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FRICTIONAL BEHAVIOR OF STEEL SLIDING ON POLYMERIC MATERIALS

Tarboosh M. M.[1], Khashaba M. I.[2] and Ali W. Y.[2]

[1]National Institute for Standards, Giza, EGYPT,
[2]Production Engineering and Mechanical Design Department, Faculty of Engineering,
Minia University, P. N. 61111, El-Minia, EGYPT.

ABSTRACT
The aim of the present study is to investigate the friction coefficient displayed by sliding of bearing steel on polytetrafluoroethylene (PTFE) and polymethyl methacrylate (PMMA) at dry and in the presence of paraffin and glycerin oils. Besides, particles of iron (Fe), copper (Cu), aluminum (Al) and graphite (C) powders are added to the oils in 10 wt. % concentration. The grain size of the particles was ranging between 50 - 80 µm. The normal loads used are 2, 4, 6, 8, 10, 12, 14 and 16 N. While sliding velocity was 2 mm/s.

It was found that dispersing the surfaces of PMMA and PTFE by Fe, Cu, Al and C particles decreased friction coefficient at dry sliding, where the effective decrease was presented by C. Sliding on PTFE showed lower friction than that observed for sliding on PMMA. At oil lubricated sliding, steel/PMMA displayed higher friction than that detected for oil dispersed with the tested particles. Sliding of steel on PMMA lubricated by paraffin and glycerin oils and dispersed by Al displayed lower friction values than that shown by sliding on PTFE. For lubricated sliding by paraffin and glycerin oils, the use of PMMA as bearing material can be recommended.

KEYWORDS
Friction, bearing steel, polymethyl methacrylate, polytetrafluoroethylene, paraffin, glycerin oils.

INTRODUCTION
Oil additives are added to the base oil to improve its performance. Recently, the effect of dispersing the base oil by talc, C and PTFE to a blend of glycerin and motor oil on the friction coefficient wear resistance is investigated, [1]. It was found that talc showed the lowest wear. When particle size of the graphite increased friction coefficient increased. The lowest friction coefficient was found for oil dispersed by 3 wt. % graphite of 0.012 mm particle size. Several attempts were performed to enhance the lubricating properties of oils by adding multiple additives, [2, 3]. The function of oil additives is to give special properties to the oil, [4 – 15]. There are multiple types

of oil additives, such as detergent, [16 – 18], anti-rust, [19, 20], anti-foam, [21, 22], viscosity improver additives, [23 – 25] and anti-wear additives, [26, 27].

Certain materials are used as anti-wear additives such as talc that can be used as solid lubricant and anti-wear additive, [28, 29]. Besides, PTFE is used as a solid lubricant due to its ability of PTFE layers to slide on each other with a minimal friction coefficient, [30]. Graphite (or graphene) works like PTFE, where its layers slide with relatively lower friction coefficient, [31, 32]. The anti-wear performance of talc and graphite were compared, where talc was found to give a smoother microstructure on the bronze surface tested with steel, [33].

The particle size of the dispersed materials in oils has critical effect on the behavior of the additive. The lower the particle size, the better performance due to the ability of smaller particles to penetrate the tight contact areas of the moving surfaces and provide lubricated film. In addition to that, the increased surface area relative to volume offers excellent mechanical properties, [2, 34]. Nanomaterials are also usually used as lubricant additives, [35, 36].

In this study the friction coefficient displayed by sliding of bearing steel on PMMA and PTFE at dry and in the presence of paraffin and glycerin oils was investigated. 10 wt. % concentration of Fe, Cu, Al and C granulates were added to the oils.

EXPERIMENTAL

The test rig used to carry out the experiments is shown in Fig. 1. The values of applied loads were 2.0, 4.0, 6.0, 8.0, 10, 12, 14 and 16.0 N. Load cell connected to digital monitor was used to measure the friction force. Then, friction coefficient was determined by the ratio between the friction force and the normal load. The experiments were performed at room temperature.

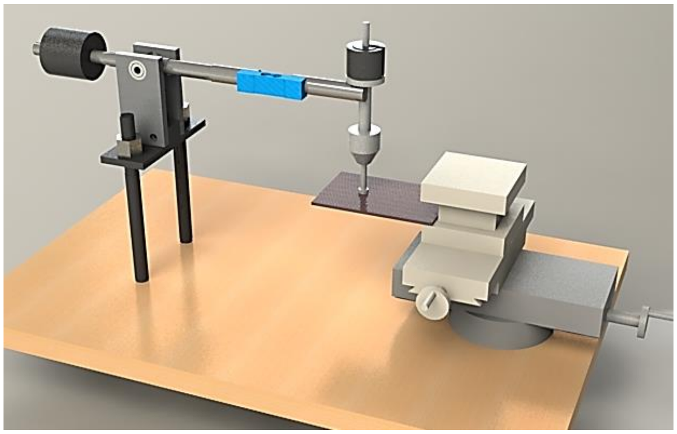

Fig. 1 Arrangement of the test rig.

Experiments were carried out at dry and oil lubricated sliding conditions. Granulates of Fe, Cu, Al and C of grain size ranging between 50 - 80 µm were used to disperse the tested oils at 10 wt. % concentration. Two oils were tested paraffin and glycerin

oils. The steel pin (steel 51200) of 14 mm diameter was sliding on PMMA and PTFE sheet of 4 mm thickness for 60 mm. The pin surface is assumed to have the same surface roughness. This assumption is because of using a grinding paper after each track. In addition to, each track is only for one test related to one normal force value. Every experiment was repeated ten times then the average values were considered.

RESULTS AND DISCUSSION

The dry sliding of the steel pin on PMMA displayed relatively higher values of friction coefficient, Fig. 2. Dispersing the sliding surface by Fe, Cu, Al and C particles showed slight friction decrease. C particles drastically decreased friction coefficient. This behavior may be attributed to the ability of C to adhere to the two contact surfaces and conduct the electrostatic charge (ESC) to the pin surface. ESC is generated by triboelectrification of the surfaces of both PMMA and steel pin. It is known that when different materials are rubbing each other then one of them will gain electrons from the other and the other one will lose electrons. The ability of the dispersed materials to conduct ESC to the steel surface control the value of friction coefficient because ESC increases the adherence force between the two sliding surfaces and consequently friction coefficient increases.

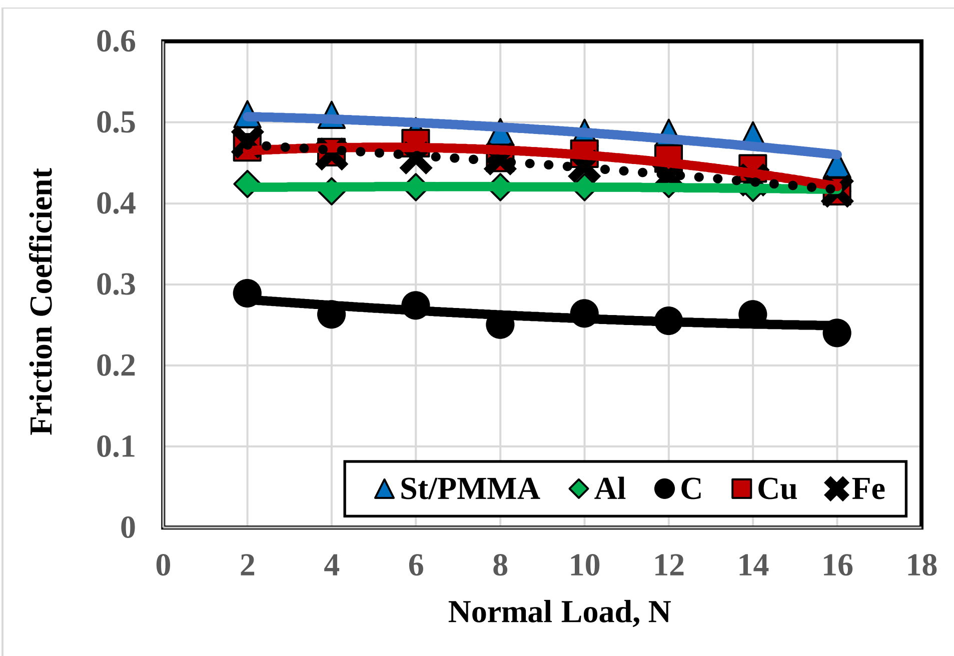

Fig. 2 Friction coefficient displayed by sliding of steel pin on dry PMMA sheet.

The sliding of steel pin on PTFE sheet displayed the lowest friction values followed by C, Fig. 3, while, the highest friction values were shown in the presence of Fe, Cu and Al. The lowest friction shown for PTFE may be due to high value of generated ESC that caused the strong adherence of PTFE layer into the steel surface leading to change the friction to be between PTFE/PTFE instead of PTFE/steel. The known low friction of PTFE controlled the sliding performance. Presence of C as conductive material released the generated ESC out of the contact area through the steel surface.

Besides, C could separate the two contacting surfaces. Al particles separated PTFE from interaction with steel making the contact to be Al/PTFE and Al/steel. The same behavior was observed for Fe and Cu particles.

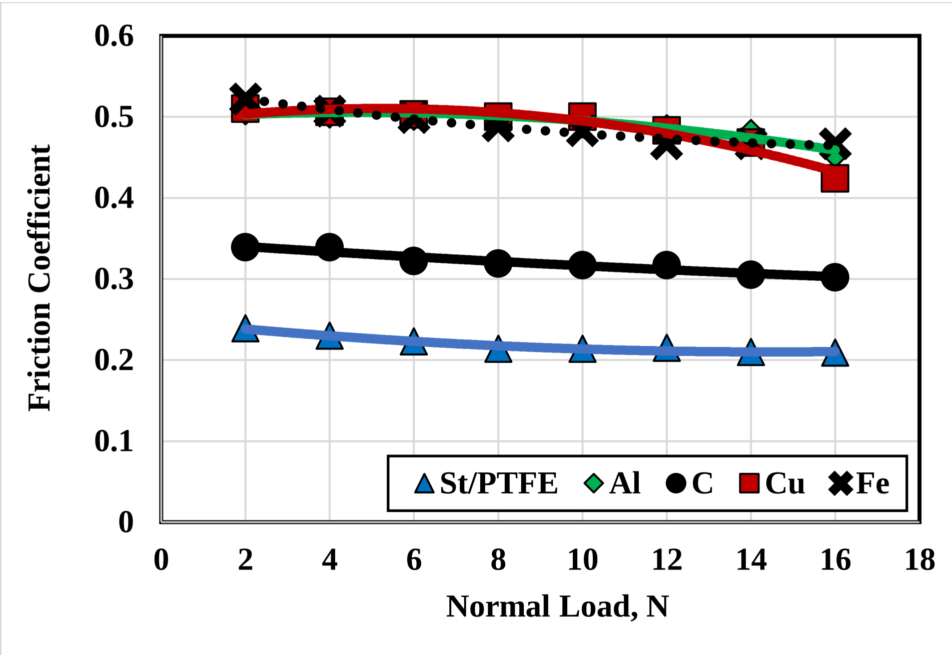

Fig. 3 Friction coefficient displayed by dry sliding of steel pin on dry PTFE sheet.

At oil lubricated conditions, the friction coefficient displayed by sliding of steel sliding on PMMA and PTFE in the presence of Al particles is shown in Fig. 3. Two oils were tested paraffin and glycerin oils were dispersed by 10 wt. % Al, C, Cu and Fe particles, Figs. 4, 5, 6 and 7 respectively. Generally, friction coefficient drastically decreased in oil lubricated sliding compared to the dry sliding.

In the presence of clean paraffin oil, sliding of steel on PMMA caused higher friction coefficient values than that observed for oil dispersed with the tested particles, Fig. 4. Sliding on the surface of PMMA in the presence of paraffin and glycerin dispersed by Al represented lower friction values than that recorded by sliding on PTFE. Friction coefficient showed increasing trend with increasing the load when sliding on PTFE. It seems that the adherence of Al particles into PTFE was quite strong because of the relatively higher magnitude of the generated ESC so that the friction was between Al and steel surface. While sliding on PMMA that generated lower values of ESC displayed decreasing trend as the load increased. In this condition the adhesion of Al into PMMA was weak enabling for some of Al particles to roll between steel and PMMA surface and limiting friction coefficient.

Dispersing the tested oils with C displayed slight decrease in friction with increasing the applied load, Fig. 5. Because C is an electrical conductive material, it dissipates ESC into the steel pin surface decreasing the ability of C particles to be adhered layer on the contact surfaces. The slight reduction in friction may be from the easy motion of the C laminates on each other. Besides, sliding of steel on PMMA in the presence of glycerin showed the lowest friction values.

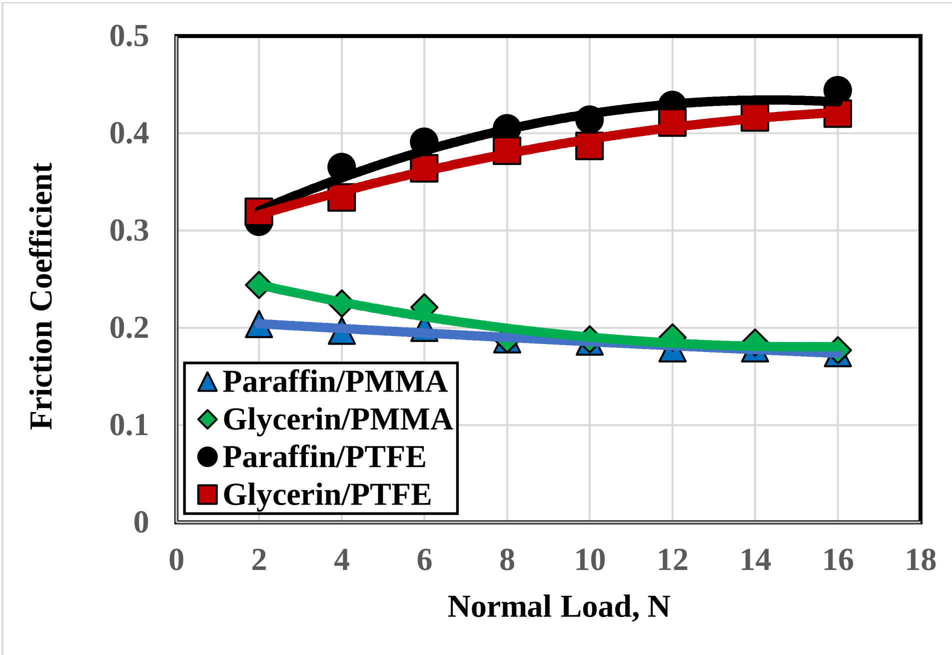

Fig. 4 Friction coefficient displayed by oil lubricated sliding in the presence of Al particles.

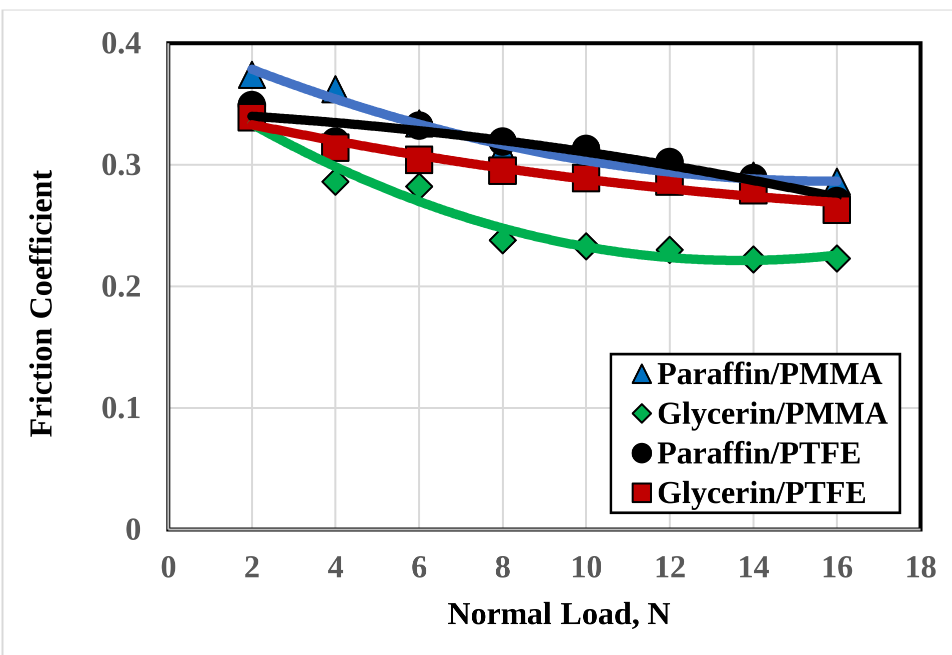

Fig. 5 Friction coefficient displayed by oil lubricated sliding in the presence of C particles.

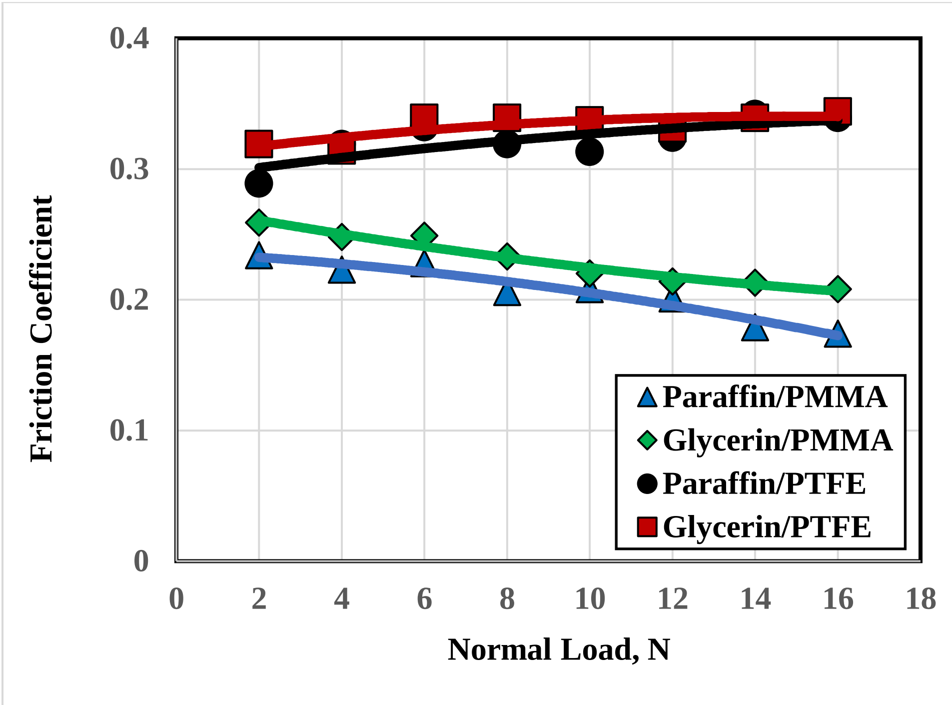

Fig. 6 Friction coefficient displayed by oil lubricated sliding in the presence of Cu particles.

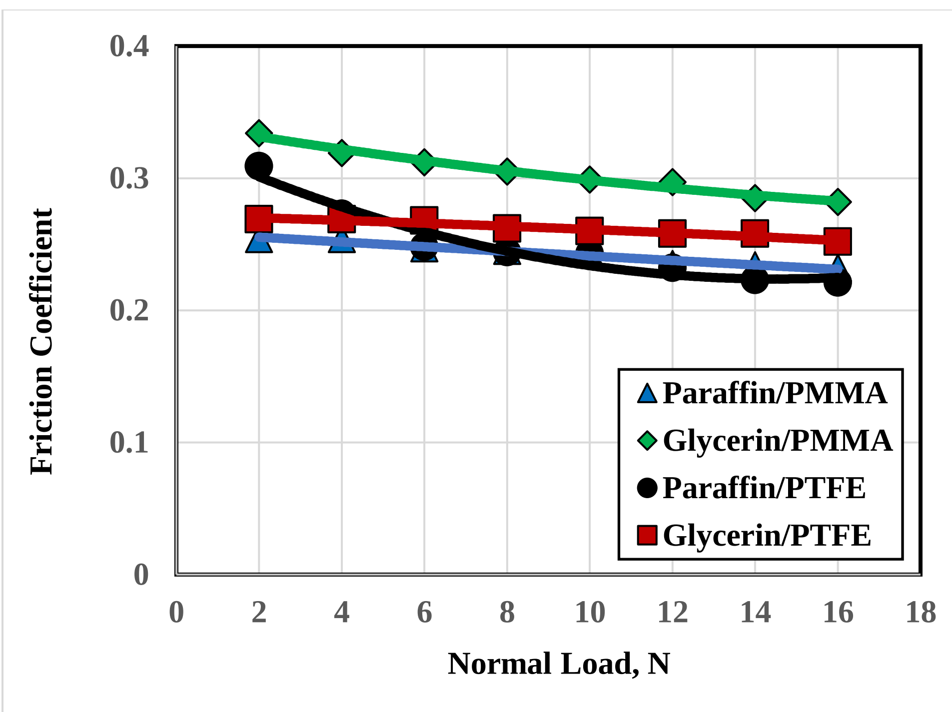

Fig. 7 Friction coefficient displayed by oil lubricated sliding in the presence of Fe particles.

In condition of dispersing the tested oils with Cu particles, further friction decrease was observed compared to the oil dispersed by C, Fig. 6. That behavior may be attributed to the increase of Cu adhesion into the PMMA surface, while PTFE surface showed friction increase. The relatively high magnitude of ESC generated from sliding on PTFE was easily conducted out of the contact surface due to the good conductivity of Cu particles. Based on that observation, it can be recommended to use PMMA as bearing material in the presence of paraffin and glycerin oils.

Fe dispersing the tested oils gave friction values higher than that observed for Al and Cu, Fig. 7, due to the embedment of particles in the PTFE and PMMA surfaces and abrading the steel surface. Glycerin medium showed relatively higher values than paraffin. The polarity of paraffin oil enables its molecules to be adhered into the two contact surfaces so that friction decreases.

CONCLUSIONS

1. Dry sliding of the steel pin on PMMA displayed relatively higher values of friction coefficient, while sliding on PTFE displayed the lowest friction values.
2. In the presence of the tested particles, C displayed lower friction followed by Fe, Cu and Al.
3. At oil lubricated conditions, friction coefficient drastically decreased compared to the dry sliding.
4. Sliding of steel on PMMA caused higher friction coefficient values than that observed for oil dispersed with the tested particles.
5. Sliding on the surface of PMMA in the presence of paraffin and glycerin dispersed by Al represented lower friction values than that recorded by sliding on PTFE.
6. Dispersing the tested oils with C displayed slight decrease in friction with increasing the applied load. Besides, sliding of steel on PMMA in the presence of glycerin showed the lowest friction values.
7. In condition of dispersing the tested oils with Cu particles, further friction decrease was observed compared to the oil dispersed by C.
8. Fe dispersing the tested oils gave friction values higher than that observed for Al and Cu.

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