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Synergistic effect of contact pressure and sliding speed on the friction coefficient of palm kernel activated carbon-epoxy composite

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ABSTRACT – The objective of this paper is to explore the influence of contact pressure along with the sliding speed on the coefficient of friction of palm kernel activated carbon-epoxy (PKAC-E) composite under dry sliding conditions. A ball-on-disc tribometer was used to conduct the dry sliding test at different degree of contact pressures and sliding speeds with constant sliding distance and operating temperature. The results found that regardless of the sliding speed used in this test, the friction coefficient of the composite increased drastically when exceeding a critical limit of contact pressure. As with the sliding speed, the friction coefficient increased first and then decreased at a higher speed of 500 rpm, where the friction coefficient could reduce to 0.05 below the critical limit of contact pressure.

1. INTRODUCTION

The exploit of agricultural waste as a new composite material has been made to be renewable and relatively produced with a significant reduction in cost and the waste ultimately could have been utilized effectively into wealth [1-3]. Therefore, this motivated us to investigate the potential of activated carbon being made into use and derived from one of the largest waste palm oils called palm kernel to be a new tribological material.

The PKAC, also known as palm oil extraction waste materials, is composed of carbonaceous, highly porous adsorptive medium that has a similar atomic structure to that of graphite, but in a disorganised form [4]. Furthermore, this activated carbon in the form of composite has high potential to be a self-lubricating material with a little friction coefficient and more durable wear resistance caused by the presence of the remaining natural oils in palm kernel [5-7].

According to Tahir et al. [5] found that there was no significant impact of sliding distance on the friction coefficient of a PKAC reinforced polymer composite. However, a change in working temperature was seen to influence its tribological performances. Chua et al. [8] discovered that there is a potential use of the PKAC reinforced with polymer composite as a lubricant in solid state, which can reduce the friction coefficient and wear due to the applied load.

There were several researches mentioning about the effects to the operating conditions on the tribological characteristics of PKAC-E composite, such as load that were applied, temperature and the distance of the sliding. Still, the studies on the simultaneous effects of contact pressure and sliding speed were limited to studying the tribological characteristics of this composite. Therefore, the purpose of this study is to investigate the influence of contact pressure and sliding speed on the friction coefficient of PKAC-E composite under dry sliding conditions.

2. EXPERIMENTAL PROCEDURE

The 74 mm in diameter, 5 mm thickness disc was produced by mixing 60 wt % PKAC (250 µm particle size) with 40 wt.% epoxy, where the hardener to resin ratio is 1:4. The mixture was then put into a mould and pressed using a hot-press machine

The dry sliding experiment was carried out utilising a ball-on-disc tribometer, in accordance with ASTM G99-05. All tests were performed at different applied loads between 20 and 100 N, with a 200–500 rpm sliding speed at 3,000 m of perpetual sliding distance. The operating temperature is 27°C. ASTM 52100 (EN31) chrome steel ball, as a counter surface, with two different diameter sizes of 10 mm and 12.7 mm, was used in this study. Each of the test was then repeated for three times to lessen the errors in the experimental. The physical–mechanical properties of both disc and ball are shown in Table 1.

Table 1 Physical-mechanical properties of the ball and disc materials before testing

Properties	**[a]Disc (60 wt% PKAC + 40% epoxy)**	**[b]ASTM 52100 (EN31) chrome steel ball**
Hardness, H	8.36 Gpa	7.45 Gpa
Young Modulus, E	7.61 GPa	210 Gpa
Poisson's ratio, v	0.23	0.3
Density, ρ	1.4 g/cm^3	7.81 g/cm^3
Surface roughness, R_a	0.4 µm	0.022 µm

[a] Properties acquired from laboratory measurements.
[b] Properties acquired from manufacturer.

3. RESULTS AND DISCUSSION

Figure 1 presents the data on friction coefficient of PKAC-E. It can be perceived that at the beginning, friction coefficient decreases with contact pressure. Then, at a certain level of contact pressure, friction coefficient increase significantly. This could imply that after the contact pressure was elevated, the real surface contact area also enlarged, causing more plastic deformation to the asperities resulting in energy dissipation. This causes the frictional force to increase. This study used Coulomb's friction law $F = \mu W$. The law was originally defined in a general per area form: $\tau = \mu q$, where τ is friction per area and q is normal pressure. This law only applies at low normal pressures. When frictional force continues to increase, the rate (friction coefficient) at which it increases with respect to normal load decreases. Applying additional pressure, therefore, cannot flatten asperities further, and the contact area is constant at higher pressure. Therefore, friction should remain constant for higher pressure, as the law states, and only depend on the material strength. However, while the contact pressure increased to the critical limit, it caused the friction coefficient to rose dramatically due to the critical surface energy. This could be further clarified through the piece of information that the frictional heat raises the temperature of the friction surfaces, which leads to reduction in the material strength.

As for the sliding speed, the friction coefficient increased first and then decreased at a higher speed of 500 rpm, where friction coefficient could reach as low as 0.05 below the critical limit of contact pressure. This is due to frictional heating as discussed above. However, at a higher sliding speed of 500 rpm, there was a major decrease in the friction coefficient. Raising the sliding speed resulted in increasing the surface temperature that reduced the adhesion between the composite surfaces with the steel ball [9]. The conduct can be explained in the outline where the adhesive theory of friction can provide better self-lubrication and protection to surfaces. This can be explained by the fact that the tribolayer, produced from the initial wear of the carbon substance, was caused by a tribofilm that was adhered to the contact surface, that, in result; dissolves the adhesive joints between the asperities [10-11].

From Figure 2(a), the transfer layer formation, as observed on the counter surfaces, could have accounted for the decrease of the friction coefficient due to the surface contact changes from carbonised-steel to carbonised-carbonised materials. Another explanation for the friction coefficient dramatic increase, at a certain level of contact pressure for sliding speed of 500 rpm, could be caused by the deterioration of the transfer layer, thus forcing the counter surface of the protective layer to disappear. This also signifies that the contact surface has experienced high abrasion due to the ploughing between the contact surfaces, which might have influenced the increment of the friction force [12]. Figure 2(b) shows an elevated magnification of micrograph of the damaged regions; in which the abrasive wear starts materialising on the counter surface. Consequently, this may have caused the increasing value of friction coefficient of the composite at contact pressure, which led to removal of the material.

4. CONCLUSION

In summary, regardless of sliding speed, at the time where the contact pressure exceeds to a critical limit, the friction coefficient of PKAC-E composite will rapidly increase. Meanwhile, friction coefficient increase first with the sliding speed and then decrease at higher speed of 500 rpm, where friction coefficient can reduce to 0.05 below a critical limit of contact pressure.

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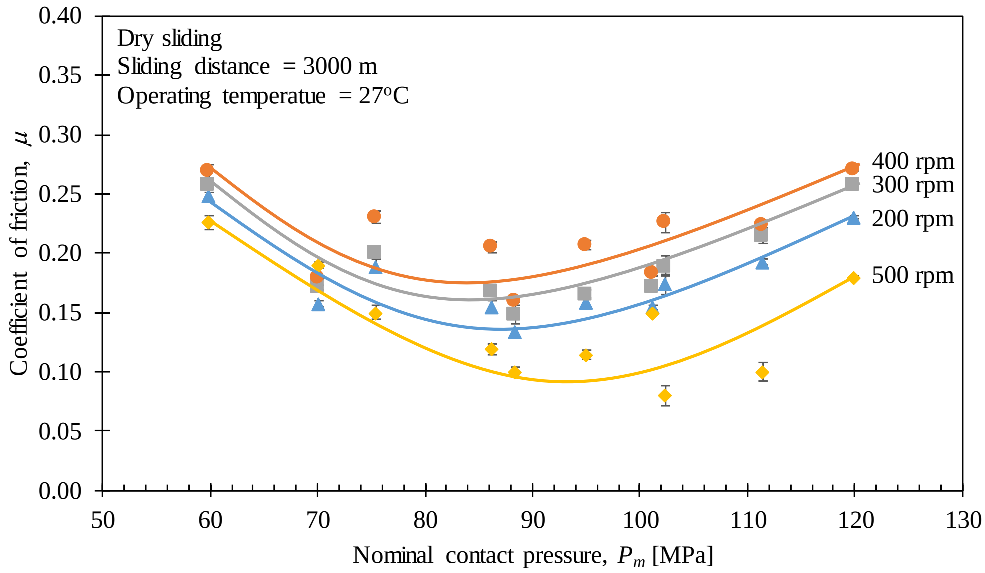

Figure 1 Effect of contact pressure on the friction coefficient PKAC-E at different sliding speeds

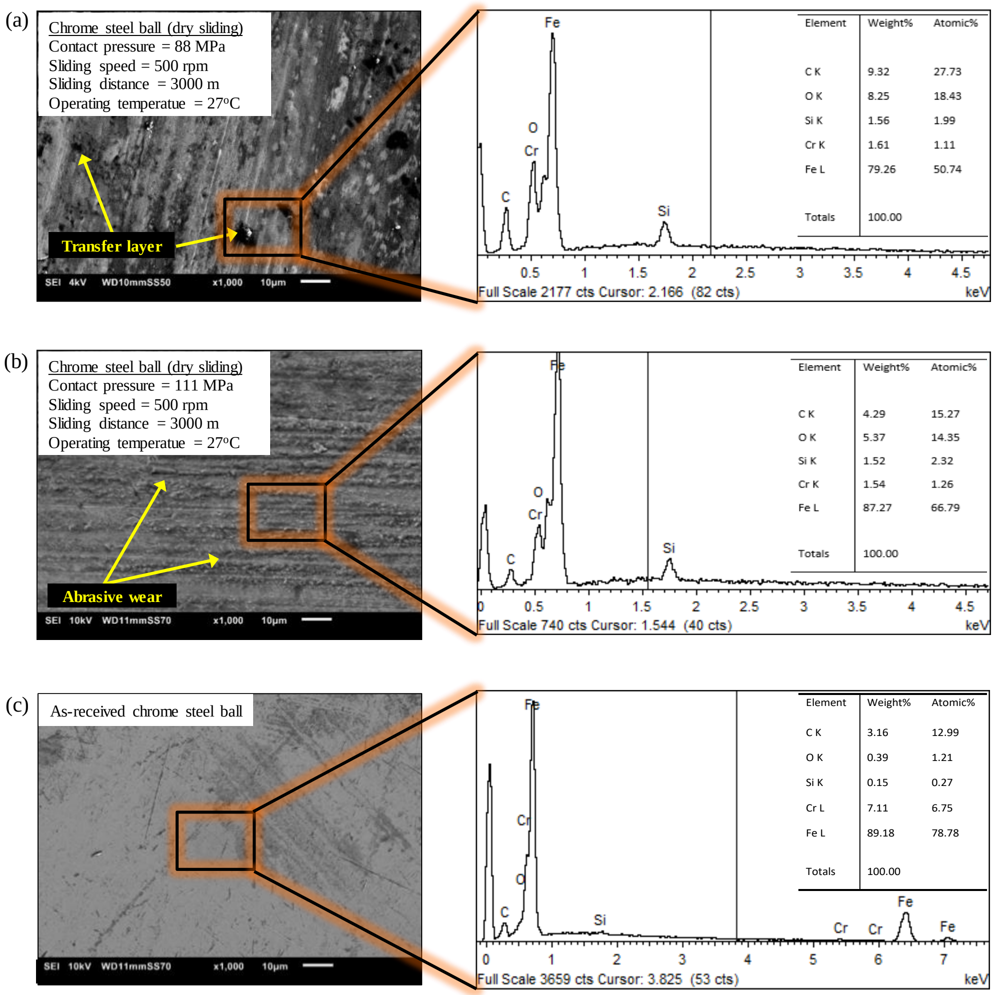

Figure 2 Scanning Electron Microscopy (SEM) micrograph and Energy Dispersive X-Ray (EDX) spectrum of the counter surfaces (a) tested at 88 MPa, (b) 111 MPa and (c) as-received chrome steel ball