RESEARCH ARTICLE

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Study of the Mechanical Properties of the Fly Ash Composite Bricks

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Abstract

Fly ash brick is an eco-friendly construction material comprised of fly ash, bottom ash, cement and rice husk. Fly ash, a by-product of coal-fired power plants is utilized in place of typical clay or lime in the manufacturing process. One of the key benefits of fly ash brick is its long-term viability. Utilizing fly ash in the manufacturing process lowers waste generated by power stations and the requirement for virgin resources. Fly ash brick also has a reduced carbon impact than typical clay bricks. In terms of performance, fly ash brick offers various benefits. The bricks are more robust and resistant to weathering because they have a higher compressive strength and lower water absorption rate than ordinary clay bricks. They are also well insulated and have a low thermal conductivity. Fly ash brick is also cost-effective since it takes less energy to produce and is less expensive than typical clay bricks. Fly ash bricks are better for the environment since they have a reduced carbon footprint than ordinary clay bricks. They also offer numerous advantages, such as sturdy, long-lasting, and weather-resistant. They also have strong insulation characteristics, which means they can keep a structure cool in the summer and warm in the winter. Fly ash bricks are also a suitable alternative for construction since they are less expensive than regular clay bricks. They also take less energy to manufacture, making them more cost-effective. In this paper, we study the comparison of conventional break and fly ash brick on various dimensions like compressive strength and water absorption test. In this study, the Taguchi technique of parameter design is used to describe the findings of an experimental investigation into the mix proportions of fly ash bricks. With four factors and three levels per factor, the experiments were created using a L9 orthogonal array.

Keywords: Fly ash, cement, Taguchi method, compressive strength, water absorption, Mechanical properties.

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Introduction

India is the world's second-largest producer of bricks, with an annual production of around 250-300 billion bricks. 1500 billion bricks are produced globally each year. Of these 1300 billion bricks (or 87%) are from Asia. The brick's intended qualities mostly depend on the kiln's firing temperature. This poses a significant hazard to the environment and raises the initial cost of production since it requires expensive firing procedures. Thermal power plant coal ash is mostly used in the building sector in nations such as China, India, the United States (US), and the European Union (EU). According to estimates, around 86, 66, 51, and 35% of coal ash is utilized in the building sectors of China, India, the United States, and the European Union, respectively. Coal is the source of energy for the specific area's emerging nations. Fly ash is the term used to describe the waste disposed of in greater quantities from thermal power stations that burn coal for energy. The fraction of coal that is not combustible and is used to fuel a coal-fired power plant is called fly ash. The fraction of coal used in a coal-fired power plant that is made up of non-combustible minerals (material) is called fly ash. In electricity-generating facilities that burn coal as fuel, a powdery material known as fly ash is extracted from the dust collectors. It is an environmentally damaging non-biodegradable trash that people and animals breathe easily. Hence, it has been highlighted that waste materials may be reused. Natural resources may be utilized more effectively and the environment can be safeguarded from waste deposits by turning trash into new goods.

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Taguchi Method

Taguchi and Konishi created the Taguchi technique, a statistical methodology. Its original purpose (manufacturing process development) was to improve the quality of manufactured items, but it is now used to a wide range of technological fields, including biotechnology. The strategy is also referred to as the factorial design of experiments. The use of a full factorial design allows for the discovery of all possible combinations of a given set of variables. The full factorial design requires numerous tests since most industrial trials have a significant number of components.

Statistical methods like the signal-to-noise ratio are employed while using a Taguchi orthogonal array. These methods provide data normalization or unification without the need of unit conversion.

For the creation of products, the Taguchi technique has been used in a variety of technical applications.

To address this issue, Taguchi developed the orthogonal array (OA), which allows for fewer trials.

Materials And Methods

Materials Used

Fly Ash

Fly ash is a by-product of thermal power plants from coal combustion products. Fly ash contains a high percentage of silica-alumina and other oxides. It has pozzolanic properties.

Bottom Ash

Burning coal in thermal power plants produces bottom ash as a by-product. It is usually coarser in texture than fly ash and gathered near the boiler's bottom. When making fly ash bricks, bottom ash can be used with fly ash due to its advantageous qualities.

Cement

The manufacturing of fly ash bricks uses cement as a binding agent. A solid mass is created when cement is combined with fly ash because the cement serves as a binder to keep the fly ash particles together. Bricks are made stronger and last longer when cement is added to the mixture.

Rice Husk

The stalks of the rice plant that are left over after the grains have been harvested and are dry and stiff are known as rice husks. It is a rice by-product that has a wide range of applications. Rice husk may be used as a mulch in agriculture to help keep moisture in the soil and prevent weed development. Additionally, rice husk may be processed to create a variety of goods, including furniture, paper, and building supplies.

Methods

The orthogonal array approach served as the foundation for the experiment design. The number of test runs may be reduced while concurrently estimating the influence of several process factors on the performance characteristic using an orthogonal array design. A L9 (34) conventional orthogonal array was used for this experiment, as indicated in Table 1.

An L9 (34) standard orthogonal array is chosen for the present investigation S/N ratios are two types, i.e. smaller the better and larger the better.

Larger the better

$$S/_N = -10Log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right]$$

Smaller the better:

$$S/_N = -10Log\left[\frac{1}{n}\sum_{i=1}^{n}y_i^2\right]$$

The Taguchi optimization method must be used once the correct orthogonal array has been identified. The orthogonal array is created by taking into account a number of attributes and percentage levels. The L9 orthogonal array was used to optimize the mix possibilities of the Fly ash composite bricks since there are four parameters and three levels or ratios of parameters to take into account. The parameters for the Taguchi optimization method are shown in Table 2.

The completely factorial technique requires 81 trials or tests (3^4 where 3 signifies levels and 4 denotes parameters). The Taguchi L9 orthogonal array is employed, which reduces the number of tests required to discover the optimum result to nine because it is nearly impossible to do all trials to find the most suitable combination. Taguchi's special structure-based tests are performed after implementing the L9 orthogonal array.

The Taguchi L9 optimization experimental design values are represented in Table: 3.

Table 1: L9 (34) Standard orthogonal array

Trial Combination	*Parameter A Fly ash*	*Parameter B Bottom ash*	*Parameter C Cement*	*Parameter D Rice husk*
C1	1	1	1	1
C2	1	2	2	2
C3	1	3	3	3
C4	2	1	2	3
C5	2	2	3	1
C6	2	3	1	2
C7	3	1	3	2
C8	3	2	1	3
C9	3	3	2	1

Table 2: Parameters and levels

S. No.	*Parameters*		*Level 1*	*Level 2*	*Level 3*
1	Fly ash	A	50	55	60
2	Bottom ash	B	10	15	20
3	Cement	C	15	20	25
4	Rice husk	D	00	01	02

Table 3: Taguchi L9 (3^4) optimization experiment design

Trial Combination	*Parameter A Fly ash %*	*Parameter B Bottom ash %*	*Parameter C Cement %*	*Parameter D Rice husk %*
C1	50	10	15	00
C2	50	15	20	01
C3	50	20	25	02
C4	55	15	20	02
C5	55	15	25	00
C6	55	20	15	01
C7	60	10	25	01
C8	60	15	15	02
C9	60	20	20	00

Result And Discussion

Experimental Results

The results of experimental studies to examine the mechanical durability of mix combinations created by using Taguchi L9 orthogonal array are provided.

Mechanical Property Test

Compressive Strength Test

The compressive strength of all the nine mixes along with the conventional clay brick when tested at the end of 7 days of curing are presented in Table 4. Conventional clay brick exhibited a compressive strength of 12 N/mm2. We have nine trial combinations and one conventional clay brick. After curing 7 days, we find C1, C5 has more compressive strength then conventional clay bricks and some of C2, C3, C4, C6, C7, C8, C9 has less compressive strength then conventional clay brick. C5 has a maximum compressive strength in compression to all other eight combinations which has the following percentage of materials mix- fly ash (55%), bottom ash (15%), cement (25%) and rice husk (0%).

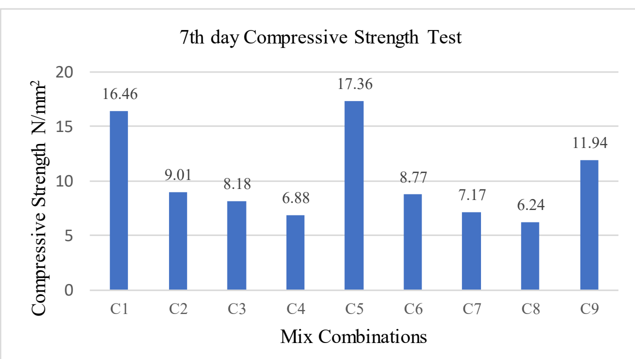


Figure 1: 7th day Compressive Strength Test

Signal-To-Noise Ratio

The major impacts plot for the compressive strength S/N Ratio is shown in Figure 2.

The S/N number for compressive strength decreases from 20.71 to 20.10 and then decreases to 18.06 when the fly ash is changed from 50 to 55% and then to 60%, respectively. The rice husk has rank 1. Fly ash has a rank of 2 while the bottom ash has rank 3. Cement has no significant effect on the compressive strength as the S/N Ratio varies over a small range of values as illustrated in Table 5.

It was observed that for fly ash, bottom ash and rice husk the maximum value corresponds to level 1, while for cement it corresponds to level 3. The ratios corresponding to these levels (for cement level 3 corresponds to 25%, for fly ash it corresponds to 50%) are noted, giving a new mix ratio as shown in Table 6.

Table 4: Compressive strength test results for the - 7th day

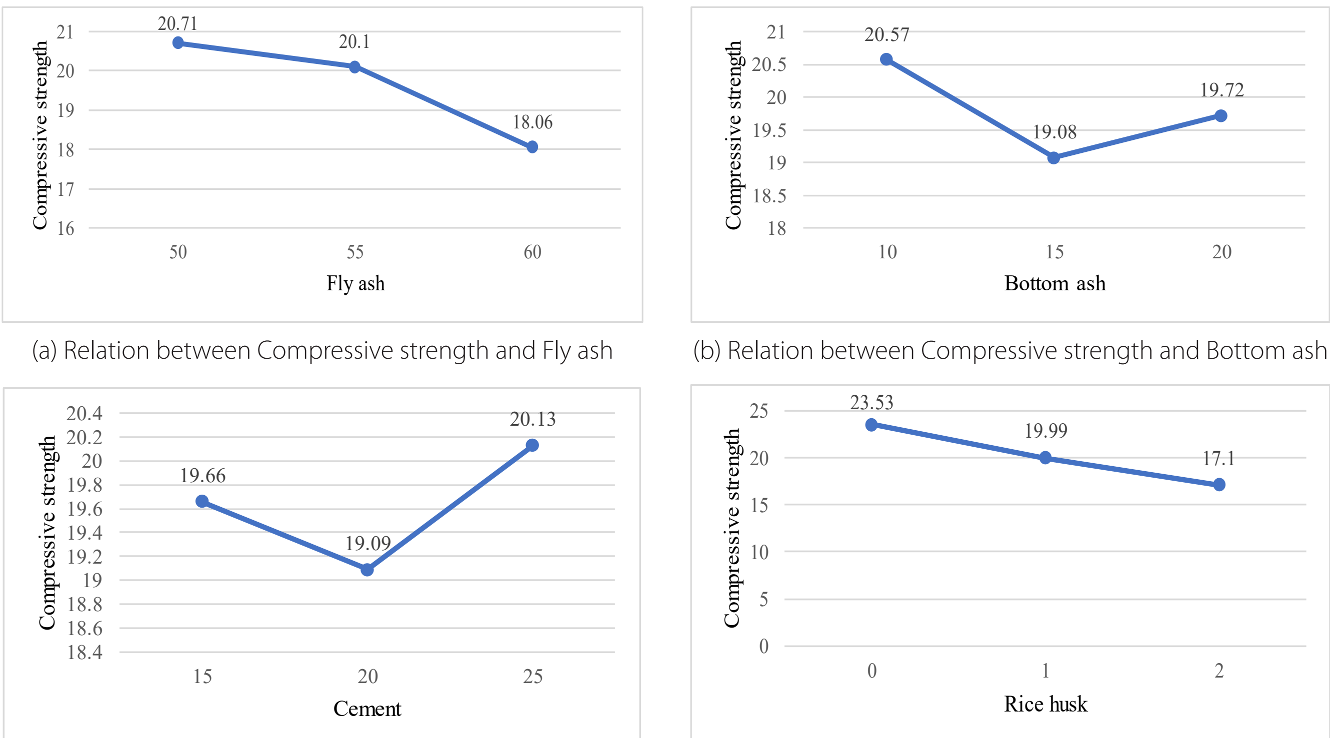
Trial Combination	*Parameters*				*Sample 1*	*Sample 2*	*Sample 3*	*Compressive strength N/mm2*
	Fly ash	*Bottom ash*	*Cement*	*Rice husk*				
C1	50	10	15	00	15.6	16.41	17.39	16.46
C2	50	15	20	01	8.42	9.60	9.01	9.01
C3	50	20	25	02	8.40	7.88	8.28	8.18
C4	55	10	20	02	6.33	6.81	7.52	6.88
C5	55	15	25	00	17.82	17.23	17.03	17.36
C6	55	20	15	01	9.04	8.45	8.84	8.77
C7	60	10	25	02	5.87	7.33	8.32	7.17
C8	60	15	15	02	5.73	6.25	6.72	6.24
C9	60	20	20	00	12.02	12.26	11.54	11.94

Table 5: Signal to Noise Ratio value for compressive test value - 7th day

Taguchi Analysis: Response versus Fly ash (%), Bottom ash (%), Cement (%),…...				
Response Table for SNR				
Larger is better				
Level	*Fly ash*	*Bottom ash*	*Cement*	*Rice husk*
1	20.71	20.57	19.66	23.53
2	20.10	19.08	19.09	19.99
3	18.06	19.72	20.13	17.10
Delta	2.65	1.49	1.04	6.43
Rank	2	3	4	1

Table 6: Confirmation Experiments for compressive strength

Level	*Fly ash*	*Bottom ash*	*Cement*	*Rice husk*
1	20.71	20.57	19.66	23.53
2	20.10	19.08	19.09	19.99
3	18.06	19.72	20.13	17.10
Taking levels of Maximum values	1	1	3	1
Confirmation Experiment	50	10	25	0



(a) Relation between Compressive strength and Fly ash

(b) Relation between Compressive strength and Bottom ash

(c) Relation between Compressive strength and cement

(d) Relation between Compressive strength and Rice husk

Figure 2: (a, b, c, d) S/N Ratio Compressive Strength Test at 7th day

Table 7: Water absorption test for the – 7th day

Trial Combination	*Parameters*				*Sample 1*	*Sample 2*	*Sample 3*	*Water absorption %*
	Fly ash	*Bottom ash*	*Cement*	*Rice husk*				
C1	50	10	15	00	16.12	16.17	16.14	16.143
C2	50	15	20	01	16.62	16.58	16.66	16.62
C3	50	20	25	02	15.16	15.19	15.33	15.22
C4	55	10	20	02	17.13	17.18	17.15	17.15
C5	55	15	25	00	14.02	14.07	14.04	14.04
C6	55	20	15	01	18.33	18.40	18.37	18.36
C7	60	10	25	02	16.14	16.17	16.14	16.146
C8	60	15	15	02	21.45	21.50	21.46	21.46
C9	60	20	20	00	17.81	17.85	17.85	17.85

Durability Property Test

The water absorption test is conducted under the durability property test.

Water Absorption Test

The experimental results of water absorption test of all the nine mix combinations when tested on the 7th day is represented in Table 7. From Table 7 it can be observed that the C5 mix exhibits minimum water absorption capacity of 14.04% as compared to all the other mixes when tested on the 7th day.

Figure: 3 illustrates the comparison of the water absorption capacity of all the nine mixes on the 7th day.

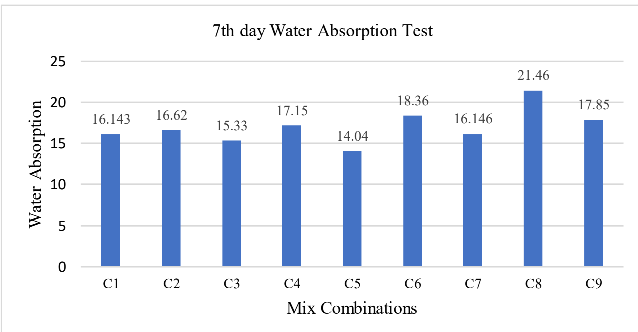


Figure 3: 7th day water absorption test

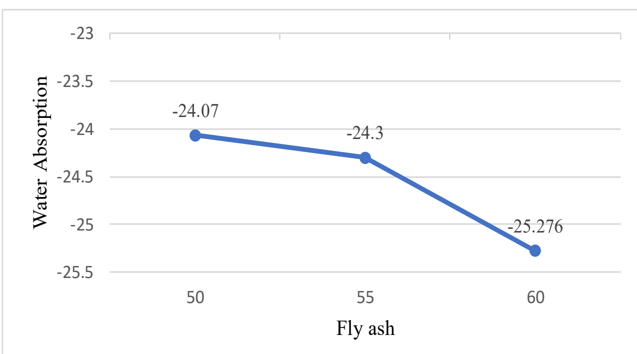
Signal-To-Noise Ratio

The Signal to Noise Ratio (S/N) analysis was conducted on 7th day saturated water absorption strength value of all the mixes. Figure 4 represents the main effects plot for S/N Ratio for 7th day for water absorption strength.

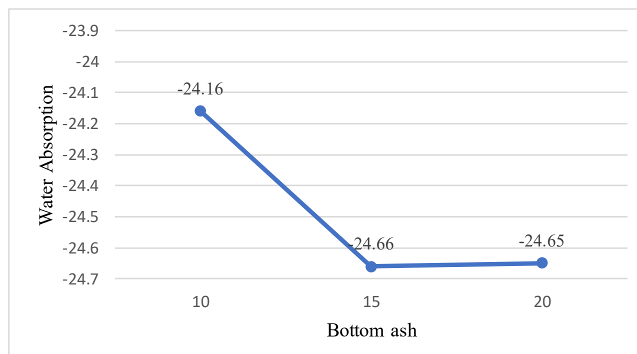
It can be shown that, for the 7th day, when the cement is changed from 15 to 25% and subsequently to 20%, respectively, the S/N value for the water absorption strength improves from -25.35 to -23.58 and decreases to -24.71.

Table 8: Signal to Noise Ratio value for water absorption test value -7th day

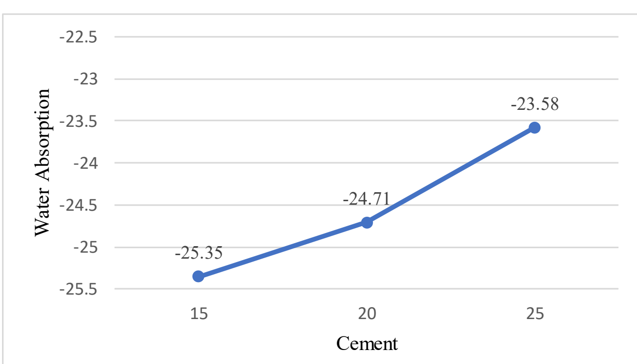
Taguchi Analysis: Response versus Fly ash (%), Bottom ash (%), cement (%) and Rice husk (%).				
Response Table for SNR				
Smaller is better				
Level	*Fly ash*	*Bottom ash*	*Cement*	*Rice husk*
1	-24.07	-24.16	-25.357	-24.045
2	-24.30	-25.66	-24.711	-24.61
3	-25.276	-24.656	-23.584	-24.99
Delta	1.206	0.5	1.773	0.945
Rank	2	4	1	3



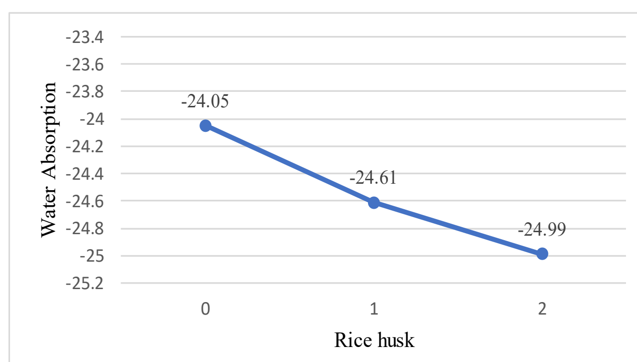
(a) Relation between Water Absorption and fly ash



(b) Relation between water absorption and bottom ash



(c) Relation between Water Absorption and Cement



(d) Relation between Water Absorption and Rice husk

Figure 4: (a, b, c, d) S/N Ratio water absorption test at 7th day

Table 9: Confirmation experiment for water absorption

Level	*Fly ash*	*Bottom ash*	*Cement*	*Rice husk*
1	-24.07	-24.16	-25.357	-24.045
2	-24.30	-25.66	-24.711	-24.61
3	-25.276	-24.656	-23.584	-24.99
Taking levels of Maximum values	1	1	3	1
Confirmation Experiment	50	10	25	0

The cement has a rank of 1, fly-ash has a rank of 2, the rice husk has rank 3, and bottom ash has no significant effect on the 7th water absorption test.

It was observed that for fly ash, bottom ash and rice husk, the maximum value corresponds to level 1, while for cement, it corresponds to level 3. The ratios corresponding to these levels (for cement level 3 corresponds to 25%, for fly ash corresponds to 50%) are noted, giving a new mix ratio as shown in Table 9.

Conclusions

This research deals with the results of the Taguchi optimization approach used to find the best solution on Fly Ash Composite Bricks using sustainable resources. The findings of the experimental studies are reported, together with the statistical analysis done to verify the findings.

The Taguchi L9 orthogonal array is used to reduce the number of tests required to get the optimal solution from 81 to 9. With the least number of tests possible, an ideal mix ratio has been reached thanks to the use of this approach. The fewer tests mean less raw material is used, resulting in less waste, less expense and a more sustainable final product.

This is highly significant as the research in Mechanical Engineering involves large number of experimental analyses.

Mechanical Property of Fly Ash Composite Bricks

A maximum compressive strength value of 17.36 N/mm^2 was exhibited by C5 mix which had 25% cement, 55% fly ash, 15% bottom ash and 0% rice husk. Compared with the conventional clay brick, the compressive strength is 30% more.

Durability Tests of Fly Ash Composite Bricks

The C5 mix exhibited a minimum water absorption value of 14.04% with 25% cement, 55% fly ash, 15% bottom ash and 0% rice husk on the 7th day.

S/N Ratio was performed on the test results of all the experiments and C5 mix with 25% cement, 55% fly ash, 15% bottom ash and 0% rice husk exhibited grade 1 for all the mechanical as well as the durability properties tests.

All of the experiment test data were analysed using the Signal-To-Noise Ratio (S/N Ratio) method to determine the characteristics of the various fly ash composite bricks.

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