Effect of Fly Ash on the Mechanical Properties of Polyvinyl Chloride-Fly Ash Composite

A. W. Nugroho, M. K. P. Prasetyo, and C. Budiyantoro

Abstract Fly ash (FA), a fine powder obtained during the combustion of coal at a thermal power station, possesses several environmental issues, including atmosphere contamination and huge land area for dumping. One potential use of FA is as filler in polymers in order to improve their properties and to reduce production costs. Polyvinyl chloride (PVC) is a well-known thermoplastic and the most commonly used polymers in building industries due to its advantageous properties. This study investigated the influences of the FA as filler material on the mechanical properties of PVC/FA composites. PVC in powder form was mixed with addictive substances (Tribasic Lead Sulfate, Normal Lead Stearate, Calcium Stearate, and Stearate Acid) at a temperature of 100 °C. Following this, the FA was added to the mixed PVC in various compositions (0, 8, 10, 20, and 30 phr) and shook. The Hot Press Molding machine fabricated the PVC/FA composites under pressure of 13 MPa at a temperature of 200 °C for 300 s. Tensile and impact tests were carried out in accordance with ASTM D638-02A type IV and ASTM D6110-04, respectively. The results revealed that the incorporation of FA had significantly improved the tensile strength, Young's Modulus, and the elongation at break of the composites. The composite containing 8 phr FA showed the highest value of the respective properties. Those properties tended to decrease with the increase of FA content. The impact properties also showed a similar phenomenon. The value of impact strength and impact energy for the composite containing 10 phr were found the highest. Scanning electron microscopy images showed that FA particles were precipitated and mechanically interlocked in the PVC matrix. Particle agglomeration was found in the composites containing higher amounts of FA. The study indicates a remarkable potential for FA to produce useful PVC/VA composite.

Keywords Polyvinyl chloride · Fly ash · Filler · Mechanical properties · Composite

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1 Introduction

Pulverized coal is widely used to be burned as a heat source at a thermal power station to generate electricity accompanied by the solid residues. While the unburned residue drop to the bottom of the furnace, known as bottom ash (BA), the dust collection system extracts lighter fine ash particles from the flue gas called fly ash (FA). The composition of the remaining coal combustion is Silicon Dioxide (SiO_2), Aluminum Trioxide (AL_2O_3), Ferric Oxide (Fe_2O_3), Calcium Oxide (CaO), and others. Coal combustion produces ash, which has a percentage of 5–15% is BA, and 85–95% is FA. Due to the storage and handling difficulties in terms of environmental concern, the application of FA become challenges to be developed. Although FA is commonly dumped in lagoon and dams due to its many advantages, such as low cost, low density, smooth particle surface, good processability as filler material, and well-distributed internal stress [8]. It has been used in various engineering applications, for instance, soil stabilization, cement mixture, asphalt filler, concrete products, and tile making [20]. By doing so, it may reduce the usage of non-renewable natural resources and the replacement of materials that may be energy-intensive to fabricate. As filler in polymers and rubber is one potential use of FA to lower the fabrication cost and to improve certain properties. Those physical properties of FA make it an appropriate filler for rubber and polymer.

Many studies have also revealed the reinforcing effect of FA in polymer matrix composites. It was applied in various polymers such as epoxy [11], polyvinyl alcohol (PVA) [12], high density polyethylene (HDPE) [4], polyurea elastomer [16], polypropylene (PP) [13, 18, 19], polyetheretherketone (PEEK) [14], ethylene-octene copolymer (EOC) [1], acrylonitrile butadiene styrene(ABS) [10] and more recent polyvinyl alcohol (PVC) [8, 20]. In general, the addition of FA indicates an enhancement of the mechanical and thermal properties of the polymer composites.

Polyvinyl Chloride (PVC) is the second most common plastic material mainly used for fabricating pipe fittings, sheets, cables, etc. Pipes and fittings need good tensile strength and impact properties, short and long-term pressure sustainability. The use of PVC is growing fast in the research due to its properties such as low cost, low density, low thermal conductivity, improved acoustic damping properties, chemical stable, and excellent fire retardancy [5, 17, 21]. However, the low thermal stability and brittleness cause limitation of its application at high temperatures. Hence, enhancement in these properties of PVC will expand its application [2, 9]. Although many researchers have studied the impact and tensile properties of PVC-FA, most of them used injection molding or extruder machine to fabricate the composite. The present paper evaluated the effect of fly ash (FA) as a filler on the impact and tensile strength properties on PVC-FA composite fabricated using a hot press machine.

2 Experimental Method

FA was obtained from the thermal power station at a company in Cilegon Banten. The coal consumption was 300 tons, along with 30 tons FA by product. The company used coal as a fuel for power stations in steam generators unit to manufacture PVC plastic powders. The main constituent of FA consisted of silicon dioxide (SiO_2), aluminum trioxide (Al_2O_3), ferrite oxide (Fe_2O_3), and calcium oxide (CaO). The manufactured Polyvinyl chloride (PVC) required PVC K-65R powder and an additive compound, including tribasic lead sulfate as a heat stabilizer and normal lead stearate, calcium stearate, and stearate acid as a lubricant. Processing was conducted in two steps. In the first stage, those elements were formulated in the LAboplastomill mixer. The FA was added in the second stage of the composition, as shown by Table 1. The composition is expressed in part per hundred rubber (phr) unit.

The mixed powder was then poured into the flat mold and hot pressed using Hot Press Molding Collin P300E machine with two-stage for heating processes. The temperature was set up at 200 °C for 600 s in 60 Bar. Following this, the pressure was increased up to 130 bar for 300 s at a temperature of 200 °C. After that, the temperature was cooled to room temperature for 300 s with a pressure increase to 160 Bar. The PVC/FA plate composite being fabricated is shown in Fig. 1. Type specimens, as per ASTM D-638-02, were cut from the hot-pressed sheet. The specimens were tested

Table 1 Composition

No.	Code	Constituent as phr		
		PVC	Additives	FA
1	Phr0	200	11	0
2	Phr8	200	11	16
3	Phr10	200	11	20
4	Phr20	200	11	40
5	Phr30	200	11	60

Fig. 1 PVC/FA composite plate (**a**), tensile test specimen (**b**), un-notched impact charpy specimen (**c**)

on a universal testing machine with a 10 kN load cell and a crosshead speed of 5 mm/min.

The notched Charpy Impact for a plastic material test as per ASTM D6110-04 was carried out using Zwick/Roell Impact Test Machine. The impact Charpy specimens were cut using profile cutting machines to avoid the micro crack. Five specimens were tested for each parameter of tensile or impact testing. Optical microscopy (OM) and Scanning Electron Microscopy (SEM) was used to examine the morphology of the composite.

3 Results and Discussion

3.1 Tensile Properties

Tensile properties were evaluated by tensile tests, including tensile strength, elastic modulus, and strain at break. Tensile strength and the elastic modulus of the PVC/FA composite as a function of the FA content are shown in Fig. 2.

Ultimate tensile stress initially found to increase on the addition of FA as expected to achieve a maximum of 64.57 MPa at 8 phr of FA but later decreases with the increase of FA content [3]. The addition of FA as filler encouraged inhomogeneity in the matrix, causing interference of filler in the mobility or deformability of the matrix. In addition, since the hardness of FA is higher than that of the PVC [8], the load is sufficiently transferred from the matrix into the filler. It may obstruct

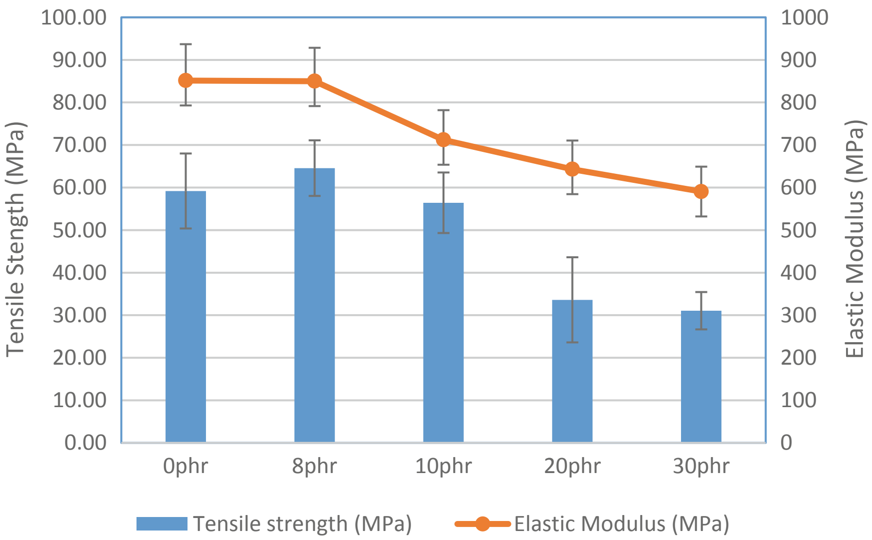

Fig. 2 Tensile strength and elastic modulus of the PVC/FA composites

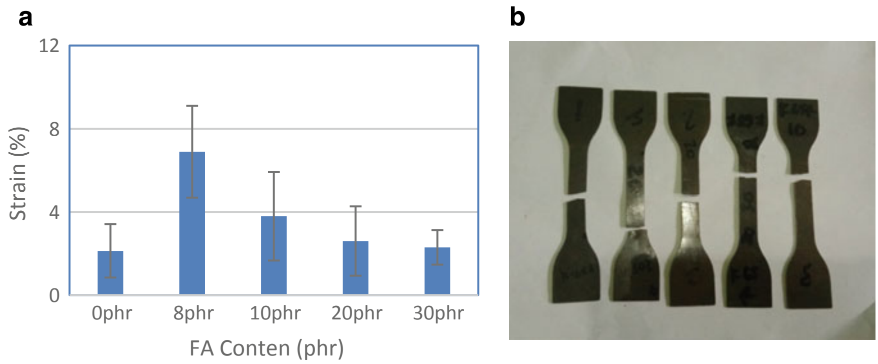

Fig. 3 The relation between FA content and strain at break (**a**), tensile specimen failure (**b**)

matrix deformation resulting in an increase of the tensile strength [15]. However, due to the absence of a coupling agent and higher probability of agglomeration of FA particle in the matrix at higher FA content, weak bonding between filler and matrix at higher FA content occurred, leading to a lack of stress transfer between them, resulting in a decrease in the tensile strength and reducing the elastic modulus as shown in Fig. 2. Those decrease may attribute to restriction of polymer chain movements leading to reduce in strain at break as shown in Fig. 3. Khoshnoud et al. [8] have demonstrated that tensile strength and elongation of composite decreases with increase in filler content. Correspondingly, incorporation of a small amount (8 phr) of filler improved the elastic modulus of the composites and later decreased at higher filler content. The tensile strength result is comparable to previous research [6], showing the tensile strength in the range of 23–38 MPa.

3.2 Impact Strength

The effect of FA content on the impact strength of the PVC/FA composites is shown in Fig. 4. In general, by adding FA filler, the impact strength and impact energy increased slightly.

It points out that at higher speed rate loading load could be transferred by the filler. It was because the FA particle occupied the interstitial between PVC particles. It tended to reduce void content, which led to an increase in the impact strength and impact energy. At 10 phr of FA filler, the impact strength and impact energy increased dramatically due to most void might be occupied by the filler. On the further addition of FA, there was inadequate wetting of FA by PVC. It tended to increase in void content, and thus impact energy and impact strength decreased and later remained nearly constants on further addition of FA. Previous research revealed that their impact strength and impact energy are in the range of 2.6–4.8 kJ/m^2 and 0.18–0.3 J, respectively [7], which is close to the current research. However, their values

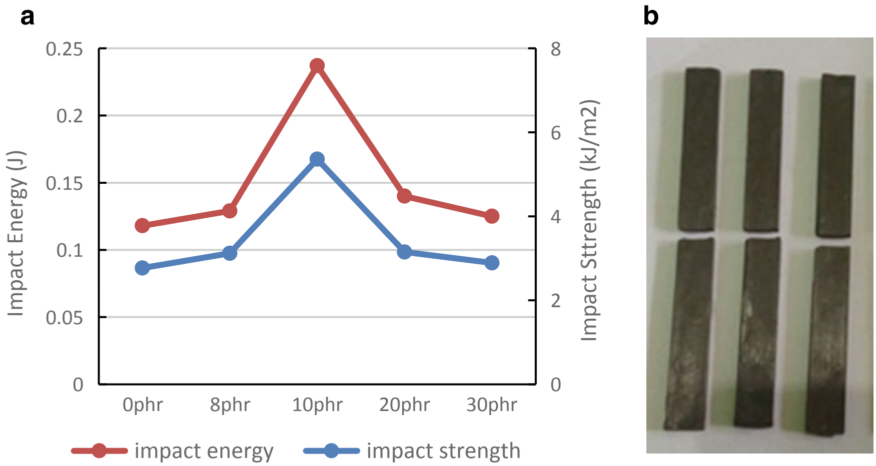

Fig. 4 Variation of impact strength of the PVC/FA composites with filler content (**a**), impact test specimen (**b**)

decreased along with the increase of the filler content. From an optical microscope image, it could be seen that the surface failure of the 8 phr content specimen showed gold-colored grains scattered, inhomogeneity, and agglomeration filler might exist. FA was spread evenly on the upper side of the specimen and was not completely mixed. Therefore, the impact test results were 8 phr variations lower than that of the 10 phr specimen. The surface failure on the v-notch side and impact hammer showed cleavage with smoother surface representing brittle failure (Fig. 5a). Optical micrograph of the surface 10 phr specimens of impact test showed rougher look like dimples (Fig. 5b), which was associated with less brittle failure. The gold-colored brown area representing FA was occasionally scattered on the sides of the specimen.

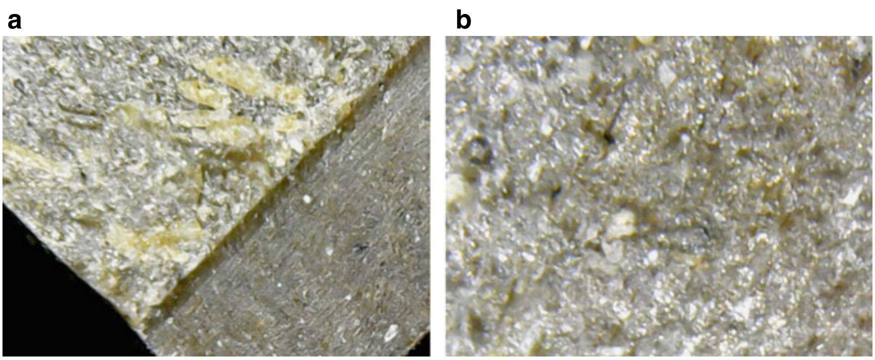

Fig. 5 Optical image of the failure impact testing specimen with FA filler 8 and 10 phr

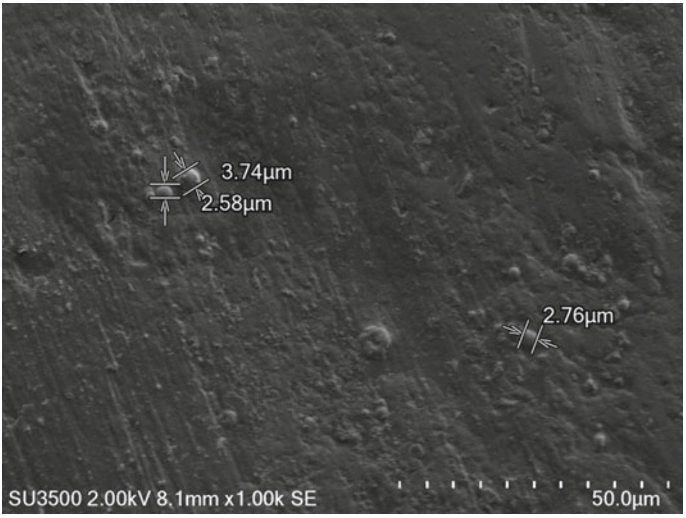

Fig. 6 SEM micrograph of the PVC/FA with 10 phr of FA

SEM was applied to evaluate the morphology of the PVC/FA composites. Figure 6 presents the SEM micrographs of the PVC/FA composites with 10 phr of FA content. The morphological study revealed that FA possessed a smooth spherical surface providing more surface area for interaction. There was a good dispersion of filler particles in the polymer matrix. The excellent interaction between the matrix and the filler was also presented in the SEM image. In addition, the figure shows the size of the FA embedded in the PVC matrix. It could be seen that the FA particle does not diffuse into the matrix. The particle size of FA in the range of 2.58–7.11 µm in a spherical shape and rounded occupied the edges of the specimen. The FA particles were well dispersed in the polymer matrix. This image also supports those of the mechanical properties, as stated above.

4 Conclusions

The PVC/FA composite had already been fabricated using a hot press machine successfully. Inorganic filler, i.e., FA added to the PVC, improved the strength, rigidity, and impact strength at a certain amount and then decreased at a higher amount of the filler. The maximum strength and impact strength were achieved at different compositions, namely 8 phr and 10 phr, respectively. The tensile strength slightly increased due to the existence of the filler particle resulting in mechanical restraints. At higher speed loading, the presence of filler particles might adsorb the energy better. The morphological evaluation revealed that the filler particles in spherical shaped were well dispersed in the matrix and possessed an excellent interaction surface area.

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