International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048
Volume 8, Issue 5, pp 185-189, May-2024
https://doi.org/10.47001/IRJIET/2024.805028

Mechanical Properties of Fly Ash, Gravel, and Epoxy Resin Minerals Composite

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***Abstract* - This study aims to develop mineral composites for machine tool beds. This study utilizes fly ash from coal power plants with gravel rocks. The gravel size was reduced in the ball mill to 100 mesh size. The received fly ash was used. The composition variations between fly ash and gravel fly ash are 100% fly ash, 75% Gravel-25% Fly Ash, 50% Gravel -50% Fly Ash; 25% Fly ash - 75 % Gravel, and Gravel 100%. The epoxy resin used is Bakelite® EPR 174 with Bakelite® EPH 555 hardener, where the ratio is 2 : 1. The process of mixing epoxy resin with fly ash and gravel with a mixing ratio of 82% Fly Ash Gravel and 18% Epoxy Resin. Then tensile tests, compressive tests and impact tests were carried out. From the test results, it was found that the highest density test results in the 50% gravel 50% fly ash composition were 2.03 gr / cm³, the highest tensile strength in 25% gravel 75% fly ash was 10.45 Mpa, the highest compressive strength in 50% gravel 50% fly ash was 35.99 Mpa with the highest impact energy of 0.72 joules in the 50% gravel 50% fly ash composition.**

Keywords: fly ash, gravel, epoxy, physical properties, mechanical properties.

I. INTRODUCTION

Machinery materials have evolved from wood to metal. Recent research trends in the development of machinery materials show a tendency to replace metal materials (cast iron) with composites. Polymer resin mixed with minerals produces composites for alternative materials replacing metal [1]. Mineral composites are one of the materials that have good technical properties and economic value as engine materials [3]. Mineral composites, or polymer concrete (PC), are complex materials composed of inorganic aggregate particles, such as basalt, spodumene, fly ash, river gravel, sand, lime, etc., combined with resin, usually epoxy [2]. Fly ash and gravel can be utilized as composite mineral materials or polymer concrete. Mineral composites made with fly ash and gravel as reinforcement are combined with a polymer matrix. This composite mineral can then be used in CNC machine components because of its several advantages. An important consideration for polymer concrete is its high damping capacity compared to gray cast iron for structural applications [4].

The production of electricity from burning coal has led to the construction of coal-fired power plants around the world, producing many by-products, such as coal ash, in the form of fly ash and bottom ash. Statistics reveal that global figures reach 150 to 200 million tons of bottom ash and between 600 and 800 million tons of fly ash [5]. The energy mix in Indonesia in 2019, according to the Ministry of Energy and Mineral Resources, was dominated by coal at 38%. In addition, coal production in Indonesia reached 461 million tons. The coal combustion process will produce 5% solid pollutants in the form of ash, with 10 to 20% being bottom ash and 80 to 90% being fly ash from the total ash produced [6].

Fly ash is mostly composed of SiO_2, Al_2O_3, and CaO (essential minerals). Fly ash can be categorized based on its mineral content. Based on ASTM C618, if the amount of SiO_2+Al_2O_3+Fe_2O_3 content is more than 70%, fly ash is categorized as class F, while if it is between 50 and 70%, fly ash is categorized as class C [7].

Gravel is an important commercial product of geological processes with a large number of applications, especially in concrete reinforcement for structural applications. Gravel can be defined as rock formed due to the common geological phenomena of erosion and weathering. Processes from waves and river currents tend to accumulate gravel in the form of large aggregates [8]. According to [9] the main content is SiO_2.

The combination of epoxy resin with fly ash and gravel in an effort to utilize waste and also natural minerals can be an alternative composite material, where the utilization of this composite material can be used in the bed or column of the CNC machine. Mineral composites are one of the materials that have good technical properties and economic value as machine materials [10]. Epoxy resin is one of the most widely used thermosets in structural composite applications because epoxy has a unique combination of properties that cannot be achieved with other thermoset resins. Epoxy resins are available in a wide variety of phase forms ranging from low-viscosity liquids to high-melting solids; these materials can be used for a variety of processes and applications. Epoxy offers

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high strength, low shrinkage, excellent adhesion to various substrates, effective electrical insulation, chemical and solvent resistance, low cost, and low toxicity. Epoxy resins are also chemically compatible with most substrates and tend to wet out quickly, making them particularly suitable for composite applications [11].

II. LITERATURE REVIEW

Keong et al. [12] studied the mechanical properties of composites reinforced with incineration ash and epoxy matrix. The investigation was conducted by varying the concentration of incineration ash with different percentages of fly ash and bottom ash. The results showed that the tensile and flexural strength of the composites decreased with the incorporation of incineration ash into the epoxy-based composites.

In addition, A. et al. [13] conducted experiments by testing the damping ratio of polymer composite materials. This study used quartz particles <2 mm in size as reinforcement. Matrix types of polyester and epoxy were used as composite materials for comparison. Furthermore, the resin mass fraction composition was varied, ranging from 10%, 20%, and 30%. The results of this experiment show that the composite with polyester matrix has a higher damping ratio than the epoxy matrix.

In addition, there is also research from Rajput et al. [14], which utilizes stone dust city as reinforcement with epoxy. The particle size used in this study is 75 µm with variations in composition from 10% to 40% of the total mass. Adding city stone dust content can increase the hardness and compressive strength of the material. Meanwhile, tensile and flexural strength increases only up to 20% composition, after which there is a decrease in tensile and flexural strength. Thus, it can be concluded from this study that the most optimal stone dust city content is 20%.

Sheshkar et al. [15] made a composite material made from graphite combined with polydimethylsiloxane (PDMS). The composite material was then tested for mechanical and thermal properties. The results of this study generally illustrate that the mechanical and thermal properties of the material increase with increasing graphite content.

Indra Reddy et al. [16] studied the mechanical properties of composites made with jute reinforcement, pineapple leaf fiber, and glass fiber. The ratio of the three reinforcements was 1:1:1. Then, polyester matrix and epoxy resin were used. The fiber content in the composites varied from 0.18 to 0.42 volume fraction, and the variation of mechanical properties such as tensile, flexural, and impact properties in each case was studied. The results show that composites with epoxy matrix have better mechanical properties than composites with polyester matrix.

In addition, there is also research from Rajput et al. [14], which utilizes stone dust city as reinforcement with epoxy. The particle size used in this study is 75 µm with variations in composition from 10% to 40% of the total mass. Adding city stone dust content can increase the hardness and compressive strength of the material. Meanwhile, for tensile and flexural strength, it increases only up to 20% composition, after which there is a decrease in tensile and flexural strength. Thus, it can be concluded from this study that the most optimal stone dust city content is 20%.

III. MATERIALS AND METHODS

The following materials are used to manufacture mineral composites fly ash, gravel, and epoxy resin.

3.1 Fly Ash

Fly ash is a fine powdery particle formed by burning coal. It is primarily round, solid, or hollow; most is amorphous. The specific gravity of coal ash is about two but varies from 1.6 to 3.1. This variation is due to several factors, such as particle shape, gradation, and chemical composition [17].

Fly ash mainly comprises SiO_2, Al_2O_3, and CaO (essential minerals). Fly ash can be categorized based on its mineral content. Based on ASTM C618, if the amount of SiO_2+Al_2O^3+Fe_2O_3 content is more than 70%, fly ash is categorized as class F, while if it is between 50 and 70%, fly ash is categorized as class C [7].

3.2 Gravel

Gravel is an important commercial product of geological processes with many applications, especially in concrete reinforcement for structural applications. Gravel can be defined as rock formed due to the common geological phenomena of erosion and weathering. Processes from waves and river currents tend to accumulate gravel in the form of large aggregates [8]. Gravel can be categorized into sedimentary rocks derived from the weathering of gravel, sand, silt, and clay, which can become hard due to subsoil pressure and cementation by elements such as iron oxide and calcite [18].

3.3 Epoxy Resin

The epoxy resin used in this research is Bakelite® EPR 174. Bakelite® EPR 174 is a liquid epoxy resin epichlorohydrin bisphenol A purpose without standard modification, has medium-high viscosity and high heat

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distortion temperature. Bakelite® EPR 174 is excellent when cured in chemical and thermal resistance, adhesion, physical, and electrical properties and is versatile for various applications. The hardener used as a mixture of Bakelite® EPR 174 resin is Bakelite® EPH 555 Curing Agent. Curing Agent Bakelite® EPH 555 has a very low viscosity, light color, and room temperature humidity for liquid and solid epoxy.

3.4 Manufacturing Process

This mineral composite is made by mixing fly ash, gravel, and resin directly into the mold, as shown in Figure 1. Fly ash is shieving using mesh 100, while gravel is ball milled first and then shieving using mesh 100. The ratio of epoxy resin to hardener was 2 : 1, while the mineral composition used is fly ash 100% (F1), fly ash 75% Gravel 25% (F2G1), fly ash 50% gravel 50% (FG), fly ash 25% gravel 75% (1F 2G) and gravel 100% (G1). In this mineral composite, the percentage of resin used is 15%. The mold used uses steel with a mold size of 250 mm x 180 mm x 15 mm for tensile and bending tests, while for compressive tests, cylindrical molds with a size of 20 mm x 40 mm. Before use, the mold is coated with wax to make releasing composite minerals easier.

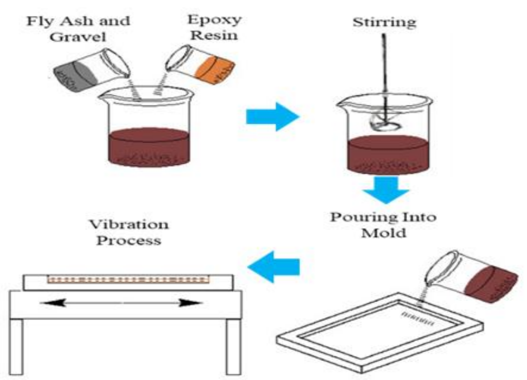

Figure 1: Manufacturing Process of Mineral Composite

IV. RESULTS AND DISCUSSIONS

4.1 Density

This density test aims to obtain the density of the composite material reinforced with gravel and fly ash particles. The density values are 3,00 gr/cm³ for fly ash and 2,97 gr/cm³ for gravel. This test was conducted using specimens from the compressive test. Tests were carried out on three specimens for each variation by calculating the volume and weighing the mass of the specimen, which then obtained the density as shown in Table 1.

The density test results in Table 1 show that adding gravel particles will increase the density value; the highest density results are in composites with variation code F1G1 (fly ash 50% gravel 50%).

Table 1: Density and mechanical properties test results

Variation Code	Density (gr/cm^3)	Compression on Strength (Mpa)	Flexural Strength (Mpa)	Tensile Strength (Mpa)	Impact (Joule)
F1	1.91	26.78	1.33	7.00	0.59
F2G1	2.00	30.22	1.99	9.87	0.39
F1G1	2.02	32.64	1.78	1.70	0.66
F1G2	2.00	29.13	1.95	5.00	0.56
G1	1.97	31.49	1.86	7.44	0.32

4.2 Compression Strength

From the test results in Table 1, it can be concluded that adding gravel increases the compressive strength value of the mineral composite; the highest value in F1G1 is 32,64 Mpa, and the lowest value in F1 is 26,78 Mpa. This can also be seen in Figure 2 below.

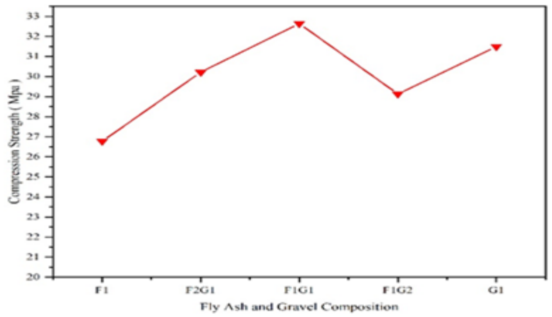

Figure 2: Compressive Strength Test Results

4.3 Tensile Strength

From the results of tensile strength testing, the highest value in F2G1 is 9,87 Mpa, while the smallest value in F1G1 is 1,70 Mpa. The results of this tensile test show that the effect of the addition of gravel or fly ash composition on this composite mineral cannot be concluded, as shown in Figure 3. Adding gravel composition has almost no effect on the tensile test results.

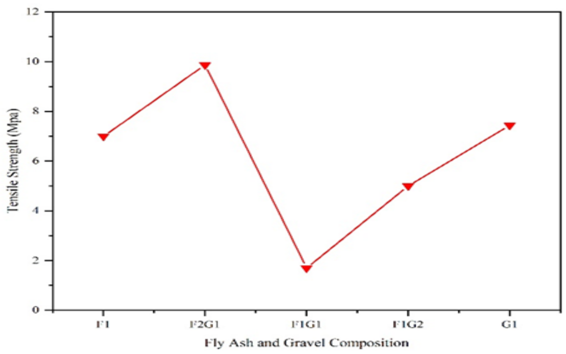

Figure 3: Tensile Strength Test Results

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https://doi.org/10.47001/IRJIET/2024.805028

4.4 Flexural Strength

Figure 4 shows that from the flexural test results of mineral composite with different compositions of fly ash and gravel, the highest flexural strength value is obtained at F2G1, which is 1,99 Mpa, and the smallest value at F1, which is 1,33 Mpa. In composition G1, the flexural strength value of 1,86 Mpa was obtained. This experiment indicates that adding gravel composition can increase the flexural strength of the composite mineral, where the flexural strength value of G1 (100% gravel) is 40% higher than the flexural strength value of F1 (100% fly ash).

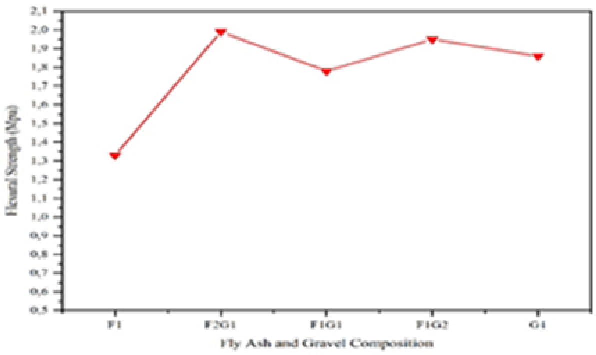

Figure 4: Flexural Strength Test Results

4.5 Impact Energy

From the test results shown in Figure 5, the highest impact energy value was obtained in F1G1, which amounted to 0.66 Joules, while the lowest impact value in G1 was 0.32 Joules. This experiment indicates that with the addition of gravel impact strength value, there is almost no significant effect, but the value of impact energy between F1 (fly ash 100%) has a higher value of 84% or 0.59 Joules compared to the impact energy of mineral composite G1 (Gravel 100%).

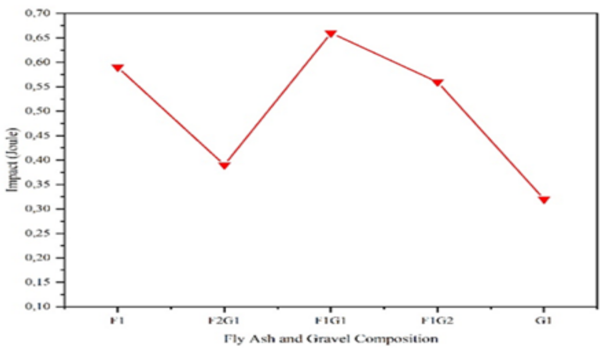

Figure 5: Impact Energy Test Result

V. CONCLUSION

The effect of the composition of fly ash and gravel on the mechanical properties of mineral composite after testing can be concluded:

- The density value tends to increase with the addition of gravel composition in the mineral composite.
- The highest tensile strength of mineral composite is in the composition of F2G1 (Fly Ash 75% Gravel 25%) which is 9.87 Mpa.
- The results of the impact strength test on the F1 composition (fly ash 100%) have a higher value of 84% than the G1 composition (gravel 100%).
- The flexural strength value of composite minerals with composition G1 (gravel 100%) is 40% higher than that of composite minerals with composition F1 (fly ash 100%), with the addition of gravel composition affecting flexural strength.

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Volume 8, Issue 5, pp 185-189, May-2024
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Citation of this Article:

Andiyanto, Sulardjaka, Agus Suprihanto, "Mechanical Properties of Fly Ash, Gravel, and Epoxy Resin Minerals Composite", Published in *International Research Journal of Innovations in Engineering and Technology - IRJIET*, Volume 8, Issue 5, pp 185-189, May 2024. Article DOI https://doi.org/10.47001/IRJIET/2024.805028

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