# INFLUENCE OF BRONZE FILLER UPON THE FRICTION AND WEAR OF POLYTETRAFLUOROETHYLENE AND POLYOXYMETHYLENE

تأثير اضافة البرونز على الاحتكاك والتآكل للبولى تترافلوروإثلين والبولى أوكسى ميثلين

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الخلاصة – البحث المقدم يتناول فحصا معمليا لتأثير اضافة عنصر فلزى وآخر بلمورى على معامل الاحتكاك ومعدل التآكل لكل من البولى تترافلورو اثلين والبولى أوكسى ميثلين وقد أضيفت بودرة البرونز وبودرة البولى تترافلوروإثلين بنسب مئوية مختلفة حجما الى المادة الاساسية لتكوين مركب جديد . وقد تمت الدراسة على ماكينة " أصبع على قرص دوار " تحت تأثير حمل ثابت مقداره ٥٠ نيوتن وسرعة انزلاقية ثابتة مقدارها ١ متر/ث فى ظروف تشغيل جافة وقد أوضحت النتائج ان اضافة البرونز أو البولى تترافلورو اثلين تخفض دائما من قيمة معاملات الاحتكاك والتآكل للمواد المختبرة وأن الانخفاض يزيد بزيادة نسبة الاضافات حتى ٤٠٪ تقريبا وقد وجد أن أقل قيم للاحتكاك والتآكل كانت لمادة البولى أوكسى ميثلين التى تحوى ٣٦٪ بولى تترافلوروإثلين والبحث يرجع الانخفاض فى الاحتكاك والتآكل الى تكوين طبقة بلمورية منقولة وملتصقة على سطح الصلب المقابل والتى تسهل الانزلاق وتقلل الالتصاق .

## ABSTRACT

The present paper deals with an experimental investigation carried out to elucidate the role played by polymeric and metallic fillers upon the coefficient of friction and wear rate of Polyoxymethylene (POM) and Polytetrafluoroethylene (PTFE). Lead bronze powder and PTFE powder were added by different percentages of volume to the base material to form a composite.

The study was performed on a pin-on-disk machine under constant load of 50 N and constant sliding speed of 1.0 m/s under dry sliding conditions.

The results indicate that the addition of bronze or PTFE fillers always reduces the coefficients of friction and wear rates of tested materials and that reduction increases with the increase of filler content up to about 40%. The minimum values of friction and wear were experienced by POM containing 36% PTFE. The paper attributes the reduction in friction and wear to the formation of polymeric transfer film adhering to the steel counterface which facilitates sliding and decreases adhesion.

## 1. INTRODUCTION

During the past decade and up to now, there has been a continuous increase in the utilization of polymers and polymer-based composites in a wide range of tribological and bioengineering applications. In particular, polymeric materials are used as bearing materials [1]. Such bearings are generally self-contained, self-lubricated, chemically stable in aggressive media, bioinert, cheap, easy to fabricate into complex shapes and they do not exhibit scuffing, seizure and corrosion. There tribological characteristics, in particular thermoplastics, are very promising as they exhibit low friction and wear when sliding against themselves or against metals. However, certain disadvantageous features limit, to some extend, the usage of thermoplastics. Such features include the low ultimate strengths, low moduli, low thermal conductivities and high thermal expansion coefficients of thermoplastics compared to metals. The addition of fillers and reinforced fibres has significantly improved the tribological and mechanical characteristics of these thermoplastic materials [2-6].

Most polymers exhibit viscoelastic behaviour and the friction becomes time-dependent [7-8]. It is important to keep this point in mind when comparing the results of friction tests on identical polymers carried out on different machines and at different speeds [9]. In addition, when wear tests are carried out on polymers, different investigators use different ways in expressing the rate of wear, but the most satisfactory way is to relate the polymeric bearing life to the well-established wear equation in which the volume of material removed by wear is expressed as a function of the applied load and sliding distance [10].

Among the wide spectrum of thermoplastic polymers PTFE and POM are of major importance. Attempts are made to improve their tribological and mechanical characteristics by the addition of fillers. The addition of fillers is not only capable of reducing friction and wear but also reduces expansion coefficients and increases strength and thermal conductivity [5]. Some fillers are used to improve mainly the mechanical properties of the polymer as asbestos, carbon, glass, metal oxides, textile, silica,...etc, while some others are used to reduce friction like graphite, PTFE, $MOS_2$, mineral oils, silicones, fatty acids, ...etc. Bronze in particular, as a filler, tend to improve the mechanical properties, to reduce friction and to improve thermal conductivity [5]. PTFE is also of major importance as a matrix material suitably reinforced, as an additive to other polymers to reduce friction and wear, as a thin film solid lubricant and as a grease additive. One of the interesting features of PTFE and POM, when sliding against smooth solid counterface, is the built-up of a polymeric transfer, highly oriented in the direction of sliding. The transfer film formation is connected with the smooth molecular profile of the polymer [11-12], and results in a significant reduction in both friction and wear due to the improvement of the counterface surface roughness [13-15] and the reduction of adhesion and the ease of sliding [2].

## 2. EXPERIMENTAL

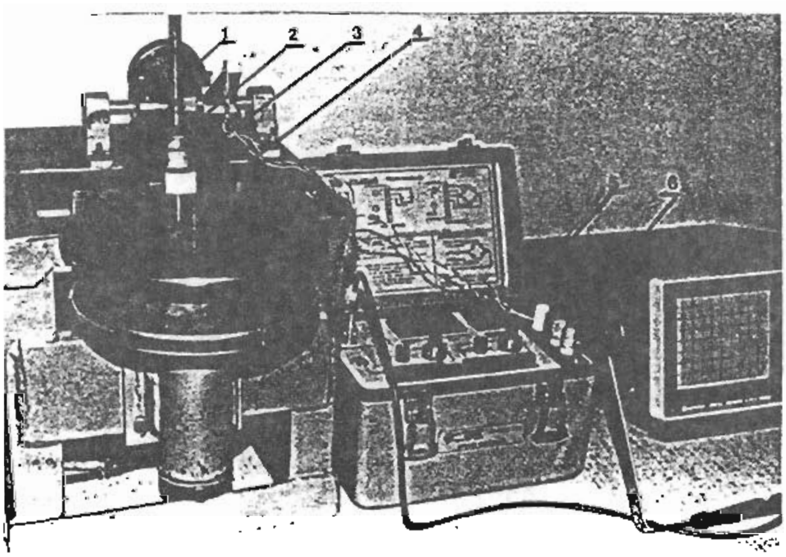
The sliding tests were performed on a pin-on-disk type of friction and wear machine, shown in Fig. 1. The sliding system consists of a 20.0 cm diameter and 0.8 cm thick ground AISI 4340 Steel disk and a cylindrical polymeric pin. The sliding occured between the circular end of the polymeric pin and the metal disk counterface. The pin was secured to a horizontal arm which carries the vertically applied dead loads. The deflection of the horizontal arm indicated the friction torque which was measured by strain gages. The volume loss due to wear of the pin was assessed by weighing the pin before and after a specific period of time under a constant normal load and sliding speed.

The tested pins of 100% PTFE, 100% POM, POM with PTFE, POM with Bronze and PTFE with Bronze, were 8 mm in diameter and 10 mm long. The pins were machined from blocks of polymeric materials formed by pressure injection according to Table 1. The circular end of the cylindrical pins was finished by polishing against 600 grade emery paper under running water. The disk counterface had a roughness in the range 0.4-0.6 μm Ra. Both pins and counterface were cleaned thoroughly by alcohol to remove any grease traces or contaminants. The pins were recleaned after testing by alcohol soaked tissues to ensure that they are free from polymer deposit. The pins were left to dried for a few hours before weighing in an accurate digital balance of accuracy $10^{-5}$ grs. A specific wear rate was calculated according to the equation :

$$\text{Specific Wear Rate} = V / (P.L) \qquad mm^3 / N.m$$

Where
- V : The wear volume in $mm^3$
- P : The applied normal load in N.
- L : The sliding distance in m.

A sliding speed of 1.0 m/s and a normal load of 50 N were used in the present investigation. Each pin was allowed to rub against the steel counterface for a distance of about 10 km. Tests were carried out at room temperature and humidity conditions.




1. Balancing Weight
2. Dead Weights
3. Strain Gages
4. Pin on Disk
5. Strain Indicator
6. Oscilloscope

Fig. 1 View for the Pin-on-disk Friction and Wear Machine with Measuring Equipment.

Table 1. Investigated Polymeric Pin Materials

| MATERIAL | PERCENTAGE OF COMPONENTS |
| --- | --- |
| POM | 100 % POM |
| PTFE | 100 % PTFE |
| POM + PTFE | 82 % POM + 18 % PTFE |
| | 70 % POM + 30 % PTFE |
| | 64 % POM + 36 % PTFE |
| POM + BRONZE | 85 % POM + 15 % BRONZE |
| | 70 % POM + 30 % BRONZE |
| | 40 % POM + 60 % BRONZE |
| PTFE + BRONZE | 80 % PTFE + 20 % BRONZE |
| | 60 % PTFE + 40 % BRONZE |
| | 50 % PTFE + 50 % BRONZE |

## 3. RESULTS AND DISCUSSION

### A) Friction of Investigated Materials

#### I) Friction of Pure POM and Pure PTFE

The variation of coefficients of friction with sliding distance for pure POM and PTFE pins, sliding against a steel disk under dry conditions, is shown in Fig. 2. The test corresponding to each condition was repeated twice so as to obtain reliable friction and wear data. The coefficient of friction, plotted in figures, was the average of multiple values recorded throughout the sliding test.

Fig. 2 demonstrates that in the early stages of sliding, the coefficients of friction for POM and PTFE are relatively high. Briscoe et al. [11] have elucidated this behaviour for PTFE and called it "stick". The "stick" was accompanied by the formation of a lumpy transfer of polymer which adheres to the steel counterface. Immediately after this initial unsteady high friction stage, the coefficient of friction decreases with continuous sliding over the same friction and wear track to a steady state value of about 0.27 for POM and 0.10 for PTFE. The decrease in coefficients of friction from the first high-friction stick to the steady state friction is due to the modification of surface topography brought about by the transfer of polymer to the counterface. The transfer film in the steady state condition takes the form of a thin transferred film, and the contact between polymer and steel is now converted to a contact between the polymer and the polymeric transfer film. It is beleived that once the first high-friction stick has occurred, the polymer is pulled into a direction which favors easy drawing of the polymer chains which, as sliding continues, adhere to the metal counterface. The force required to draw out the polymer chains from the bulk pin specimen is essentially the same as the force needed to slide the polymer, thus, the additional drawing of fiber may not occur and the transfer film thickness remains constant. Therefore, the coefficients of friction remain almost constant. It is clear from Fig. 2 that the transfer film formation has a greater effect upon the friction of PTFE rather than POM. The reason for that may be due to the

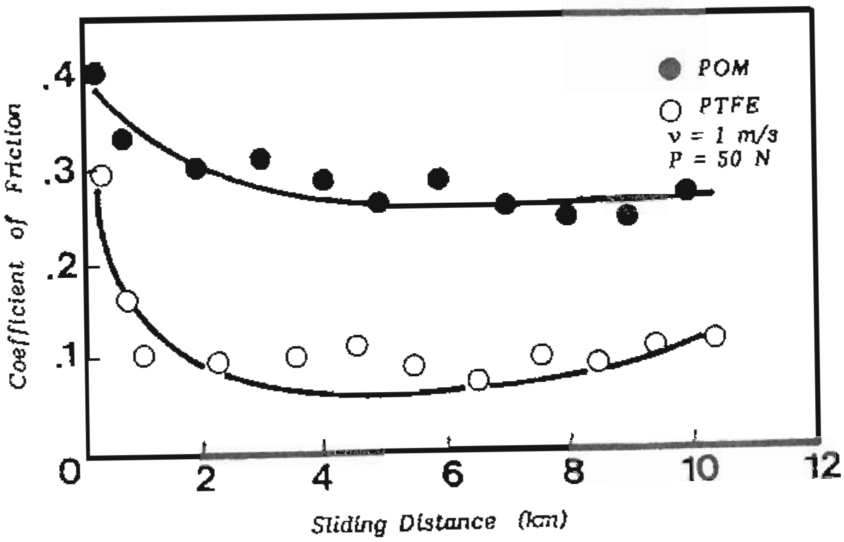



*Fig. 2 Coefficient of Friction versus Sliding Distance for POM and PTFE under Dry Sliding Conditions.*

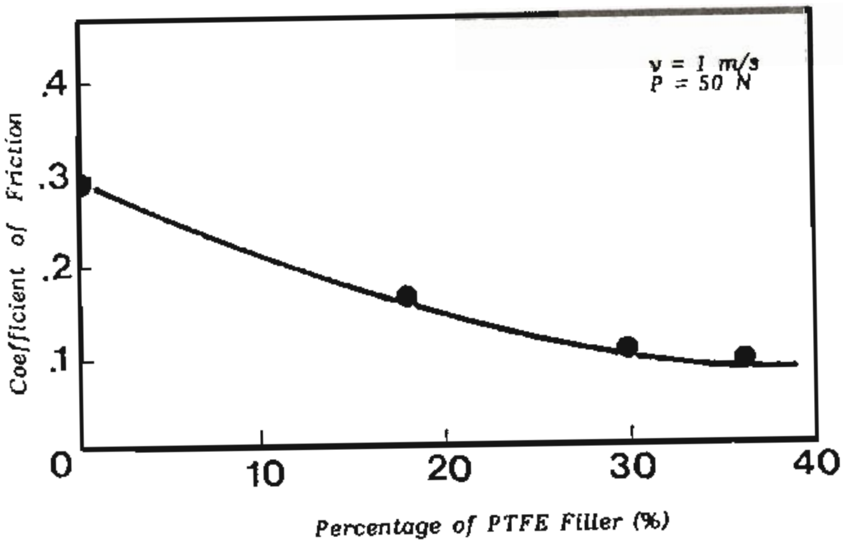



*Fig. 3 Influence of PTFE Percentage Filler in POM on the Coefficient of Friction.*

crystal texture of PTFE, which is formed by thin crystalline bands of oriented chains separated by disordered or amorphous regions. Easy slip is postulated within the disordered regions, leading to the drawing out of thin oriented film from the crystalline bands. Pooley and Tabor [16] and Lancaster [17] have attributed the low friction of PTFE to the smooth molecular profile of the chains. On the other hand, POM has less smooth molecular profile than PTFE, thus POM exhibits higher steady state friction values.

II) Friction of POM with PTFE Powder Filler

Fig. 3 demonstrates the variation in coefficients of friction for POM and POM composites containing 18 %, 30 % and 36 % by volume PTFE powder. As can be seen, the addition of PTFE as a filler to POM reduces the dry friction coefficients to more acceptable values compared to pure POM. Although the unfilled POM gives a coefficient of friction around 0.3, but the addition of PTFE powder to the POM matrix reduces the coefficient of friction to about 0.1 for 30-36 % PTFE filler.

A strong adhering polymeric film is formed with the filled polymer on the counterface during sliding. This transfer film plays the major role in reducing the friction between the filled POM and the steel counterface. Briscoe et al [11] suggest that with most unfilled polymers, there is transfer of polymer to the counterface but it is relatively weakly held; but for filled polymers, the adhesion is stronger and the transfer film once formed, further transfer is small and the friction and wear are light. The figure also indicates that the coefficients of friction decrease rapidly with increasing PTFE filler content to the lowest experienced friction value at about 36 % PTFE.

III) Friction of POM and PTFE with Bronze filler

Fig. 4 shows the variations in the coefficients of friction for POM and PTFE with variable percentages of lead-bronze filler. As can be seen, the coefficients of friction for PTFE with the addition of different percentages of bronze, remains virtually constant; which means that the frictional behaviour for the filled and unfilled PTFE are indistinguishable. Presumably the filler has little or no effect upon the low friction polymers like PTFE. The same behaviour was observed for high-density polyethylene (HDPE) when incorporating a mixture of copper and lead oxides into HDPE, which is classified as a low friction polymer [11]. On the other hand, the coefficient of friction for POM composite decreases from 0.3 to 0.18 when the percentage of filling bronze attains 30 %, but then the coefficient of friction values rise again with the increase of bronze content. The results, therefore, suggest that the minimum friction coefficient, for filled POM with bronze, is experienced at about 30 % by volume bronze.

B) Wear of Investigated Materials

I) Wear of POM with PTFE Filler

The wear rates of POM against steel counterface, decrease rapidly with increasing PTFE filler content to a minimum value at around 30 % PTFE

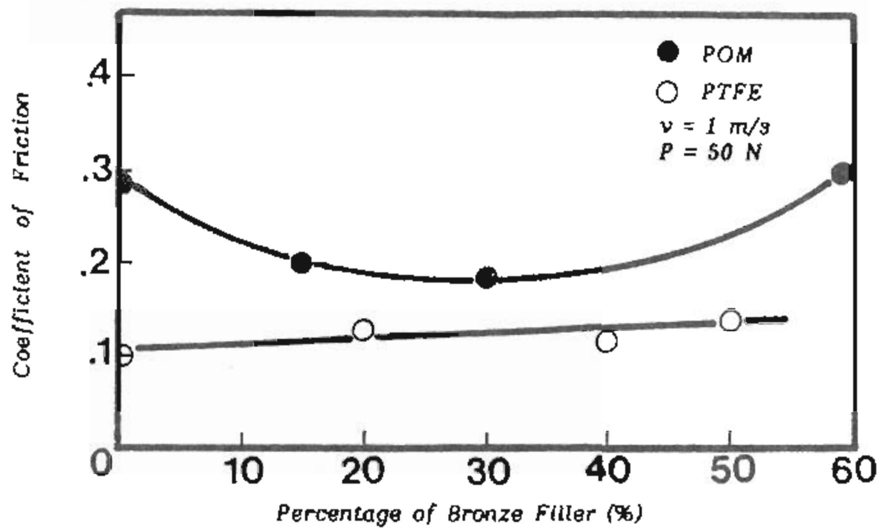



*Fig. 4 Variation of Coefficient of Friction of POM and PTFE Containing Different Percentage of Bronze Filler.*

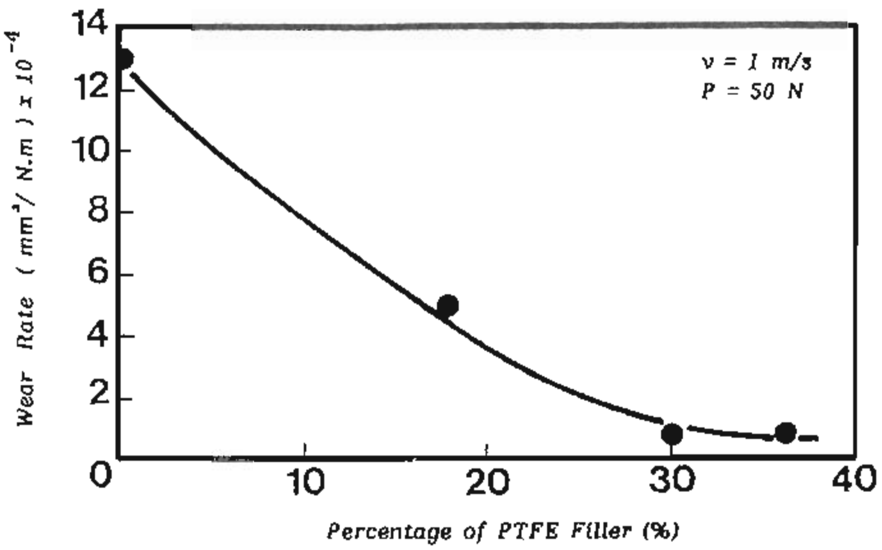



*Fig. 5 Variation of Wear Rate of POM Containing Different Percentages of PTFE Powder Filler.*

The results indicate that there is an appreciable reduction in wear rates due to the addition of PTFE powder to POM. The wear rates fall from 12.5 × $10^{-4}$ $mm^3$/ N.m to 0.75 x $10^{-4}$ $mm^3$/ N.m by the addition of 30% PTFE to POM matrix. This dramatic reduction in the wear rates is also attributed to the formation of a strongly adhering transfer film on the steel counterface. Variety of explanations has been proposed in the literature to account for the way in which fillers reduce the wear of specific polymer. Some explanations reflect the role played by chemical reactions, some attribute it to mechanical actions, but the more general explanation focus upon the role of transfer film and the modification of the counterface surface roughness.

II) Wear of POM and PTFE with Bronze Filler

In Fig. 6, the wear rates of both POM and PTFE containing different percentages of lead-bronze filler, are illustrated. The variations in the wear rate of POM and the added percentage of bronze, exhibit a linear relationship. As the bronze percentage increases, the wear rate of POM consequently decreases. By increasing the bronze content to 60 % in POM, the wear rates decrease from 12.5 x $10^{-4}$ $mm^3$/ N.m to about 4.0 x $10^{-4}$ $mm^3$/ N.m.

The filled PTFE with bronze exhibits lower wear rate values compared with filled POM. Although the wear rate of 100 % PTFE is higher than that of 100 % POM, but the addition of bronze filler has decreased significantly the wear rates of PTFE. It is known that the addition of bronze to polymers always results in an improvement in the mechanical properties, in particular the polymer strength, and also improve the resistance to heat [18-19]. Furthermore, bronze acts as a solid lubricant between rubbing surfaces which results in a reduction in both friction and wear.

C) Comparison between Friction and Wear for Investigated Materials

In general, both investigated polymers (POM and PTFE) benefit from the presence of filling elements and they show a reduction in friction and wear with the increase of filling percentage. The percentage reduction in either friction or wear varied from material to material. Fig. 7 shows a histogram for the coefficient of friction and wear rate values.

As illustrated, PTFE and filled PTFE with bronze experienced lower friction coefficient values compared with POM and POM composites.

PTFE is known to be a low-friction polymer and the addition of bronze to its matrix has demonstrated little effect upon the coefficient of friction. Meanwhile, the addition of PTFE to POM has improved its friction behaviour. The friction of POM with PTFE filler continue to decrease with the increase of PTFE content. On the other hand, the addition of bronze to POM up to 30 % bronze, decreases its coefficient of friction while it tends to increase the coefficient of friction for higher percentage of bronze.

For the wear rate of tested materials, pure PTFE shows the highest value, but this value falls significantly to much lower one by the addition of bronze. Increasing the bronze percentage results in further reduction in the wear rate. On the other side, the lowest wear rate was obtained for POM with 30 % PTFE filler. Nevertheless, PTFE + 50 % bronze also exhibits very

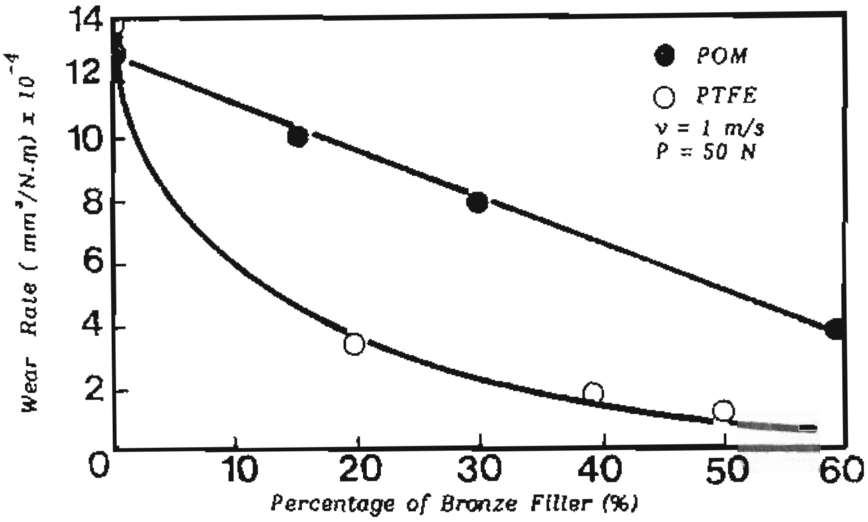



*Fig. 6 Variations in Wear Rate for POM and PTFE Containing Different Percentages of Bronze Filler.*

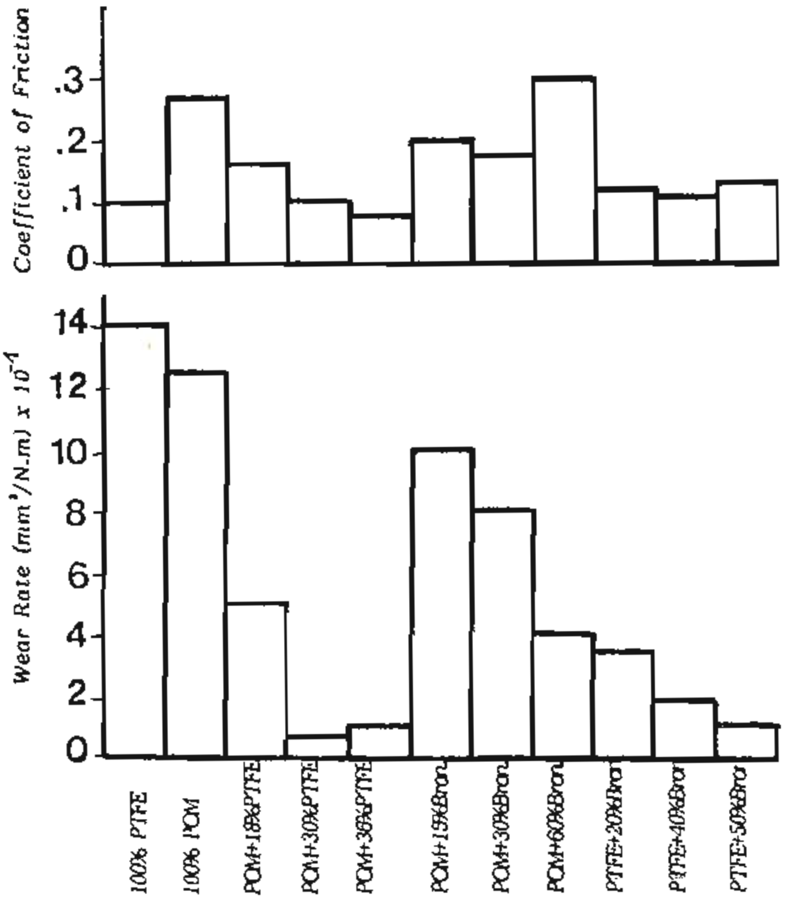



*Fig. 7 Histogram for the Coefficient of Friction and Wear Rate of Investigated Materials.*

low wear rate comparable with that of POM + 30 % PTFE.

## CONCLUSIONS

Based on the experimental investigation presented in this paper, the following conclusions were made :

1. The initial coefficients of friction for POM and PTFE, sliding against steel counterface under dry conditions, are relatively high due to the lumpy fashion of polymeric transfer to the metal counterface. This is followed by a steady state friction values when the transfer takes the form of a thin film oriented in the direction of sliding.

2. PTFE exhibits lower steady state friction values compared with POM and that is attributed to the smoother molecular profile of PTFE. In addition, the adhesion of PTFE is lower than that of POM which also contributes to the higher friction of POM than PTFE.

3. The addition of PTFE powder as a filler to the matrix of POM reduces the coefficient of friction values of POM (0.3) to that of pure PTFE (0.1) when the percentage of PTFE in POM reaches about 30 % by volume.

4. The addition of bronze filler to PTFE does not affect the friction coefficients of this low-friction polymer.

5. Bronze filler slightly decreases the coefficient of friction of POM containing up to 30 % bronze. The existance of bronze over 30 % in POM has a deleterious effect upon friction.

6. Remarkable reduction in wear rates is obtained for POM when PTFE powder is used as a filler. Increasing the percentage of PTFE filler tends to decrease the wear rate of POM.

7. PTFE benefits to a large extend from the presence of bronze filler, in reducing its wear rate. Lowest wear rate was obtained for 50 % bronze with 50 % PTFE composite.

8. The polymeric transfer film from the pin surface to the steel counterface, plays the major role in reducing adhesion between sliding surfaces, ameliorating the counterface friction track roughness, easing sliding between surfaces. Thus the friction and wear decrease with the formation of this film.

## EFERENCES

. D. Dowson, M. Godet and C.M. Taylor (eds) "The Wear of Non-Metallic Materials". Mechanical Engineering Publications, London, 1978.

. H. Czichos "Influence of Adhesive and Abrasive Mechanisms on the ribological Behaviour of Thermoplastic Polymers". Wear, 88 (1983), 27-43.

3. S.C. Cohen and D. Tabor, "The Friction and Lubrication of Polymers". Proceeding of The Royal Society, 291, (1965), 186-207.

4. J.P. Giltrow and J.K. Lancaster "The Role of the Counterface in the Friction and Wear of Carbon Reinforced Thermosetting Resins". Wear, 16 (1970), 359-374.

5. D.C. Evans and J.K. Lancaster "The Wear of Polymers". Wear, 13 (1979), 85-136.

6. J.K. Lancaster "Lubrication of Carbon Fibre-Reinforced Polymers". Wear, 20 (1972), 315-333.

7. K.C. Ludema and D. Tabor "The Friction and Visco-Elastic Properties of Polymeric Solids". Wear, 9 (1966), 329-348.

8. J.K. Lancaster "Basic Mechanisms of Friction and Wear of Polymers". Plastic and Polymers, Dec. (1973), 297-306.

9. L.H. Lee (ed)."Advances in Polymer Friction and Wear". Polymer Science and Technology, 5A (5B), Plenum Press, New York and London, (1974).

10. H. McKellop, I.C. Clarke, K.L. Markoff and H.C. Amstutz "Wear Characteristics of UHMW Polyethylene : A Method for Accurately Measuring Extremely Low Wear Rates". Journal of Biomedical Materials Research, 12 (1978), 895-972.

11. B.J. Briscoe, C.M. Pooley and D. Tabor "Friction and Transfer of Some Polymers in Unlubricated Sliding". Polymer Science and Technology "Advances in Polymer Friction and Wear", L.H. Lee (ed)., Plenum Press, New York and London (1974).

12. D. Dowson, J.R. Atkinson and K. Brown "The Wear of High Molecular Weight Polyethylene with Particular Reference to its Use in Artificial Human Joints". Advances in Polymer Friction and Wear, 5B, L.H. Lee (ed), Plenum Press, (1975), 533-548.

13. M. Zaki "A Study of the Influence of Interfacial Electrical Potential and Counterface Surface Roughness Upon the Friction and Wear of Polyethylene and Articular Cartilage". Ph. D. Thesis, Leeds University, 1984.

14. D. Dowson, J.H. Challen, K. Holmes and J.R. Atkinson "The Influence of Counterface Roughness on the Wear Rate of Polyethylene". Proceeding of The 3rd Leeds-Lyon Symposium on Tribology, Mechanical Engineering Publications Ltd., London, (1976).

15. V.K. Jain and S. Bahadur "Surface Topography Changes in Polymer-Metal Sliding". Journal of Lubrication Technology, Transaction of The ASME, 105, (1983), 526-533.

16. C.M. Pooley and D. Tabor "Friction and Molecular Structure : Behaviour of Some Thermoplastics". Proceeding of The Royal Society, A 329, (1972), 251-274.

7. J.K. Lancaster "Wear Mechanisms of Metals and Polymers". Transaction of The Institute of Metal Finishing, 56, (1978), 145-153.

8. A.A. Fote, A.H. Wildvank and R.A. Slade "Coefficient of Friction of PTFE-Impregnated Porous Bronze Versus Temperature". Wear, 47 (1978), 255-261.

9. K. Tanaka and S. Kawakami "Effect of Various Fillers on the Friction and Wear of PTFE-based Composites". Wear, 79 (1982), 229-234.