Thermal Stability of Fly Ash by TGA Analysis for the Development of Composite Railway Brake Blocks

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Abstract. This study aims to determine the thermal characteristics of fly ash. The fly ash used in this study comes from the Paiton PLTU. The test was carried out using the TGA method. The TGA test was carried out at a temperature of 0°–1000 °C with a heating rate of 20 °C/min and nitrogen (N_2) as a carrier gas. The TGA test provides information that there is a decrease in mass at temperatures of 600 °C–680 °C and 700 °C–950 °C. This indicates a decomposition process of the compounds contained in the fly ash. From the test results, it can be seen that the thermal stability of fly ash occurs at a temperature of 600 °C. This high heat resistance allows fly ash to be developed into a composite material for railroad brake blocks.

Keywords: Fly Ash · TGA · Composite Railway Brake Blocks

1 Introduction

The use of composites in the world of transportation has also begun to develop, especially for automotive components, trains and aircraft [1]. Likewise, in the world rail industry, including in Indonesia, composite brake blocks are starting to be widely used as an alternative to cast iron brake blocks. The development of composite materials for railway brake blocks continues to be carried out, such as carbon composites and composites with natural fibers such as coconut husk fiber [2], hibiscus leaf fiber [3], coconut shell [4], and composites from a mixture of cast iron and Al-SiC [5].

Fly ash, which is one of the dominant wastes produced by coal-fired power plants, is currently quite abundant and not commensurate with its limited utilization. This waste is generally disposed of in landfills or left to accumulate in industrial areas. Currently fly ash and bottom ash are only used as building and road construction materials. In studies that have been carried out that Fly ash is used as a substitute for aggregate in the production of paving blocks [6], Hollow Blocks [7, 8], hollow concrete bricks [9], additional material to ceramics [10, 11]. The dominant elements of Ca, Si and Fe are contained in the fly ash produced by the Paiton PLTU. Fly ash is classified as type C fly ash. This fly ash is also known as High Calcium Fly Ash because it has a high calcium

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content of 29.7%. The dominant phases contained in this fly ash are *silicate*, *molybneum oxide* and aluminum oxide. *Tricalcium silicate* which has high strength and is widely used in concrete and aggregates in dental canal treatment, tridymite compounds (SiO_2), *molybneum oxide* which is applied in electronics, catalysis, sensors, energy storage unit lubricants, superconductors, thermal materials, biosystems, and electrochromic system, as well as aluminum oxide which has several advantages compared to some ceramic materials including its chemical, physical and thermal properties. Aluminum Oxide is also abrasive, making it suitable for use as a composite material for brake linings.

The main characteristics for friction materials are and the wear rate and coefficient of friction. Along with its development and application, other important properties must also be met in order to be well applied as a friction material. These properties are mechanical properties and thermal properties, mechanical properties include tensile strength, shear strength and compressive strength. While the thermal properties include thermal conductivity and heat dissipation. In addition, aspects of vibration, sound and environmental pollution must also be considered. Thermal characteristics are one of the important characteristics that need to be considered for friction materials in brake linings because the working principle of the braking system is to convert kinetic energy into thermal energy. The braking mechanism is carried out by rubbing two different materials so that the rotation will slow down and result in a reduction in speed or a stop of the vehicle. Thus, the material in the brake lining material must be heat resistant and not change at high temperatures.

Nylon In this study, the thermal stability of fly ash will be investigated to develop the use of fly ash. This is the first step to determine the thermal characteristics of fly ash which is expected to be one of the building blocks for composite railway brake blocks. This thermal characteristic is important because as a rail brake material requires high heat resistance to be able to create a good braking system.

2 Experimental Details

Fly ash produced by Paiton Power Plant is heated in a heating furnace at a temperature of 100 °C for 5 h with the aim of drying the material before testing. Fly Ash which has gone through the drying process is then filtered using a sieve to obtain a fine sample for testing. The TGA test was carried out at the Energy Laboratory of the Sepuluh Nopember Institute of Technology, Surabaya. The instrument used in the TGA test is the Thermogravimetric Analyzer by METTLER TOLEDO. The TGA test was carried out at a temperature of 0°-1000 °C with a heating rate of 20/minute and nitrogen (N_2) as a carrier gas. The TGA test is analyzed and supported by previous tests.

3 Result and Discussion

The diagram of the results of the fly ash test with TGA is shown in Fig. 2,

In the TGA test, there are influential parameters such as heating rate, gas flow rate and carrier gas. Therefore, in this study these parameters are also considered. The use of nitrogen gas in this study is intended to prevent other thermal reactions such as recondensation and repolymerization. The use of nitrogen may result in a decomposition process

Fig. 1. Fly Ash from Paiton Power Plant

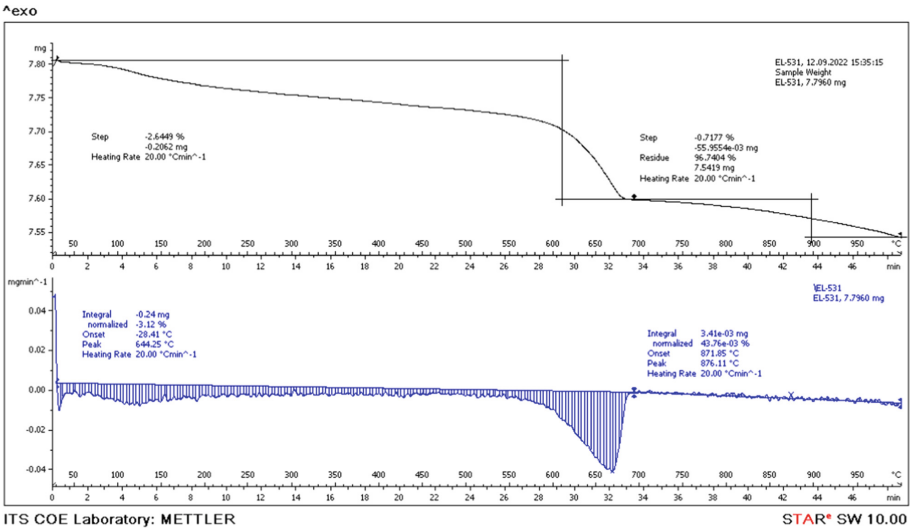

Fig. 2. Fly Ash Thermogram from Paiton Power Plant

of the compounds contained in the material. The use of a heating rate of 20 °C/min is also based on several references that the optimum heating rate for the decomposition of solid materials is 100 °C/min and 20 °C /min [12]. This heating rate is considered optimum because if the heating rate is too low, the decomposition products will undergo a secondary reaction. Likewise, if the heating rate is too high, it will result in thermal fragmentation.

Solid material when given heat treatment will reduce its mass so that thermal decomposition occurs. Thermal decomposition is chemical decomposition caused by heat. Thermal decomposition reactions are usually endothermic because heat is needed to break the chemical bonds in these compounds. The reduced mass can also provide information about the thermal stability of a material and the kinetic parameters of the chemical reactions that occur in the sample.

Table 1. XRF Testing Result of Fly Ash

Compounds	Amount (%)
CaO	29.7
Fe_2O_3	26.3
SiO_2	26
Al_2O_3	8.51
MoO_3	4.4
K_2O	1.39
TiO_2	1,3
HgO	1
P_2O_5	0.57
BaO	0.49
MnO	0.24
V_2O_5	0.06
CuO	0.06
Cr_2O_3	0.03

Figure 1 shows the TGA thermogram which provides information that when there is an increase in temperature in the range of 600 °C–680 °C, there is a decrease in mass of 0.12 mg or 1.55%. In addition, a decrease in mass was also seen in the range of 700 °C–950 °C, which was 0.05 mg or 0.6%. This shows the decomposition process of the compounds contained in the fly ash. To find out the compounds undergoing decomposition, it is necessary to test related to the compounds contained in fly ash. Based on research conducted by previous authors, the compounds contained in the fly ash of Paiton Power Plant are shown in Table 1,

Table 1 shows that the largest compound contained in fly ash from Paiton Power Plant is CaO that is equal to 29.7%. Fly ash is classified as type C so it is also known as *High Calcium Fly Ash* (HCFA). CaO is a decomposition product of $CaCO_3$. According to [13], the decomposition of anhydrous calcium-based carbonates can occur at different temperatures according to the crystal size and crystallinity. [14] stated that calcium carbonate is a polymorphous which has three phases, namely calcite, vaterite and aragonite. In Fig. 1 it can be seen that the decomposition process occurs in the temperature range of 600 °C–680 °C and 700 °C–950 °C. At this temperature, it is a decomposition process of calcium carbonate into CaO. This is in accordance with research conducted by [15] which stated that carbonate species decomposed between 600 °C–700 °C and 750 °C–900 °C. In addition, [16] also stated that the peak decomposition process in calcium carbonate was vaterite takes place at 600 °C–790 °C. [17] also said that the decomposition of calcium carbonate in the calcite phase occurs at a temperature between 700 °C–800 °C.

TGA test can be used to see the stability of the material against temperature. A material is said to be stable if there is no change in mass that occurs in a certain temperature

Table 2. Technical specifications for rail composite brake blocks

Physical and Mechanical Properties	Standard Value
Density (gr/cm^2)	1.8–2.4
Friction coefficient	0.14–0,22
Hardness (HRR)	70–105
Compressive Strength (N/mm^2)	>25
Bending Strength/Modulus of rupture, (MOR) (N/cm^2)	2400–4000
Shear Strength (N/cm^2)	1500–3500
Young's Modulus/Modulus of elasticity (MOE) (N/cm^2)	24000–150000
Thermal Conductivity (W/mK)	>0.8
Operational Heat Resistance	250 °C Result: does not melt and does not burn for continuous use ≥500 °C Result: may burn but should not there is a flame

range. Mass loss in materials can occur through chemical reactions and decomposition processes. It is in this state that the material is no longer in a thermally stable state. In Fig. 4.1 it can be seen that there is a decrease in mass in fly ash at a temperature of 600 °C. This means that fly ash has thermal stability at 600 °C.

Train brake block serves to reduce the speed of the train or stop the train. For decades, railroad brake blocks used cast iron. There are several disadvantages of cast iron brake blocks such as being difficult and expensive to install [18], having a short service life, producing noise and containing toxic particles in the air [19]. Currently, more composite brake blocks are being developed to be an alternative to cast iron brake blocks. Composite materials are in demand because they can be designed in such a way according to the wishes and needs. Composite brake block building materials consist of binders, fillers, friction materials and adhesives. PT. KAI stipulates technical specifications for composite brake blocks [4] in the following Table 2,

Seeing the technical specifications of the composite rail brake block, fly ash which has a thermal stability of up to 600 °C is possible to be created as a composite material because fly ash has a fairly high heat resistance. However, further studies are needed regarding the effect of adding fly ash on the properties of the composites made and what materials can be combined with fly ash to become composite brake blocks on trains that meet the established technical specifications.

4 Conclusion

TGA test conducted on fly ash shows that fly ash has a fairly high heat resistance, which is up to 600 °C. This allows fly ash to be developed as a composite material that is applied as a train brake lining.

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