DISSERTATION

CHARACTERISTICS OF GEOPOLYMER ARTIFICIAL AGGREGATE USE IN NORMAL CONCRETE

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

Bimo Brata Adhitya
NIM. 03013682025011

DEPARTMENT OF ENGINEERING SCIENCE
FACULTY OF ENGINEERING
UNIVERSITY OF SRIWIJAYA

2024

CHARACTERISTICS OF GEOPOLYMER ARTIFICIAL AGGREGATE USE IN NORMAL CONCRETE

FINAL DISSERTATION REPORT

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

Prepared by:

Bimo Brata Adhitya
NIM: 03013681924022

Approved on
Palembang, March , 2024

Promoter:

Prof. Dr. Ir. H. Anis Saggaff, MSCE, IPU, MKU, ASEAN.Eng, APEC-Eng
NIP. 196210281989031002

Co-Promoter-1:	Co-Promoter-2:
Dr. Ir. Saloma, ST, MT, IPU	Dr. Ir. Hanafiah, MS, IPM
NIP. 197610312002122001	NIP. 195612311985031020

Acknowledge by,

Dean of Engineering Faculty	Coordinator of Study Program
Prof. Dr. Eng. Ir. H Joni Arliansyah, MT.	Prof. Dr. Ir. Nukman, MT.
NIP. 196706151995121002	NIP. 195903211987031001

PAGE OF APPROVAL

This is to certify that the dissertation by Bimo Brata Adhitya, entitled "Characteristics of Geopolymer Artificial Aggregate use in Normal Concrete" has been defenced in front of the examination committee of Engineering Science Department, Faculty of Engineering, University of Sriwijaya on the 27th of February 2024.

Palembang, March 2024

Signed by the examination committee

Chairman of commitee:

Prof. Dr. Eng. Ir. H Joni Arliansyah, MT.
NIP. 196706151995121002 ( )

Committee Members:

1. Prof. Dr. Ir. Mahmood Md Tahir
   Universiti Teknologi Malaysia ( )

2. Associate Prof. Ir. Dr. Shek Poi Ngian
   Universiti Teknologi Malaysia ( )

Acknowledge by,

Dean of Engineering Faculty	Coordinator of Study Program
Prof. Dr. Ir. H. Joni Arliansyah, MT	Prof. Dr. Ir. Nukman, MT.
NIP. 196706151995121002	NIP. 195903211987031001

Declaration of Originality/Plagiarism Declaration

Name : Bimo Brata Adhitya

NIM : 03013682025011

Title : Characteristics of Geopolymer Artificial Aggregate use in Normal Concrete

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.

Palembang, March 2024

Bimo Brata Adhitya

NIM. 03013682025011

FOREWORD

Praise be to the presence of Allah SWT for all His mercy and grace in allowing me to complete the dissertation entitled "Characteristics Of Geopolymer Artificial Aggregate Use In Normal Concrete" 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:

1) Mother, father, and extended family, who are the author's source of strength, thank you for all the prayers and love that are continuously poured out and for all the examples that have been given so that the author can be patient and continue to persevere in completing this education.
2) Prof. Dr. Ir. H. Anis Saggaff, MSCE, IPU, MKU, ASEAN.Eng, APEC-Eng as Promoter, has shared and taken the time to provide direction, motivation, and guidance in this dissertation's research and writing process.
3) Dr. Ir. Saloma, ST, MT, IPU as Co-Promoter, has provided extraordinary guidance and input for the perfection of this dissertation.
4) Dr. Ir. Hanafiah, MS, IPM as Co-Promoter, has provided guidance, inspiration, and convenience so that this dissertation can be completed quickly.
5) Prof. Dr. Eng. Ir. H. Joni Arliansyah, MT, as Dean of the Faculty of Engineering, Sriwijaya University.
6) Prof. Dr. Ir. Nukman, MT, as Head of the Engineering Science Study Program Doctoral, Faculty of Engineering, Sriwijaya University.
7) My beloved wife and my children who have provided prayers, encouragement, and support while completing this education, thank you for being able to endure to accompany and understand; your endless love enabled the author to achieve this dissertation.

8) The leadership and all lecturers at Sriwijaya University for the assistance given to the author both morally and materially while the author completed his education.
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, Mei 2024

Bimo Brata Adhitya

SUMMARY

CHARACTERISTICS OF GEOPOLYMER ARTIFICIAL AGGREGATE USE IN NORMAL CONCRETE

This papers is in the form of a dissertation, May 2024

Bimo Brata Adhitya; Promoted by Prof. Dr. Ir. H. Anis Saggaff, MSCE, IPU, Dr. Ir. Hanafiah, MS, and Dr. Saloma, ST, MT

The amount of natural coarse aggregate available is decreasing as construction demand grows and rock resources are exploited. The present decrease in the amount of natural aggregates poses an imminent threat to the concrete industry's sustainability, necessitating a quest for alternatives for natural coarse aggregates in concrete manufacturing. Artificial Geopolymer Aggregate manufactured from fly ash is a substitute to natural aggregate as a concrete filler. In the present study, class F fly ash from coal combustion residue at PT. Pupuk Sriwijaya was utilized as a precursor, with Na_2SiO_3 and NaOH solution acting as alkali activators.

This study assessed the compressive strength of geopolymer using 5 cm x 5 cm x 5 cm cube specimens dated 7 days. The geopolymer mixture is constructed based on numerous parameters, including fly ash (FA)/alkali activator (AA) mass ratio, Na_2SiO_3/NaOH mass ratio, NaOH concentration, sand/fly ash mass ratio, oven curing temperature, and oven curing time. After obtaining the highest compressive strength for each parameter, the mixtures were blended and the compressive strength test was performed again to determine the optimal compressive strength. The mixture with the greatest capacity for compression is subsequently used for manufacturing artificial geopolymer aggregates via pelletization and crushing.

Artificial geopolymer aggregates generated by pelletization and crushing were evaluated for aggregate characteristics and compared to natural coarse aggregates from the Merak quarry. This study examined moisture content, specific gravity, water absorption, sieve analysis, and aggregate impact value (AIV). Concrete test specimens were subsequently manufactured using three different types of coarse aggregate and a design compressive strength f'c of 30 MPa. Furthermore, The present research examined the compressive strength, split tensile strength, and density of concrete at ages 3, 7, 14, and 28 days as well.

The research indicates that the ideal geopolymer composition involves a mass ratio of 2.75 FA/AA and 3.5 Na_2SiO_3/NaOH. The Sand/FA possesses an added mass ratio of 0.15. To achieve the highest compressive strength, apply 15M NaOH and cure at 80℃ for 24 hours in the oven. The optimum mixture has a compressive strength of 71.28 MPa. Natural aggregate has a bulk-specific gravity SSD value of 2.55, while crushing aggregate has a value of 2.08, and pelletization aggregate has a value of 2.078. Natural aggregate contains 4.30% water content, while crushing aggregate has 1.81% and pelletization aggregate has 1.05%. Water absorption values for natural aggregate are 4.96%, crushing aggregate is 10.66%, and pelletization aggregate is 6.413%. The AIV values for natural aggregate is 1.452%, crushing aggregate is 17.4%, and pelletization aggregate is 8.66%. Natural aggregate concrete has a compressive strength after 28 days of 32.13 MPa, whereas crushing aggregate concrete has the lowest value of 29.13 MPa. Pelletization aggregate concrete has a compressive strength of 31.78 MPa. Natural aggregate concrete has a 28-day split tensile strength of 4,153 MPa, while crushing aggregate concrete has the lowest at 3.7 MPa. Pelletization aggregate concrete has a split tensile strength of 4,017 MPa. The density of natural aggregate concrete is 2307.78 kg/m^3, while crushing aggregate has a density of 2023.92 kg/m^3. Pelletization aggregate concrete has a density of 2023.92 kg/m^3.

Concrete with geopolymer aggregate using the pelletization method has a compressive strength that is 1.09% smaller than natural aggregate concrete and has a lighter density of 11.57%. Pelletization aggregate concrete has a compressive strength above design f'c of 30 MPa. Meanwhile, concrete with crushing aggregate has a compressive strength that is 9.34% lower than the compressive strength of concrete with natural aggregate and has a concrete density that is 12.30% lighter than concrete with natural aggregate. Crushing concrete aggregate has a compressive strength that is slightly below the design compressive strength f'c of 30MPa. This shows that artificial geopolymer aggregate using the pelletization method can achieve the design compressive strength and with a lighter weight it will reduce the self-load on the building so that it can lighten the load carried by a building structure. For further research regarding the use of geopolymer artificial aggregate in concrete, it can be studied further regarding the manufacturing process which is easier to work on and can be studied from an economic perspective.

Keywords: fly ash, artificial aggregate, compressive strength

LIST OF CONTENTS

LIST OF TABLE

LIST OF FIGURE

CHAPTER 1
INTRODUCTION

1.1. Introduction

Earthquakes pose significant risks to buildings and infrastructure, causing widespread destruction and loss of life.To mitigate these risks, the use of lightweight construction materials has emerged as a crucial factor in earthquake resilience. The use of lightweight construction materials offers several advantages in earthquake-prone areas. One key advantage is that lightweight materials reduce the overall mass of the structure, which can decrease the forces exerted on the building during an earthquake. Additionally, these materials are often more flexible than traditional construction materials, allowing them to better withstand the lateral forces and vibrations experienced during an earthquake.

In earthquake-prone areas, the choice of construction materials can significantly impact the structural integrity and safety of buildings. Therefore, it is essential for architects, engineers, and policymakers to prioritize the use of lightweight construction materials in their designs and building codes. By incorporating these materials, communities can enhance their resilience to seismic events, ultimately reducing the impact of earthquakes on both infrastructure and human life.

Furthermore, ongoing research and development in the field of lightweight construction materials are leading to innovative solutions that offer improved strength, durability, and cost-effectiveness. (Xin Lu, 2023). As such, the continued exploration and utilization of these materials are vital to advancing earthquake resilience in vulnerable regions. In recent years, advancements in the production of lightweight construction materials have resulted in the development of new composite materials that exhibit exceptional strength and resilience (Yong et al., 2023). These innovative materials offer the potential to further enhance the earthquake resilience of structures in vulnerable areas. Additionally, the use of lightweight materials can also contribute to sustainable construction practices, as they often require less energy to produce and transport compared to traditional construction materials.

Incorporating lightweight construction materials into building codes and standards can lead to a significant reduction in the vulnerability of buildings to earthquake damage. This proactive approach not only ensures the safety of occupants but also minimizes the need for costly repairs and reconstruction in the aftermath of seismic events.

Since Indonesian territory is situated on the line of the equator, there are numerous slopes and mountains. According to the Ministry of Education and Culture, Indonesia spans three plates: Australian, Eurasian, and Pacific. This places Indonesia within the ring of fire. This is the reason why earthquakes in Indonesia to occur frequently: as of early August 2021, the National Board of Natural Disaster (BNPB) reported 22 earthquakes. Building in earthquake-prone areas requires careful consideration of construction technologies. The casualties were not directly caused by the earthquake, but by the fallen construction that impacted them. Because of this, lightweight construction is critical.

Natural or crushed stone is commonly utilized as coarse aggregate in the making of concrete. Various forms of natural rock have been utilized in the concrete business, depending on the local geology conditions, such as limestone, basalt, and gravel. However, with the increasing demand for construction and the rapid consumption of rock resources, the amount of natural rock available has decreased, posing a significant challenge for the sustainable development of the concrete industry to find other alternatives to replace natural stone as coarse aggregate in concrete production. To achieve sustainable development, additional efforts must be made to eliminate natural aggregate scarcity and improve the sustainability of the concrete industry (Xu *et al.*, 2021).

To overcome the challenges of decreasing the availability of natural coarse aggregate in nature, three technological routes have been proposed as an alternative to natural aggregate in concrete production: recycling aggregates from waste concrete, using coarse waste particles as aggregates such as large particle bottom ash and steel slag, and producing artificial aggregates. According to industrial waste or by-products. As technology advances, artificial production methods become a viable option for producing fine and coarse aggregates that meet waste requirements (Xu *et al.*, 2021).

Lightweight concrete is a type of construction that has a lower density than standard concrete. The maximum unit weight for lightweight concrete is 1800 kg/m^3 (SNI-03-3449-2002). In order to achieve this weight, a lighter replacement material is required. Fly ash and bottom ash are lightweight materials that can be utilized to replace traditional concrete components.

Fly Ash and Bottom Ash, also known as FABA, are ash created during combustion that is considered waste and must be disposed according to (Ministry of Industry, 2021), FABA production from Electric Steam Power Plant (Pembangkit Listrik Tenaga Uap/PLTU) is expected to reach 12 million of tons in 2021, and 16.2 million tons by 2027. FABA is commonly found in the power generation business, particularly in plants that use coal as a raw material. The amount is abundant and only becomes waste material, necessitating processing to minimize it. The amount of FABA produced has been significantly reduced, although it is still insignificant in comparison to the FABA generated today.

The use of waste resources is one of the way to reduce the problem of waste processing. From a different perspective, waste re-use can significantly save natural resource reserves that cannot be recovered, reduce environmental contamination, and lessen the need for recycled energy production. Industrial trash and byproducts must be recognized as materials having a high potential for reuse. With the proper treatment and processes, it is possible to manufacture environmentally friendly items. FABA is one of the materials that can be used as a substitute for cement by combining it with an activator to achieve geopolymer bond strength. It can be used as a raw material in addition to being an FABA binder. Fly ash (FA) and alkali activator (AA) can be used to form artificial aggregates. Alkali activator is a chemical that can react with fly ash to generate a binding similar to a binder. The most commonly used alkaline activators are NaOH and Na_2SiO_3. The common mix ratio for artificial aggregates is 3:1 (Dewa Made Alit Karyawan *et al.,* 2020).

The production of artificial aggregates necessitates an additional procedure that comprises the design of the FA/AA mixture ratio, $N_{a2}SiO_3$/NaOH ratio, and NaOH concentration. Following the determination of the mixture ratio, the production process proceeds with the mixing of the ingredients. There are two methods for producing artificial aggregates: utilizing a stone crusher and mixing.

The components with a granulator tool (Hui-Teng *et al.*, 2021; Xu *et al.*, 2021). This study focuses on the crushing process for producing geopolymer lightweight aggregates, which have an important future for large-scale industrial production. Geopolymer cubes measuring 100 mm × 100 mm × 100 mm were manufactured using one-part technology and crushed into coarse aggregates with angular shapes (Xu *et al.*, 2021). Figure 1.1 shows the outcomes of making aggregates.

Figure 1.1. Artificial coarse aggregate by stone crusher method (Xu *et al.*, 2021)

Coarse aggregate was made by mixed material and input into a granulator, this mixing also has parameters that must be met in order to achieve the best outcomes, as proven by various publications that have conducted study by focusing on mixing aspects such as granulator slope, rotation speed, mixing duration, and water content. The results of making aggregates can be seen in Figure 1.2.

Figure 1.2. Artificial Aggregate by granulator tool (Hilda Yuliana *et al.,* 2019)

The curing process, which comes after the aggregates are mixed, can be broken down into three categories: water curing (which requires temperatures between 21 and 25 degrees Celsius), oven curing (which requires temperatures between 70 and 100 degrees Celsius), and sintering (which requires temperatures above 900 degrees Celsius) (Zhao *et al.*, 2021). Depending on the curing procedure employed, this treatment method has varying results.

1.2. Research Questions

The goal of this study was to provide an insight into the manufacture of lightweight concrete using artificial aggregates using activator and fly ash. This aggregate can be used to study the characteristics of artificial aggregates in terms of strength, durability, and ease of production, as well as to substitute environmentally friendly aggregates. Once manufactured, the aggregate can be used to make lightweight concrete. This is how the dissertation's problem is formulated:

1. What is the optimal material composition for geopolymer artificial aggregate in light-weight concrete production?
2. How do granular tool and stone crusher procedures affect the mechanical properties of Geopolymer Artificial Aggregates?
3. What characteristics and properties does the proposed geopolymer artificial aggregated concrete possess?

1.3. Research Objective

The following are the research goals for the production of artificial aggregates:

1. To identify the optimal material composition for geopolymer artificial aggregates.
2. To investigate the mechanical properties of artificial geopolymer aggregates produced utilizing the stone crusher and granular tool technologies.
3. To investigate the properties of the proposed artificial aggregated concrete composed of geopolymer.

1.4. Scope of Work

The focus of this research is a laboratory-scale investigation into the production of lightweight concrete using fly ash-based geopolymer artificial aggregates. Based on previous research findings, the initial composition of artificial aggregate production has been determined. Next, mixed test specimens are made for each change in the parameter being examined. The FA/AA weight ratio, Na_2SiO_3/NaOH, and NaOH concentration, as well as the percentage of sand added to the fly ash, the drying temperature in the oven, and the duration of drying in the oven, are the parameters.

The most optimal compressive strength is then obtained from the new mixture which is then used as an artificial aggregate mixture using crushing and pelletization methods. Compared with natural aggregates, the characteristics of artificial aggregates produced using both processes were evaluated according to ASTM criteria.

Lightweight concrete made using artificial aggregates was tested for its properties, and the results were compared with control concrete made with natural aggregates.

To examine research on lightweight concrete using geopolymer artificial aggregates using pelletization and crushing methods, scope of work for this research has been prepared so that the discussion is more focused and can be directed so that it can answer the research questions carefully and not be divided into other discussions. The following is the scope of work in this research :

1. The fly ash used comes from burning coal from PT. Pupuk Sriwijaya with varying FA/AA weight ratios of 1.75, 2, 2.25, 2.5, 2.75, 3, 3.25.
2. The alkali activator used is sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) with varying weight ratios of 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5.
3. The sodium hydroxide (NaOH) used in this research uses variations of 9 M, 10 M, 11 M, 12 M, 13 M, 14 M, 15 M, 16 M, and 17 M.
4. Adding sand to the geopolymer mixture uses sand from Tanjung Raja with variations of 0, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.40, and 0.60 to the weight of fly ash.

5. Geopolymer mixture with oven curing time parameters varying 6, 12, 18, 24, 48, and 72 hours.
6. Geopolymer mixture with oven curing temperature parameters varying from 50, 80, 110, and 140°C.
7. Test the fly ash properties with XRD, XRF, and SEM.
8. The three types of coarse aggregate, namely natural aggregate, pelletization aggregate, and crushing aggregate, have their properties tested using specific gravity, water absorption, water content, sieve analysis, and aggregate impact value (AIV).
9. Concrete is tested for its mechanical properties by testing compressive strength, tensile strength, and density at ages 3, 7, 14 and 28 days.

1.5. Significant of Study

One of the technologies that can be used to reduce the consumption of natural aggregates is the production of artificial aggregates. A need to utilize the fly-ash from coal so as to minimize the environmental impact due to coal production. Due to the demand for extremely quick construction, there are less natural aggregates in the environment. Fly ash-based artificial aggregate is one type of artificial aggregate that can be used as a substitute for natural aggregates. Because fly ash is lightweight, it can be utilized as an element in lightweight concrete. Fly ash is used as an artificial aggregate.

1.6. Dissertation Layout

The structure of the research is described in this section according to each chapter ; **CHAPTER 1: INTRODUCTION;** This chapter describes the research background which includes the formulation of the problem, research background, research objectives, scope of work, and Dissertation framework. **CHAPTER 2: LITERATURE REVIEW;** In this chapter, many previous studies are discussed as the basis for research knowledge. Several studies on mix composition and literature on the manufacture of lightweight concrete aggregates are also presented. **CHAPTER 3: RESEARCH METHODOLOGY;** This chapter presents the research flowchart. The proposed connection is described and the test settings are presented in the table. **CHAPTER 4: RESULTS AND DISCUSSIONS ;**This chapter describes the result of the experiment resuls and disscused by comparing and enriching the result from previous studies accordingly. **CHAPTER : CONLUSIONS;** This chapter contains the conclusions and suggestions of the research.

REFERENCES

Abas, M., Salem, A., & Pandey, R. K. (2015). Influence of Specific Gravity on Weight of Proportions of Concrete. *International Journal of Engineering Research & Technology*, *4*(2), 1–3. www.ijert.org

Abdullah, A., Abdullah, M. M. A. B., Hussin, K., Junaidi, S., & Tahir, M. F. M. (2018). Effect of fly ash/alkaline activator ratio on fly ash geopolymer artificial aggregate. *AIP Conference Proceedings*, *2045*(January 2021). https://doi.org/10.1063/1.5080915

Abdullah, S. F. A., Liew, Y. M., Abdullah, M. M. A. B., Heah, C. Y., & Zulkifly, K. (2018). The effect of aggregate content on the expanded lightweight aggregate geopolymer concretes. *AIP Conference Proceedings*, *2045*(December). https://doi.org/10.1063/1.5080910

Adak, D., Sarkar, M., & Mandal, S. (2014). Effect of nano-silica on strength and durability of fly ash based geopolymer . *Construction and Building Materials*, *70*, 453–459. https://doi.org/10.1016/j.conbuildmat.2014.07.093

Aldin, Z. (2017). Optimization of a geopolymer mixture for a Reinforced cantilever concrete bench. Thesis project TU DELFT.Reinforced cantilever concrete bench. Thesis project TU DELFT.

A.M. Mustafa Al Bakri, Kamarudin, H., Bnhussain, M., Nizar, I. K., & Mastura, W. I. W. (2013). Mechanism and Chemical Reaction of Fly Ash Geopolymer Cement- A Review. *Journal of Chemical Information and Modeling*, *53*(5), 1689–1699.

Almukabir, Muhammad Romadinu; Fitri, R. (2020). Scanned with CamScanner. *Narratives of Therapists' Lives*, 231.

Al, M., & Ahyudanari, E. (2019). *ScienceDirect* Analysis the Use of Artificial Aggregates As a Substitute of Coarse Agreggates for Surface of Flexible Pavement on Optimum Bitument Content. 00(2).

Anugraha, R. B., & Mustaza, S. (2010). Beton Ringan dari Campuran Styrofoam dan Serbuk Gergaji dengan Semen Portland 250, 300 dan 350 kg/m3. *Jurnal Aplikasi Teknik Sipil*, *8*(2), 57. https://doi.org/10.12962/j12345678.v8i2.2722

Avanaki, M.J., Moradikhou, A.B., & Esparham, A. (2020). Effect of Various

Alkaline Activator Solutions on Compressive Strength of Fly Ash-Based Geopolymer Concrete, *Journal of Civil Engineering and Materials Application*, 4(2), 115-123.

Balapour, M., Zhao, W., Garboczi, E. J., Oo, N. Y., Spatari, S., Hsuan, Y. G., Billen, P., & Farnam, Y. (2020). Potential use of lightweight aggregate (LWA) produced from bottom coal ash for internal curing of concrete systems. *Cement and Concrete Composites*, *105*, 103428. https://doi.org/10.1016/j.cemconcomp.2019.103428

Baykal, G., & Döven, A. G. (2000). Utilization of fly ash by pelletization process; theory, application areas and research results. *Resources, Conservation and Recycling*, *30*(1), 59–77. https://doi.org/10.1016/S0921-3449(00)00042-2

Bui, L. A. T., Hwang, C. L., Chen, C. T., Lin, K. L., & Hsieh, M. Y. (2012). Manufacture and performance of cold bonded lightweight aggregate using alkaline activators for high-performance concrete. *Construction and Building Materials*, *35*, 1056–1062. https://doi.org/10.1016/j.conbuildmat.2012.04.032

Cahyaka, H. W., Wibowo, A., Handayani, K. D., Wiyono, A., & Santoso, E. H. (2018). The Effect Of Substitution Of Marble Waste In Fly Ash On Compressive Strength And Porosity Of Geopolymer Concrete At Molarity 10M. Journal of Civil Engineering, 1(1), 186–194.

Canpolat, F., & Naik, T. R. (2017). Effect of curing conditions on strength and durability of high-performance concrete. *Scientia Iranica*, *24*(2), 576–583. https://doi.org/10.24200/sci.2017.2419

Castillo, H., Collado, H., Droguett, T., Sánchez, S., Vesely, M., Garrido, P. & Palma, S. (2021)

Chanh, N.V., Trung, B.D., Tuan, D.V. (2008) “Recent research geopolymer concrete” The 3 rd ACF International Conference – ACF/VCA.

Chung, S. Y., Elrahman, M. A., & Stephan, D. (2017). Effect of different gradings of lightweight aggregates on the properties of concrete. *Applied Sciences (Switzerland)*, *7*(6). https://doi.org/10.3390/app7060585

Dewa, M. A. K. I., Ekaputri, J. J., Iswandaru, W., & Ervina, A. (2019). The effects of Na2SiO3/NaOH ratios on the volumetric properties of fly ash geopolymer artificial aggregates. *Materials Science Forum*, *967*, 228–235. https://doi.org/10.4028/www.scientific.net/MSF.967.228

Dewa Made Alit Karyawan, I., Ekaputri, J. J., Widyatmoko, I., & Ahyudanari, E. (2020). The effect of various Na2SiO3/NaOH ratios on the physical properties and microstructure of artificial aggregates. *Journal of Engineering Science and Technology*, *15*(2), 1139–1154.

Endaryanta, Faqih Ma'arif, I. M. (2012). Studi Eksperimental Kinerja Struktural Beton Ringan Aerasi (Autoclaved Aerated Concrete) Dengan Variasi Thin Bed . In *Inersia* (Vol. 8, Issue 2, pp. 92–109).

Erwin, S., Asep, S., M, I., Ferry, J., & Syahrudin, S. (2022). The Effect of Coarse Aggregate Size On Pervious Concrete Mixture. Jurnal Teknik Sipil, 22(1), 33. https://doi.org/10.26418/jtst.v22i1.55159

Frankovič, A., Bosiljkov, V. B., & Ducman, V. (2017). Lightweight aggregates made from fly ash using the cold-bond process and their use in lightweight concrete. *Materiali in Tehnologije*, *51*(2), 267–274. https://doi.org/10.17222/mit.2015.337

Gesoğlu, M., Güneyisi, E., & Öz, H. Ö. (2012). Properties of lightweight aggregates produced with cold-bonding pelletization of fly ash and ground granulated blast furnace slag. *Materials and Structures/Materiaux et Constructions*, *45*(10), 1535–1546. https://doi.org/10.1617/s11527-012-9855-9

Ghosh, B. (2017). *Fly-Ash Pellets : a Replacement of*. *5*(2), 3–7. https://doi.org/10.13140/RG.2.2.34619.11047

Gomathi, P., & Sivakumar, A. (2012). Characterization on the strength properties of pelletized fly ash aggregate. *ARPN Journal of Engineering and Applied Sciences*, *7*(11), 1523–1532.

Gomathi, P., & Sivakumar, A. (2013). Crushing strength properties of furnace slag-fly ash blended lightweight aggregates. *ARPN Journal of Engineering and Applied Sciences*, *8*(4), 246–251.

Hadi, M. N. S., Al-Azzawi, M., & Yu, T. (2018). Effects of fly ash characteristics and alkaline activator components on compressive strength of fly ash-based geopolymer . *Construction and Building Materials*, *175*, 41–54. https://doi.org/10.1016/j.conbuildmat.2018.04.092

Hanjitsuwan, S., Hunpratub, S., Thongbai, P., Maensiri, S., Sata, V., & Chindaprasirt, P. (2014). Effects of NaOH concentrations on physical and electrical properties of high calcium fly ash geopolymer paste. *Cement and Concrete Composites*, *45*, 9–14. https://doi.org/10.1016/j.cemconcomp.2013.09.012

Harijono, P. G. T. dan A. (2020). KESELAMATAN LINGKUNGAN TAHAN RESONANSI DENGAN BETON RINGAN BAHAN STYROFOAM (Suatu Kajian Teori Tahan Gempa). *Jurnal Ilmiah Teknologi FST Undana*, *14*(1), 30–36.

Harikrishnan, K. I., & Ramamurthy, K. (2006). Influence of pelletization process on the properties of fly ash aggregates. *Waste Management*, *26*(8), 846–852. https://doi.org/10.1016/j.wasman.2005.10.012

Hassan, A., Arif, M., & Shariq, M. (2019). Use of geopolymer concrete for a cleaner and sustainable environment – A review of mechanical properties and microstructure. *Journal of Cleaner Production*, *223*, 704–728. https://doi.org/10.1016/j.jclepro.2019.03.051

Hilda Yuliana, A., Dewa Made Alit Karyawan, I., Murtiadi, S., Ekaputri, J. J., & Ahyudanari, E. (2019). The effect of slope granulator on the characteristic of artificial geopolymer aggregate used in pavement. *Journal of Engineering Science and Technology*, *14*(3), 1466–1481.

Hui-Teng, N., Cheng-Yong, H., Yun-Ming, L., Abdullah, M. M. A. B., Ern Hun, K., Razi, H. M., & Yong-Sing, N. (2021). Formulation, mechanical properties, and phase analysis of fly ash geopolymer with ladle furnace slag replacement. *Journal of Materials Research and Technology*, *12*, 1212–1226. https://doi.org/10.1016/j.jmrt.2021.03.065

Huiskes, D. M. A., Keulen, A., Yu, Q. L., & Brouwers, H. J. H. (2016). Design and performance evaluation of ultra-lightweight geopolymer concrete. *Materials and Design*, *89*, 516–526. https://doi.org/10.1016/j.matdes.2015.09.167

Ikomudin, R. A., Herbudiman, B., & Irawan, R. R. (2016). Ketahanan Beton

Geopolimer Berbasis Fly Ash terhadap Sulfat dan Klorida. *Jurusan Teknik Sipil Itenas*, *Vol.2*(No.4), 33–43.

Khedmati, M., Alanazi, H., Kim, Y. R., Nsengiyumva, G., & Moussavi, S. (2018). Effects of Na2O/SiO2 molar ratio on properties of aggregate-paste interphase in fly ash-based geopolymer mixtures through multiscale measurements. *Construction and Building Materials*, *191*, 564–574. https://doi.org/10.1016/j.conbuildmat.2018.10.024

Kockal, N. U., & Ozturan, T. (2011). Characteristics of lightweight fly ash aggregates produced with different binders and heat treatments. *Cement and Concrete Composites*, *33*(1), 61–67. https://doi.org/10.1016/j.cemconcomp.2010.09.007

Kumar, S., Gautam, P.D., Sarath, B., & Kumar, C. (2019) Effect of Alkali Activator Ratio on Mechanical Properties of GGBS based Geopolymer Concrete International Journal of Innovative Technology and Exploring Engineering, .8(12), 947-952.

Kupaei, R. H., Alengaram, U. J., & Jumaat, M. Z. (2014). The Effect of Different Parameters on the Development of Compressive Strength of Oil Palm Shell Geopolymer Concrete. Scientific World Journal,

Lăzărescu, A. V., Szilagyi, H., Baeră, C., & Ioani, A. (2017). The Effect of Alkaline Activator Ratio on the Compressive Strength of Fly Ash-Based Geopolymer Paste. *IOP Conference Series: Materials Science and Engineering*, *209*(1). https://doi.org/10.1088/1757-899X/209/1/012064

Le, H. B., Bui, Q. B., & Tang, L. (2021). Geopolymer recycled aggregate concrete: From experiments to empirical models. *Materials*, *14*(5), 1–22. https://doi.org/10.3390/ma14051180

Leong, H. Y., Ong, D. E. L., Sanjayan, J. G., & Nazari, A. (2016). The effect of different Na2O and K2O ratios of alkali activator on compressive strength of fly ash based-geopolymer. *Construction and Building Materials, 106,* 500–511. https://doi.org/10.1016/j.conbuildmat.2015.12.141

Louis, Y. M., & Hardjito, D. (2004). Peningkatan Durbalita Brton Konvensional Dan HVFA Yang Menggunakan Metode Perawatan Steam Curing Dengan Coating Larutan Alkali Dan Pasta Geopolimer. *Jurnal Teknik Sipil*, 1–8.

Manikandan, R., & Ramamurthy, K. (2007). Influence of fineness of fly ash on the aggregate pelletization process. *Cement and Concrete Composites*, *29*(6), 456–464. https://doi.org/10.1016/j.cemconcomp.2007.01.002

Nath, P., & Sarker, P. . . (2012). Geopolymer concrete for ambient curing condition. *Australasian Structural Engineering Conference 2012: The Past, Present and Future of Structural Engineering*, *January*, 1–9.

Nath, P., & Sarker, P. K. (2014). Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition. *Construction and Building Materials*, *66*, 163–171. https://doi.org/10.1016/j.conbuildmat.2014.05.080

Niveditha, M., & Koniki, S. (2020). Effect of Durability properties on Geopolymer concrete - A Review. *E3S Web of Conferences*, *184*, 1–4. https://doi.org/10.1051/e3sconf/202018401092

Okoye, F. N., Durgaprasad, J., & Singh, N. B. (2015). Flyash/Kaolin Based Geopolymer Green Concretes and Their Mechanical Properties. *Data in Brief*, *Elsevier Inc*, 739–744.

Oktaviastuti, B., Pandulu, G. D., & Lusyana, E. (2021). Kuat Tekan Beton Geopolymer Berbahan Dasar Abu Terbang (Fly Ash) Sebagai Alternatif Perkerasan Kaku di Daerah Pesisir. *Reka Buana : Jurnal Ilmiah Teknik Sipil Dan Teknik Kimia*, *6*(1), 78–87.https://doi.org/10.33366/rekabuana.v6i1.2271

P Iyappan G R, I. A. (2023). The Study on The Effect of Clay Content in Fine Aggregate and its Impact on The Compressive Strength of Concrete. *IJIRST-International Journal for Innovative Research in Science & Technology*|, *2*(11), 435–440. www.ijirst.org

Pane, F. P., Tanudjaja, H., & Windah, R. S. (2015). Pengujian kuat tarik lentur beton dengan variasi kuat tekan beton. *Jurnal Sipil Statik, 3*(5), 313–321.

Parvathy S, S., Sharma, A. K., & Anand, K. B. (2019). Comparative study on synthesis and properties of geopolymer fine aggregate from fly ashes. *Construction and Building Materials*, *198*, 359–367. https://doi.org/10.1016/j.conbuildmat.2018.11.231

Rabiaa, E., Mohamed, R. A. S., Sofi, W. H., & Tawfik, T. A. (2020). Developing Geopolymer Concrete Properties by Using Nanomaterials and Steel Fibers.

Advances in Materials Science and Engineering, *2020*. https://doi.org/10.1155/2020/5186091

Rahman, A., & Jaya Ekaputri, J. (2018). The effect of additional aluminium to the strength of geopolymer paste. *MATEC Web of Conferences*, *195*, 1–8. https://doi.org/10.1051/matecconf/201819501011

Rajamane, N. P., Nataraja, M. C., Lakshmanan, N., Dattatreya, J. K., & Sabitha, D. (2012). Sulphuric acid resistant eco-friendly concrete from geopolymerisation of blast furnace slag. *Indian Journal of Engineering and Materials Sciences*, *19*(5), 357–367.

Ramesh, V., & Srikanth, K. (2020). Mechanical Properties and Mix Design of Geopolymer concrete - A review. *E3S Web of Conferences*, *184*. https://doi.org/10.1051/e3sconf/202018401091

Risdanareni, P., Schollbach, K., Wang, J., & De Belie, N. (2020). The effect of NaOH concentration on the mechanical and physical properties of alkali activated fly ash-based artificial lightweight aggregate. *Construction and Building Materials*, *259*, 119832.
https://doi.org/10.1016/j.conbuildmat.2020.119832

Rommel, E., Kurniawati, D., & Putra Pradibta, A. (2015). Perbaikan Sifat Fisik Dan Reaktifitas Fly Ash Sebagai Cementitious Pada Beton. Jurnal Media Teknik Sipil, 12(2), 111–118. https://doi.org/10.22219/jmts.v12i2.2282

Rytis Skominas., Vincas Gurskis., Raimondas Šadzevičius., Dainius Ramukevičius. (2019). Effect Of Aggregates Impurity On Concrete Properties. *Proceedings of the 9 th International Scientific Conference Rural Development 198-202,*.

Ryu, G. S., Lee, Y. B., Koh, K. T., & Chung, Y. S. (2013). The mechanical properties of fly ash-based geopolymer concrete with alkaline activators. *Construction and Building Materials*, *47*(2013), 409–418.
https://doi.org/10.1016/j.conbuildmat.2013.05.069

Saxena, S. K., & Kumar, M. (2018). Influence of alkali solutions on properties of pond fly ash-based geopolymer cured under different conditions. *Advances in Cement Research*, *30*(1), 1–7. https://doi.org/10.1680/jadcr.17.00038

Shivaprasad, K. N., & Das, B. B. (2017). *Influence of Alkali Binder Dosage on the Efficiency of Pelletization of Aggregates from Iron ORE Tailing and Flyash.*

2(3), 388–392.

Shivaprasad, K. N., & Das, B. B. (2018). Determination of optimized geopolymerization factors on the properties of pelletized fly ash aggregates. *Construction and Building Materials*, *163*, 428–437. https://doi.org/10.1016/j.conbuildmat.2017.12.038

Shivaprasad, K. N., Das, B. B., & Sharath, B. P. (2020). Pelletization factors on the production of fly-ash aggregates and its performance in concrete. *Proceedings of the Institution of Civil Engineers - Construction Materials*, 1–20. https://doi.org/10.1680/jcoma.19.00053

Saleem N. *et al.,* Appraisal of geopolymer lightweight aggregates sintered by microwave radiations, J. Asian Concr. Fed, vol. 6, pp. 37–49, 2020.

Srinivasan, K., & Sivakumar, A. (2013). Geopolymer Binders A Need for Future Concrete Construction. *ISRN Polymer Science,*

Sun, D., Huang, W., Liu, K., Ma, R., Wang, A., Guan, Y., & Shen, S. (2022). Effect of the Moisture Content of Recycled Aggregate on the Mechanical Performance and Durability of Concrete. Materials, 15(18). https://doi.org/10.3390/ma15186299

Tadesse Abegaz, G., Khan, I., & Mosisa Legese, A. (2020). Investigating the Effects of Coarse Aggregate Physical Properties on Strength of C-25 Concrete. American Journal of Engineering and Technology Management, 5(5), 84. https://doi.org/10.11648/j.ajetm.20200505.12

Tajra, F., Abd Elrahman, M., Lehmann, C., & Stephan, D. (2019). Properties of lightweight concrete made with core-shell structured lightweight aggregate. *Construction and Building Materials*, *205*, 39–51. https://doi.org/10.1016/j.conbuildmat.2019.01.194

Tajra, F., Elrahman, M. A., & Stephan, D. (2019). The production and properties of cold-bonded aggregate and its applications in concrete: A review. *Construction and Building Materials*, *225*, 29–43. https://doi.org/10.1016/j.conbuildmat.2019.07.219

Tang, P., Florea, M. V. A., & Brouwers, H. J. H. (2017). Employing cold bonded pelletization to produce lightweight aggregates from incineration fine bottom ash. *Journal of Cleaner Production*, *165*, 1371–1384.

https://doi.org/10.1016/j.jclepro.2017.07.234.

Waghmare, J. D., Patil, S. S., Patil, S. M., & Maske, M. M. (2022). ASEAN Journal of Science and Engineering Study and Review of Properties and Applications of Portland Pozzolana Cement. *Ajse*, *2*(3), 217–222.

Wattanachai, P., & Suwan, T. (2017). Strength of Geopolymer Cement Curing at Ambient Temperature by Non-Oven Curing Approaches: An Overview. IOP Conference. Series: *Materials Science and Engineering 212*.

Xu, L. Y., Qian, L. P., Huang, B. T., & Dai, J. G. (2021). Development of artificial one-part geopolymer lightweight aggregates by crushing technique. *Journal of Cleaner Production*, *315*(January), 128200.

Yu, R., Van Onna, D. V., Spiesz, P., Yu, Q. L., & Brouwers, H. J. H. (2016). Development of Ultra-Lightweight Fibre Reinforced Concrete applying expanded waste glass. *Journal of Cleaner Production*, *112*, 690–701. https://doi.org/10.1016/j.jclepro.2015.07.082

Yu, Q. L., Spiesz, P., & Brouwers, H. J. H. (2015). Ultra-lightweight concrete: Conceptual design and performance evaluation. *Cement and Concrete Composites*, *61*, 18–28. https://doi.org/10.1016/j.cemconcomp.2015.04.012

Zhao, J., Wang, K., Wang, S., Wang, Z., Yang, Z., Shumuye, E. D., & Gong, X. (2021). Paste Cured at Room Temperature. *Polymers*, *13*, 1473.