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Potential of palm kernel activated carbon epoxy (PKAC-E) composite as solid lubricant: Effect of load on friction and wear properties

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HIGHLIGHTS

- *Wear rate and friction coefficient of PKAC-E composite decreases with applied load.*
- *However, at higher load, friction coefficient increases slightly and remains almost invariant with applied load.*
- *Palm kernel activated carbon epoxy composite (PKAC-E) has a potential to act as a self-lubricating material at low load under unlubricated conditions.*

ABSTRACTS

The aim of this study is to investigate the effect of load on the friction and wear properties of palm kernel activated carbon epoxy (PKAC-E) composite. The PKAC-E composite specimen was fabricated by hot compression molding method. Dry sliding test was performed by using a pin-on-disc tribometer at various load conditions with constant sliding speed and distance. The experimental results show that wear rate and friction coefficient of PKAC-E composite decreases with applied load. However, at higher load, friction coefficient increases slightly and remains almost invariant with applied load. In addition, some adhesive and abrasive wear types were identified on the worn surfaces. The main conclusion of this work is that PKAC-E composite show unique properties as solid lubricant at low load under unlubricated conditions.

Keywords:
| Palm kernel activated carbon | wear | coefficient of friction |

1.0 INTRODUCTION

For a decade, many researchers have investigated different types of solid lubricants as reinforcement or coating materials for tribological applications (Erdemir et al., 2000; Heimberg et al., 2001; Tokoroyama et al., 2006; Liu et al., 2009; Baradeswaran, 2011; Abdollah et al., 2012; Masripan et al., 2013). Recently, the potential of local waste materials as substitute reinforcement in fabrication of lightweight materials, such as metal matrix composites and polymer matrix composites has attracted lots of attentions due to its self-lubricating properties and adopt zero waste strategy at affordable cost (Zamri et al., 2010; Zamri et al., 2011; Aigbodion et al., 2011; Bakry et al., 2013). A few researcher found out that porous carbon also known as activated carbon, such as palm shell activated carbon (PSAC), exhibited its potential to act as a self-lubricating material when reinforced in aluminium alloy, which significantly improved wear resistance by increasing PSAC content up to 10 wt.% (Zamri et al., 2010; Zamri et al., 2011). Gomes et al., 2001 stated in his study of carbon-carbon composites, the friction coefficient is almost independent in sliding speed but highly affected by test temperature. In general, as observed from prior studies, there are a limited number of studies to investigate the potential of activated carbon materials as solid lubricants in polymer matrix composites. Hence, the goal of this paper is to study the effect of applied load on the friction and wear properties of palm kernel activated carbon epoxy (PKAC-E) composite.

2.0 EXPERIMENTAL

2.1 Specimen preparation

In this study, the materials used are palm kernel activated carbon (PKAC), West System 105 Epoxy Resin (105-B) and West System 206 Slow Hardener (206-B). All specimens were fabricated by hot compression molding method. The PKAC particulate was ground into smaller particle and mixed with epoxy resin (E) and hardener at a composition ratio of 70 wt.% PKAC and 30 wt.% E. The compression process was conducted using hot press machine at 80^{o}C and 2.5 MPa of compression pressure. The green specimen was then cured under room temperature for 2 – 3 days. The length and diameter of the specimen was 30 mm and 10 mm, respectively, as shown in Figure 1.

Figure 1 PKAC-E specimen

2.2 Dry sliding test

The dry sliding testing was performed to determine the friction coefficient and wear rate between the contact surfaces using a pin-on-disc tribometer. The testing procedure followed the ASTM standard G99-95a (Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus). All tests were performed at room temperature with a constant sliding speed and distance at 200 rpm and 3770 m, respectively. Prior to the sliding test, pin was ground by sliding against 600grit silicon carbide (SiC) paper at one end. Then, both pin and disc were cleaned using acetone in an ultrasonic bath. As illustrated in Figure 2, The pin was then mounted vertically on the tester arm at one end and the other pin surface was hold against the rotating EN-31 carbon alloy steel disc (hardened to HRC 62; ground to R_a = 0.8μm) with a diameter and thickness of 16.5 mm and 8 mm, respectively. A coefficient of friction and frictional force encounter by the ball in sliding were measured by a PC based data logging system. The coefficient of friction is then being determined as follows:

$$\mu = F/W \tag{1}$$

Where F is the frictional force in N and W is the applied load in N.

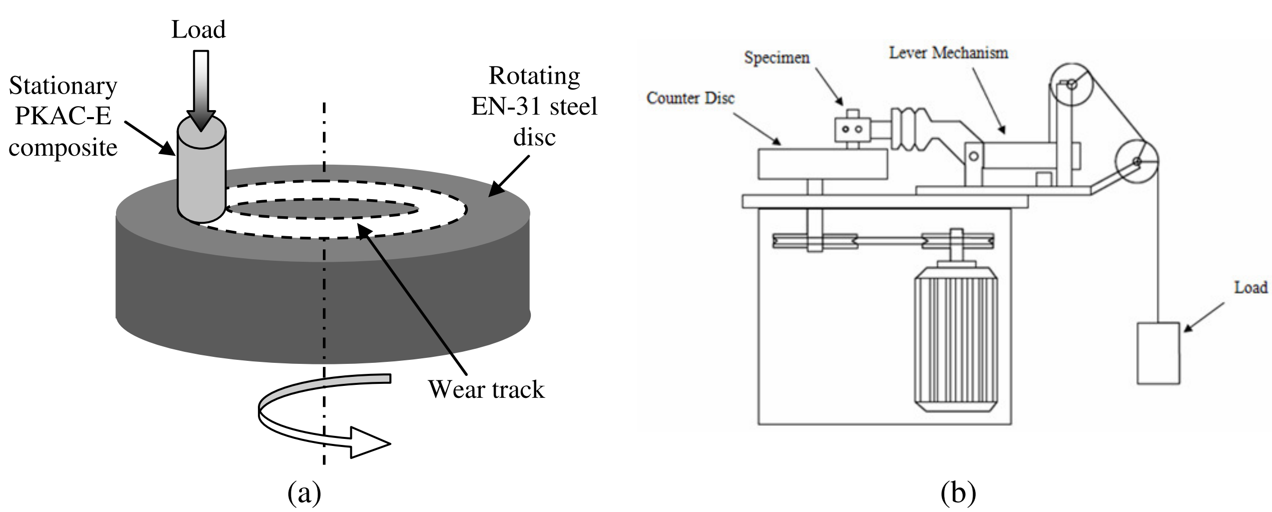

Figure 2 (a) Illustration and (b) schematic diagram of the sliding test using a pin-on-disc tribometer

The wear at the pin was recorded by measuring the mass of the pin before and after the wear test. The mass loss in mass unit is converted to the volume loss by dividing with bulk density of material. The specific wear rate is then being determined as follows:

$$V_{loss} = m_{loss}/\rho \tag{2}$$

$$k = V_{loss} / WL \quad (3)$$

Where V_{loss} is the volume loss in mm^3, m_{loss} is the mass loss in g, ρ is the bulk density of material in g/mm^3, k is the specific wear rate of material in mm^3/Nmm, W is the applied load in N and L is the sliding distance in mm.

The worn surfaces morphology was observed using a digital microscope and profilometer.

3.0 RESULTS AND DISCUSSION

Figure 3 indicates the friction coefficient decreases with the increase of applied load within the observed range though from 60 N, it increases slightly and remains almost invariant with applied load (Figure 4). The frictional heating, which will induce tribofilm formation, is believed to be responsible for the decrease of friction with the increase of applied load. There was a strong dependence of tribofilm formation on temperature (Komvopoulos et al., 2002). The tribofilm generated from the preferential wear of the soft carbon material results in a carbon based tribofilm adhering on the worn surface which breaks the adhesive joints between the asperities and thereafter leads to low friction (Luo, 2013). However, as stated by Bakry et al. 2013, at higher load, the tribofilm was broken and carbon shows a drastic reduction in lubricity; consequently increases friction coefficient.

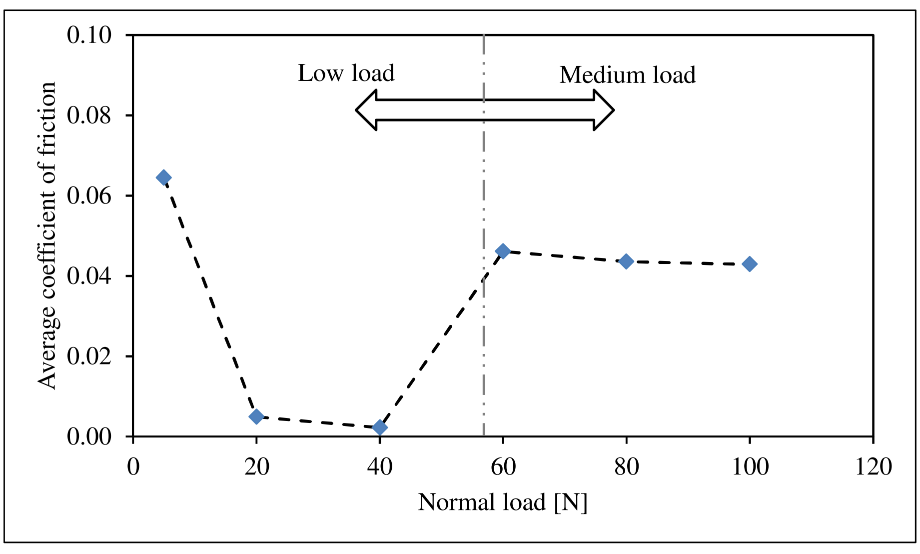

Figure 3 Relationship between applied loads and average friction coefficient of PKAC-E composite

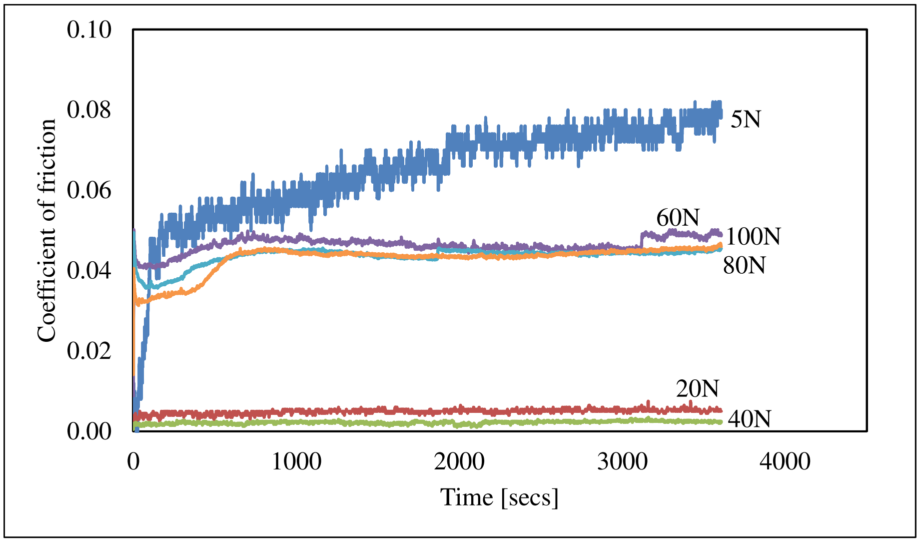

Figure 4 Comparison of friction coefficient as a function of time at different load

As regard to the wear, Table 1 shows the distribution of calculated wear rate with applied load. As shown in Figure 5, the wear rate of PKAC-E composite decreased significantly with applied load. From Figure 6, worn surfaces of the material were characterized by some adhesion wear and abrasive wear. However, at higher load, adhesion wear was slightly reduced with smoother surfaces and show signs of fine scratches. A reduction in adhesion is directly responsible for the reduction in friction and wears (Zhao et al., 2014). These results agree with the calculated wear rate values as in Figure 5. Among the experiments conducted there was no seizure condition noticed.

Table 1 Weight of specimen before and after tribo testing with calculated wear rate

Sample	Load [N]	m_1 [g]	m_2 [g]	m_{loss} [g]	k [mm^3/Nmm]
A	5	3.3483	3.3443	0.0040	0.7800
B	20	3.1647	3.1643	0.0004	0.0780
C	40	3.0090	3.0073	0.0017	0.3315
D	60	3.4947	3.4943	0.0004	0.0780
E	80	3.5783	3.5767	0.0016	0.3120
F	100	3.3530	3.3513	0.0017	0.3315

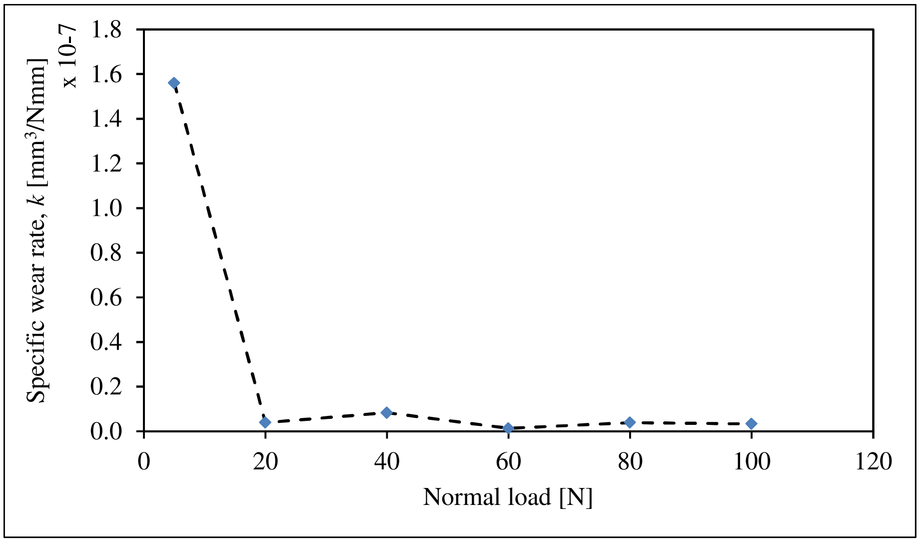

Figure 5 Relationship between applied loads and wear rate of PKAC-E composite

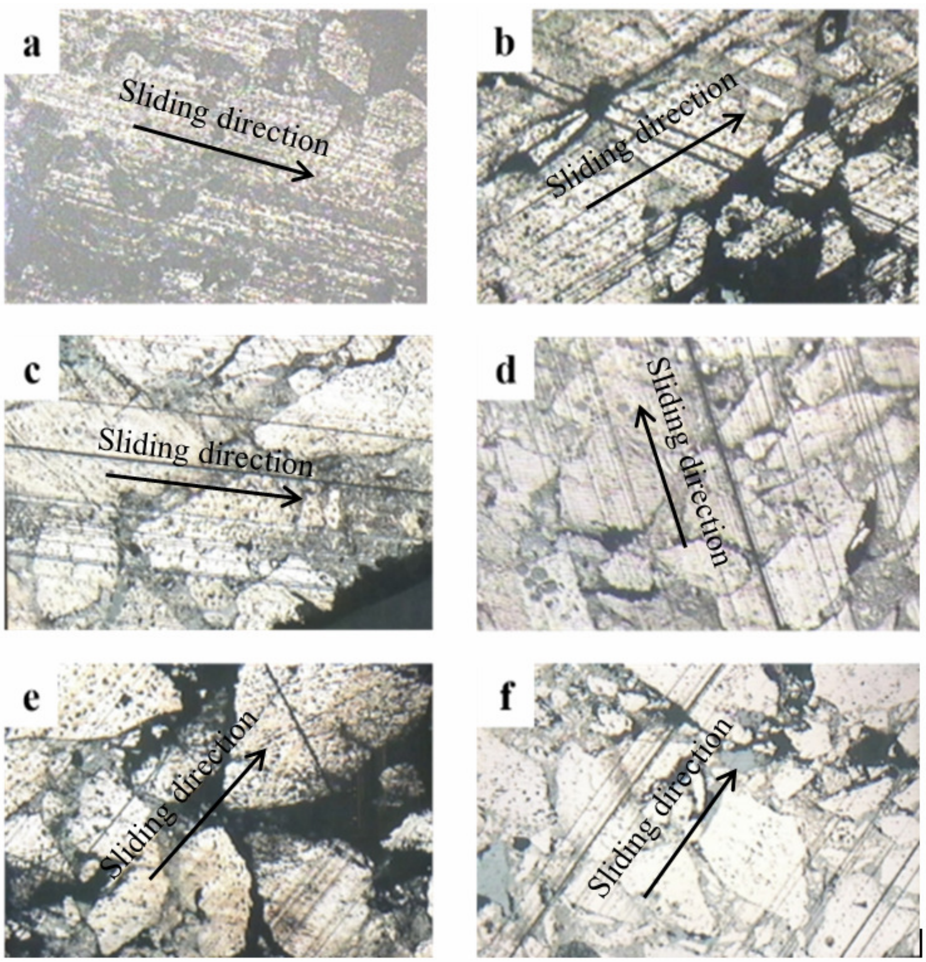

Figure 6 Digital microscope images of worn surfaces of PKAC-E composite testing at (a) 5N, (b) 20N, (c) 40N, (d) 60N, (e) 80N and (f) 100N

CONCLUSIONS

As a conclusion, it was found that the wear rate and friction coefficient of PKAC-E composite was decreasing with the increasing in applied load. However, at higher load, friction coefficient increases slightly and remains almost invariant with applied load. In addition, some adhesive and abrasive wear types were identified on the worn surfaces. From the overall findings, PKAC-E composite show unique properties as solid lubricant at low load under unlubricated conditions.

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