EFFECTS OF PHENOLIC RESIN AND FLY ASH ON COEFFICIENT OF FRICTION OF BRAKE SHOE COMPOSITE

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ABSTRACT

The friction performance of brake shoe composite indicated by coefficient of friction is influenced by braking conditions including contact pressure, sliding speed or temperature. This behavior is influenced by composite formulation. In the present work, we focus to investigate effect of phenolic resin and fly ash with variation in braking condition on coefficient of friction. Particular attentions are paid to changes in coefficient of friction with respect to the variation of contact pressure, sliding speed and disc temperature. Friction wear test was performed using pin on disc machine. The results show that coefficient of friction decreases with increasing volume fraction of phenolic resin and increases as the amount of fly ash is increased. In addition, phenolic resin affects load and speed sensitivity of coefficient of friction. In contrast, fly ash does not affect load and speed sensitivity of coefficient of friction. The coefficient of friction increases as disc temperature is increased from 29^{o}C to 200^{o}C. Phenolic resin does not affect disc temperature sensitivity of coefficient of friction. Conversely, fly ash affects disc temperature sensitivity of coefficient of friction.

Keywords: phenolic resin, fly ash, brake shoe composite, braking conditions, sensitivity of coefficient of friction.

INTRODUCTION

The function of a brake system is to decelerate or stop vehicle speed. Friction brake works by transforming kinetic energy into thermal energy. When a brake shoe or pad presses against rotor (drum, disc or wheel tread), brakes will convert kinetic energy of vehicle into thermal energy by friction, and then dissipate heat to the surrounding. Temperature of brake shoe and rotor rises during braking. This condition can affect brake shoe performance.

The material characteristics of a brake shoe have effect on its braking ability. The important characteristic of brake shoe material is indicated by its high value of coefficient of friction. The magnitude of coefficient of friction should fulfill a requirement and be stable at a wide range of variation of braking conditions. Materials used on brake shoe must be able to stop the vehicle smooth and quiet. To fulfill several brake performances, composites are widely used as brake shoe material for automotive application. In train brake system, composite brake shoes with relatively low coefficient of friction also have replaced cast iron brake shoe.

Characteristics of a brake shoe composite are affected by braking conditions such as braking pressure, sliding speed and temperature. Many papers have reported ingredient and braking condition effects on friction composite characteristics. The results show that coefficient of friction of brake shoe composites decrease with increasing braking pressure [1, 2]. However, change in trend of coefficient of friction due to increasing of sliding speed is affected by composite formulation. Yi and Fan [2] reported that the coefficient of friction of phenolic resin composites without friction modifier decreased with increasing sliding speed. But, after incorporation with inorganic particulate of friction modifier, the composites showed that the coefficient of friction increased with increasing sliding speed. Gopal *et al*. [3] showed that coefficient of friction of a glass fiber reinforced friction material dropped considerably with higher speeds. Meanwhile, a carbon fiber reinforced friction material decreased slightly at high speed. Other result showed that the coefficient of friction decreased as sliding speed was increased for composite with steel fiber reinforcement [4].

Phenolic resin is the most common composite component used as a binder or matrix in the formulation of friction brake composite. It holds all of ingredients so that a brake shoe composite is able to withstand mechanical and thermal loading. Phenolic resin affects coefficient of friction of brake shoe composite. The coefficient of friction increases with increasing amount of phenolic resin [5]. However, other opposite result showed that the coefficient of friction decreased with increasing amount of phenolic resin [6]. The characteristics of phenolic resin are affected by temperature so that this behavior gives impact on friction composite performance. Storage modulus of phenolic resin decreases with increasing composite temperature [7, 8]. When brake shoe composites are used above 300^{o}C, they will markedly drop in coefficient of friction due to phenolic resin decomposition [8, 9].

Abrasive materials are incorporated to brake shoe composite in order to enhance coefficient of friction and to clean of mating surfaces. A few examples of abrasive material that are used in brake shoe composite are aluminum oxide, iron oxide and zirconium silicate. Fly ashes contain substantial amounts such as silica, alumina and iron oxide so that it also can be used as abrasive material in brake shoe composite. Fly ashes are industrial wastes that have been developed as fillers materials for brake shoe composite [10-13]. Dadkar *el al*. [13] reported that mechanical properties of friction composite increased with increasing fly ash content and coefficient of friction did not change significantly with increasing fly ash from 55% to 70%. The effect of abrasive materials on coefficient of friction of brake shoe composite is affected by their size [14].

Brake shoe composites consist of many ingredients. Each ingredient in composite has a different function and effect on composite characteristics. In friction composite, phenolic resin plays a key role as binder and it has effect on friction characteristics. Meanwhile, in friction composite, fly ash can be used as abrasive materials due to its contents. Previous papers have reported effect of phenolic resin [5, 6, 15-17] and fly ash [10-13] on friction composite performances. However, those papers did not examine the effect of phenolic resin and fly ash toward contact pressure and sliding speed on friction characteristics. A lot of papers have reported that braking conditions affect friction performance of brake shoe composites. Therefore, in this study, we focused to investigate the effect of phenolic resin and fly ash with variations of braking conditions on coefficient of friction. We investigated the changing of coefficient of friction toward the variations of contact pressure, sliding speed and disc temperature.

MATERIALS AND METHODS

In this work, a straight novolac of phenolic resin was used as a binder. The composition of brake shoe composite and its specimen designation are shown in Table-1. Materials used in this paper i.e. cast iron chip and fly ash were industrial wastes. Cast iron chip with a particle size of 60 mesh and fly ash with a particle size of 100 mesh were obtained from ferro casting industries and power plant, respectively.

A sequence of composite specimen preparation was carried out as follows: dry formulation, dry mixing, pre-forming, hot pressing and heat treatment. An analytical balance was used to weigh the ingredients. These ingredients were mixed using a commercial blender and then a specific amount of the mixture was loaded into a cavity mold to fabricate friction composite specimens. Pre-forming was done by pressing the mixture under pressure of 40 MPa. Pre-formed specimens were placed in the hot mold and then pressed under pressure of 40 MPa at 150-165^{o}C for 8 minutes. In the beginning of hot pressing, five intermittent pressing was allowed to release the gases that evolved from the cross linking reaction of the phenolic resin. Hot pressed specimens were then heated in oven at 120 ^{o}C for 1 hour, 150 ^{o}C for 1 hour, and 180 ^{o}C for 8 hour. Friction composite specimens had cylindrical shape with diameter of 10 mm and length of 22 mm. In this experiment, we produced three specimens for each variation of composite formulation.

Friction wear testing was performed using pin on disc machine as shown in Figure-1. In the present study, a specimen or pin with flat end surface (diameter of 10 mm) was mounted on specimen holder and pressed against the surface of rotating disc. Material used for the disc was a DIN X 153 CrMoV 12 steel. The disc was heat treated and its hardness of 54 R_C. It ground to a roughness level 0.43 - 1.37 µm. An electric resistance heater was mounted underneath the disc for varying disc temperature. Disc temperature was controlled by digital temperature controller and infrared thermometer that was integrated with an electric resistance heater. Friction test was performed using test parameters as shown in Table-2. The friction tests were performed to measure an average of coefficient of friction. The normal force used was measured before wear testing began. Meanwhile, the friction force was measured directly using a load cell that mounted on the machine for 200 second when wear testing was performed. The average of coefficient of friction was calculated using friction and normal force data. Two time observations of wear testing were performed for each specimen.

Table-1. Composition (in % volume) and specimen designation.

Ingredients	Variation of phenolic resin amount			Variation of fly ash amount	
	20% R*	30% PR	40% PR	5% FA	10% FA
NBR rubber, cashew dust, graphite, glass fiber, cast iron chip	49	49	49	49	49
Phenolic resin	20	30	40	20	20
Fly ash	0	0	0	5	10
Barite	31	21	11	26	21

*The formulation of 20% PR also was used for variation of fly ash amount with 0% volumeof fly ash (0% FA).

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Table-2. Parameters of friction wear test used in this study.

Parameters	Variation of contact pressure			Variation of sliding speed			Variation of disc temperature		
	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Contact pressure (MPa)	1	1.75	2.5	1	1	1	1	1	1
Sliding speed (m/s)	5	5	5	5	10	15	5; 10; 15	5; 10; 15	5; 10; 15
Disc temperature (^oC)	29	29	29	29	29	29	29	100	200

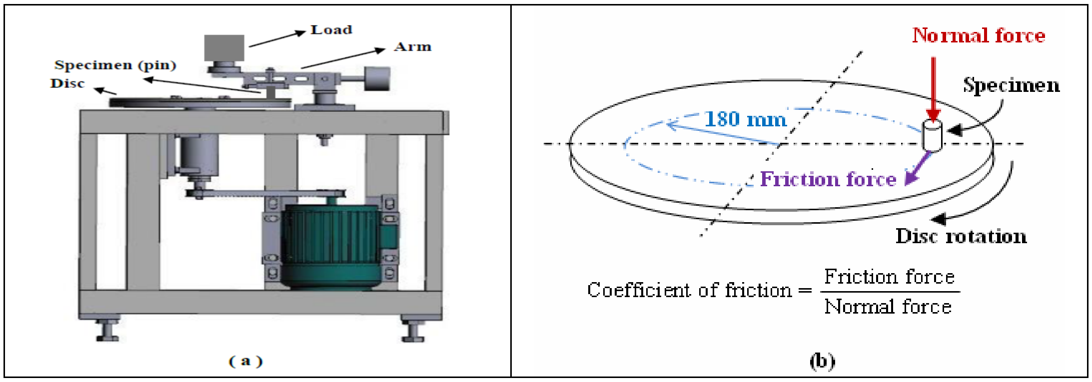

Figure-1. Test set up of friction wear testing: (a) schematic of pin on disc machine, (b) the friction force acts on contact surface.

RESULTS AND DISCUSSIONS

A. Effect of phenolic resin and fly ash on coefficient of friction toward variation of contact pressure

Figure-2 shows an example of coefficient of friction data for wear testing in which the sliding speed and contact pressure were held constant. The coefficient of friction fluctuation in Figure-2 is related to stick-slip phenomenon [4, 18, 19]. Six data of average of coefficient of friction for each variation of parameter wear testing were obtained by testing on 3 specimens for each composite formulation and 2 observations for each specimen. They were calculated to get average of coefficient of friction for each variation of parameter wear testing. Then, the average of coefficient of friction was plotted in Figure in order to show the relationship among parameter wear testing, amount of phenolic resin or fly ash, and coefficient of friction.

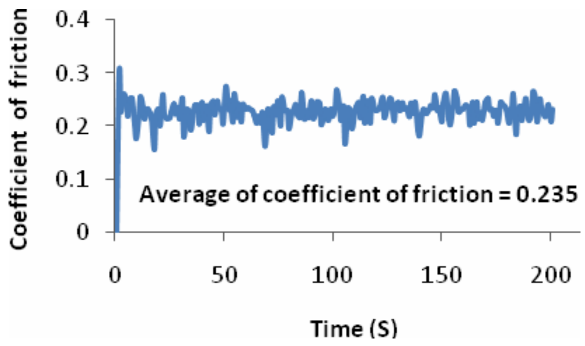

Figure-2. An example of coefficient of friction record shows the average of coefficient of friction with sliding speed 15 m/s and contact pressure 1 MPa (for specimen of composite 30% PR).

Figure-3a shows the relationship between coefficient of friction and contact pressure for variation of phenolic resin percentage. The result indicates that coefficient of friction decreases with increasing phenolic resin content for all contact pressure variation. This behavior is attributed to the fact that increasing volume fraction of phenolic resin was compensated by reducing the amount of barite. Barite is mineral which has Mohs scale hardness of 3-3.5 [20]. It can contribute in increasing coefficient of friction [21] through an abrasive action against the counter disk.

Figure-3(a) also shows that phenolic resin has effect on load sensitivity of coefficient of friction. Variation in coefficient of friction as a function of contact

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pressure or sliding speed is referred load or speed sensitivity of coefficient of friction [22] and indicated by the slope of a line. Coefficient of friction slight decreases as contact pressure is increased for 20% PR. Meanwhile, for 30% PR and 40% PR, coefficient of friction is relatively stable toward the changing of contact pressure. This behavior is closely related to the function of phenolic resin in composite which maintains structural integrity of composite under mechanical load. Phenolic resin is most common used as a binder or matrix in the formulation of friction brake composite. Ingredients in composite are more strongly held in composite when phenolic resin amount increases. Compressive and tensile strength of composite increase as phenolic resin content is increased [6, 15]. Therefore, the load that caused composite fracture at sliding surface increases with increasing phenolic resin amount. For 20% PR, phenolic resin does not provide reasonable strength to hold hard particles on composite surface at higher contact pressure. Friction at higher contact pressure causes mechanically overloaded on composite surface. This condition leads to fracture hard particle on the friction surface so that it can reduce the magnitude of coefficient of friction [23]. Meanwhile, hard particles in composite 30% PR and 40% PR are more strongly held than in composite 20% PR so that composite 30% PR and 40% can maintain magnitude coefficient of friction.

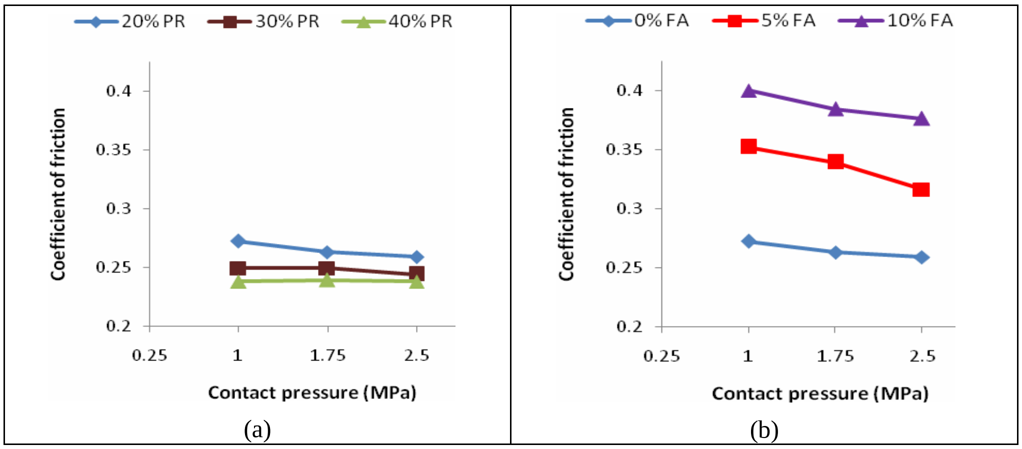

Figure-3. Effect of: (a) phenolic resin, and (b) fly ash on coefficient of friction toward variation of contact pressure (with sliding speed 5 m/s).

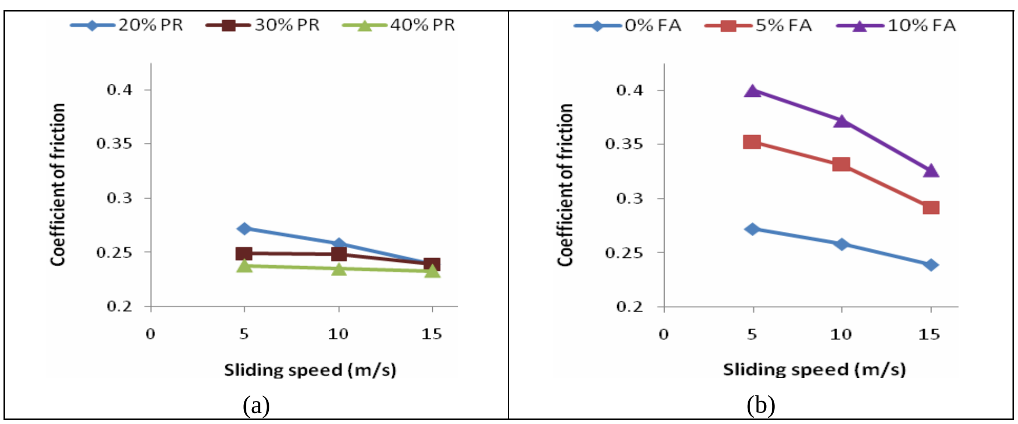

Figure-4. Effect of: (a) phenolic resin, and (b) fly ash on coefficient of friction toward variation of sliding speed (with contact pressure 1 MPa).

Figure-3(b) shows the relationship between coefficient of friction and contact pressure for variation of fly ash percentage. The result shows that coefficient of friction increases with increasing volume fraction of fly ash for all contact pressure variation. This behavior was attributed to the fact that F-class of fly ashes contains substantial amounts of abrasive material such as silica and alumina. Therefore, fly ashes enhance coefficient of friction via abrasive action against the counter disc. Moreover, due to shear stress at sliding interface, fly ash in composite is loose from composite surface and then generates wear debris to form friction layer in contact zone [11, 13, 24, 25]. Wear debris of fly ash in contact zone also act as enhancing abrasive action via third body abrasion mechanism [11, 13]. This mechanism also contributes on an increase of coefficient of friction [11].

Figure-3b also indicates the load sensitivity of coefficient of friction with variation of fly ash amount. All variation fly ash amount show the same trend i.e. coefficient of friction decrease with increasing contact pressure. This result indicates that the load sensitivity of coefficient of friction is not affected by fly ash.

B. Effect of phenolic resin and fly ash on coefficient of friction toward variation of sliding speed

Figure-4(a) shows the relationship between coefficient of friction and sliding speed for variation of phenolic resin amount. The result indicates that coefficient of friction decreases with increasing phenolic resin content for all sliding speed variation. This result also indicates that phenolic resin has effect on speed sensitivity of coefficient of friction. Speed sensitivity of composite decreases with increasing phenolic resin percentage. Composite 20% PR has highest speed sensitivity. Coefficient of friction significant decreases with increasing sliding speed for composite 20% PR, while coefficient of friction relatively stable with increasing sliding speed for composite 30% PR and 40% PR. The phenomenon of decreasing coefficient of friction with increasing sliding speed is related to reducing of shear strength of composite material in contact surface and the formation of oxides which have lubricating characteristic at sliding interface [1]. Friction between composite material and disc generates heat that causes enhancing temperature at sliding interface. Temperature at sliding interface increases with increasing sliding speed. Furthermore, increasing temperature at sliding interface has effect on decreasing shear strength in composite surface. Other reason states that the phenomenon occurs due to the ejection of wear debris at high sliding speed [19]. During friction sliding, ingredients are loose from surface of composite due to shear stress on sliding interface and forms wear debris. In next stage, due to combination of contact pressure and friction heat, wear debris that pile up around the primary plateau is able to form new plateau and it is called secondary plateau [26]. At high sliding speed, the ejection of wear debris causes interrupted formation of secondary plateau [19].

Figure-4b shows the change in coefficient of friction with selected speed and variation of fly ash amount. The result indicates that coefficient of friction increases with increasing fly ash amount for all sliding speed variation. All variation fly ash amount show the same trend i.e. coefficient of friction decrease with increasing sliding speed. This result also shows that fly ash does not affect speed sensitivity of coefficient of friction.

C. Effect of phenolic resin and fly ash on coefficient of friction toward variation of disc temperature

Figure-5 (a, b, and c) shows effect of disc temperature, sliding speed and volume fraction of phenolic resin on coefficient of friction. It indicates that the coefficient of friction increases with increasing disc temperature. This phenomenon is attributed to the fact that real contact area at interface increases with increasing disc temperature [7]. Storage modulus of phenolic resin decreases as composite temperature is increased [7, 8]. This characteristic causes an increase in area of contact plateaus and the matrix tends to absorb more energy during sliding [7]. However, other articles have reported that friction composite will drastically drop in coefficient of friction when temperature increases over 300^{o}C [8, 17]. Figure-5 shows that phenolic resin do not affect the trend of increasing of coefficient of friction toward disc temperature. However, the result shows that for 15 m/s of sliding speed, the coefficient of friction slight increases when disc temperature increases from 100^{o}C to 200^{o}C. This phenomenon may be due to the fact that combination of high disc temperature and high sliding speed reduce shear strength of composite surface.

Figure-5 (e, f, and g) shows effect of disc temperature, sliding speed and volume fraction of fly ash on coefficient of friction. Similar to variation of phenolic resin percentage, it also indicates that the coefficient of friction of increases with increasing disc temperature. However, there is different trend between composite with and without fly ash. At 5 m/s, coefficient of friction of 10% FA specimen do not increase significantly as the disc temperature increases from 100^{o}C to 200^{o}C. At 10 m/s, coefficient of friction of 10% FA and 5% FA specimen do not increase significantly as the disc temperature increases from 100^{o}C to 200^{o}C. At 5 m/s and 10 m/s, composite 0% FA still increases significantly in coefficient of friction as the disc temperature increase from 100^{o}C to 200^{o}C. Those indicate that fly ash affects disc temperature sensitivity of coefficient of friction. This phenomenon may be due to the fact that addition of fly ash in composite causes a decrease in shear strength of composite interface at high temperature.

CONCLUSIONS

Effects of phenolic resin and fly ash on coefficient of friction of brake shoe composite have been studied with conclusions are as follows:

a) The coefficient of friction decreases with increasing volume fraction of phenolic resin. Phenolic resin affects load and speed sensitivity of coefficient of friction.
b) The coefficient of friction increases as the amount of fly ash is increased. Fly ash does not affect load and speed sensitivity of coefficient of friction.
c) The coefficient of friction increases as disc temperature is increased from 29^{o}C to 200^{o}C. Phenolic resin does not affect disc temperature sensitivity of coefficient of friction. Conversely, fly ash affects disc temperature sensitivity of coefficient of friction.

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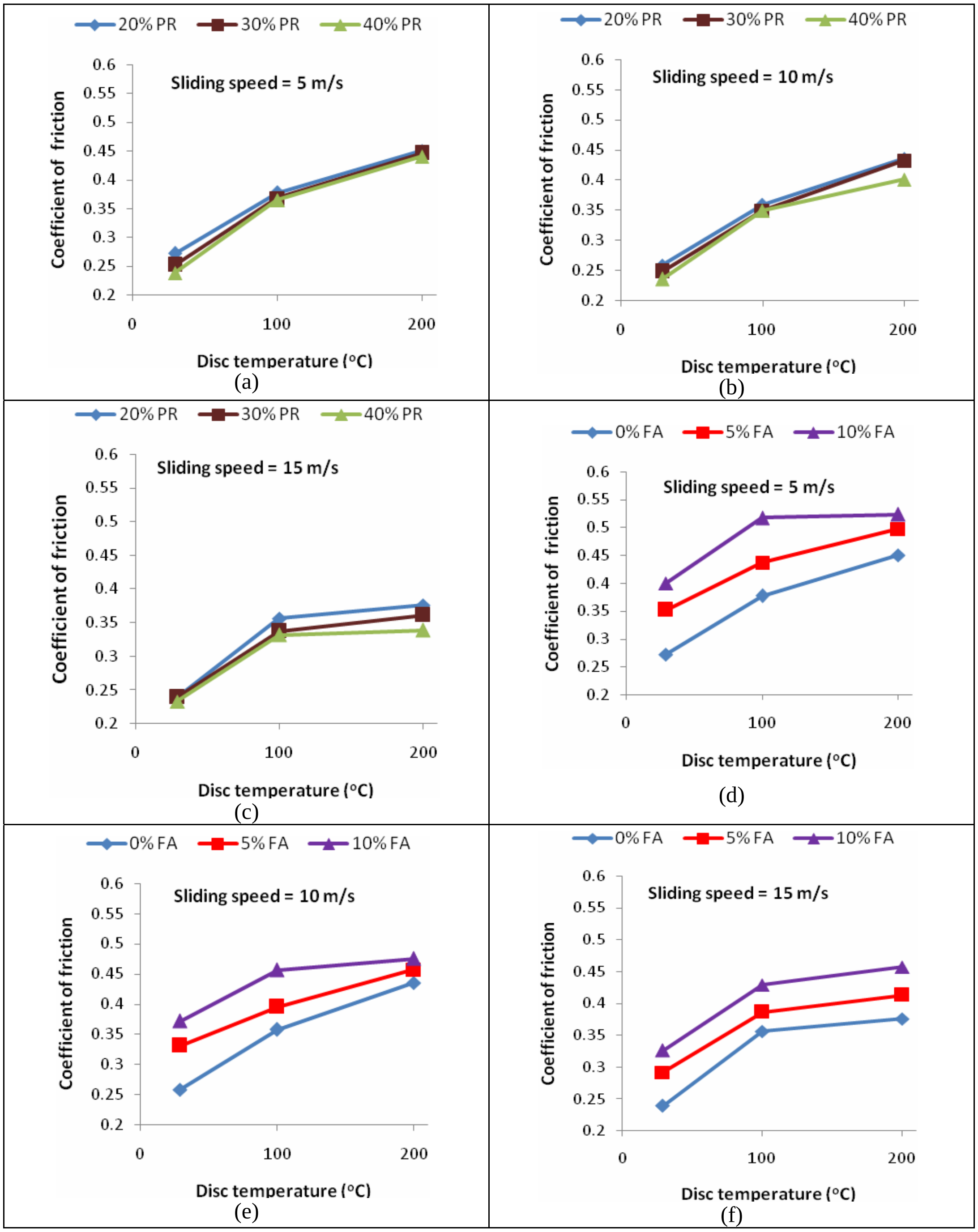

Figure-5. Effect of phenolic resin (a, b, and c) and fly ash (d, e, and f) for 1 MPa of contact pressure on coefficient of friction toward variation of disc temperature and sliding speed.

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