in PKNU. All memories we have got will last for ever.

Finally, and perhaps most importantly, I wish to express my sincere appreciation to my parents, who have brought up and taught me how to live. Moreover, thanks to my lover and friends, who encouraged me in this study. Without all of you, this study would not have been possible.

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December 05th, 2008

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