IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
Volume 2, Issue 2, February 2022
Impact Factor: 6.252

Development of Coarse and Fine Aggregates Using Fly Ash and Geopolymer

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Abstract: *Infrastructure industry is still dominant in developing countries. These activities requires a large number of aggregates. To make cement concrete and asphalt concrete, it requires 60% to 75% of aggregate in total volume of the mixture. This high volume of aggregates may cause reduction on availability of natural aggregate. Another problem is that not all area in Indonesia has the ability to provide adequate aggregates so that it can support the infrastructure development, especially in remote areas. The aggregate mobilization may face disruption. This research attempts to present an idea of creating an artificial aggregate. The artificial aggregate is made of power plant waste that is mixed with alkali silica, named as fly ash geopolymer. Previous study indicates that the use of fly ash geopolymer as filler replacement in asphalt concrete mixture, is able to double the stability of Marshall test. This experiment serves a role to design an artificial aggregate.*

Keywords: Artificial Aggregate, Fly Ash Geopolymer, Asphalt Mix Materials

I. Introduction

Increasing infrastructure development in most parts of the world, especially in developing countries, has resulted in reduced availability of raw materials. The use of natural resources to produce raw materials on an ongoing basis can threaten environmental conditions. Aggregates are one of the raw materials produced from rock exploration in nature. The aggregate is made of stone-crusher installation. The provision of aggregates to meet the natural aggregate needs of the infrastructure industry leads to depletion of natural resources. This is understandable considering to make concrete cement and asphalt concrete, it requires 60% to 75% of aggregate of the total mixed volume. The need for raw materials in the form of aggregate to support this infrastructure development cannot be fully met in every Indonesia area, especially in remote areas. There can be various obstacles in aggregate mobilization because all of Indonesian areas are not provided by adequate transportation facilities and infrastructures. Thus, it is necessary for sustainable efforts to develop alternative materials such as construction and dismantling waste and industrial waste to be used as replacements of natural aggregates. There have been many studies using waste as artificial aggregates.

II. Methodology

The geopolymer paste is made in 3 mixtures design based on Na2SiO3 ratio with NaOH, namely 1.5, 2.0, and 2.5. The composition of fly ash and alkali is 75%: 25%. Each design mixture is used in 6 samples, therefore it requires total of 18 samples. The mixture design can be seen in Table 1 below.

III. Development History

NTPC Ltd, India's largest power producer and a PSU under Ministry of Power, has successfully developed Geo-polymer coarse aggregate from fly ash. The development will help in replacing natural aggregates reducing the impact on environment. NTPC's research project on production of Geo-polymer coarse aggregate from fly ash has met the statutory parameters of Indian Standards and was confirmed by National Council for Cement and Building Materials (NCCBM). NTPC has successfully developed Geo-polymer coarse aggregates as a replacement to natural aggregates. The technical parameters as per Indian standards for its suitability to use in concrete works were tested by NCCBM,

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Hyderabad and the results are in acceptable range. The development is NTPC's R & D achievement in expanding the horizon in ash utilization. India's demand for these aggregate touches close to 2000 million metric tons mark every year. The aggregate developed by NTPC from fly ash will help in meeting the demand to a great extent and also will reduce the impact on environment caused by Natural aggregates which require quarrying of natural stone.

No.	Code Samples	Fly ash (%)	Alkali (%)	Molarity NaOH (mol / liter)	Na_2SiO_3/ NaOH
1	1.5-1	75	25	8	1.5
2	1.5-2	75	25	8	1.5
3	1.5-3	75	25	8	1.5
4	1.5-4	75	25	8	1.5
5	1.5-5	75	25	8	1.5
6	1.5-6	75	25	8	1.5
7	2.0-1	75	25	8	2.0
8	2.0-2	75	25	8	2.0
9	2.0-3	75	25	8	2.0
10	2.0-4	75	25	8	2.0
11	2.0-5	75	25	8	2.0
12	2.0-6	75	25	8	2.0
13	2.5-1	75	25	8	2.5
14	2.5-2	75	25	8	2.5
15	2.5-3	75	25	8	2.5
16	2.5-4	75	25	8	2.5
17	2.5-5	75	25	8	2.5
18	2.5-6	75	25	8	2.5

Table 1: The Design of A Fly Ash Geopolymer Paste Mixture

In India, every year, approximately 258 MMT of ash is produced by the coal fired thermal power plants. Out of this around 78% of the ash is utilized and the balance remains unutilized which remain in ash dykes. NTPC is exploring alternate ways to utilize the remaining ash which includes the current research project to generate aggregates using more than 90% ash.

The Geo-polymer aggregates finds its extensive usage in construction industry turning the ash eco-friendly. These aggregates are extremely environment friendly and does not require any cement for application in concrete where the fly ash based Geopolymer mortar acts as the binding agent. The Geo-polymer aggregates will help in reducing carbon emission and has great potential for reduction of water consumption.

Figure 1: Fly Ash and Geopolymer Aggregates

IV. MATERIALS

4.1 Fly Ash

Fly ash used is the remaining coal combustion from Paiton Steam Power Plant unit 5 and 6, Probolinggo Regency, East Java Province. The chemical element content testing is done at PT. Sucofindo Surabaya as shown in Table 2. Visual fly ash can be seen in Fig. 1. Based on their chemical content shown in Table 2, fly ash Patient is categorized in class F. This indicates by the amount of Al_2O_3, SiO_2 and Fe_2O_3 content by 74.39%, greater than 70% (ASTM C 618-96). According to the results obtained, generally coal is grouped in anthracite or bitumminous coal types. Anthracite or bitumminous coal is a type of coal having high carbon content, low moisture content, and slow speed in combustion.

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According to the American Concrete Institute (ACI) Committee 116R, fly ash is defined as 'the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gasses from the combustion zone to the particle removal system' (ACI Committee 232 2004). Fly ash is removed from the combustion gases by the dust collection system, either mechanically or by using electrostatic precipitators, before they are discharged to the atmosphere. Fly ash particles are typically spherical, finer than Portland cement and lime, ranging in diameter from less than 1 µm to no more than 150 µm. The types and relative amounts of incombustible matter in the coal determine the chemical composition of fly ash. The major influence on the fly ash chemical composition comes from the type of coal. The combustion of sub-bituminous coal contains more calcium and less iron than fly ash from bituminous coal.

4.2 Alkali Activator

The alkaline activator to the fly ash geopolymer mixture is a mixture of Sodium Hydroxide (NaOH) and Sodium Silicate (Na2SiO3). More detail description of the alkali activator used can be seen as follows: (a) Sodium Hidroksida (NaOH) It is used Sodium Hydroxide in the form of flake with a purity rate of 98%. It is also used Sodium Hydroxide in the form of flake as a solution that is dissolved by aquades. The concentration of Sodium Hydroxide used in this study is 8M. Fig. 2 (a and b) shows the flake and Sodium Hydroxide (NaOH) solutions. (b) Sodium Silicate (Na2SiO3) It is used Sodium Silicate in the form of viscous liquid (gel) with ready-made state. The most common alkaline activator used in geo polymerization is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate concluded that the type of activator plays an important role in the polymerization process. Reactions occur at a high rate when the alkaline activator contains soluble silicate, either sodium or potassium silicate, compared to the use of only alkaline hydroxides. It is confirmed that the addition of sodium silicate solution to the sodium hydroxide solution as the alkaline activator enhanced the reaction between the source material and the solution. Furthermore, after a study of the geo polymerization of sixteen natural Al-Si minerals, they found that generally the NaOH solution caused a higher extent of dissolution of minerals than the KOH solution.

4.3. Geopolymer

Polymer is a class of materials made from large molecules that are composed of a large number of repeating unit. The molecular structure of the unit that makes up the large molecules controls the properties of the material. The non-crystalline or amorphous state is the state when the regularity of atomic packing is completely absent. The most familiar kind of an amorphous solid is glass. Geopolymers are a member of the family of inorganic polymers, and are a chain structures formed on a backbone of Al and Si ions. The chemical composition of this geopolymer material is similar to natural zeolitic materials, but they have amorphous microstructure instead of crystalline.

V. KEY HIGHLIGHTS

- The Geo-polymer coarse aggregates will replace natural aggregates such as cement.
- NCCBM tested the technical parameters and the suitability to use it in concrete works.
- The results were found in acceptable range by the National Council for Cement and Building Materials (NCCBM) and was recommended for use in building construction as a substitute for natural aggregates such as cement.
- Fly ash will help in meeting India's demand of 2000 million metric tons every year for these aggregates for infrastructural development.
- The NTPC-Ramagundam's achievement will also help in minimizing the impact on the environment.
- Geo-polymer aggregate is an achievement in expanding the horizon in ash utilization and has been developed as a part of the concept of waste-to-best, using fly ash generated in the thermal power plant.

VI. RESULTS

The results of the compressive strength test as well as the complete density of the geopolymer paste samples in various compositions are shown in Table 2 below.

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TABLE 3.Test results of fly ash geopolymer samples

Mixed Number	Code Sample	Weight (gr)	Density (gr/cm^3)	Compressive strength (MPa)	Mixed Number	Code Sample	Weight (gr)	Density (gr/cm^3)	Compressive strength (MPa)
1	1.5-1	29,50	2,35	36,35	10	2.0-4	29,80	2,37	25,91
2	1.5-2	29,40	2,34	23,27	11	2.0-5	28,90	2,30	30,01
3	1.5-3	30,10	2,39	53,33	12	2.0-6	29,40	2,34	78,99
4	1.5-4	30,00	2,39	49,83	13	2.5-1	28,80	2,29	19,72
5	1.5-5	29,30	2,33	78,07	14	2.5-2	28,80	2,29	27,73
6	1.5-6	29,10	2,31	47,71	15	2.5-3	28,80	2,29	40,66
7	2.0-1	30,20	2,40	48,77	16	2.5-4	29,00	2,31	27,07
8	2.0-2	31,60	2,51	36,50	17	2.5-5	29,30	2,33	30,47
9	2.0-3	29,50	2,35	23,93	18	2.5-6	28,60	2,28	37,06

Table 2: Test Result of Fly Ash Geopolymer Samples

VII. Conclusion

- Fly ash-based geopolymer is potentially used as an artificial aggregate material for as a replacement aggregate in a concrete asphalt mixture.
- The quality of artificial aggregate can be increased by increasing the compressive strength of the geopolymer paste.
- The compressive strength of the fly ash base-geopolymer paste can be increased by modifying the alkali activator, ie the ratio of Na2SiO3 to NaOH, and the molarity of NaOH.
- Higher compressive strength leads to better result of artificial aggregate properties therefore, it is necessary for well plan of the fly ash based-geopolymer paste mixture.
- The successful utilization of aggregate made from fly ash based-geopolymer, will reduce the use of natural aggregate, so that it can be considered as a form of attention to the depletion of natural resources.

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