The Synergetic Effect of Fly Ash Concrete Mixed With Coconut Husk Ash for the Application of Sustainable Construction

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Abstract. Cement production has increased as cement is a crucial building material for residential and infrastructural development. However, cement production has become one of the significant contributors to environmental pollution as carbon dioxide emissions come from all stages of cement manufacturing. This encouraged researchers to look into industrial and agricultural wastes as partial replacements for cement. This research study investigated the synergetic effect of using fly ash (FA) from industrial waste and coconut husk ash (CHA) from agricultural waste as a mix into concrete, enhancing concrete properties and as an eco-friendly building material. Four series of concrete sample mixes were prepared, incorporating fly ash and coconut husk ash, beginning with a reference mix as the baseline, (M0): 0% FA + 0% CHA, then (M1): 10% FA + 5% CHA, (M2): 20% FA+ 10% CHA and (M3): 30% FA + 15% CHA as cement replacement were designed. The ratio of cement to sand was fixed at 1:1, where the cement content was gradually decreased and substituted with fly ash and coconut husk ash content, and the amount of water per cement ratio was fixed at 0.5. After 24 hours of hydration, the hardened concrete samples were water-cured for 3, 7 and 14 days before performing density, water absorption, and compressive strength tests. The sample morphology was examined using a field scanning electron microscope (FESEM). Results show that the incorporation of fly ash and coconut husk ash does not increase the compressive strength of concrete. The results of the density test, water absorption test, and concrete morphology were presented. Although the concrete strength was not achieved, the results suggest using a superplasticiser as a reducing agent to reduce cement bleeding and improve concrete strength.

1 Introduction

Cement is a crucial building material for residential and infrastructural developments and an economic growth driver. Cement demand is strongly related to economic growth, and several rising countries are striving for rapid infrastructure construction, resulting in a

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considerable increase in cement production [1]. Extensive energy usage in the cement industry has become one of the significant contributors to climate change and global warming. Large amounts of non-renewable raw materials, such as fossil fuels, are needed in cement production [2]. With cement production's increasing environmental and health impacts, the construction industry has taken an environmentally safe approach, aiming to incorporate natural materials into building materials that could minimise cement production [3].

Currently, the focus on recovering usable materials such as industrial or agricultural waste products is utilised in construction whenever possible. Fly ash is a waste byproduct from burning pulverised coal in an electric power plant. The rising production of fly ash requires a wide area for disposal [4]. However, the disposal of non-treated fly ash is harmful, which could lead to air and water pollution and can destroy the flora and fauna [5]. Transparency Market Research's recent report on the fly ash market for the forecast period of 2021 to 2031 shows that an increase in the use of fly ash re-lining and construction applications is expected to boost the fly ash market during the global forecast period.

According to [6], concrete's cement content can be reduced using supplemental cementitious materials such as fly ash, blast furnace slag, natural pozzolans, and biomass ash. Coconut shells and husks are agricultural waste widely available in tropical countries such as India, Malaysia, Indonesia, Nigeria, Brazil and Ghana. Even so, most countries consider coconut shells and husk as waste material and are subject to open burning, where they can significantly contribute to air pollution, releasing CO_2 and methane emissions, which later cause a significant health risk to humans and animals. Studies by [7] state that the 5% replacement of coconut fibre ash has an optimum compressive strength of 59.25N/mm² at 90 days of age. Under this study, an experimental investigation was conducted on the mechanical, durability and microstructural performance of Coconut Husk Ash (CHA) and Fly Ash (FA) with varying dosages to substitute cement materials.

There is no doubt that concrete is an essential building material that is frequently used all around the world today. However, carbon dioxide (CO_2) emissions from cement manufacture are among the highest in the world. According to a study by Li Yin Shen et al. (2005), construction industries have been recognised as the primary cause of environmental pollution compared to other industries. Approximately 900 kg of carbon dioxide (CO_2) is emitted for every ton of cement produced [8].

For conventional cement manufacture, limestone and clay must be extracted, mixed, ground, and fired in a rotating kiln. The conversion of calcium carbonate (limestone) into calcium oxide and burning fossil fuels while the mixture is being heated requires significant energy and resources, resulting in significant carbon dioxide emissions. In 1990, global cement plants emitted approximately 576 million tonnes of CO_2. By 2022, this figure had risen to 1.6 billion tonnes, doubling over three decades. This increase underscores the significant environmental impact of cement production, which now accounts for about 8% of global CO_2 emissions [9].

Previous research has been done to study the possibility of using agricultural and industrial waste ashes as partial replacements for cement in concrete manufacturing [10]. Fly ash is the byproduct of coal combustion and is usually used as a replacement for cement. Researchers [11] claimed that Malaysia alone produced approximately 6.8

million tons of fly ash in 2016. The increasing production of fly ash has raised concerns, as improper disposal of fly ash may cause environmental and health issues. However, due to the lack of understanding of fly ash properties and characteristics, the application of fly ash is still limited [12].

Agricultural wastes such as coconut husk and fibre in Malaysia and other tropical countries are usually disposed of by open burning. The burning of coconut fibre gives CO_2 and methane emissions to the environment. A study by [13] proved that adding an optimum 10% coconut fibre ash in concrete as cement replacement has increased the concrete's compressive strength. Therefore, using both industrial and agricultural waste byproducts will aid in reducing cement production, saving energy and reducing the environmental impact. Hence, this research is conducted to study the synergetic effect of fly ash and coconut husk ash as cement replacements in concrete, which is expected to enhance the mechanical properties of concrete itself. By integrating fly ash and coconut husk ash, the research seeks to optimise the material composition, improve performance, and contribute to sustainable construction practices by reducing cement consumption and utilising industrial and agricultural waste.

The particular significance of this study lies as follows: The incorporation of fly ash and coconut fibre ash as cement replacement in concrete to promote the use of industrial and agricultural solid waste, as well as create a sustainable environment, along with the concrete's ability to minimise water absorption and improve its strength properties. Developing mix proportions to produce concrete with fly ash and coconut fibre ash to study the strength and durability of concrete in terms of density, water absorption, compressive strength and microstructural characterisation of concrete performance. Introducing industrial wastes may reduce cement production, save energy and cost, and keep the greenhouse effect at bay. This research concentrates on the synergetic effect of fly ash and coconut husk ash as cement replacement on concrete's mechanical and durability properties in terms of density, water absorption and compressive strength. Four concrete sample mixes containing 0% FA + 0% CHA, 10% FA + 5% CHA, 20% FA + 10% CHA and 30% FA + 15% CHA as cement replacement were prepared. The ratio of cement to sand was fixed at 1:1, with the fixed amount of water per cement ratio at 0.5. The hardened concrete samples were cured in water and tested for 3 days, 7 days and 14 days for density and water absorption, followed by a compressive strength test. The curing was limited to 14 days because the study aimed to observe early-age strength and durability behaviour**,** not the long-term performance. Testing at 3, 7, and 14 days helps evaluate the rate of strength development**,** hydration progress**,** and comparative performance of different mixtures or additives within a shorter timeframe.

2 Materials and Methods

The composite concrete mixture, incorporating fly ash and coconut husk ash as partial cement replacements, consists of five key materials: Ordinary Portland Cement (OPC), fly ash, coconut husk ash, coarse aggregates, and water. The basic mix design is based on the strength requirement, workability, water-cementitious ratio, cement replacement percentage and durability properties.

Ordinary Portland cement (OPC) is widely used in concrete construction as it is the fundamental component in manufacturing [14]. In this study, Portland cement was manufactured by Lafarge. Coconut husk was used in this study to obtain its ash. In this study, coconut husk was burned in a furnace to produce ash, which was subsequently used as a partial replacement for cement in the concrete mix. The replacement of coconut husk ash (CHA) in concrete samples is 0%, 5%, 10% and 15% by weight of cement in concrete. Figure 1(a) shows the coconut husk obtained from the local store, and (b) the ash obtained from burning and grinding the coconut husk. Fly ash (FA) is a fine grey powder primarily made of spherical, glassy particles produced as a byproduct of coal-fired power plants. Fly ash is often used as a partial cement replacement material and has a fineness of 45μm. The replacement of fly ash in concrete samples is 0%, 10%, 20% and 30% by weight of cement in concrete. This study uses coarse sand because it consists of rough, jagged, angular, coarse granules with high binding capabilities. Coarse sand is broadly utilised in building construction because it is easily blended with water, aggregate, and cement to make substantial concrete structures. The grading for coarse sand is between 2.0 mm and 4.75mm. Tap water was used to proportion and cure concrete samples. During proportioning, tap water was carefully measured and mixed with cement, fly ash, coconut husk ash, and aggregates to ensure proper hydration and workability of the concrete mix. For curing, the hardened concrete samples were immersed in tap water for a specified period to maintain adequate moisture, allowing for continued hydration and strength development.

Previous studies reveal that an optimum content of 10% FA and 20% CHA as a partial cementitious material shows a high compressive strength at 28 days of curing date, where the compressive strength was found to be 22.09N/mm² [15]. Four samples with different percentages of fly ash and coconut husk ash were designed for this study. The ratio of cement to sand was fixed at 1:1, with the fixed amount of water per cement ratio at 0.5. Table 1 shows the proportion of cement samples

The coconut husk was collected from the local store and sun-dried in an open field for 7 days. The dried husk is then burned in an oven at an average temperature of 150^0C for 1 hour and 30 minutes until the husk obtains its brownish colour. Allow the husk to cool down before grinding it. Then, the husk was inserted in a milling machine along with a ball mill and left overnight to achieve fine ash, as shown in Figure 1(c). The ash product was then sieved using a sieve size of 100μm, where the passing sieve ash was collected and used for the practical work.

The casting of the sample was done in sequence as conventional concrete, with a reference sample of 0% ash replacement along with 10% FA + 5% CHA, 20% FA + 10% CHA and 30% FA + 15% CHA as replacement percentages were done by weight of cement as shown in Figure 1(d). Each hardened concrete sample was prepared with dimensions of 5.5 cm × 4.0 cm × 3.5 cm, following common laboratory practice for small-scale specimens (BS 1881: Part 108, 1983), which allows reduced-size samples for early-age testing and evaluation of experimental concrete mixes. Firstly, the raw materials were mixed and hand-compacted before filling the wet mortar into its moulds. The moulds should be filled and compacted by spreading an equal stroke throughout their surface using a trowel. After 24 hours, the samples were moulded and cured in water for 3, 7 and

14 days before performing any testing. Water curing of concrete samples was illustrated in Figure 1(e).

(a) (b) (c) (d) (e)

Fig. 1. (a) Coconut Husk, (b) Ground coconut husk ash, (c) Fly Ash, (d) Mixing of materials, (e) Water curing of concrete samples

Table 1. Proportion of cement, FA and CHA samples for Mortar Mixes

Sample Mix	FA + CHA Weight Percentage (%)	Cement to Sand Ratio	Water to Cement Ratio (W/C)
M0	0%	1:1	0.5
M1	10% FA + 5% CHA	0.95:1	0.5
M2	20% FA + 10% CHA	0.90:1	0.5
M3	30% FA + 15% CHA	0.85:1	0.5

The density of the sample was determined by the mass of the dry sample that was needed to fill a container with a specific unit volume. The sample was allowed to dry for 24 hours before measuring its dimensions in centimetres and the overall volume in cubic centimetres. The mass of the sample was determined in grams. The density, ρ, of each block sample was calculated as follows:

$$\rho = \frac{m}{v} \quad (1)$$

where
ρ = density of sample, g/cm³
m = mass of dry sample, g
v = volume of sample, cm³

By IS 3495 (Part 2), the bricks tested should have an average water absorption of no more than 20% by mass, up to 12.5% and 15% by mass for higher courses, after 24 hours of immersion in cold water. In a ventilated oven, the samples were dried until their mass was nearly consistent at 105–115°C. The samples were weighed once they cooled to room temperature (M_1). In this research, the dried samples were immersed in clean water for 3, 7 and 14 days at room temperature. A moist cloth was used to dry the samples before weighing them. The samples were weighed after 5 minutes from the removal from water (M_2). The following formula gave the percentage of water absorption in the samples:

$$\frac{M_2 - M_1}{M_1} \text{ x } 100 \quad (2)$$

where

M_1 = initial weight of the sample after 24 hours of drying, g
M_2 = final weight of the sample after water immersion, g

The compressive strength test was carried out in line with IS 516 (1959): Method of Tests for Concrete Strength. After curing for 3, 7 and 14 days, the samples were tested using a Universal Testing Machine. Weighing and measuring were done on the samples. After that, the samples were placed on a testing machine. The sample axes aligned precisely with the machine plate's centre of thrust. The load was applied to the samples without shock and increased carefully until it broke with its maximum load as a compressive load. The following formula gave the compressive strength formula:

$$f_c = \frac{P}{A} \quad (3)$$

f_c = compressive strength, MPa
P = maximum load sustained by the sample, N
A = cross-sectional area of sample to which load is applied, mm²

3 Results and Discussion

3.1 Density

The density of concrete is essential to indicate its mechanical strength. Denser concrete provides higher strength, durability and resistance to permeability due to the minor amounts of voids and porosity. Based on Table 2, the reference sample with 0% ash replacement shows the highest density of 1.56g/cm³, whereas 30% FA+15% CHA replacement has the lowest density of 1.41g/cm³. The reduction in density is primarily due to fly ash (30% replacement), with coconut husk ash (15%) also contributing slightly because of its porous, lightweight structure. Both materials reduce the overall mass of the concrete per unit volume compared to the reference mix.

Table 2. Density of Samples

FA + CHA Weight Percentage (%)	Density (g/cm³)
0%	1.56
10% FA+5% CHA	1.43
20% FA+10% CHA	1.42
30% FA+15% CHA	1.41

3.2 Water Absorption Test

Water absorption plays a significant role that should be considered when examining the durability of concrete, as it refers to the amount of water penetrating concrete samples

when submerged. Table 3 illustrates the water absorption percentage for 3, 7 and 14 days of curing.

Table 3. Water absorption results

Samples Mix	FA+CHA Weight (%)	Water Absorption (%)		
		3 days	7 days	14 days
M0	0%	0.16	0.27	0.10
M1	10% FA+5%CHA	0.27	0.32	0.23
M2	20% FA+10% CHA	0.29	0.34	0.20
M3	30% FA+15% CHA	1.40	1.03	0.55

Water absorption results for concrete samples after 3 days show the increasing weight percentage of FA+CHA; the water absorption was increased linearly, as shown in Figure 2. Therefore, this study showed that an increase in fly ash and coconut husk ash in the sample was inversely proportional to density and water absorption. Additionally, the ash content affected the concrete's water absorption. The inclusion of FA, with its spherical particles, helped to fill voids and reduce permeability, whereas the porous CHA slightly increased water absorption. Overall, the combined effect of FA and CHA shows that careful selection of replacement levels can optimise the balance between density and durability-related properties in concrete. Similar findings were observed in previous research, indicating that the water absorption of coconut fibre-based lightweight concrete is inversely proportional to its density.

3.3 Compressive Strength Test

The compressive strength of concrete was tested by fracturing the concrete block in a compression strength machine to test the mechanical and durability properties of the concrete to satisfy the structure's design standards. Compressive strength was calculated by dividing the failure load by the load-resisting cross-sectional area, given in megapascals (MPa). Compressive strength test was carried out on cured concrete block samples at 3 days, 7 days and 14 days curing age using a Universal Testing Machine (Gotech). Table 4 shows the compressive strength development for different percentages of fly ash and coconut husk ash for 3, 7 and 14 days cured.

Table 4. Compressive strength results

Samples Mix	FA+CHA Weight (%)	Compressive Strength (MPa)		
		3 days	7 days	14 days
M0	0%	38.44	34.61	43.16
M1	10% FA+5%CHA	7.51	9.82	10.8
M2	20% FA+10% CHA	1.03	4.52	9.07
M3	30% FA+15% CHA	0.80	0.30	1.87

From the data given in Table 4, it can be observed that the reference sample had the highest compressive strength compared to the sample with fly ash and coconut husk ash replacement. It showed that curing ages influence the compressive strength of concrete. Fourteen days of curing age illustrated the highest compressive strength value for all

sample mixes. However, samples with 10% FA + 5% CHA and 20% FA + 10% CHA show a promising compressive strength improvement compared to samples with 30% FA + 15% CHA ash replacement, as shown in Figure 3. During this experimental study, excessive bleeding was observed in some concrete mixes, indicating that specific proportions of fly ash (FA) and coconut husk ash (CHA) were not workable. These mixes exhibited the lowest compressive strength, suggesting an improper balance between FA and CHA can reduce the expected synergistic effect. Optimising the combination of FA and CHA is essential to achieve their synergistic potential in enhancing concrete properties while utilising industrial and agricultural waste as eco-friendly building materials. Thus, studies by [19] have proved that in specific mix designs, increasing the water-cement ratio beyond the required workability level lowers the concrete's compressive strength. Other than that, as water absorption increases, compressive strength typically decreases. This relationship is crucial in evaluating the durability and performance of concrete. A higher water-to-cement ratio increases porosity, raising water absorption and declining strength. A lower water-to-cement ratio leads to a denser mix, reducing water absorption and improving strength.

3.4 Field Scanning Electron Microscope

The characteristics and morphology of concrete samples were investigated using a field scanning electron microscope (FESEM) at x10 000 magnification. Figure 4 (a) depicts a FESEM image of a reference sample demonstrating the production of calcium silicate hydrate (C-S-H) and calcium hydroxide (C-H) in concrete. The primary product of cement hydration is calcium silicate hydrate gel, which accounts for approximately 50% to 60% of the volume of hydrated Portland cement [20]. This product is essential in developing the strength and durability of cement and concrete. On the other hand, calcium hydroxide was formed with water and Portland cement that sets and hardens as it produces calcium, which later crystallises from the solution.

However, it can be observed that Figures 4(b), 4(c), and 4(d) showed an increasing presence of ettringite and void spaces as the addition of fly ash and coconut husk ash increased in concrete. Ettringite is the mineral name for calcium aluminate tri sulphate hydrate ($C_6AS_3H_{32}$), which is commonly found in Portland cement concretes. Gypsum is a calcium sulphate source that is intentionally added to Portland cement to control early hydration reactions, avoid flash setting, promote strength development, and reduce drying shrinkage. Ettringite is a needle-shaped crystalline mineral. It accounts for 10% to 20% of the total solid composition. Although it has little role in developing strength, it significantly impacts durability. From the FESEM images below, void spaces in the concrete increased with the increased addition of fly ash and coconut husk ash. This explains the rise in the percentage of water absorption of each sample and the increase in the addition of fly ash and coconut husk ash in concrete. Thus, the presence of void spaces allows water absorption into concrete.

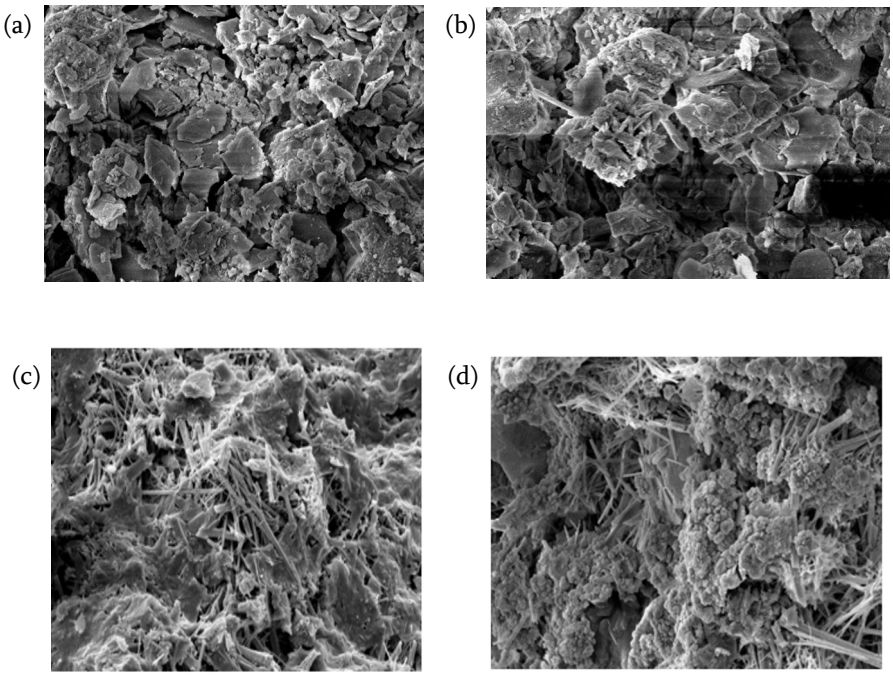

Fig. 4. FESEM image of (a) reference sample, with 0% FA + 0% CHA, (b)10% FA + 5% CHA, (c) 20% FA + 10% CHA, (d) 30% FA + 15% CHA. All figures using magnification x10 000

As partial replacement materials, fly ash and coconut husk ash in concrete are essential in improving its mechanical and durability properties in terms of density, water absorption, compressive strength, and microstructure characterisation and performance. The density, water absorption, compressive strength, and concrete morphology test results were analysed in detail. Hence, adding fly ash and coconut husk ash improved the concrete's durability.

4 Conclusion

The first objective of this study was to evaluate the ratio of fly ash and coconut husk ash as cement replacements in concrete production. This was achieved as four samples with different percentage replacements of fly ash and coconut husk ash were successfully designed for this study, with the ratio of cement to sand fixed at 1:1 and the fixed amount of water per cement ratio at 0.5. Using fly ash and coconut husk ash has helped reduce the amount of cement in concrete.

The second objective was to investigate the durability and strength of fly ash and coconut husk ash mixed in concrete. Incorporating fly ash and coconut husk ash in concrete as cement replacement with 10% FA + 5% CHA and 20% FA + 10% CHA has decreased water absorption compared to the 30% FA + 15% CHA sample. In terms of concrete density, the results showed that the reference sample was denser than the sample with fly ash and coconut husk ash mix. However, there is not much difference in

the density value between the reference concrete sample and the concrete samples with the addition of fly ash and coconut husk ash. The compressive strength of samples increased during the curing period. The reference sample compressive strength illustrated the highest compressive strength of 43.16 MPa at 14 days compared to the other sample mixes. According to the findings, increasing the percentage of fly ash and coconut husk ash by more than 20% and 10%, respectively, does not result in a satisfactory compressive strength. This indicates that employing a more significant amount of coconut fibre ash itself or combined with fly ash cannot be applied for construction purposes.

The third objective is to study the characterisation of fly ash and coconut husk ash as cement replacement that affects concrete performance. The FESEM images of concrete samples show a significant difference in the concrete's morphology. A concrete sample with 10% FA + 5% CHA shows less void space than 20% FA + 10% CHA and 30% FA + 20% CHA concretes. The lesser void spaces in concrete indicate lower water absorption, resulting in more durable concrete for construction.

For suggestion, using a superplasticiser as a water-reducing agent helps minimise cement bleeding and enhance concrete strength. By reducing the required water content in the mix while maintaining workability, superplasticisers improve the compactness and density of concrete, leading to higher compressive strength. Additionally, they prevent excessive water segregation, reduce void formation, and improve the overall durability and performance of the concrete structure.

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