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Experimental Study On Development Of Sustainable Concrete Using Agro-Industrial Waste

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Abstract
The demand for sustainable construction materials has driven the search for alternatives to conventional Portland cement, which is energy-intensive and environmentally taxing. This study explores the usage of agro-Industrial wastes fly ash, wheat husk ash, and chana husk ash as partial replacements for cement in concrete. Five mix designs were prepared: Mix 1 (control mix) with 100% cement; Mix 2 with 30% fly ash, 10% chana husk ash, 20% wheat husk ash, and 40% cement; and Mix 3 with 40% fly ash, 10% chana husk ash, 20% wheat husk ash, and 30% cement. Standard concrete specimens were cast, including cubes (15 cm × 15 cm × 15 cm), cylinders (15 cm diameter × 30 cm height), and beams (10 cm × 10 cm × 50 cm), and tested for workability, compressive strength, split tensile strength, and flexural strength. The outcome demonstrated that significant cement replacement using these waste materials can produce concrete with acceptable strength and improved sustainability, particularly in Mix 2. This study supports the feasibility of using agricultural and industrial by-products to reduce environmental impact and promote sustainable construction practices.
Keywords: *Cement, Fly ash, Wheat Husk ash, Chana Husk ash, M20*

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I. Introduction

In Modern era construction industry, a growing Concentration on producing high-quality cement while also reducing environmental damage. Cement production is one of the biggest sources of Carbon Dioxide outflow and pollution, making it necessary to look for eco-friendly alternatives. One of the best solutions is to partially replace cement with industrial and agricultural waste materials such as fly ash, wheat husk ash, and chana husk ash. Cement acts as a binding agent, and when mixed with water, it reacts to form a strong, solid structure. However, making cement produces a lot of carbon dioxide, which is harmful to the environment.

To reduce this pollution, experts are now using supplementary cementitious materials like fly ash, wheat husk ash, and chana husk ash. These materials not only reduce the pollution caused by cement production but also improve the quality of cement. Fly ash is a waste product from coal industries and helps make cement stronger and more durable while reducing the amount of cement needed. Wheat husk ash, which contains silica, increases the strength and water resistance of cement. Chana husk ash, an agricultural byproduct, improves the binding properties of cement, helping it gain strength faster.

The global construction industry depend on ordinary (OPC), and that produces a substantial amount of Carbon Dioxide outflow, since the production of OPC is an energy-intensive process. Because of this, researchers have been trying to find a more sustainable alternative to cement by finding ways to reduce cement consumption and by using industrial and agricultural waste by-products with cementitious properties that can be used as supplementary cementitious materials (SCMs) [1]. Examples of these are fly ash, wheat husk ash (WHA), and chana husk ash (CHA), which show promise as materials for partial substitution of cement in concrete.

Fly ash, a by-product of coal Burning in thermal power stations, has been used widely in concrete and has been researched due to its pozzolanic properties. Fly ash can be used as a partial cement replacement and has been shown to increase workability, decrease heat of hydration, and increase the long-term strength and durability of concrete [2]. Siddique [3] mentioned that replacing cement with up to 30% fly ash resulted in the positive improvement of compressive strength and reduction in permeability. Mehta and Monteiro [4] added that fly ash can be used in the production of high-performance concrete, with increases in durability; Chindaprasirt et al. [5] noted that fly ash will increase sulfate attack resistance and mitigate thermal cracking risk.

Another agricultural waste exhibiting pozzolanic activity when burned in controlled conditions is wheat husk ash (WHA). WHA is a high silica, reactive agricultural waste that is suitable for blending with cement.

Ganesan et al. [6] found that optimal strength and setting properties of concrete could be obtained with a cement replacement of 10–15% WHA. For durability characteristics, Rukzon and Chindaprasirt [7] proposed that concrete with WHA demonstrated better resistance to chloride ion penetration. Meanwhile, Kumar and Dhaka [8] cited that WHA improved compressive strength only to respective replacement levels; beyond that mechanical properties may decrease due to excess unburnt carbon or poor packing of particles.

Unlike fly ash and wheat husk ash, chana husk ash (CHA) has not been investigated as thoroughly. CHA is a type of agricultural waste derived from chickpea processing. Because of its composition, CHA is promising, as it is rich in both silica and alumina. Kumar et al. [9] conducted experimental studies which explored CHA as an ingredient in concrete. They reported good early strength and decreased density whereby they suggested the potential for lightweight concrete. Gupta and Verma [10] explored the microstructure of concrete containing CHA and reported densification of the matrix and improved packing of particles. Patel and Shah [11] provided evidence that CHA promotes resistance to alkali-silica reactions, as well as the resistance to thermal degradation.

The current study presents a novel methodology utilizing three waste materials-fly ash, wheat husk ash, and chana husk ash for cement long term replacements in concrete. Whereas previous studies assessed these wastes singularly, this research explores their combined effects, in different proportions, on four concrete mixes. The multi-waste approach was utilized to better reflect practical methods employed to substitute and blend waste materials based on availability from local waste producers.

In addition, the ashes were obtained as local materials, utilizing waste from within the community and region for contribution towards a circular economy. The study also assesses the workability, compressive strengths, setting times and other aspects of concrete, including potential durability implication. By means of the combined experimental framework, the study illustrates how using a combination of industrial waste and agricultural waste can generate concrete with strong mechanical properties and environmentally friendly design aspects.

II. Literature Review

Siddique (2004)

Siddique studied the effects of high volume Class F fly ash replacing cement in concrete. The study decide that the Fly ash could be applied up to a 30% partial replacement without affecting compressive strength. Furthermore, the Longer term strength and durability characteristics improved, including permeability and resistance to aggressive chemicals, with increased fly ash [2].

Mehta and Monteiro (2014)

Mehta and Monteiro emphasized the importance of fly ash in sustainable concrete in their widely used textbook. They discussed how fly ash reduces the heat of hydration, improves workability, and increases concrete durability leading to high-performance and mass concrete [1].

Chindaprasirt et al. (2007)

This study looked at the Impact of Fly ash in terms of strength and water permeability. The authors discuss how fly ash increases a concrete's resistance to sulfate attack, increasing long-term strength and reducing water permeability which are vital for durable concrete structures [3].

Ganesan et al. (2008)

This study examined the Impact of wheat husk ash as partial replacement material of cement. The results indicated that the range that gives optimal strength and durability is between 10–15%. After that, everything was reduced because the packing and porosity were worse [4].

Rukzon and Chindaprasirt (2012)

This study investigated the durability properties of concrete with agricultural waste ashes, including wheat husk ash. The authors found that wheat husk ash increased chloride ion penetration resistance, reduced water absorption, and improved all of the durability performance properties and almost all of the physical performance properties. This is attributed to the presence of silica and pozzolanic reactivity in wheat husk ash [5].

Kumar and Dhaka (2016)

This study reviewed the influence of wheat husk ash as cement replacement material. The review indicates that wheat husk ash really can significantly contribute to strength development - especially at lower cement replacements. However, the authors mention that burning conditions must be carefully controlled in order to ensure pozzolanic activity [6].

Kumar et al. (2018)

Kumar and others had conducted experiments with CHA used as a partial replacement for cement and found it useful in producing lightweight concrete. They showed that it is possible to have a 15% replacement of cement with CHA, where compressive strength was of acceptable standards and workability was improved. This work is one of the few early studies that brings attention to the implications of using CHA [7];.

Gupta and Verma (2020)

It was recognized in this work that CHA will improve the packing of the particles and densification of the cement matrix, thereby improving compressive strength as well as reducing micro-cracks [8].

Patel and Shah (2021)

The work recommended the performance of concrete with CHA, where they recognized improvements in its resistance to alkali-silica reaction and better performance under thermal stress. Their discoveries were indicative of the role of CHA in improving durability of concrete, especially in harsh environments [9].

III. Methodology

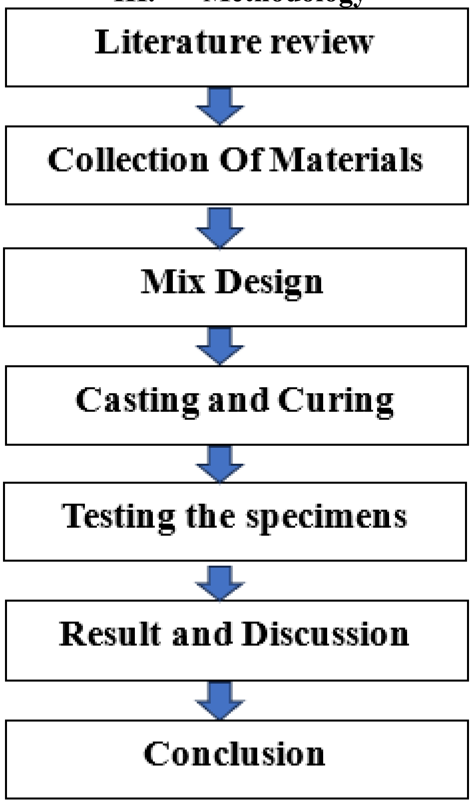

Figure: 1. Methodology

In this study, we replaced some of the cement in our M20 target concrete mix with fly ash (from industry), chana husk ash and wheat husk ash (obtained from local shops), in order to create a more sustainable concrete. We produced our test specimens (cubes, cylinders and beams). After 24 hours, the specimens were cured in water for a period of 14 or 28 day. After completing the curing conditions, we completed the following tests: Crushing Strength or compressive strength Testing ,Split Tensile Strength Testing ,Flexural Strength Testing

We will then be able to discuss and analyze these tests, to assess how the concrete has performed and what the impacts of using crude-materials as partial replacement for cement.

Used Materials

Cement

Ordinary Portland Cement (OPC) of 53 grade was utilized as primary binding material. Its conforms to IS 12269:2013 standards and was stored in airtight conditions to prevent moisture absorption and ensure consistent quality.

Fig:2 Cement

Table 1: Test on Cement

S.NO	Properties	Values
1	Fineness of Cement	4%
2	Initial settling Time	95 min
3	Final setting time	245 min
4	Specific Gravity	3.15

A variety of standard tests performed to evaluate physical properties of the cement utilized in this project. Fineness of cement indicated the particle size and is generally important for the rate of hydration was found to be 4%. This also indicates that there was4% of the cement retained on a 150 micron sieve which indicates reasonable fineness and reactivity of the cement. The initial setting time known as the time to start hardening the cement paste was found to be 95 minutes. This is within an acceptable range and allows for sufficient working time to mix and to place the materials. The final setting time indicates the time until the cement has completely lost its plasticity was found to be 245 minutes indicating a proper hydration process and hardening protocol. The specific gravity of the cement was found to be 3.15 typically for ordinary Portland cement indicating reasonable density and reasonable quality of the material. Overall, these test results indicate that this is appropriate cement for construction and will have reasonable strength and durability.

Fine aggregate

Locally available river sand passing through a 4.75 mm IS sieve was used as fine aggregate. The sand was clean, well-graded, and complied with Zone II classification as per IS 383:2016.

Fig:3 Fine aggregate

Table 2: Test on Fine aggregate

S.NO	Properties	Values
1	Specific Gravity	2.68
2	Fineness Modulus	2.72
3	Water absorption	1.2%
4	Silt Content	3.5%

The fine aggregate specific gravity test indicated that sand density (relative to that of water) equals 2.68. This is within the typical limits when considering natural sand, indicating good quality sand that will provide acceptable strength. The fineness modulus (FM) was measured to give a value of 2.72. This is an index number used to represent the average size of the fine aggregate particles. The fine aggregate (sand) is therefore generally classified as medium sand suitable for concrete work, based on the FM test.

The water absorption test was measured as 1.2%. Water absorption is a measure of how much water can be absorbed by the fine aggregate. This value is important for adjustment of the water-cement ratio at the time of mix design. Finally, the silt test showed an average of 3.5%. Commonly, the acceptable limit is 3%, and while this is slightly above the typical limit, it still should have little effect on concrete materials. High silt content can affect the bond between cement and aggregates, which may be handled by washing or relying to adjust for it. All of the properties measured indicate this fine aggregate should generally be acceptable to use for construction, but will require some silt content control.

Coarse Aggregate

Crushed angular aggregates of 20 mm nominal size were used as coarse aggregate. They were clean, hard, durable, and free from organic impurities, as specified in IS 383:2016.

Fig:4 Coarse aggregate

Table 3: Test on Coarse Aggregate

S.NO	Properties	Values
1	Specific gravity	2.70
2	Water absorption	0.8%

The coarse aggregate's specific gravity is reported to be 2.70, and it is important to note that this is typical of natural aggregates and confirms that the material is good quality and capable of providing strength and stability in concrete.

The water absorption is 0.8% and is considered low which is ideal. Low water absorption indicates that the aggregate will not absorb very much water from the mix; therefore the water-cement ratio is maintained as intended, and the strength and durability of the concrete will be consistent. The data shows that the coarse aggregate is dense, durable and suitable for construction use.

Water

Clean potable tap water was used for mixing and curing, conforming to IS 456:2000 guidelines. The water was free from harmful salts, oils, and organic materials.

Fly Ash

Fly ash, collected from a nearby thermal power plant, was used as a supplementary cementitious material. It met the requirements of IS 3812 (Part 1):2003 and exhibited pozzolanic behavior beneficial to long-term strength and durability.

Fig:5 Fly ash

Table 4: Test on Fly Ash

S.NO	Properties	Values
1	Specific gravity	2.21
2	Fineness	18%
3	Moisture Content	0.4 %

Fly ash has a sp gravity of 2.21 That is lower than that of cement and quite common for pozzolan materials. This less specific gravity helps to reduce the total weight of the concrete, which is beneficial for light-weight construction.

The fineness of the fly ash is recorded as 18 percent which is most likely the residue volume left on a 45-micron sieve. Lower residue or greater fineness is synergistic to fly ash reactivity, blending with cement, and improving concrete workability, strength, and durability. The moisture content is 0.4 percent, which is very low indicating that the fly ash is dry, ideal for storage and mixing, and will not significantly alter the water-cement ratio.

These values are sufficient to conclude that the fly ash is of good quality and suitable for eco-friendly concrete construction.

Wheat Husk Ash

Wheat husk ash was obtained by controlled burning of dry wheat husks, followed by grinding and sieving through a 150-micron sieve. WHA is a silica-rich pozzolanic material and contributes to the strength and sustainability of concrete.

Fig:6 Wheat Husk Ash

Table 5: Test on Wheat Husk Ash

S.NO	Properties	Values
1	Specific Gravity	2.12
2	Fineness	6%
3	Moisture Content	0.6%

The specific gravity of 2.12 measured for wheat husk ash is lighter than ordinary Portland cement, suggesting that it is a lightweight material which could decrease the density of concrete. The fineness is probably 6% which relates to the residue kept on a 45-micron sieve. Fineness lesser than this is favorable as it helps in proper adhesion with the cement and pozzolanic activity of the ash. At 0.6%, the moisture content is low and ideal for storage, ensuring that it will not affect the water-cement ratio significantly for concrete preparation.

This decalcification is indicative of an eco-friendly approach. The wheat husk ash is embedded with the alkalis that we usually find in metakaolin.

Chana Husk Ash

Chana husk ash was prepared through open-air burning of dry chana husks, then ground and sieved through a 90-micron sieve. The ash contains reactive components such as silica and alumina, making it a potential cement replacement material.

Fig:7 Chana Husk Ash

Table 6: Test on Chana Husk ash

S.NO	Properties	Values
1	Specific Gravity	2.09
2	Fineness	5%
3	Moisture Content	0.7%

The specific gravity of the ash is reported as 2.09, which suggests that it is very light for a cementitious material. The fineness,which is defined as the percentage of residue retained on the sieve during the fineness test,was 5%,which confirms that the material is fine enough to be used in concrete, this may allow it to blend better and possibly develop pozzolanic activity. The moisture content is at 0.7%, because it is low enough to not show any adverse effects of material storage, handling and mixing actions in concrete applications. These properties allow for the further promotion of chana husk ash as a resource in sustainable concrete uses..

Mix Design of M20 Grade

As per IS 10262-2009 & MORT&H

1. Grade of Concrete: M20
2. Cement Type: OPC 53 grade
3. Maximum Nominal Aggregate Size: 20 mm (crushed angular aggregate)
4. Water-Cement Ratio (w/c): 0.5
5. Target Mean Strength: 30 MPa (to ensure minimum characteristic strength)
6. Cement Content: 290 kg/m³ (which is more than the minimum required 250 kg/m³)
7. Water Content: 145 liters/m³
8. Fine Aggregate: 696 kg/m³ Coarse Aggregate: 1429 kg/m³ (65% of total aggregate by volume)
9. Mix Proportion (by weight): Cement: Fine Aggregate: Coarse Aggregate = 1: 2.4: 4.93
10. Workability (Slump): 25 mm (for normal exposure condition)
11. No chemical admixtures were used in the base mix design.

Concrete Mix Ratio

Table 7: Mix Ratio

Contents	Fly ash	Wheat husk ash	Chana husk ash	Cement
Control mix	0%	0%	0%	100%
mix-1	40	20	10	30
mix-2	40	30	10	20
mix-3	35	30	20	15
mix-4	30	25	20	25

Test Result

Test On Fresh Concrete

Workability Test

Fig:8 Slump cone

The control mix was recorded having a slump of 25 mm, which means it has low workability. On the other hand, the mixes that partially replaced cement using fly ash, wheat husk ash, and chana husk ash showed increases in workability as evidenced by the following slump values: Mix 1: 35 mm (Medium), Mix 2 and Mix 4: 40 mm (Medium to High), Mix 3: 45 mm (High). The addition of agro-industrial waste appeared to improve the flow properties of the concrete.

Table 8: Workability table

Mix	Slump (mm)	Workability
Control mix	25	low
Mix 1	35	Medium
Mix 2	40	Medium to high
Mix 3	45	High
Mix 4	40	Medium to high

Test on Harden Concrete
Compressive strength

Compressive strength is a critical property of concrete that measures its ability to withstand axial loads. It is tested by casting cubes or cylinders and applying a compressive load using a Universal Testing Machine (UTM). The strength is typically evaluated at 7, and 28 days, with results expressed in megapascals (MPa). For this study, the Crushing strength on 28 days was compared to standard requirements for structural applications

Fig:9 Compressive strength

Table 9: Compressive strength test results (N/mm^2)

Compressive strength	7 Days [N.mm^2]	28 Days [N.mm^2]
Control Mix	13.6	20.4
Mix-1	17.2	24.3
Mix-2	11.6	22.1
Mix-3	15.9	20.2
Mix-4	11.6	16.3

Compressive Strength Results

Compressive strength tests were conducted at 7 and 28 days for the control mix and four different concrete mixes. The specimens were tested using a Universal Testing Machine (UTM), and results were recorded in N/mm. At 28 days, Mix-1 exhibited the highest strength of 24.3 MPa, followed by Mix-2 with 22.1 MPa, the control mix with 20.4 MPa, Mix-3 with 20.2 MPa, and Mix-4 with the lowest value of 16.3 MPa. The results indicate that Mix-1 outperformed the control, while Mix-4 showed a significant reduction in strength. These findings were evaluated against standard requirements for structural-grade concrete.

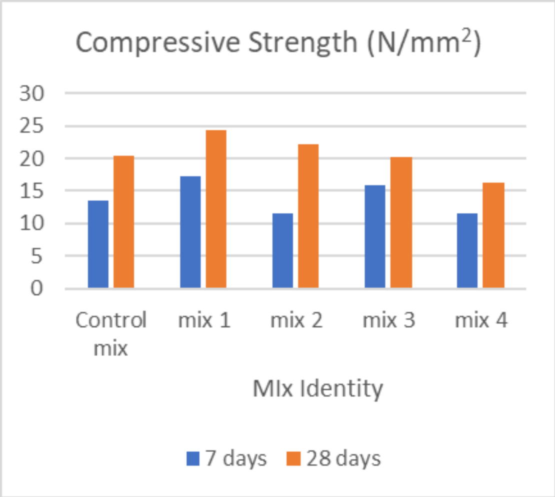

Fig:10 Graphical representation of Compressive strength

Split Tensile Strength

The test is conducted by applying a diametral compressive load on cylindrical specimens using a Universal Testing Machine (UTM), causing the sample to fail in tension. This test is generally performed at 7 and 28 days, and results are expressed in N/mm². In this study, the Split Tensile strength was evaluated on 28 days for all four mixes and compared with the control mix to assess the influence of different materials on the tensile performance of concrete.

Fig:11 Split Tensile Strength

Table 10: Split Tensile test results (N/mm^2)

Split Tensile Strength	7 Days N/mm^2	28 Days N/mm^2
Control Mix	2.64	1.35
Mix-1	2.61	1.42
Mix-2	2.4	1.7
Mix-3	2.3	2.8
Mix-4	2.1	3.1

Split Tensile Strength Results

Split tensile strength was evaluated at 7 and 28 days to assess the tensile performance of the concrete mixes. The tests were conducted using a Universal Testing Machine (UTM) on cylindrical specimens, and the results were recorded in N/mm². At 28 days, Mix-4 exhibited the highest split tensile strength of 3.1 MPa, followed by Mix-3 (2.8 MPa), Mix-2 (1.7 MPa), Mix-1 (1.42 MPa), and the control mix (1.35 MPa). These results indicate a significant improvement in tensile strength for Mixes 3 and 4 compared to the control, suggesting enhanced crack resistance in those formulations.

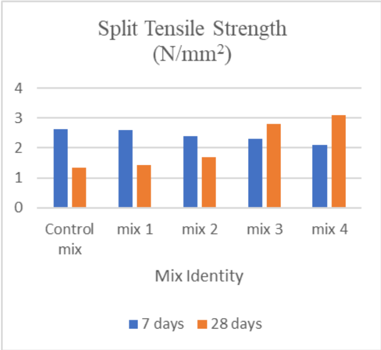

Fig:12 Graphical representation of Split Tensile strength

Flexural Strength

Flexural strength is a measure of a concrete beam or slab's ability to resist failure in bending. It reflects the tensile strength of concrete in the tension zone and is critical for pavements and structural elements subjected to flexural loads. In this study, Flexural strength was measured after 7 days and 28 days of curing using standard beam specimens.

Fig:13 Flexural Strength

Table 11: Flexural Strength (N/mm^2)

Flexural Strength	7 Days (N/mm^2)	28 Days (N/mm^2)
Control Mix	2.3	3.1
Mix-1	3.95	4.15
Mix-2	4.2	4.35
Mix-3	4.26	4.6
Mix-4	4.1	4.4

Flexural Strength Results

Flexural strength tests were conducted at 7 and 28 days to evaluate the bending performance of concrete. These tests help in understanding the concrete's resistance to tensile stresses in flexure. At 28 days, all modified mixes showed improved flexural strength compared to the control mix. Mix-3 recorded the highest flexural strength of 4.6 MPa, followed by Mix-2 (4.35 MPa), Mix-4 (4.4 MPa), Mix-1 (4.15 MPa), and the control mix (3.1 MPa). The enhancements in flexural strength suggest better ductility and crack resistance in the modified concrete formulations.

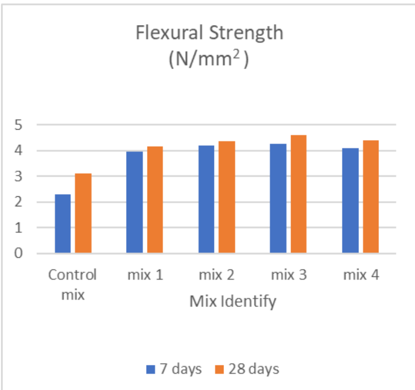

Fig:14 Graphical representation of Flexural Strength

IV. Conclusions

The Use of agricultural and industrial waste materials such as fly ash, wheat husk, and chana husk in concrete not only contributes to improved mechanical performance but also offers significant environmental benefits. Fly ash enhances workability and long-term strength through its pozzolanic activity, while organic wastes like wheat husk and chana husk can improve specific properties such as tensile and thermal performance when properly processed. This study demonstrated that using fly ash, wheat husk, and chana husk in concrete can enhance specific mechanical properties while promoting sustainability. Mix-1 showed the highest compressive strength, Mix-4 had the best split tensile strength, and Mix-3 achieved the highest flexural strength. These results indicate that agro-industrial wastes can improve concrete performance and reduce environmental impact, making them suitable for eco-friendly structural applications.

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