DISSERTATION

ENGINEERING PROPERTIES OF LIGHTWEIGHT CONCRETE USING POLYMER ARTIFICIAL LIGHTWEIGHT AGGREGATES

Submitted in partial fulllment of the requirements for the degree of Doctor in Engineering Science, Academic Discipline of Civil Engineering

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FINAL DISSERTATION REPORT

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I hereby declare the originality of this dissertation. This dissertation is supervised by a promoter and two co-promoters and does not involve any plagiarism. If it's found any plagiarism in this dissertation, I am willing to accept any academic sanction complying with the determined deregulation of Sriwijaya University for its consequences.

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FOREWORD

Praise be to the presence of Allah SWT for all His mercy and grace in allowing me to complete the dissertation entitled "Engineering Properties of Lightweight Concrete Using Polymer Artificial Lightweight Aggregates" on time. This dissertation is one of the requirements for obtaining a Doctorate degree in the Engineering Science Study Program (S3) at the Faculty of Engineering, Sriwijaya University. On this occasion, the author would like to express his appreciation and sincere thanks to all parties who have provided moral and material support so that this dissertation can be completed well. The author would like to express his thanks to:

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9) Friends from the same class have struggled with the author in completing this dissertation.

Even though I have tried to complete this dissertation as well as possible, the author realizes that there are still several shortcomings in writing this dissertation. Therefore, the author expects constructive criticism and suggestions from readers to improve any deficiencies in the preparation of this dissertation. Finally, the author hopes that this dissertation can be useful for readers and other interested parties.

Palembang,   March 2024

Ani Firda

SUMMARY

ENGINEERING PROPERTIES OF LIGHTWEIGHT CONCRETE USING POLYMER ARTIFICIAL LIGHTWEIGHT AGGREGATES

DISSERTATION

Ani Firda; Supervised by Prof. Dr. Ir. H. Anis Saggaff, MSCE, IPU, MKU, ASEAN.Eng, APEC-Eng, Dr. Ir. Saloma, ST, MT, IPU, Dr. Ir. Hanafiah, MS, IPM

viii + 166 pages, 46 Tables, and 97 Figures

Concrete is a very important element and is widely used in various construction work industries, but concrete has a weakness: its specific gravity is quite large (2200 – 2500 kg/m3). In concrete, aggregate occupies 60% -80% of the concrete volume, affecting the specific gravity of the concrete. Using lightweight aggregate is one way to reduce weight and increase the strength and durability of concrete. In Indonesia, coal fly-ash (CFA) availability is relatively abundant, but the utilization level is still low, causing environmental problems. To overcome this, CFA can be used as a raw material for making polymer artificial ligtweigth aggregates (PLA). In this research, PLA was made by mixing CFA taken from PT. Pupuk Sriwijaya with epoxy resin hardener (ERh) which has low viscosity and meets ASTM standards with a ratio of 2:1. In this research, PLA was made by mixing CFA taken from PT. Pupuk Sriwijaya with Epoxy Resin + Hardener (ERh) which has low viscosity and meets ASTM standards with a ratio of 2:1. The resulting PLA will have characteristics like natural coarse aggregate (split), both in terms of specific gravity and compressive strength.

The PLA manufacturing process is carried out using a simple mixing method using 15 different compositions. The ratio between CFA: ERh is 50:50; 55:45 ; 60:40, 65:35 ; 70:30 ; 72:28 ; 74;26 ; 76:24 ; 78:22 ; 80:20 ; 82:18 ; 84:16 ; 86:14 ; 88:12 ; 90:10. Hardening time (PLA) was taken for 6 hours, 12 hours, 24 hours, 3 days, 7 days, 14 days, 21 days, and 28 days, each with a total of 1200 test objects. Based on the 15 PLA compositions made, 3 PLA compositions were selected which had a hardening time of 6 hours, specific gravity of 1400-1800 kg/m3, and met the standards for compressive strength of structural concrete (>17 MPa). PLA_70:30 is used as a substitute for coarse aggregate for lightweight concrete with a quality of 30 MPa, PLA_76:24 with a concrete quality of 20 MPa, and PLA_80:20 with a quality of 17.5 MPa. The use of PLA in lightweight concrete mixtures can reduce the bulk weight of concrete by 12.72%.

The compressive strength produced by concrete using PLA_76:24 and PLA_80:20 can meet the planned compressive strength quality, but PLA_70:30 does not meet the planned quality compressive strength. From the results of SEM tests carried out on lightweight concrete samples, the bond between PLA_70:30 and the mortar in lightweight concrete looks weak; this is due to the smooth texture of PLA_70:30 with tiny pores causing the adhesive strength of the mortar. PLA_70:30 is weak and affects the compressive strength value of the resulting concrete. The results of durability testing using sulfuric acid and brackish water immersion showed that lightweight concrete had higher resistance than normal concrete; however, the resistance of lightweight concrete to high temperatures with combustion for 3 hours was lower than that of normal concrete. This decrease was caused by the PLA used in lightweight concrete mixtures containing epoxy resin susceptible to high temperatures (fire). Apart from that, the age of PLA when used in lightweight concrete mixtures does not significantly influence the strength of the concrete.

Keywords: Coal Fly-Ash, Epoxy Resin, Polymer Artificial Lightweight Aggregate, Lightweight Concrete

Reference: 47

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CHAPTER I
INTRODUCTION

1.1. Background

Concrete is a very important element and is widely used as a building material in the construction sector. Several advantages of concrete include relatively inexpensive price, high compressive strength, greater resistance to the environment, different shape configurations, and relative safety against fire. However, concrete also has several weaknesses, including low tensile strength, brittle properties, and a relatively large specific gravity, namely 2200 – 2500 kg/m^3. To overcome this, a lighter type of concrete is made, called lightweight concrete.

In mixing concrete, aggregate is a reinforcing and filler material which occupies 60% - 80% of the total volume of concrete. Therefore, the aggregate is one part that is very influential in the properties of concrete or mortar. For example, it can determine the weight of concrete. The use of lightweight aggregates as a concrete mix will reduce the weight of the concrete and affect its strength.

Structural lightweight aggregate concrete is made with structural lightweight aggregates as defined in ASTM C330. Light-weight concrete has a minimum 28-day compressive strength of 2500 psi (17 MPa) and an average density of 70 to 120 lb/ft^3 (1120 to 1920 kg/m^3). It consists entirely of lightweight aggregate or a combination of lightweight aggregate and aggregate normally (ACI 213R-03). Artificial lightweight aggregates must pass a stability test, have an absorbency that does not exceed 20%, and not dissolve more than 12% in magnesium sulfate (ASTM C330 – 09).

Lightweight aggregate can be divided into two parts, namely natural lightweight aggregate, and artificial lightweight aggregate. Natural lightweight aggregates are natural rocks that have been crushed, such as pumice, scoria, tuff, breccia, and volcanic ash. According to Aiman (2016), artificial lightweight aggregates can be made using industrial waste such as metal sludge, mining waste, palm shells, paper sludge, waste sludge, steel slag, bottom ash, coal fly-ash, sea clay, and others. The use of artificial lightweight aggregates can help conserve natural resources because the amount of aggregate available in nature is decreasing. Continuous extraction of natural aggregates can damage the environment. The use of lightweight aggregates made from waste can reduce costs as well as overcome environmental problems caused by this waste.

In Indonesia, one of the easily available abundant wastes is coal fly-ash, a waste product from burning coal in a steam power plant furnace. It is smooth, circular and pozzolanic due to its high silica and alumina content. Based on data from the Directorate General of Electricity, Ministry of Energy and Mineral Resources in 2018, the projection and demand for coal until 2027 are 162 million tons. The challenges faced in utilizing coal fly-ash include waste volume, quality, and location. The volume of coal fly-ash used is still low, with only a maximum of 45 per cent as a substitute for raw materials. The quality of coal fly-ash itself varies and fluctuates, making it easier to use. The location of the factory determines the transportation costs, which will affect the overall cost of fly-ash waste management. (Directorate General of Electricity, Ministry of Energy and Mineral Resources, 2018).

One solution that can be done is to utilize coal fly-ash (CFA) by making lightweight aggregates. Lightweight aggregates are made using the same principle of mixing raw materials, agglomeration, hardening or binding of particles, and then further processing such as curing and sintering. According to Shanko (2017), four methods can be used to produce aggregates from this waste, including sintering, autoclaving, cold bonding, and geopolymer methods.

Several studies related to the manufacture of lightweight fly-ash aggregates using the sintering method have been carried out, including those conducted by Punlert et al. (2017). This research was conducted by making lightweight aggregates from a mixture of clay and fly-ash with a ratio of 80:20, using a sintering temperature of 1210ºC. The results of the study were able to form lightweight aggregates with a density of 1660 kg/m^3, a compressive strength of 25 MPa, and a water absorption of 0.55%. The use of this lightweight aggregate as a substitute for coarse aggregate in lightweight concrete can produce concrete with a specific gravity of 1780kg/m^3, water absorption of 3.55%, compressive strength of 40.94 MPa, and heat conductivity of 0.77 Wm $^{-1}$ K $-^{1}$. The research results can reduce the weight of concrete by more than 25% but have the same compressive strength as ordinary concrete. This shows that lightweight aggregates can be applied to structural concrete to reduce workload and increase construction safety.

In addition to using the sintering method, lightweight aggregates can also be made using the polymerization method. Joseph Davidovits, 2020, in his book entitled "Geopolymer Chemistry and Applications", says that geopolymer lightweight aggregates are lightweight aggregates that use basic materials such as silicon (Si) and aluminium (Al). Yliniemia et al. (2017) made lightweight geopolymer aggregates using fly-ash and alkaline activation. The results showed that geopolymer lightweight aggregates had physical properties comparable to commercial clay lightweight aggregates (LECA). Mortar and concrete made with geopolymer aggregates have higher mechanical strength, dynamic modulus of elasticity, and density than concrete produced with LECA.

The use of fly-ash has also been carried out in various other industrial fields, such as research by Sim et al. (2020), in his research entitled "Preparation of Fly-ash/Epoxy Composites and Its Effects on Mechanical Properties". This study aims to increase the strength and electrical properties and reduce the weight of polymer matrix composite materials. A fly-ash/epoxy composite is made using fillers from fly-ash and epoxy. The type of epoxy used is a type of thermoset resin, namely epoxy resin. Epoxy resin was chosen because it has shrinkage properties, good adhesion, and high strength. The mechanical properties of the composite were determined by changing the volume of fly-ash to 10%, 30% and 50% by weight. Two fly-ash sizes were used to determine the effect of particle size on the composite, namely 90 μm and 53 μm sieve sizes. To optimize the fabrication conditions, the viscosity of the fly-ash/ epoxy slurry was measured at various temperatures with different fly-ash volume fractions. In terms of mechanical properties, the tensile strength increases with the increasing amount of fly-ash up to a critical limit and then decreases with a greater increase. Fracture behaviour tensile test specimens show weak interlocking bonds face filler /matrix and correlate with tensile properties. Therefore, the optimum fly-ash content to increase tensile properties is 30 % by volume. The compressive strength increases continuously due to differences in the compressive properties of the epoxy matrix.

In concrete, strength is affected by the mechanical strength of the aggregate and the characteristics of the aggregate's adhesion to the mortar. Aggregate gradation must consist of various sizes and shapes to obtain a better bond. Better bonds lead to better interlocking between aggregate and mortar particles. The higher the elastic modulus of the aggregate, the higher the strength. The strength value of the concrete obtained from the test results is generally lower than the strength value of the aggregate forming it.

In high-strength concrete, concrete collapse usually occurs due to the failure of the bond between the cement paste and aggregate. Therefore, the aggregate used must have a strong bond with the mortar. The bond strength of mortar and aggregate in the transition zone is the main factor that determines the abrasion resistance of concrete. The release of the bond between the coarse aggregate and the cement paste generally causes structural failure in the splash zone area.

The availability of fly-ash, which has abundant pozzolanic properties and the advantages of epoxy resin as a binder, has the potential to be used in the manufacture of artificial aggregates. A mixture of fly-ash and epoxy resin with an optimum composition is expected to be an alternative material for making polymer-made aggregates that have superior physical and mechanical properties. This polymer-made aggregate will be formed like crushed aggregate with properties similar to natural aggregates to provide bonding and *interlocking* between the aggregate and mortar particles.

This crushed aggregate will have several exposed sides/broken areas, where these parts have fly-ash grains still attached and not coated with epoxy resin (due to the breaking process). When mixed into the concrete mix, crushed aggregate with fly-ash grains on each side will react with the mortar and form a better bond, which is expected to increase strength and improve the quality of lightweight concrete.

Based on the problems mentioned above, this dissertation will present and discuss the effect of using polymer artificial lightweight aggregates made from fly-ash and epoxy resin as a substitute for coarse aggregates in lightweight concrete mixtures on physical properties, mechanical properties, and microstructural properties.

1.2. Research Background

Concrete is a mixture of cement, water, fine aggregate, and coarse aggregate in the form of crushed stone or gravel and other additives. Concrete is currently widely used in the world of construction as a building structure that functions to withstand loads. However, concrete is a relatively heavy material, with a specific gravity ranging from 2.5 or 2500 kg/m^3. One way to overcome this is to make concrete lighter, namely with a weight of less than 1850 kg/m^{3,} which is called lightweight concrete.

There have been several previous studies discussing lightweight concrete technology, one of which is by replacing some or all of the natural aggregates in the concrete mixture to become lighter aggregates. Lightweight aggregates are made from a mixture of fly-ash plus other materials such as clay, alkaline, etc., using various methods such as sintering, autoclaving, cold bonding, and geopolymer methods. Besides requiring quite a long time, the process of making lightweight aggregates also requires quite a lot of energy because it uses a combustion temperature of more than 1000ºC.

Based on the preceding, this dissertation research proposes the use of polymer artificial lightweight aggregates made from a mixture of coal fly-ash and epoxy resin with a certain composition. The method used in the manufacture of polymer artificial lightweight aggregates uses a simple mixing method with a short processing time, making it easy for mass production. This polymer artificial lightweight aggregate will be crushed to resemble the shape of natural broken aggregate.

The process of breaking polymer artificial lightweight aggregates into crushed aggregates uses a *stone crusher*. This crushed aggregate has a combination of grain sizes and shapes that are rounded, elongated, and angular. This shape can provide good interlocking between aggregates, good adhesion to the concrete mortar, and affect *workability* during the concrete mixing process. It is hoped that on some sides of the broken aggregate, there will be coal fly-ash grains attached to the aggregate and not coated with epoxy resin so that if the aggregate is mixed into the concrete mix, the coal fly-ash grains can react with the cement, resulting in a better bond between the aggregates, with mortar. This aggregate is expected to have characteristics like natural aggregates, have a lower specific gravity than natural aggregates, and meet the compressive strength requirements for lightweight structural aggregates. This polymer artificial lightweight aggregate, when used as a concrete mix, will produce concrete that meets the standards for lightweight structural concrete, namely concrete that has a specific gravity of less than 1920 kg/m^3 and a compressive strength of more than 17.5 MPa.

1.3. Research Objective

Based on the problems above, it can be formulated the objectives of the research to be carried out as follows:

1. To determine the characteristics of the materials used in the manufacture of polymer artificial lightweight aggregates.
2. To determine the optimal composition of a mixture of coal fly-ash and epoxy resin as a raw material for polymer artificial lightweight aggregates by a proposed new polymer.
3. To investigate the physical, mechanical, and microstructure properties of the proposed new polymer artificial lightweight aggregates.
4. To investigate the effect of the proposed new polymer artificial lightweight aggregates on concrete.

1.4. Scope of Work

The limitations of this study are:

1. *Coal fly-ash* used for the manufacture of lightweight aggregates comes from the coal-burning waste of PT. Pupuk Sriwidjaja Palembang.

2. *The epoxy resin* used is a type *of epoxy resin grout* which has super low viscosity (super dilute), high strength, is solvent-free and meets ASTM C 881 – 78 type I, Grade 1, Class B + C standards. The ratio between Epoxy Resin: Hardener is 2:1 by weight.

3. The method for making polymer artificial lightweight aggregates (PLA) uses a simple mixing method. Composition between Coal Fly-Ash (CFA): Epoxy Resin Hardener (ERh) is 50:50, 55:45, 60:40, 65:35, 70:30, 72:28, 74:26, 76:24, 78:22, 80:20, 82:18, 84:16, 86:14, 88:12, 90:10 against weight.

4. The hardening time for polymer artificial lightweight aggregate (PLA) is taken for 6 hours, 12 hours, 24 hours, 3 days, 7 days, 14 days, 21 days, 28 days, each with a total of 1200 speciments.

5. Pengujian polymer artificial lightweight aggregate mengacu pada standar ASTM untuk pengujian agregat kasar, meliputi pengujian berat jenis, absorpsi, kadar air, keausan, dan impact. Testing of polymer artificial lightweigt aggregates (PLA) refers to ASTM standards for testing coarse aggregates, including specific gravity, absorption, air content, abrasion and impact tests.Design concrete quality f'c = 30 MPa using a CFA : ERh composition of 70:30, f'c = 20 MPa using a CFA : ERh composition of 76:24, f'c = 17.5 MPa using a CFA : Erh composition of 80:20. The polymer artificial lightweight aggregate (PLA) is shaped like crushed aggregate, with a maximum size of 20mm.Variables in this research include PLA composition, PLA density, PLA compressive strength, design concrete quality, concrete age, concrete density, concrete compressive strength, flexural tensile strength, and concrete durability. Laboratory examination and testing of lightweight concrete materials refers to the *American Standard Testing and Materials* (ASTM).

6. The concrete mix design refers to the *American Concrete Institute* (ACI) standards.

7. The tests carried out on lightweight concrete included testing the compressive strength of the concrete with 56 speciments and testing the flexural strength with 9 speciments.

8. Concrete durability testing was carried out by immersion in 1% and 2% sulfuric acid water for a total of 18 speciments, immersion in brackish water for a total of 9 speciments, and high temperature firing for 1 hour, 2 hours and 3 hours for a total of 27 speciments.The control sample uses concrete quality f'c = 30 MPa with 68 spaciments, f'c = 20 MPa with 50 speciments and f'c = 17.5 MPa with 50 speciments.

1.5. Research Benefits

The benefits of this research can be described as follows:

1. Optimum utilization of coal fly-ash as a polymer artificial lightweight aggregate forming agent for lightweight concrete mixes could reduce the environmental pollution from by-product of coal.

2. Generate new materials made from waste that have similar properties to typical aggregates.

3. Alternatives to the use of new materials in the manufacture of lightweight concrete, namely the use of coal fly-ash + epoxy resin to form polymer artificial lightweight aggregates, have the potential to replace coarse aggregates.

4. The proposed material can be produced easily and quickly, thereby saving time in the construction process, and providing economic value for the community to open new business fields.

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