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The ACE Project: Creation of an Eco-Friendly Brick Best Suited for the Indonesian Environment

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Abstract
This paper presents a comparative analysis to address the question: Can eco-friendly cement bricks outperform traditional Indonesian clay bricks and regular cement bricks in terms of cost, strength, and performance, thus being a viable building material in the Indonesian construction sector? Throughout this experiment, the researcher determined the validity of alternative cement through three factors: cost, carbon emissions produced, and the strength of the bricks tested. The cost and carbon emissions produced were determined by the data from scholarly sources; however, the brick strength was tested both in a lab, through a compression strength test, and in the current environment, through building a 2m by 2m prototype house.

Despite initial test and research suggesting that alternative cement offers environmental, structural, and economical benefits, further investigation is required to validate these findings, as the experiment remains in its early stages.

Keywords: fly-ash cement, eco-friendly cement bricks, clay bricks, carbon emissions, environmental sustainability

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I. Introduction

8% of global emissions arise from cement production (Ellis et al., 2019), which is equivalent to 1.7 billion metric tons of global carbon dioxide emissions caused by the cement manufacturing industry alone (Tiseo, 2023). In the thriving and vibrant construction industry of Jakarta, many faults persist, including poor air quality and the need to enhance environmental sustainability. As Indonesia strives to reduce carbon emissions, alternative cement emerged as a possible solution. Thinking of implementing this solution for Indonesia, the researcher developed her own version of fly-ash cement - a form of alternative cement, proven to produce stronger, less permeable, and more cost-effective construction materials, as it utilizes the by-product of coal-burning power plants to replace some of the cement and water in bricks. This eco-friendly variant of cement intrigued this researcher during her time at an Environmental Solutions course at Stanford University. Using a polluting waste product to replace the majority of cement in bricks will reduce the carbon dioxide produced by creating cement, which allows for a sustainable and eco-friendly brick. Every kilogram of cement replaced by fly-ash saves 0.9 kilograms of carbon dioxide from being emitted into the atmosphere (Fayomi et al., 2019).

II. Literature Review

The most influential resources used to aid the information provided in this research were these two sources:

1. Evaluation of Alternative Home-Produced Concrete Strength with Economic Analysis: Muhammad Rauf Shaker, Mayurkumar Bhalala, Qayoum Kargar, and Byungik Chang.
    a. This paper compared the costs of ready-mix concrete to alternative materials used in concrete such as fly-ash, wood-ash, and recycled aggregates. This paper also investigates the percentage in which users can replace cement with the materials mentioned above without compromising the original compressive strength of regular cement. Additionally, this paper mentions the carbon dioxide emissions saved from using alternative materials.
2. Perspectives on environmental CO2 emission and energy factor in Cement Industry: Gbenga Fayomi, Simphiwe Enoch Mini, Ojo Sunday Isaac Fayomi, and Ayodeji Ayoola.
    a. This paper analyzes the carbon emissions released through the cement-making process, more specifically the additive ratio, consumption mix, and manufacturing process. The authors investigated the components of clinker used in Portland cement, the carbon dioxide emissions released through the different types of fuel and clinker ratios used for the different cement formula ratios, and historical trends of cement production in different countries. Experimental Program (Method)

III. Experimental Program (Method)

For the first experiment, the concrete mixture was poured into a 10cm 22cm 6.5cm wooden brick mold. The materials used, fly-ash, cement, and river sand, were sourced from the same location. A nearby construction shop provided the cement and river sand, while the fly-ash was sourced from the Paiton PLTU power plant factory. The cement (including fly-ash if applicable) to sand ratio was 1:2. There are two main mixtures: Control (regular Portland cement), and the fly-ash replacement.

The total number of mixtures is 8, where the cement is partially replaced by different dosages of fly-ash. The replacement fly-ash to cement ratios are 2:0.5, 3:0.5, 2:1, 4:0.5, 5:0.5, 1:1, and 1.5:1. The bricks were dried outside for at least two days to solidify. The table below reflects the following proportions and labels that will be discussed during the Tests section of this paper.

Formula (labeled on brick)	Fly-Ash to Cement Ratio
1	2:0.5
2	3:0.5
3	2:1
4	5:0.25
5	4:0.5
6	5:0.5
7	1:1
8	0:1 (control)
9	1.5:1

Table 1 *Composition (fly-ash to cement ratio) of each brick*

Figure 1. *Handmade bricks used in the testing stage*

The next phase of the testing stage was to determine whether alternative cement bricks could withstand the current Indonesian environment; therefore, after analysis of the lab results, the researcher proceeded to mass-manufacture the strongest brick formula at a local workshop. Additionally, traditional Indonesian clay and sand bricks, Portland cement bricks, and a 80% fly-ash and 20% clay brick were created for a comparative analysis of alternative cement and commonly used bricks in Indonesia. Each wall consisted of a different type of brick supported by concrete pillars. A local workshop in Malang mass-manufactured 500 of each brick. The clay bricks are 4cm 9.5cm 19cm in size, and the bricks including cement are 6cm 10.5cm 21cm. The proportions and composition of each brick is described in Table 2. To track the progression of each brick, the researcher compiled pictures of each wall every two weeks to analyze any changes in the brick appearance or degradation (refer to the Appendix A.).

Brick Code/Name	Composition Ratio
Bata 1 and Bata 2	100% (Clay)
Bata 3 and Bata 4	4:1 (Fly-ash to clay)
Parling 1 and Parling 2	100% (Cement)
Parling 3 and Parling 4	1.5:1 (Fly-ash to cement)

Table 2. *Proportions and composition of each brick(Shaker et al., 2020)*

Figure 2. *Tracking the progression of each brick*

IV. Tests

4.1 Compressive Strength Test

The test is conducted to evaluate whether the strength of different fly-ash mixtures could surpass the strength of concrete bricks. Furthermore, this test also determines whether these bricks adhere to the regular FC20 standard. The first test was performed on 10cm 22cm 6.5cm bricks. The second experiment tested the two types of 4cm 9.5cm 19cm clay bricks and the two variations of the 6cm 10.5cm 21cm cement bricks that were used in building the prototype house, which served to determine which type of the brick could withstand the current Indonesian environment the best. All compression strength tests were carried out in the construction and concrete technology lab in Universitas Tarumanagara (UNTAR). The machinery was handled by UNTAR lab personnel.

4.2 Price

Another aspect of this report was analyzing the cost-effectiveness of alternative cement compared to regular Portland cement. The price comparison was determined by the cost analysis of a research paper titled “Evaluation of Alternative Home-Produced Concrete Strength with Economic Analysis” (Shaker et al., 2020), which also analyzes the price of resources required to manufacture bricks with recycled aggregates, fly-ash, and regular cement bricks.

4.3 Carbon Emission

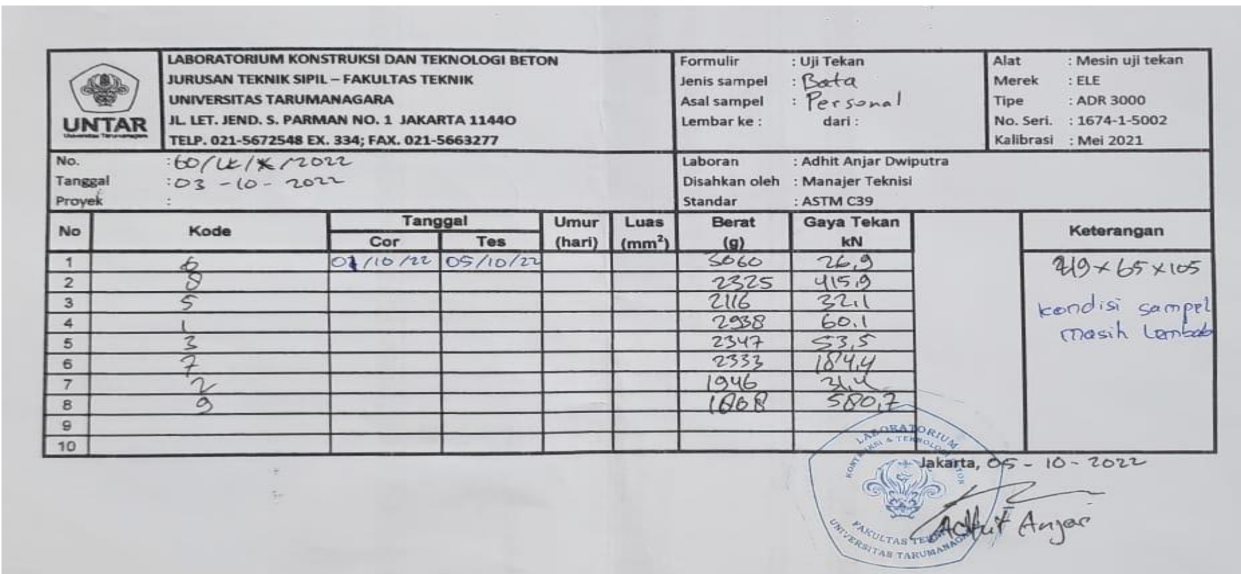
The purpose of this test was to determine the carbon emissions produced through manufacturing regular Portland cement compared to fly-ash cement. This comparison is based on the idea that fly-ash is readily available nearby the manufacturing area; therefore, the emissions of transporting the fly-ash from the source to the workshop are not accounted for. However, the transportation emissions from transporting these bricks to Jakarta is included.

V. Results and Discussion

Based on this experiment and the conclusions from other research-based papers, the results strongly suggest that fly-ash bricks are stronger, more environmentally-friendly, and cost-effective compared to traditional clay or regular Portland cement bricks.

5.1 Compressive Strength Test

Below are the lab results from the first experiment, which is the strength compression test carried out at Universitas Tarumanegara (UNTAR) for the nine bricks. Refer to Table 1 for the specific composition (fly-ash to cement ratio) of each brick.



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Laboran : Adhit Anjar Dwiputra
Disahkan oleh : Manajer Teknisi
Standar : ASTM C39

No	Kode	Tanggal Cor	Tanggal Tes	Umur (hari)	Luas (mm^2)	Berat (g)	Gaya Tekan kN	Keterangan
1	6	0[illegible]/10/22	05/10/22			3060	26,9	219 × 65 × 105
2	8					2325	415,9	
3	5					2116	32,1	kondisi sampel
4	1					2938	60.1	masih Lembab
5	3					2347	53,5	
6	7					2333	184,4	
7	2					1946	21,4	
8	9					1868	580,7	
9								
10								

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Figure 3. *Lab results from the first experiment*

The second strength compression test was carried out after the building of the prototype house. Each type of brick was tested twice, and the following results are shown below.

Brick Code/Name	Composition Ratio	Average Weight (kN)
Bata 1 and Bata 2	100% (Clay)	236.25
Bata 3 and Bata 4	4:1 (Fly-ash to clay)	122.45
Parling 1 and Parling 2	100% (Cement)	214.20
Parling 3 and Parling 4	1.5:1 (Fly-ash to cement)	277.85

Table 4. *Second strength compression test results*

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Tanggal : 02 Maret 2023
Proyek : Rumah

Laboran : Adhit Anjar Dwiputra
Disahkan oleh : Manajer Teknisi
Standar : ASTM C39

No	Kode	Tanggal		Umur	Luas	Berat	Gaya Tekan		Keterangan
		Cor	Tes	(hari)	(mm^2)	(g)	kN		
1	Bata 1	08/01/23	02/03/23			940	321,4		156 x 7,7 x 4,4
2	Bata 2					1020	151,1		
3	Bata 3					1040	150,8		
4	Bata 4					1190	94,1		
5									
6	Parling 1	08/01/23	02/03/23			2520	254.6		
7	Parling 2					2620	173.8		
8	Parling 3					2820	313.7		
9	Parling 4					2780	242.0		
10									

Jakarta, 02 Maret 2023
Adhit Anjar

Figure 4. *Lab results from the second experiment*

<u>5.1.1 Construction Aspect</u>

According to table 2, the initial strength compression test results, brick number 9, consisting of the formula with the 60% fly-ash and 30% cement ratio (table 1), was the brick that could withstand the most weight. The compression strength of brick 9 was 580.7 kN and the strength for the regular cement was 415.9 kN (table 3), portraying how brick 9 could withstand more force compared to a regular cement brick. According to the lab professional executing the compression test, the minimum strength for a brick to pass the FC20 standard was 300 kN, which brick 9 exceeded by 280.7 kN. Therefore, the results portrayed how alternative cement bricks could potentially be a stronger building material compared to the traditional cement bricks. The second compression test, comparing the different types of house bricks, conveyed similar results (table 4). The order of bricks from weakest to strongest based on the average kN is as follows: fly-ash and clay bricks (122.45 kN), cement bricks (214.20 kN), clay bricks (236.25 kN), and fly-ash bricks (277.85 kN). Theoretically, despite cement bricks being more resistant to heat and water, clay bricks can prove to have a higher compressive strength than cement (Ayu, 2009). However, the crumbly appearance on the surface of the cement bricks could suggest the lack of cohesion of the ingredients in the cement mixture; thus, lowering the compressive strength. To increase the validity and accuracy of the data presented, the researcher strongly recommended to repeat this experiment to confirm how fly-ash bricks are the strongest building material alternative. Furthermore, according to the construction worker building the 2m by 2m house, the fly-ash-cement bricks are easier to work with because they are "lighter but do not break as easily compared to the other bricks" (translated from Indonesian to English), and the worst brick was the fly-ash and clay mixture. Fly-ash has been proven to enhance the strength of bricks in the long-term due to reduced thermal cracking, as less heat is given off when fly-ash reacts with the cement and water. The very fine, powdery substance of fly-ash creates better cohesion within the cement, creating less segregation and rock-pockets compared to regular cement (Kumar Behera, 2009). Not only is fly-ash better strength-wise; however, despite the heavy rainy season these past months, the fly-ash house bricks remain intact and undamaged.

5.2 Price

Price of Regular Bricks ($/yd3):

Material	Unit Cost ($/lb)	Quantity (lbs/yd^3)	Total Cost (lbs/yd^3)
Water	$0.0010	237.67	$0.24
Cement	$0.1380	433.33	$56.33
Coarse Aggregate	$0.0098	1755.76	$16.68
Fine Aggregate	$0.0090	1583.24	$13.46
Total Cost			$85.47

***Table 6** (Shaker et al., 2020)*

Price of Fly-Ash Bricks ($/$yd^3$):

Material	Unit Cost ($/lb)	Quantity (lbs/yd^3)	Total Cost (lbs/yd^3)
Water	$0.0010	237.67	$0.24
Cement	$0.1380	173.37	$23.93
Coarse Aggregate	$0.0098	1755.76	$16.68
Fine Aggregate	$0.0090	1583.24	$13.46
Fly-Ash	$0.0120	260.06	$3.12
Total Cost			$57.43

***Table** 7 (Shaker et al., 2020)*

5.2.1 Cost-Effective Aspect:

Referring to the price comparison section (table 6 and 7), the total price for fly ash bricks ($57.43) is $28.97 cheaper than regular cement bricks ($85.40) given that fly-ash is readily available. In the production process of power plants, fly-ash is inherently generated, rendering its cost lower than that of cement. The latter necessitates a mining and refining procedure involving machinery, notably the rotary kiln, which operates on electricity or fuel. This additional process contributes to the elevated cost of cement. In the United States, the average cost of fly-ash per pound is 1.75 cents compared to cement which costs 13.8 cents per pound (Shaker, 2020), and fly-ash bricks tend to be 10-20% cheaper than clay bricks (Narayanan, 2022). Due to the cheap price of fly-ash, fly-ash cement provides companies with both an economical and environmental incentive. Making cement accessible paves a possible pathway for rebuilding sustainable communities in rural areas who previously could not afford building materials.

5.3 Carbon Emission

Emissions for each kg of portland cement:

- Manufacturing Process: 0.9kg
- Transportation to Jakarta (around 26 km): 6.76 kg
- Total Emissions: 7.66 kg

Emissions for each kg of fly-ash cement:

- Manufacturing Process: 0.54kg (since fly-ash replaces cement by 60%)
- Transportation to Jakarta: 6.76 kg
- Total Emissions: 7.30 kg

Determining the costs and carbon emissions required extensive use of the data from research papers, as they encompass a plethora of quantitative data, which allows the researcher to use a reliable average value. These sources were written by a group of credible researchers who work in universities specialized in engineering. Due to their extensive knowledge on this matter, the detailed analysis and the multitude of scholarly citations (both papers cited more than 15 sources) provided, the information presented can be considered reliable. However, due to the research being limited to the researchers' location, such as China or South Africa, the data does not accurately represent the current carbon emissions in Indonesia. Both research papers prove to have no particular bias as the "Life Cycle Assessment and Impact Correlation Analysis of Fly Ash Geopolymer Concrete" report claims to have "no conflict of research" or "received no external funding." However, both sources acknowledged the support of their corresponding universities. Even though the "Perspectives on environmental CO2 emission and energy factor in Cement Industry" paper received publication funding from Covenant University CUCRID, this university has the core values of research, innovation, and discovery; therefore, it is unlikely that this paper has a bias towards a certain perspective.

5.3.1 Environmental Aspect:

According to the carbon emissions comparison section, the total amount of carbon dioxide produced in regular concrete is 60% more than the emissions produced in the fly-ash formula. Due to the lack of efficient or electric truck transportation in Indonesia, transportation emissions are inevitable; however, the carbon emissions saved from producing fly ash cement could assist in offsetting the carbon dioxide released. Reusing fly-ash, a by-product of coal-burning power plant factories, would restrict the improper disposal of this material, hence reducing waterway or soil pollution caused by the heavy metals that make-up fly-ash (U.S Environmental Protection Agency, 2014). This solution increases the efficiency of using otherwise-wasted resources produced by one of the most heavily polluting manufacturing processes on this planet. Additionally, when 20% of cement is replaced by fly-ash, the amount of water required to create cement decreases by approximately 10% (U.S Department of Transportation, 2017); therefore, fly-ash cement aids in preserving an essential and scarce natural resource. As long as coal-burning factories remain, the supply of fly-ash will be abundant; therefore, there will be a sufficient supply of fly-ash to mass-manufacture these bricks on a large-scale. The use of fly-ash in bricks assists in preserving the planet's current resources and reducing carbon emissions.

Based on this experiment and the conclusions from other research-based papers, the results strongly suggest that fly-ash bricks are stronger, more environmentally-friendly, and cost-effective compared to traditional clay or regular Portland cement bricks.

VI. Conclusion

The present study aimed at determining what type of brick would be best for the Indonesian environment uses multiple experimental approaches. Strength compression tests were utilized both in the initial prototyping and house-building stage. A 2m by 2m prototype house was built with the purpose of comparing whether the fly-ash bricks could better withstand the current Indonesian environment compared to traditional clay, regular Portland cement, or a fly-ash and clay mixture brick. Carbon emission and cost calculations were determined by the use of a transportation carbon emissions calculator and various scholarly sources, due to the lack of equipment to accurately record the emissions during the current manufacturing process. This study incorporates a wide-range of information, from interview responses from construction workers and progression photos of the house, to data from the strength compression tests paired with experimental results from credible research papers.

The findings of this study suggest that fly-ash bricks are the strongest, most cost-effective (assuming fly-ash is readily available), and eco-friendly option amongst the other types of bricks tested. The conclusion drawn from this experiment, aligned with the data found from other scientific journals and research papers. The wide variety of data-gathering techniques enhanced the reliability and validity of this experiment; however, there were some inconsistencies between the data and the opinions of professional engineers and lab reports, such as the strength of clay bricks in comparison to cement bricks. It is recommended that future research replicates this experiment to eradicate any potential flaws in the manufacturing mixing process that could have caused the decreased strength in cement bricks.

The credibility of this research is enhanced through the sources used throughout this report. Majority of sources used were research papers written by those who have a pH.D in engineering or a group of students who attend or graduated from a university with a chemical or environmental engineering degree, who do not have conflicting interests or are paid by a private company or business corporation, hence eliminating the chances of bias.

VII. Recommendations

7.1 Strengths of method:

The usage of multiple test methods allowed for the collection of quantitative and qualitative data. While lab tests supplied precise data that allowed for an accurate comparison between bricks, the prototype house tested the capability and adaptability of these bricks in the current Indonesian environment. Interviews with the house builders on the quality and workability of the bricks paired with the bi-weekly pictures of each wall, this researcher hopes to eventually see the progression of degradation of each brick type. Therefore, with a variety of data collection methods combined and supported with data from credible sources, the information provided is suitable to answer the research question.

7.2 Weaknesses of method:

Due to the nature of this experiment being in the early testing stages, the researcher only tested each prototype brick once (table 1); therefore, there might be inconsistencies in the data. To enhance the validity of this, these bricks should be tested multiple times. Furthermore, due to time constraints, creating a definitive conclusion on the progression of the house was challenging because there is an average of 50 years before bricks degrade (Ahmad, 2017); therefore, as of April 8th 2023, the prototype house had only 2 months of exposure to real-life elements, the changes or data collected from the house is not sufficient enough to create a definitive conclusion.

Amongst the limitations of this data collection process is the insufficient collection of data due to funding constraints–the costs of running multiple trials would exceed the current budget. The lack of access to a variety of testing equipment restricted the researcher from testing the strength of concrete using other methods such as the Schmidt rebound hammer or the water permeability test. Due to the lack of availability of cement manufacturers in close proximity that would satisfy the request of providing the small number of bricks required for this experiment, the researcher chose a remote workshop approximately 18 miles from Jakarta, that would meet our request at a reasonable price. However, the distance created an obstacle for the researcher to consistently observe the cement-making process and quality check the bricks. A supervisor who helped collect footage of the cement-making process was present. However, due to the difference in machinery and time spent in mixing the ingredients together, the bricks were not identical to the ones the researcher made during her initial prototyping stage.

Due to technology limitations to accurately determine the carbon emissions produced during this experiment, the total carbon emissions below were concluded based on the results from a transportation carbon emission calculator abiding to the EU Standard EN16258, validated by Swiss federal authorities and ETH University, and scholarly papers that averaged the amount of carbon dioxide produced per kilogram of cement (Fayomi et al., 2019).

Given more time and resources in the future, the researcher hopes to continue collecting data on the degradation of these bricks, run more compressive strength tests, and expand her modes of testing, such as the permeability or hammer test, to have a wider variety of data to further answer the research question.

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Appendix A.

Picture Progression of Prototype House Walls

Brick Type	Month 1	Month 2	Month 3
Fly-ash and cement			
Clay			
Cement			

Fly-ash and clay			

Appendix B.

Below are the interview questions the researcher asked. Answers were then summarized in the paper above.

- What is the compressive strength requirement for a brick to reach the FC20 requirement?
- What type of brick has the best workability when building the house?
- Which type of brick has the best and worst durability when building the house?
- Describe the texture and physical qualities of each brick type.

Appendix C.

The picture is the machinery used for the cement strength compression test conducted in the UNTAR lab.