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# Potential Assessment of Utilizing Rice Husk Ash and Fly Ash in Concrete Production to Advance Sustainable Building Materials

**Firda Septi Wulandari[1], Anggi Rahmad Zulfikar[2*], Ridho Syaibatul[3], Anastasia Nafis[4], Hanim Mafrucha[5], Tessa Rolina[6]**
[1] Universitas Negeri Surabaya, Surabaya, Indonesia
[2*] Universitas Negeri Surabaya, Surabaya, Indonesia
[3] Universitas Negeri Surabaya, Surabaya, Indonesia
[4] Universitas Negeri Surabaya, Surabaya, Indonesia
[5] Universitas Negeri Surabaya, Surabaya, Indonesia
[6] Universitas Negeri Surabaya, Surabaya, Indonesia

Rice Husk Ash
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**ABSTRACT**

*This study explores the potential use of rice husk ash (RHA) and fly ash as partial cement substitutes in concrete production, aiming to advance sustainable building materials and reduce the environmental impact of the conventional cement industry. Cement production currently accounts for approximately 8% of total global $CO_2$ emissions, making it one of the largest contributors to greenhouse gas emissions. Given the increasing demand for cement due to urbanization and infrastructure development, the search for environmentally friendly alternatives is urgent. Rice husk ash, an abundant agricultural waste in Indonesia with a high amorphous silica content (94-97%), has been shown to improve the compressive strength and durability of concrete, with 10% ASP substitution resulting in a peak compressive strength of 56.2 MPa at 28 days and 20% ASP reducing water absorption. Similarly, fly ash from coal-fired power plants, which is rich in pozzolanic silica and alumina, is effective in reducing cement use and $CO_2$ emissions, while increasing concrete density and resistance to extreme conditions. Utilizing these two types of waste not only reduces the carbon footprint of construction and the problem of waste accumulation, but also adds economic value and encourages a circular economy, thus creating a more sustainable and environmentally friendly construction future.*

## INTRODUCTION

Sustainability is a key paradigm of the 21st century calling for systems of development that balance the environment with human needs (Agyeman et al., 2002). In the context of built environment, sustainability movement means shifting from extractive and rather high-emission practices (Berardi, 2013). It moves toward something that reduce waste and emissions as well as managing long-term resilience (Berardi, 2013). As urban growth increasing, the built environment has also increasingly become bigger. The environmental footprint of the construction industry is now widely recognized (Rockström et al., 2009). The concerns are including about how building activities contribute to climate change, biodiversity loss, and other environmental problems (Rockström et al., 2009). To address those aforementioned problems, there are demands for transformation of how our way of thinking about balancing development with environmental responsibility (Guy & Farmer, 2001).

Global greenhouse gas emissions is largely due to activities related to the construction industry (Habert et al., 2020). Especially, that is concerning with cement production (Habert et al., 2020). Worldwide, there is huge demand for cement that keep rising as the urban areas expanded and infrastructure developed (Lehne & Preston, 2018). Countries with emerging economies are experiencing such demand even bigger (Lehne & Preston, 2018). Recent innovations in material usage and carbon mitigation strategies in construction have become increasingly important (Zhang et al., 2022). That's because the world community aims for climate-resilient infrastructure (Zhang et al., 2022).

It's estimated that cement production industry at least emits 0.9 tons of $CO_2$ per ton of cement produced (Andrew, 2018). Those numbers are considered as pretty major environmental footprint (Andrew, 2018). That's big matter contributing to significant ecological degradation as well as to the environmental problem concerns in regions with large-scale quarrying operations (Freitas et al., 2019).

Stakeholders are turning to various alternative materials to decrease cement usage in concrete (Imbabi et al., 2012). Those alternative materials ought to decrease $CO_2$ emissions and at the same time also align with principles of the circular economy (Krausmann et al., 2020). Pozzolanic materials are among the most promising (Singh et al., 2021). While reducing environmental costs, they are also estimated to improve the durability and compressive strength of concrete (Singh et al., 2021).

This study explores how alternative material can be used to replace part of the cement in concrete. These materials are waste products from farming and industry, but they have useful properties. They can make concrete stronger and more durable. By using them, we can help reduce pollution from cement production and support worldwide goals for sustainable development. The study aims to look at how those materials can be practical for countries that produce large amounts of agricultural and industrial waste. In the context of Indonesia, such materials are promising. Overall, this study adds to current attempts to make construction more sustainable for the better future.

## RESEARCH METHOD

This study uses the literature review method to explore and better understand a particular topic in depth (Snyder, 2019). By reviewing and connecting previous research, this method helps open up new ways of thinking, especially in areas that are just emerging or involve multiple disciplines working together (Torraco, 2016). As part of the research process, a literature review is useful for mapping out the overall structure and key themes within a field of study (Snyder, 2019). It also plays an important role in bringing together ideas from different academic disciplines, encouraging dialogue and collaboration between them (Torraco, 2016). Moreover, literature reviews can help identify areas that have not been fully explored or that may have been overlooked in past studies, which are known as blind spots (Grant & Booth, 2009). Another benefit is that this method allows researchers to compare different viewpoints and highlight contrasting perspectives on the same issue (Rowley & Slack, 2004). Lastly, literature reviews are helpful in making sense of disagreements or debates within a topic by clearly organizing the different sides of the argument (Torraco, 2016).

## RESULTS AND DISCUSSION

## A. Environmental Impact of Cement Production and the Urgency for Alternatives

Cement production releases large amounts of $CO_2$, making it one of the largest contributors to greenhouse gas emissions in the world. According to data from various studies, the cement industry accounts for about 8% of total global $CO_2$ emissions (Rodgers, 2018). The cement-making process involves the burning of raw materials such as limestone and clay at high temperatures, which results in significant carbon dioxide emissions. Additionally, the use of fossil fuels in the production process also contributes to the increase in greenhouse gas emissions (Agreement & Tracker, 2021). With the growing awareness of climate change, it is important to highlight the negative impacts of the cement industry on the environment and human health.

However, cement production is not decreasing; in fact, it is increasing. The rising demand for cement is closely related to urbanization and the growth of concrete construction (Devi et al., 2024). In recent decades, many countries, especially developing regions like Indonesia, which is developing and building the new capital city Nusantara, have experienced a rapid surge in infrastructure development (Administrator, 2024). Large projects such as roads, bridges, and high-rise buildings require vast volumes of cement. This has adverse effects on the environment, as it not only increases $CO_2$ emissions but also leads to excessive raw material extraction, which can damage ecosystems and reduce soil quality (Agreement & Tracker, 2021). With the continuously growing population, the demand for cement is expected to keep rising, making the challenge of reducing the environmental impact of cement production increasingly urgent.

Therefore, it is crucial to seek alternative materials that can partially replace cement in concrete mixtures (Safarizki & Aji, 2020). The use of substitute materials such as rice husk ash and fly ash has proven effective in reducing the amount of cement required (Abu et al., 2021). Considering that Indonesia is an agrarian country producing about 30 million tons of rice husk waste each year (Sherly et al., 2023), utilizing rice husk ash as a cement substitute not only reduces environmental impact but also adds value to agricultural waste that has been underutilized. Rice husk ash contains high silica content, ranging from 94-97%, which has pozzolanic properties, capable of reacting with calcium hydroxide in concrete, and enhancing its strength and durability (Halim & Amiruddin, 2024). Similarly, fly ash from coal-fired power plants has the potential to replace 10% of cement in concrete mixtures (Kadarningsih, n.d.).

Previous studies have shown that substituting these materials can reduce $CO_2$ emissions, decrease cement requirements, and improve the compressive strength of concrete at 28 days (Safarizki & Aji, 2020). By effectively utilizing industrial and agricultural waste, countries around the world can build a new paradigm of sustainable construction that integrates circular economy principles, energy efficiency, and locally sourced material innovations. This integrated approach will not only help the global construction industry contribute to the emission reduction targets set in international agreements but also maintain food security through the productive use of agricultural waste. With these measures, we can create a more sustainable and environmentally friendly future for generations to come worldwide.

B. Rice Husk Ash (RHA) as a Promising Cement Substitute

Rice husk is one of the abundant agricultural wastes, especially in rice-producing countries like Indonesia. Each rice milling process generates about 20% husk from the total paddy processed, resulting in millions of tons of waste each year (Wicaksono et al., 2024). However, its utilization has not been optimal, often being burned, discarded, or sold at very low prices to small and medium enterprises (SMEs) such as fertilizer industries and others (Setyorini et al., 2023). In fact, with proper processing, rice husk can be transformed into a high-value material, particularly in the construction industry (Devi et al., 2024).

One of the most promising forms of processing rice husk is through controlled burning to produce rice husk ash. Burning under certain conditions yields ash with a very high silica ($SiO_2$) content, reaching 94-97%(Halim & Amiruddin, 2024). Interestingly, the silica in rice husk ash is amorphous, which provides high reactivity. This content gives rice husk ash its pozzolanic properties, and the reaction of silica in rice husk ash with CaO in cement can enhance the quality of concrete (Safarizki & Aji, 2020).

In the construction world, rice husk ash has been researched as a partial substitute for cement in concrete mixtures. Several studies indicate that using rice husk ash up to 5-20% of the weight of cement has the potential to improve concrete performance (Halim & Amiruddin, 2024). With the presence of active silica in rice husk ash, the hydration reaction with cement becomes more effective, resulting in concrete with better compressive strength and durability (Kozlov et al., n.d.). Additionally, rice husk ash can also function as a filler in the voids of concrete (Safarizki & Aji, 2020), enhancing the concrete's resistance to water and corrosive substances, thereby extending the lifespan of the concrete structure.

Another advantage of using rice husk ash in concrete mixtures is its positive environmental impact. The cement industry is one of the largest sources of $CO_2$ emissions globally (Purton, 2024), while the use of rice husk ash as a cement substitute can reduce the carbon footprint of construction (Life et al., 2018). Furthermore, utilizing this agricultural waste helps mitigate the problem of rice husk accumulation, which is often wasted. In the context of Indonesia, where rice production is very high, using rice husk ash as a construction material has the potential to promote a circular economy while reducing dependence on environmentally damaging cement raw materials.

Several studies on the addition of rice husk ash as a partial cement replacement have been conducted, including one by Halim and Amiruddin in 2024. Their research showed that substituting rice husk ash at a percentage of 5.7723% resulted in concrete with an average compressive strength of 32.083 MPa and a tensile strength of 3.081 MPa (Halim & Amiruddin, 2024). Additionally, research conducted by Nursyamsi and Ajuhan Febrizal Aruan in 2021 also indicated that the addition of rice husk ash could enhance the compressive strength of concrete. They found that a substitution ratio of 10% rice husk ash produced the highest compressive strength of 56.2 MPa at 28 days. This study also noted that the addition of rice husk ash contributed to a reduction in water absorption of the concrete, with the lowest absorption value recorded at a variation of 20% rice husk ash (Kozlov et al., n.d.). These findings indicate that utilizing rice husk ash can not only reduce agricultural waste but also improve the quality of concrete. Thus, the use of rice husk ash in concrete mixtures provides significant economic and environmental benefits in the construction industry.

C. Utilization of Fly Ash to Improve Concrete Sustainability and Quality

Fly ash is an industrial waste generated from the combustion of coal in coal-fired power plants (Putra et al., 2014). Historically, this waste has often been disposed of in landfills without optimal utilization, despite containing valuable chemical compounds for construction (Indrayani et al., 2019). As an abundant byproduct, fly ash can be effectively managed for various beneficial applications, such as in concrete mixtures, hollow block mixtures, brick mixtures, and even in the production of other building materials (Limbah et al., 2022). ith the right approach, fly ash can serve as a sustainable solution to reduce waste and enhance resource efficiency.

Chemically, fly ash is rich in silica and alumina, which exhibit pozzolanic properties (Anggitia, 2023). Then it reacts with calcium hydroxide in concrete during the hydration process, these compounds form additional calcium silicate hydrate (C-S-H) complexes that act as the primary binder in the concrete matrix (Sukarmo, 2020). This pozzolanic reaction increases the density of concrete by filling voids and acting as a binding agent similar to cement (Prasetyo et al., 2024). Furthermore, fly ash can enhance the resilience and durability of infrastructure against extreme conditions caused by climate change (Building, 2024).

The environmental aspect is a key advantage of using fly ash in concrete construction. The technology of partially substituting cement with fly ash can significantly reduce the use of Portland cement, thereby lowering carbon dioxide emissions (Building, 2024). Given that cement production is one of the major sources of $CO_2$ emissions globally (Purton, 2024), the use of fly ash can make a tangible contribution to mitigating the environmental impact of the construction industry (Indrayani et al., 2019). Additionally, by reducing dependence on cement raw materials, the use of fly ash can help maintain the sustainability of natural resources and lessen environmental pressure (Building, 2024).

Despite its many benefits, the utilization of fly ash must be approached with careful consideration. Some types of fly ash may contain heavy metals such as mercury, arsenic, and cadmium, which can be toxic (Anggitia, 2023). Therefore, a rigorous selection process, laboratory testing, and appropriate formulation are necessary to ensure that the resulting concrete products meet safety and technical feasibility standards for construction use. Moreover, it is essential to conduct regular monitoring of the quality of fly ash used to minimize potential risks to human health and the environment (Amrdwiptra, 2025). With proper implementation, fly ash can not only reduce the volume of industrial waste but also contribute to the creation of stronger, more durable, and environmentally friendly construction materials (Redaktur, 2025).

## CONCLUSION

This study comprehensively affirms the significant potential of rice husk ash (RHA) and fly ash as partial cement substitutes in concrete production, offering a vital solution to mitigate the substantial environmental impact of the conventional cement industry, a major contributor to global $CO_2$ emissions. The utilization of these agricultural and industrial wastes not only contributes to reducing the carbon footprint and addressing waste accumulation issues but also demonstrably enhances concrete's compressive strength and durability, aligning perfectly with circular economy principles. Therefore, the adoption of these alternative materials is crucial for advancing sustainable building materials and shaping a more environmentally friendly future for construction.

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