The effect of barite addition and graphite particle size on the specific abrasion of fly-ash/phenolic composite for brake lining application

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Abstract

Annually, million tons of fly-ash and bottom fly-ash is a waste of coal power plant. Fly ash contains Iron-oxide, alumina and silica. Those hard particle makes fly-ash can be used as a reinforcement in polymer composite. This composite is a wear resistance material and can be used as material for brake lining application. Fly ash reinforced phenolic composite has a low specific abrasion. The composite for brake lining material consisted of the reinforcement, friction modifier, solid lubricant and filler. Graphite is used as solid lubricant while barite is used as filler. Many research were carried out research on the particle size effect on the composite mechanical properties. However the size different between the constituent in composite has not investigated. Also the optimal barite weight fraction has not being observed. The composite was made by mixing all of the constituent, pressing in the mold and curing. The result show that the graphite particle size $\leq$ 150 μm has the lowest specific abrasion. The observation using scanning electron microscope shows that the composite contained small particle of $\leq$ 56 μm tends to agglomerate than the composite contained larger particle of $\leq$ 150 μm. the composite contained 15% barite has the lowest specific abrasion. The micrograph of scanning electron microscope shows the mixed of phenolic and barite evenly covered the graphite and fly-ash particles.

Keywords: *barite, graphite, fly-ash, composite polymer, brake lining.*

I. INTRODUCTION

IN year 2021, coal mine in Indonesia produced 294,252,801.68 tons of coal [1]. In April 2021, the Indonesia Government stated that the domestic market obligation (DMO) of coal was 113 million tons. If 6% of that coal produced fly ash and bottom ash (FABA), it would result in FABA waste of 6-11 million tons [2]. The power plant produces a lot of amount of fly-ash every year. Fly-ash mostly contains Fe_2O_3, Al_2O_3 and SiO_2 [3]. Fly-ash is used as material addition in Portland cement, structure filler, coagulant, waste stabilization, primary road material, mine reclamation, etc. Based on that, research interest in fly-ash such as on geo polymer, paint, metal casting, and as a filler in the composite. Fly-ash was used as a filler in the composite for brake lining materials. The material for composite reinforcement is made of metal, ceramic, glass, and mineral [4-5]. Brake lining material has a constituent that consists of reinforcement, friction modifier, solid lubricant, abrasive material, binder, and filler [6-7]. Fly-ash reinforced phenolic composite has the potential to be used as reinforcement in brake lining material [8]. Composite with 30 wt% of fly-ash has a low specific abrasion. Therefore, fly-ash can be used as reinforcement with the addition of other materials [4]. Reinforcement of Two percent of glass fiber in composite increased the compressive and impact strength of composite [9]. However, the tensile strength of the composite decreased with the addition of fly-ash. [10].

Graphite is used as a friction modifier or solid lubricant. Graphite can increase friction [11]. Lubricant forms a layer between two surfaces. This layer decreases the excessive wear. The lubrication ability of solid lubricant is affected by the temperature, pressure, speed, and environment of the machine or vehicle [12]. The addition of Sb2S3 in solid lubricant increased the lubrication stability [13]. In addition, Nitrile Butadiene Rubber (NBR) was added to enhance the adhesion between materials in composite [8]. The graphite shape affected the performance of brake lining.

During braking, the brake material containing long shape graphite has lower heat and sound than the flake graphite [14]. However, the graphite size effect on the wear resistance of composite has not been investigated yet. Two kind of powders are hardly mixed if the size of those two powders is significantly differ. In author's previous work, fly-ash do not mix well with graphite in phenolic matrix due to a significant difference in particle size between fly-ash and graphite particles [15].

Flake graphite has high thermal conductivity, low weight, and low cost. In that study, the diameter of graphite particles was 20, 60, 100, and 150 μm. The larger the particle size, the higher the thermal conductivity [16]. Another work investigated the synthetic graphite T150-600 and C-Therm 011. The synthetic graphite, T150-600, with a particle size of 75 μm, gives a higher plane thermal conductivity, while synthetic graphite C-Therm 011 offers the best result in noise vibration and heat dissipation [17].

Abrasive materials are alumina, carbon black, silicon carbide, zircon, quartz, and magnesia [18-19]. The size and shape of the abrasive particle affected the friction modifier performance. Big and rough zircon particles showed high friction stability. However, these zircon particles caused excessive wear on the brake disc. In reverse, small zircon particles show a lower friction coefficient [13]. Silicon carbide (SiC) also has high friction coefficient. However, SiC causes noise and vibration during braking and excessive wear of brake discs. Magnesia has low fracture toughness, easily breaking into small particles and resulting in a low friction coefficient [20].

Phenolic has high strength and temperature resistance and is compatible with other materials. Therefore, phenolic is used as a binder in the composite [11, 13, 21].

The organic material such as cashew dust and rubber and inorganic material such as barium sulfate (barite), mica, vermiculite, and calcium carbonate are used as filler components in the composite. The purpose is to replace the expensive material in composite and improve the manufacturability of brake lining [22-23]. Most filler in the composite for brake lining material used barium sulfate or barite as a filler. Research on the Barite effect on the coefficient of friction (COF) of phenolic/alumina brake lining material shows that the brake lining containing 20% of barite has a higher COF than the one containing 40% barite. Barite stable at high-temperature, low cost, has a good tribological properties and a high density. As the barite ratio increase, wear rate and coefficient of friction decrease [24].

The previous works show the effect of fly-ash and graphite addition on composite wear resistance. The optimal graphite addition is found [8, 15]. However the particle size difference between fly-ash and graphite has not been studied. The optimal barite in composite also has not been investigated yet.

This research investigates the effect of barite addition and graphite particle size on the wear resistance of fly-ash/phenolic composite. The Ogoshi method is used to measure the specific abrasion of the composite. The adhesion between constituent and the morphology of composite surface is observed using SEM.

II. Materials and Methods

The constituents of the composite were phenolic, fly-ash, barite, and graphite. Phenolic is a commercial phenolic. Phenolic has a density of 1.3-1.4 g/cc, a tensile strength of 34-62 MPa, a tensile modulus of 0.6-1.2 MPa, and a maximum operating temperature of 149-204 °C. Fly-ash has a density of 2.0-2.5 g/cc and a melting temperature of 1300 °C [15]. Fly-ash particle size passed 100-mesh sieve. Graphite has a density of 1.7-1.85 g/cc and compression strength of 25-70 MPa. Barite has a 4.5 gr/cc density and a melting temperature of 1345 °C.

The preparation of the composite is as follows: firstly, the ingredients were weighted before mixed according to each composition, then the mixture was pressed with the pressure of 60 MPa for 15 minutes. Finally, the specimens were cured at 150 °C for 4 hours.

The composites were made with different particle sizes to study the effect of graphite size. Graphite with a particle size of ≤56 μm, ≤100 μm, and ≤150 μm were designated PG56, PG100, and PG150, respectively. The composite ingredient was 60% phenolic, 10% barite, and 30% mixed fly-ash and graphite. The composites were made with a difference of mass fraction to study the effect of barite addition on composite, the barite addition was varied as listed in table 1. These composites were designated as Cb5, Cb10, and Cb15, respectively.

The wear resistance of the composite was characterized using Ogoshi high-speed universal wear testing machine type OAT-U with contacting pressure of 30-400 kg/cm2, abrading speed of 0.052-3.52 m/s, maximum load of 20 Kg, and abrading length of 67-600m. The testing parameters was the same as the previous work [8, 15]. The ring thickness of 3 mm, ring diameter of 30 mm, load of 3.16 Kg, a distance of 100 m, and abrasion speed of 1.97 m/s. In addition, the surface morphology and failure mechanism were observed using SEM.

III. Results and Discussions

A. The graphite particle size effect

In Figure 1, the specific abrasion decreased as graphite particle size increased within the range of graphite size being studied. The PG150 composite has the lowest specific abrasion. It indicated that the PG150 composite has higher wear resistance than PG56 and PG100 composites. The large particles tend to act as a flaw in the polymer matrix. In reverse, small particles tend to agglomerate and stick together.

Work by Duxin Li [16] also shows that the small particles tended to agglomerate; hence more than one interface is formed. High composite porosity was obtained when the ratio of small and large particles was high**.** In previous work, the size of graphite and fly-ash was significantly different [16]. Graphite particles were much bigger than fly-ash particles. In this work, fly-ash particles were averagely ≤100 μm. Hence the size of graphite and fly-ash particles was not significantly difference.

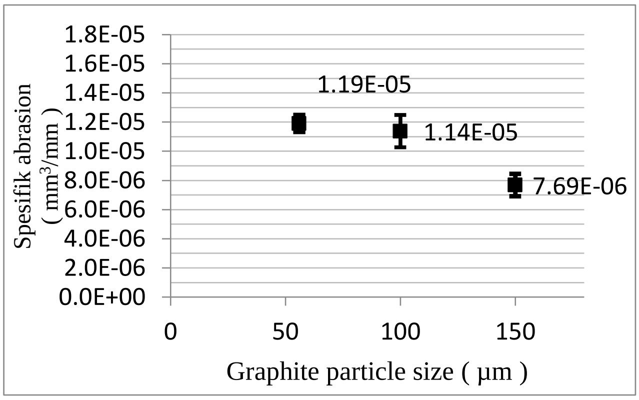

Figure 1. Specific abrasion of fly-ash/phenolic composite with different graphite particle size.

Fig. 2 shows the SEM micrograph of the composite surface with abrasion trace. The SEM micrograph of Pg56 composite (Fig. 2(a)) shows a rougher surface than the Pg150 composite (Fig. 2(b)). The surface of the Pg56 (Fig. 2(c)) composite shows many fly-ash and graphite particles were pulled out from the matrix and more agglomeration of fly-ash and graphite particles. In Pg150 composite surface (Fig. 2(d)), most of the graphite and fly-ash particles are located below the surface. It indicated that the fly-ash was well covered by the phenolic matrix, and the fly-ash distributes more evenly than the one in PG56.

It shows that the small particles, PG56, tends to agglomerate. In Figure 2(e) graphite has a light color and has flake shape. Figure 2(f) show the fly-ash and graphite particle of the same size. Figures 2(g) and (h) show half of fly-ash and graphite particles uncovered with the phenolic matrix. Figure 2(h) shows a good adhesion between graphite particles and phenolic matrix. While Figure 2(i) and (j) show a sufficient adhesion between fly-ash particles and phenolic matrix.

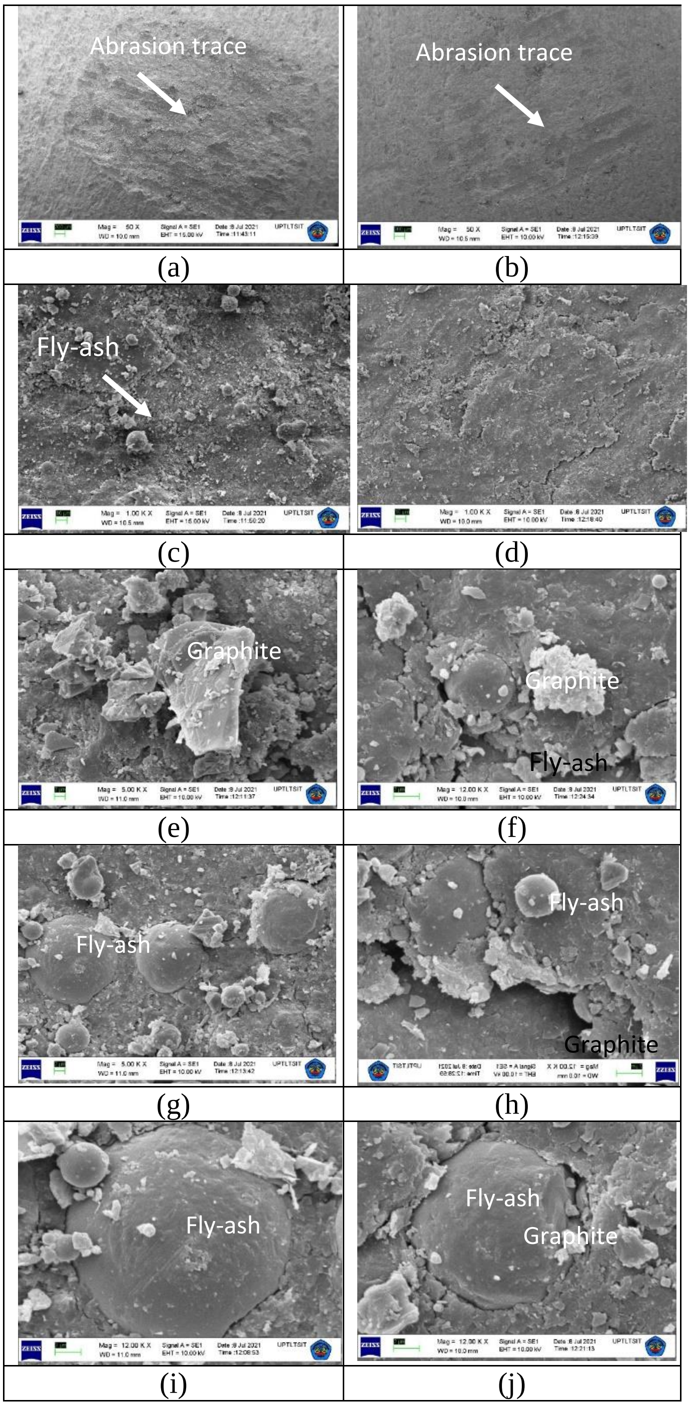

Figure 2. The SEM micrograph of fly-ash/phenolic composite contained graphite: on left side i.e. (a), (c), (e), and (g) are the composite with graphite particle size of < 56 μm, on right side i.e. (b) (d), (f), and (h) are composite with graphite particle size of < 150 μm.

B. The barite weight fraction effect

Figure 3 shows the specific abrasion of fly-ash/phenolic composite decreases as the percentage of barite increases. The composite contained 15% of barite has the lowest specific abrasion.

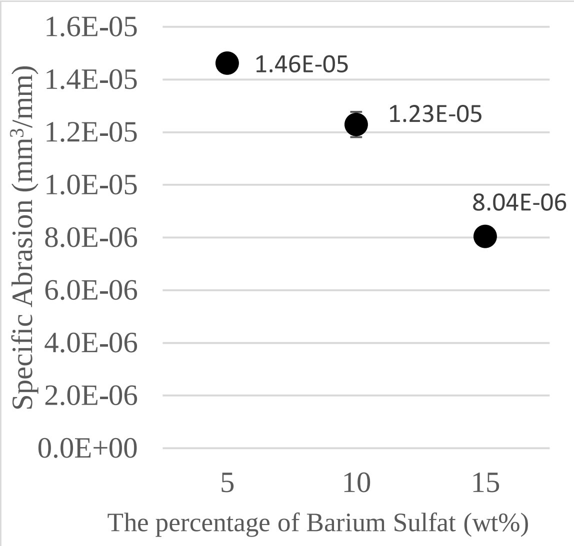

Figure 3. Specific abrasion of fly-ash/phenolic composite with difference barite addition.

Figure 4 The SEM micrograph of fly-ash/phenolic composite contained different Barite percentage: on left side i.e. (a), (c), (e), and (g) are the composite with 5% barite, on right side i.e. (b) (d), (f), and (h) are composites with 15% barite. Figure 4 shows the observation of the composite surface after the abrasion test. The abrasion trace of Pb5 composite (Fig. 4(a)) are rougher than the one of Pb15 composites surface (Fig. 4(b)). Composite contained 15% barite (Fig. 4(d)) has more fly-ash and graphite particles located below the surface than the composite of 5% barite (Figure 4(c).

The composite of fly ash particles is covered by the phenolic matrix more evenly than composite with 5% barite. The Pb15 composite show better adhesion between fly-ash and phenolic matrix since the Pb15 composite (Fig. 4(e) and (g)) contained a higher barite percentage than the PB5 composite (Fig. 4(f) and (h)). Fly-ash and graphite particles were well covered by the mixture of phenolic matrix and barite. It suggests that adding barite into the phenolic matrix increases the wetting ability of the matrix. Work by Banu did a wear test on phenolic composite with 20, 30, and 40 gr of barite [24].

Composite with 20 gr of barite has the lowest specific wear rate of 0.348E-6 cm^3/Nm. The SEM micrograph shows that barite has a spherical shape and micrometric size. Braking generates a thermomechanical distortion due to thermal gradient (Amira, 2014). Poor interface adhesion between particle and matrix lead to stress concentration and creates barriers for stress transfer from matrix to particles. Work by (Benin et al., 2021) shows that CFRP with 10% barite has higher tensile strength, impact strength, hardness, and compressive strength than CFRP without barite. However, flexural strength was reduced steadily with addition of barite.

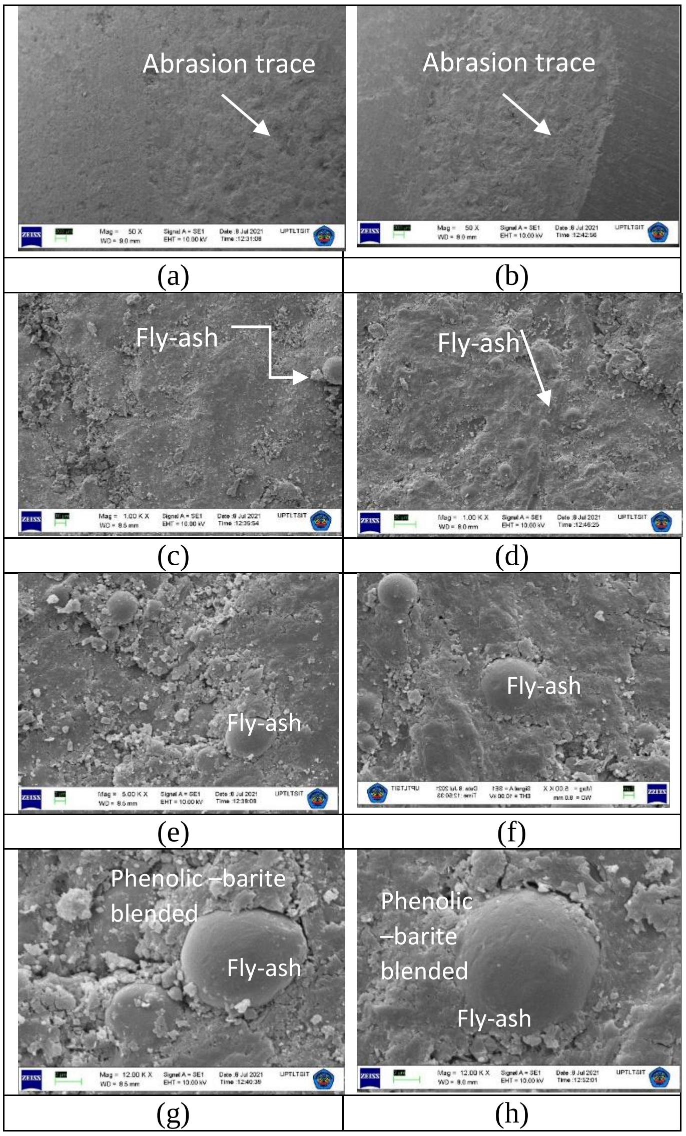

Figure 4. The SEM micrograph of fly-ash/phenolic composite contained different Barite percentage: on left side i.e. (a), (c), (e), and (g) are the composite with 5% barite, on right side i.e. (b) (d), (f), and (h) are composites with 15% barite.

IV. Conclusions

Fly-ash/phenolic composite was prepared with the different size of graphite particles and different weight percentage of barite. The Ogoshi test shows that the fly-ash/phenolic composite contained graphite particles of ≤150 μm in size has the lowest specific abrasion. From SEM micrograph with low magnification, on the abrasion area, smooth surface is observed. In reverse, composite contained of ≤56 μm graphite particle size show a rougher surface. More graphite particle is pulled out from the matrix. Small particle tend to agglomerate between them. Hence small particle cannot individually covered by the phenolic matrix. The specific abrasion decreases with the barite weight fraction. The SEM micrograph shows mixed phenolic with 15 weight % of barite evenly covered the graphite and fly-ash particles than the one with 5 weight % of barite.

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