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Optimizing Mix Proportions For Improved Strength: A Design Of Experimental Approach For Fly Ash Bricks With Marble Dust, Ground Granulated Blast-Furnace And Coconut Shell Ash

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ABSTRACT

This study focuses on optimizing the mix proportions that include marble dust, ground granulated blast furnace slag (GGBS), and coconut shell ash. Several mix combinations were methodically investigated using a Design of Experiments technique in order to determine the ideal proportions that produce the best compressive strength and durability. The experimental design allowed for a thorough analysis of interactions between materials. Bricks were tested for compressive strength, water absorption, and durability and the results were analyzed using statistical tools to determine the importance of each factor and its interactions. The results showed that the amounts of marble dust, GGBS, and coconut shell ash significantly improved the compressive strength of fly ash bricks and reduced water absorption. The optimal mixing proportions identified in this study provide a sustainable and economically viable solution for brick production, reducing dependence on traditional materials and encouraging the use of industrial and agricultural by-products. In summary, DOE's use of fly ash to optimize brick mix proportions demonstrates a systematic approach to improving brick properties while promoting environmental sustainability. The discoveries help develop strong, durable, and environmentally friendly building materials that meet the goals of modern sustainable development.

KEYWORDS: Fly ash, Marble dust, Ground granulated blast-furnace slag (GGBS), Coconut shell ash (CSA), CTM Machine.

1. Introduction

India is the third-largest coal producer, with 120 coal-based thermal power plant installations contributing 70% of the total installed capacity for power generation. India generates 260–270 million tons of coal fly ash from these plants. The Indian government is implementing measures to properly use and dispose of fly ash, with global production expected to increase to 2100 million tons in 2031–2022. Squash is a vital natural resource for sustainable development, but improper disposal can lead to environmental issues. In India, 6 million tons of energy from marble businesses are discharged annually, affecting the environment and local biological systems. The marble industry produces 7 million tons of powder, sullying water and reducing soil penetrability. Ground-granulated blast furnace slag (GGBS) has been used in composite cement and concrete since the 1800s. Its cementitious qualities were discovered in the 1800s and have gained acceptance since the late 1950s. GGBS is rich in calcium, alumina, and silica, making it suitable for construction and road construction. It offers financial and environmental benefits, resource preservation, and energy efficiency. Coconut is grown in over 90 countries, with India being the third largest. The chemical composition of coconut cinder (CSA) is influenced by temperature, soil type, and burning methods. A custom-made ashing handle was used to create CSA, which was then washed twice in an open clay pot and overnight in a bread broiler. The temperature, fuel type, and area of the CSA collection significantly affect its physical and chemical properties. When making concrete, the CSA can be used in place of cement or fine or coarse aggregate. In Cebu Territory, the CSA was gathered by burning coconut shells, and its chemical composition was contrasted with cement. The CSA has a lower specific gravity but a higher water assimilation and fineness modulus.

This paper discusses the properties and manufacturing process of fly ash bricks, comparing them to clay bricks. The study found that fly ash bricks had similar textures and durability, with spherical particles reducing density. This additive could be used for recycling and cost savings in brick production. The study concludes that fly ash bricks are a viable alternative to clay bricks (Gadling et al., 2016). A primary focus of building research is the creation of novel construction materials and the processing of industrial waste. Fly ash bricks outperform the finest load-carrying clay bricks by over 25% and are lighter with a compressive strength of over 20 MPa. They are patented and have a reddish-brown natural hue. By contrasting them with traditional burnt clay bricks, the study looks at how fly ash affects the characteristics of bricks. Compared to clay bricks, fly ash bricks are more resilient, cost-effective, and have less pollution and moisture-related problems (Kumar et al., 2016).

The construction industry is increasing its demand for concrete, primarily made from cement. However, the production of cement contributes to environmental pollution and reduces limestone. This paper reviews the use of GGBS as a partial pozzolanic replacement for cement in concrete, highlighting its potential to enhance properties at a later age (Zhao Jun, 2018). The study investigates the use of coconut shells and their ash as a partial replacement for coarse aggregate and cement in concrete. The research suggests that these materials can reduce environmental impact, reduce construction costs, and contribute to sustainable construction. The study aims to determine the suitability of coconut shell ash (CSA) as a cement substitute, determining the optimal replacement level and setting time for ordinary Portland cement (OPC) and OPC-CSA paste. The research aims to address material shortages and waste disposal issues and promote awareness about coconut shells and ash as construction materials (Khan et al., 2017). This study explores the use of coconut shell ash as an alternative to cement in concrete hollow blocks, aiming to address environmental concerns and meet the increasing demand for construction materials. The study found that 30% substitution resulted in the lowest slump height, improved compressive strength, and decreased water absorption and moisture content. (Lumbab et al., 2023)

India's electricity future relies heavily on coal-based control plants for power generation. These plants burn lignite, a byproduct of coal waste, to produce high-calorie fly ash, which is used to generate power. The article discusses the generation and utilization of Indian fly ash (Md. Emamul Haque, 2013). Marble waste, a byproduct of marble production, poses significant environmental issues. About 25% of the original marble mass is lost in dust, causing soil alkalinity and plant damage. However, marble powder can be used as an admixture in concrete, increasing its strength. This waste can be used as filler in cement or fine aggregates, reducing ecological and environmental problems. This paper suggests the feasibility of replacing marble waste with ce-

ment for economic and environmental benefits (Ankita Khatri, 2014). This paper discusses the reuse of waste materials, particularly in the marble stone industry, to produce new products or admixtures, thereby enhancing natural resource efficiency and protecting the environment. It suggests that adding marble dust powder to concrete can increase its compressive strength and split tensile strength by up to 10%, thereby reducing environmental problems (N. Kisku's, 2016). Originally composed of clay, earth, or mud, brick has developed into a dependable, weather- and acid-resistant "fly-ash" brick composed of cement and fly ash. This research aims to minimize pollution and promote sustainable development by creating a hybrid geopolymer brick with a multi-material combination of fly ash, ground-granulated blast furnace slag, silica fume, and Kadapa slab dust (Gowthami et. al., 2019).
Brick, a non-stack-bearing building component, has evolved from clay, soil, or mud to fly-ash brick, a reliable, climate- and corrosive-safe material made from cement and fly ash. A new study explores geopolymer brick, combining cement with GGBS, silica slag, and Kadapa piece tidy. The result is a cross-breed geopolymer brick with a multi-material combination, with compressive strength ranging from 75% to 75% (Khatik et. al., 2017). Fly cinder is a sustainable material used in squandered items, reducing waste transfer and compressive quality. It can also be used in clay bricks for handle production. Fly cinder bricks reduce pollution and improve performance with decreasing temperature (Dhanalakshmi et al. 2016). The study examines the use of waste materials like papercrete, plastic waste, and coconut fiber in making fly cinder bricks. It focuses on compressive quality, water retention, efflorescence, and fire tests. The study found that 10% paper mash produced the best results. Reduce plastic waste and its environmental impact by using a plastic extruder machine to soften and blend fly ash with other brick materials. The goal is to create environmentally friendly and temperate bricks that reduce soil waste during brick production (Lanjewar, 2019; Jyoti Sorout et al., 2023). This study aimed to determine the ideal blend rate of fly ash bricks using various blend rates of fly ash, gypsum, lime, and quarry dust. Results showed that the most optimal compressive quality was achieved with a blend rate of Flyash-15% Lime-30% Gypsum-2% Quarry dust-53%. (Mohan et al., 2015).
A comparison of regular cinder brick and plastic clean brick is conducted to demonstrate its advantages in quality, economy, and compression quality. The study found that plastic clean bricks have higher quality than regular cinder bricks and red clay bricks. Technological and mechanical advancements have improved human life but have also led to a massive waste era worldwide. This "throwing absent culture" has led to billions of tons of waste being produced each year, which is ineffectively managed, dumped, or burned, causing environmental damage. However, waste can be reused or judicially reused to alleviate its negative impacts. This paper reviews the use of waste materials in brick production, examining their impact on quality conduct, water retention, porosity, and heat conductivity. The study finds that bricks made from fly cinder, plastic, and waste have higher energy productivity and supportability.

2. Materials Used

2.1. *Fly ash*

Fly fiery debris, often referred to as vent cinder or pulverized fuel fiery remnants, is a type of coal-igniting material made up of pipe gases and small particles from boilers that burn coal. When combined with cement and water, it is frequently utilized as an additional cementitious fabric to improve the strength and quality of fly-fired bricks. It also has applications in soil stabilization, squander hardening, and brick production. ASTM classifies fly-fired debris into Lesson F and Lesson C, with Lesson F having less than 5% Cao and Lesson C having 10% Cao content.

2.2. *Marble dust*

Marble dust is a byproduct of marble processing, primarily calcite or dolomite crystals. It is a fine powder with tiny crushed marble particles, too small for final products. It is produced in large quantities in the marble industry and has various applications. Proper disposal minimizes environmental impacts, including soil and water pollution. It is collected near Mainpuri City.

2.3. *Ground granulated blast Furness (GGBS)*

Due to its increased concrete strength, GGBS is widely utilized in Europe, the US, and Asia, extending the life expectancy of buildings from 50 to 100 years. Portland blast furnace cement (PBFC), high-slag blast furnace cement (HSBFC), and quality-improved slag cement are all made with it. While it sets more slowly than regular Portland cement, GGBS cement gradually gets better. Additionally, it lessens the chance of sulfate assaults, chloride entrance, and alkali-silica reaction.

2.4. *Coconut Shell Ash (CSA)*

Coconut shell ash (CSA) is a byproduct from the burning or combustion of coconut shells, rich in minerals and carbon content. It has potential applications in various industries. The ash is prepared through a customized ashing technique, which involves ashing the shells in a commercial bread oven and clay pot over a kerosene stove. The chemical composition of CSA includes carbon, potassium, calcium, magnesium, phosphorus, and trace elements. Its pozzolanic properties make it useful in enhancing construction performance.

3. Methodology

Fly ash, marble dust, GGBS, and coconut shell ash must be combined in the right amounts for the production of fly ash bricks. To begin, GGBS and coconut shell ash are crushed in a pan combination using the ideal amount of water. To create a homogenous mixture, fly ash, and marble dust, GGBS, coconut shell ash is then added to the pan mixture. Fly ash bricks are more affordable than other bricks, lightweight, and environmentally benign. Fly ash, water, GGBS, marble dust, and coconut shell ash are the principal components. The procedure of casting of fly ash bricks and testing of the fly ash brick is shown in Figure 1.

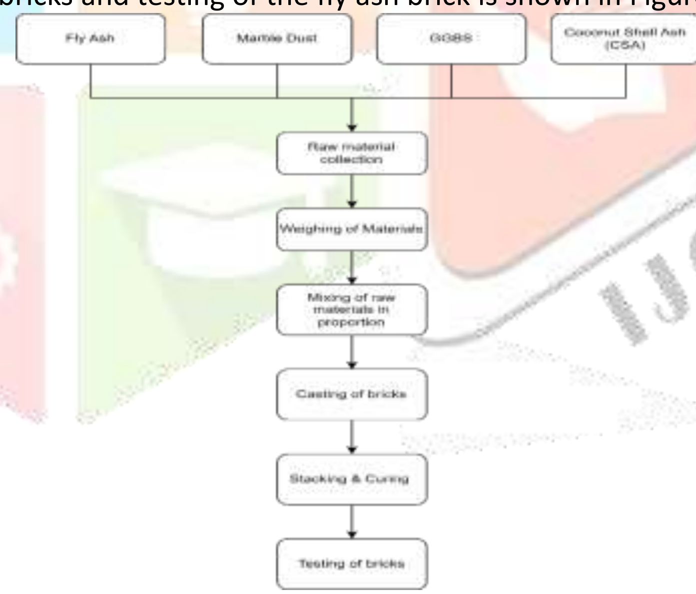

Figure 1 Procedure of casting of fly ash brick

3.1. Mix Proportion

To make fly ash bricks, the following mix proportions are found by trial and error. The varied mix proportions are displayed in the table. The amount of materials needed to cast one brick is calculated using the 2.6-3.0 kg brick weight. Show in different mix proportions without CSA of fly ash brick and with CSA of fly ash brick respectively in Table 1 and Table 2.

Table 1 Mix proportion of without CSA fly ash bricks

Brick Sample (I)	Fly ash%	Marble dust%	GGBS%
I	60	30	10
II	55	30	15
III	50	30	20
IV	45	30	25
V	40	30	30
VI	35	30	35
VII	30	30	40

Table 2 Mix proportion with CSA

Brick Sample (II)	Fly ash%	Marble dust%	GGBS%	CSA%
I	30	30	35	5
II	30	30	30	10
III	30	30	25	15
IV	30	30	20	20

4. **Procedure for testing and specimens**

4.1. *Crushing strength test:*

This is the primary test used to determine if bricks are suitable for use in buildings. This test is done using a compression testing apparatus. A brick is put inside a device that tests compression as shown in Figure 2. They stress on it till it cracks. Next, the brick's compression strength is measured using the compression testing machine's meter. After a brick has undergone a compression test, this is done for both fly ash bricks with and without CSA. Brick compressive quality is tested using the comprehensive testing apparatus. Bricks are retained for testing after the curing time. Bricks are placed in a calibrated 2000 kN compression testing machine linked to a uniform stack at a rate of 2.9 kN/min to test the examples. The stack at disappointment is the greatest stack at which the example falls flat to deliver any encourages increment in the pointer perusing on the testing machine. Each number of bricks was tried for each blend proportion testing of bricks without and with CSA material to find the value of different compressive loads shown in Table 3 and Figure 3 is compressive strength without CSA fly ash bricks and Table 4 and Figure 4 is compressive strength with CSA fly ash brick.

Figure 2 Compressive strength test of fly ash brick

Table 3 Compressive strength of fly ash brick without CSA

Brick Sample	Fly ash (gram)	Marble dust (gram)	GGBS (gram)	7day Load kN	14day Load kN	28day load kN	Crushing strength 7day	Crushing strength 14day	Crushing strength 28day
I	1560	780	260	28	61.47	154	1.03	2.43	6.12
II	1430	780	390	28	77.92	160	1.12	3.08	6.35
III	1300	780	520	31	88	177	1.22	3.48	7.03
IV	1170	780	650	36	85	188	1.44	3.36	7.46
V	1040	780	780	45	90	200	1.81	3.58	7.93
VI	910	780	910	42	102	204	1.68	4.05	8.09
VII	780	780	1040	50	106	205	1.98	4.19	8.13

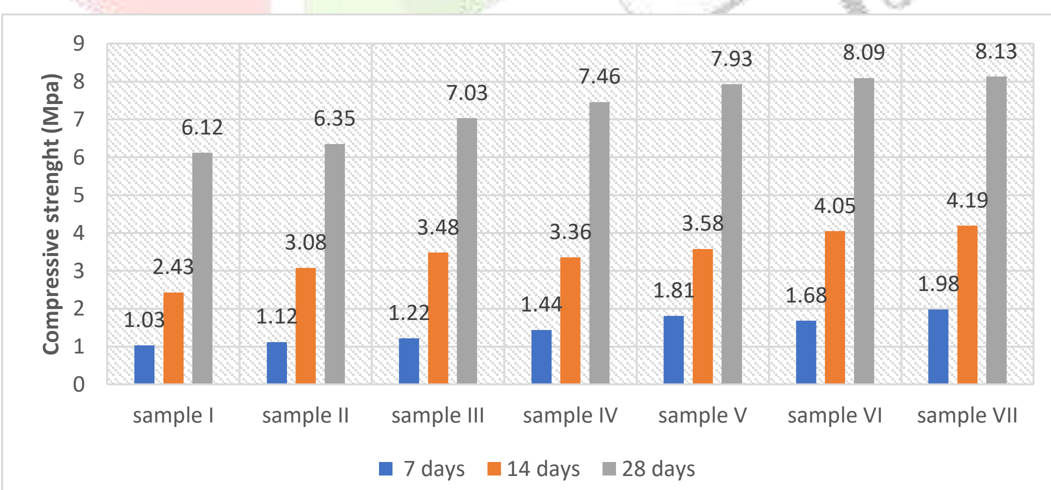

Figure 3 Compressive strength of fly ash brick without CSA

Table 4 Compressive strength of fly ash brick with CSA

Brick Sample (1)	Fly ash (gram)	Marble dust (gram)	GGBS (gram)	CSA (gram)	7day Load kN	14day Load kN	28day load kN	Crushing strength 7day	Crushing strength 14day	Crushing strength 28day
I	780	780	910	130	45	97	198	1.81	3.85	7.86
II	780	780	780	260	40	82	186	1.58	3.26	7.39
III	780	780	650	390	33	74	167	1.33	2.94	6.61
IV	780	780	520	520	26	54	139	1.03	2.14	5.53

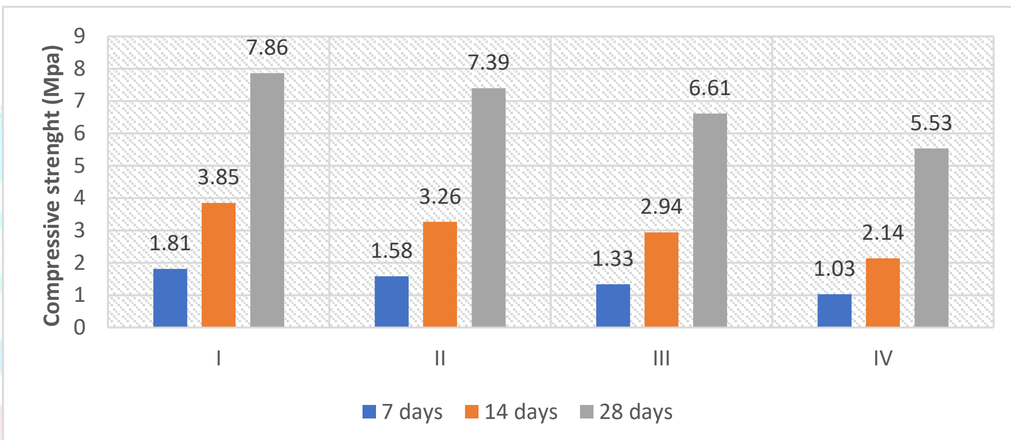

Figure 4 Compressive strength of fly ash brick with CSA

4.2. ***Water absorption***

The purpose of this test is to determine how much water the brick has consumed. Even after being immersed in water for a whole day shown in Figure 5, it shouldn't weigh more than 20% of dry brick. This test is conducted for every test using fly cinder bricks. Following the collection of all short readings, the entire test was placed in the broiler and allowed to run at a temperature between 105 and 115 degrees Celsius until the bricks were consistently cooled to room temperature and weighed (W1). It is noted that no more than 15% of the water was retained in the experiments. After expelling all the bricks from the broiler, we calculate the Water retention rate by weight with the equation. W% = [(W2 – W1)/(W1)]x 100. In Table 5 and Figure 6 the Water absorption test of fly ash brick without CSA is shown. Table 6, and Figure 7 shows Water absorption test of fly ash brick with CSA water absorption.

Figure 5 Water absorption of fly ash brick

Table 5 Water absorption test of fly ash brick without CSA

Brick sample (I)	w_1 (kg)	w_2	w_2- w_1(g)	$\frac{(w_2 - w_1)}{w_1} \times 100$
I	2.676	2.995	319	11.91
II	2.654	2.963	309	11.67
III	2.698	3.008	310	11.52
IV	2.638	2.935	297	11.28
V	2.665	2.965	300	11.25
VI	2.677	2.969	292	10.93
VII	2.649	2.934	285	10.78

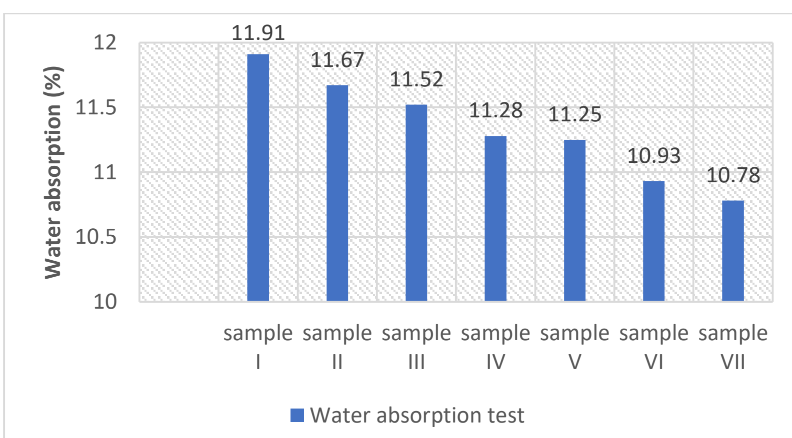

Figure 6 Water absorption of fly ash brick without CSA

Table 6 Water absorption test of fly ash brick with CSA

Brick sample (ii)	w_1 (kg)	w_2 (kg)	w_2- w_1 (g)	$\frac{(w_2 - w_1)}{w_1} \times 100$
I	2.640	2.912	272	10.30
II	2.627	2.883	256	9.74
III	2.620	2.863	243	9.29
IV	2.605	2.841	236	9.06

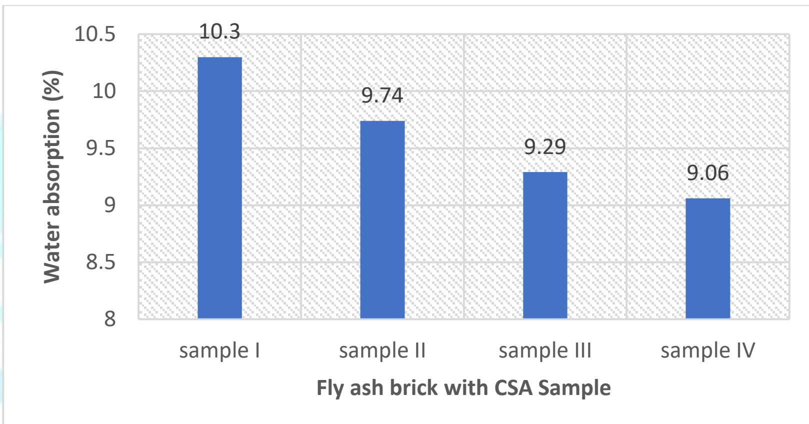

Figure 7 Water absorption fly ash brick with CSA

4.3. *Efflorescence Test*

The reason for this test is to distinguish the nearness of dissolvable salts in a brick. The brick is submerged in water for 24 hours, evacuated, and at that point permitted to dry in the shade. If the surface appears no dim or white stores, it shows the nonappearance of solvent salts. A slight efflorescence is famous when the white stores cover around 10% of the surface, whereas a direct efflorescence happens when the white de-posits cover almost 50% of the surface. An overwhelming efflorescence is distinguished when dim or white deposits cover more than 50% of the surface, and it is considered genuine when these stores turn into a fine mass. This test is conducted for both fly fiery remains bricks without CSA and fly cinder bricks with CSA shown in Table 7.

Table 7 Efflorescence test of fly ash brick

Fly Ash Bricks without CSA	Fly Ash Bricks with CSA
Nil	Less than ten percent is the gray deposit.

4.4. *Hardness test:*

The primary purpose of this test is to assess the hardness of the brick. This is achieved by indenting the surface of the brick using a fingernail, allowing for a tactile evaluation of its hardness. The test is applicable to all samples of fly ash brick without CSA as well as fly ash bricks with CSA shown in Table 8.

Table 8 Hardness test of fly ash brick

Fly Ash Bricks without CSA	Fly Ash Bricks with CSA
No impression after scratching with the help of a fingernail.	No impression after scratching with the help of a fingernail.

4.5. *Soundness Test:*

The acoustic test is performed to ascertain the production of a distinct ringing sound when two bricks are struck together without causing any breakage. The preservation of the bricks' integrity, coupled with the generation of a clear ringing sound, serves as an indicator of their structural integrity. The procedural aspects of this test are inherently self-explanatory. The test is applicable to all samples of fly ash brick without CSA as well as fly ash bricks with CSA shown in Table 9.

Table 9 Sounding test of fly ash brick

Fly Ash Bricks without CSA	Fly Ash Bricks with CSA
A clear ringing sound has been produced.	A ringing sound has been produced.

5. Analysis of results

5.1. *Compressive strength test*

Both fly ash brick (marble dust & GGBS) and fly ash brick (marble dust & GGBS& CSA) were used in a crushing strength test, and the outcomes were compared in Table 10 and also shown in Figure 8.

Table 10 analysis of compressive strength of fly ash brick

Type of Bricks	Average Crushing Strength (N/mm^2)		
Test days	7days	14days	28days
Fly ash brick without CSA	1.47	3.45	7.30
Fly ash brick with CSA	1.44	3.05	6.85

The average crushing strength of fly ash bricks without CSA is found to be in 7 days 1.47 N/mm2 in 14 days 3.45 N/mm2 and in 28 days average of 7.30 N/mm2.The average crushing strength of fly ash bricks with CSA is found to be in 7 days 1.44 N/mm2 in 14 days 3.05 N/mm2 and in 28 days average 6.85 N/mm2.

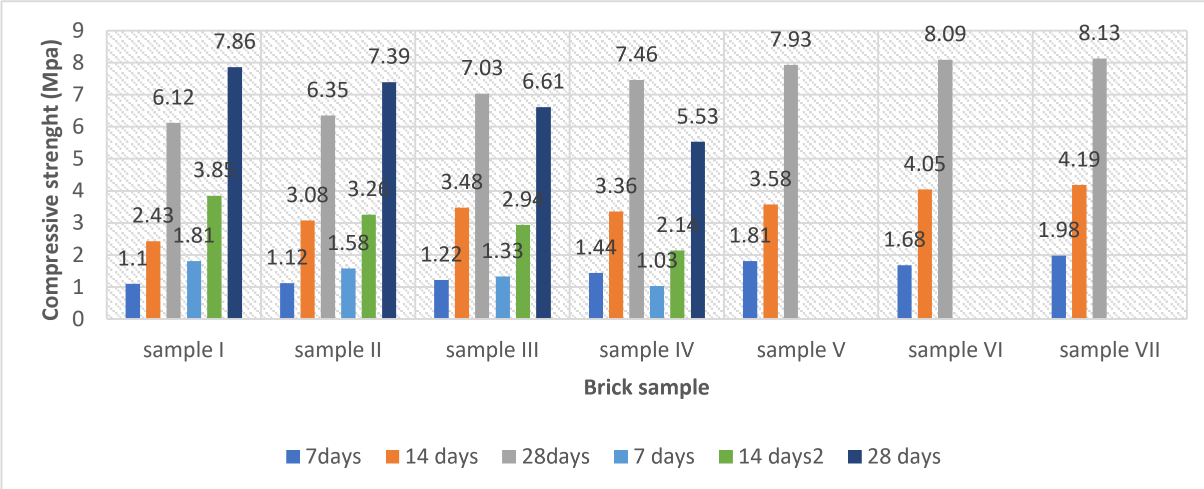

Figure 8 analysis of fly ash brick with and without CSA

5.2. Water absorption test

Fly ash bricks lacking CSA have an average absorbed moisture content of 11.90%, while those containing CSA have an average absorbed moisture content of 9.79%. Consequently, the fly ash brick containing CSA absorbs 17.73% less moisture compared to the fly ash brick without CSA. Analysis of water absorption of fly ash brick with and without CSA is shown in Figure 9.

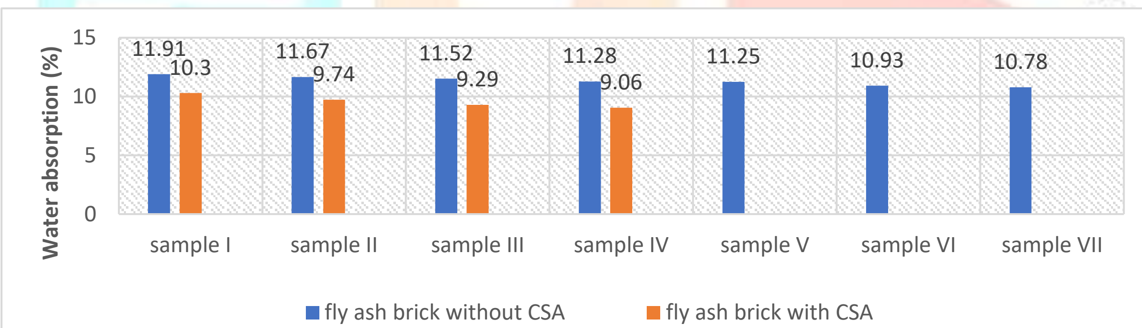

Figure 9 analysis of water absorption of fly ash brick with and without CSA

5.3. *Efflorescence Test*

The Efflorescence test for fly ash bricks without and with CSA and fly ash was conducted and the results were compared in which Grey or white deposits are not present in fly ash bricks without CSA and less than 10% on the surface area in fly ash bricks with CSA.

5.4. Hardness test

A test was done to measure the hardness of fly ash bricks with and without CSA by taking a sample brick and making a scratch on it. Using a fingernail, no marks were left after scratching the brick surface in either situation.

5.5. Soundness test

The test for the strength of fly ash bricks with and without CSA was carried out and the outcomes were compared. When two bricks were hit together, it was discovered that fly ash without CSA produced a satisfactory ringing sound. Fly ash bricks containing CSA exhibit a slightly reduced ringing sound compared to one another.

6. Conclusion

- As we increase of GGBS percentage in fly ash brick compressive strength will increase.
- No signs of efflorescence are visible on fly ash bricks with or without CSA
- When we use coconut shell ash in fly ash brick compressive strength will decrease.
- The average absorbed moisture content of fly ash bricks without CSA is found to be 11.33% and for fly ash bricks with CSA is found to be 9.59%. Thus, there is a net 15.35% decrease in moisture absorbed for fly ash bricks without CSA as compared to fly ash bricks without CSA.
- The average compressive strength of fly ash brick without CSA is 7.3 N/mm^2 and the average compressive strength of fly ash brick with CSA is 6.85 N/mm^2. Thus, there is a net percentage increase in average compressive strength is 6.17%.
- It was found that the Fly Ash Bricks with CSA had a much clearer ringing sound than the Fly Ash Bricks without CSA.
- No marks were left after scratching the fly ash brick surface in either situation.

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Data availability statement: Data related to this research can be made available on written request to the authors.

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