Parametric Optimization of Fly Ash Building Bricks Material Composition for Compressive-Tensile Strength Using Taguchi Method

By

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Abstract

Fly ash is employed in many different applications and is generated in thermal power stations by burning lignite and coal. It is kept in rooms or stock over productive land. Power plants should use fly ash as soon as possible since it includes sulphur, and the area where it is stored will become arid. To utilize and recycle fly ash with the best results—which is required for creating bricks—research was conducted to determine the percentage of maximum usage combination of a fly ash building brick. The brick size specimen is 230 mm x 100 mm x 90 mm in dimension. According to Indian standards, several combination percentages of fly ash (9 to 21%), gypsum (6%), cement (28-38%), glass powder (3%-9%), glass fiber (1cm-3cm) and coarse aggregate (26-54%) with three distinct coarse-aggregate particle sizes (450 nm, 650 nm, and 850 nm), glass powder size (50 nm, 100 nm, and 150 nm) were tested for various mix proportions. The test findings demonstrate differences in compressive strength, water absorption, and efflorescence for various mixing proportions of the materials described previously during various curing times, which are 9 days, 18 days, and 27 days. The prior research-based findings plainly anticipated that the best mixing proportion of Fly-Ash 9-10%, Cement 28-35%, Gypsum-6%, glass powder 3%-9%, glass fiber 1cm-3cm and Coarse-Aggregate dust 26-52% would yield the highest possible compressive-tensile strength.

Keywords: Fly-Ash, Cement-Binder, Gypsum, Coarse-Aggregate, Compressive-Tensile Strength, Efflorescence-Water Absorption %.

Introduction

The usage of affordable and environmentally friendly materials is of utmost importance in the current trend in the construction business. Cement is one of the primary materials utilized in the current situation. Numerous studies have shown that the heat released by cement contributes more to global warming than other heat sources. k A Sumathi SarwanaRaja Mohan, 230mm*110mm*90mm*and brick created by employing flash- (15to50%)gypsum (2%)lime (5to 30%) & amp; quarry dust (45to55%)brick is built up by Taguchi Method. This study aimed to identify the most advantageous condition or outcome of the mixed percentage of fly ash brick [1]. Laxmikant N. Vairagade and Dinesh W. Gawatre The following benefits that have emerged as additional arguments in this discussion on using flash in the safest and most beneficial ways are highlighted in this study [2]. Manas Kumar Singh, As a result, we learned that approximately 125 thermal power plants and other buildings in India had been fully identified and produced massive fly ash. Low-grade coal use produces 120 million fly ash annually, and many applications have been identified for this fly ash. We also concluded that adding too much lime to fly ash may not be beneficial [3]. Bricks are chosen according to a specification based on their qualities, including strength and longevity [4]. Cement is the most significant substance used in buildings today, according to a study by Ashish Kumar Khandelwal, it is also utilized to reduce global warming. Using the right amount of fly ash in the mix may achieve the maximum optimum compressive strength needed for building [5]. Fly ash is crucial for coal construction and is collected mechanically or electronically; on average, 30% to 40% of Indian coal contains ash. Fly ash disrupts the natural cycle, pollutes the air, water, and soil, and creates environmental concerns. To make masonry bricks, a mixture of fly ash, lime, gypsum, and sand can be utilized. Fol-G masonry units are a viable alternative to traditional masonry units. Fol-G bricks are safer, more affordable, and have more strength because of their high strength, ensuring no breakage during transit. All of the information above was offered in Guidelines for Making Quality Fly Ash Bricks [6]. A sector of the economy that deals in cement goods emits more carbon dioxide and uses many energy resources to make cement. To lessen these consequences, change the cement with pozzolanic components like fly ash, which can have a greater impact against these detrimental substances. In this study, we determine the ideal proportions of fly ash (one of the main components), sandy, hydrated lime, and gypsum, as well as the ideal pressure for moulding bricks. Fly ash is a primary element produced at the Century Pulp and Paper Thermal Power Plant. The ideal composition comprised 55% fly ash, 30% sand, 15% hydrated lime, and 14% gypsum. For the ideal mix, researchers looked at the compressive strength, tensile strength, efflorescence, water absorption, shrinkage property, flexural strength, open microstructure pore, and pore of the fly ash-sandy/clay-lime-gypsum building bricks produced with the ideal composition at varying pressures, the radioactivity of brick. The Taguchi technique is used in this study report to conduct an experimental inquiry into the fly ash brick mix proportions with various particle sizes and material compositions (based on L9 MATRIX). Lime and fly ash were employed at the bare minimum, while ratio of binder material was considered a controlling component. Therefore, utilizing mean response data and noise-to-signal ratios, the impacts of fly ash, water/binder ratio, sandy/clay, and gypsum on the performance parameters are examined. Additionally, the projected best values for the process parameters are 0.4 for the binder/water ratio, 10% for fly ash, 3% for gypsum, 35% for lime, and 52% for sandy/clay [8]. At temperatures between 1000°C and 12000°C, adding fly ash up to 30% has no appreciable negative impact on the quality of the brick. It was observed that the construction bricks with fly ash added exhibit quite superior qualities and may compete with the traditional building bricks. Applying fly ash as a raw material for the construction of building bricks is not only a viable substitute for clay but also a solution to the problematic and expensive issue of waste disposal [9]. In the current research, an attempt has been made to determine the ideal ratio of various building brick materials, such as fly ash, lime, fly ash, clay/sandy, and gypsum, to produce the highest compressive strength, tensile strength, flexural strength, efflorescence, and water absorption. Composite materials are now the most successful materials utilized in various applications for the most recent developments in the sector. Research by Deepak Singla on the composite-material made of fly ash with Al 7075 as reinforcement-material was presented. This material has the potential of economical viability, mechanical and physical qualities for use in the spacecraft and automotive sectors. Compared to other metals and alloys, the qualities of the composite material 7075-Fly Ash Composites, which was produced utilizing a stir casting arrangement, are greatly enhanced. These features include toughness, hardness, high tensile strength, low density, and superior wear resistance. Strength in every test increased as fly ash amount increased up to a specific point, after which strength decreased [10].

I. Objective

The goal of this study is to identify the ideal mixture composition design for making building bricks to maximize the compressive-tensile strength, efflorescence, and water absorption of building bricks for 3 diverse sizes of coarse-aggregate, fly ash (425, 600, and 825 nano-microns), glass powder (50, 100, and 150 nm), which are further cured at various times/days 9, 18, and 27 days in solar radiation.

Iii. Need for the Research Study

1. to enhance the engineering qualities of construction bricks, such as strength, workability, plasticity, water absorption tightness, etc.
2. To increase compressive strength to determine the brick's stability and durability.
3. to lower the thickness of the plastering while maintaining the ideal Indian standard for fly ash bricks, which is consistent in size and shape.
4. to lower the overall cost of producing very durable construction brick.
5. to reduce the amount of rich land soil used in the production of building bricks and find a solution to this issue.
6. To conveniently recycle fly ash, safeguard our rich land soil from the sulphur inherent in fly ash, and expand the use of fly ash in constructing brick,
7. This satisfied the degree of strength qualities as well as in accordance with market demand and for particular conditions like earth quack to identify the best material ratio composition of fly ash in building brick.

II. Materials and Methodology Methods

The following information relates to the procedures, methodology, and characteristics of the resources employed in this research project.

A. *Materials Used*

1. Coarse aggregate dust
2. Gypsum
3. Cement
4. Fly Ash

Fly ashis a finely separated byproduct of burning coal that is carried by the flue gases and collected by an electrostatic precipitator. Fly ash is widely divided into two classifications by ASTM. Class F: Fly ash typically contains less than 5% CaO and is typically formed while burning anthracite or bituminous coal. Only pozzolanic qualities exist in Class F fly ash. Fly ash from the combustion of lignite or sub-bituminous coal is classified as Class C. Some class C fly ash may include more than 10% CaO. Class C fly ash has cementitious qualities in addition to pozzolanic ones. The fly ash has a specific gravity of 2.19 and is class C.

Cement: Nowadays, cement is a crucial binding element widely employed in building construction. In nature, it primarily appears as a mixture of calcium oxide (CaO) and magnesium oxide (MgO). Fly ash and cement react at room temperature to create a compound having cement's characteristics or features. The reaction between fly ash, cement, and calcium silicate hydrates gives the product high strength.

Gypsum: Gypsum is a soft, crystalline rock that occurs naturally as sand or as a nonhydraulic binder. Gypsum has valuable properties, including incombustibility, a small bulk density, strong fire resistance, a good capacity for sound absorption, quick drying and hardening, a better surface quality, and little shrinkage. Additionally, it can increase viscosity or strengthen materials. Its specific gravity is 2.31 grams per cubic centimetre. The density of gypsum powder is between 2.8 and 3 grams per cubic centimetre.

Coarse Aggregate Dust: Crushed stone or natural sand are examples of coarse aggregate dust. It increases the volume of concrete and offers dimensional stability; the remainder is crushed granite. Convenient river sand is expensive due to the enormous shipment volume from natural sources. Causes a problem for nature with the massive depletion of these sources. Due to the majority of the stone particles being retained on the 4.75mm riddle, river sand in the building becomes less appealing. It is quarry-derived granite waste. Because it is expensive to transport river sand from natural sources locally, it is not widely available.

furthermore, causes environmental issues because of the widespread depletion of these sources. River sand use in construction is becoming less desirable; a new supply for the concrete industry must be discovered. Its continuing usage has created significant cost, availability, and environmental issues. In this situation, coarse aggregate dust may be more affordable than river sand. Quarry rock dust is typically used on a big scale to smooth the surface of roads. It is also used to make hollow blocks and lightweight precast concrete elements. This work uses tiny particles under 4.75 mm in size after processing. fly ash (9 to 21%), gypsum (6%), cement (28-38%), glass powder (3%-9%), glass fiber (1cm-3cm) and coarse aggregate (26-54%) with three distinct coarse-aggregate particle sizes (450 nm, 650 nm, and 850 nm), glass powder size (50 nm, 100 nm, and 150 nm) were tested for various mix proportions. The bricks are cast using standard fly ash brick dimensions of 230 mm × 110 mm x 90 mm. 18 bricks are cast for each percentage, nine of which are used to calculate the compressive-tensile strength of the brick in N/mm2 after seven, fourteen, and twenty-one days of curing and three of which are used to calculate the water absorption. Compressive stress is calculated using a Compression Testing Machine (CTM) with a 3000 KN capability. The process for making fly ash bricks with a chosen material composition is shown in the following flow chart.

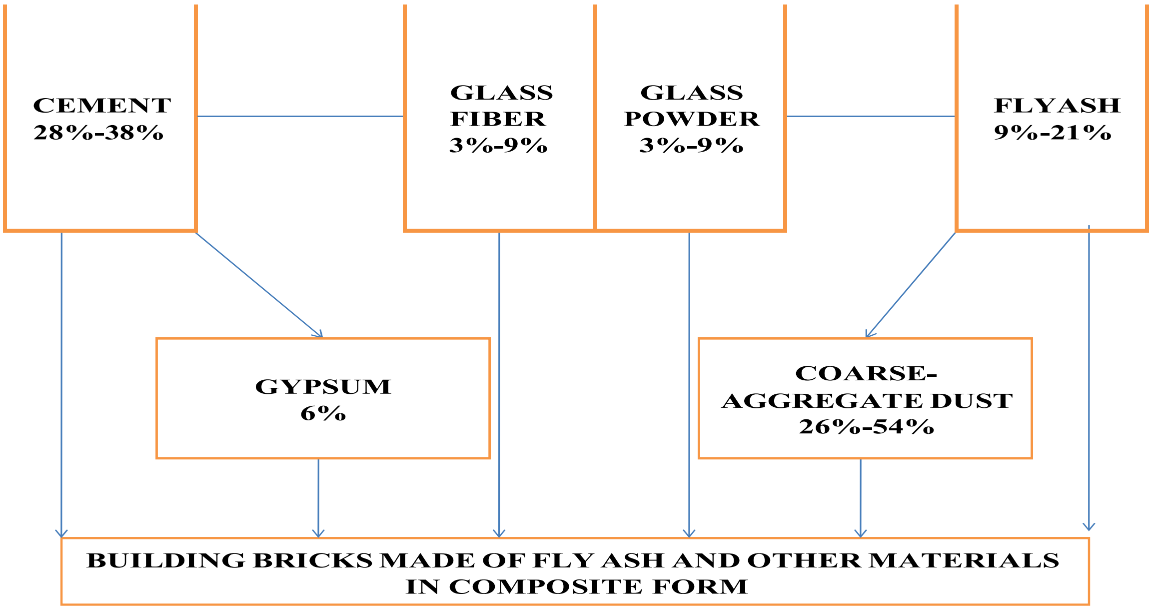

Figure 1. *Details of Materials used and Material Composition % in Building Bricks made of diverse Materials.*

Figure 2. *Detail view of Diverse Material used in Fly-Ash Building-Bricks with Samples and Mould.*

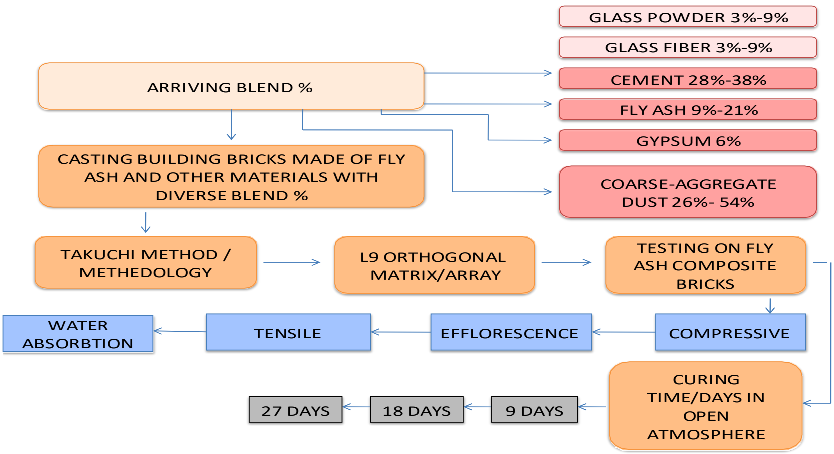

Figure 3. *Detailed Flow Chart of Methodology*

B. *Methedology Used*

As per Figure number 3, Table number 2 and 3, the Taguchi approach is used in this study paper's methodology to determine the ideal mixing % with various materials, as well as the ratio of material composition and fly ash particle size for assessing compression-tensile strength, water absorption ratio, and Efflorescence test results. In table number 1 and 4, where the proportion of gypsum is assumed to be constant across all samples, the material composition ratio % of various materials with three distinct particle sizes is displayed. Using the Taguchi approach, we choose four components with three distinct levels using an L9 orthogonal array, as indicated in table 1. This L9 orthogonal array was used to guide the preparation of nine experiments for the compression test. We determine the ideal composition ratio with various particle sizes for producing the best fly ash building bricks for the target market.

Table Number 1. *Details of Material % Composition with Diverse Factors and Levels*

LEVEL	FACTORS			
	CEMENT (%) + FLY-ASH (%) + COARSE AGGREGATE (%) + GLASS POWDER (%)	**GLASS POWDER / FIBER SIZE**	**COARSE AGGREGATE PARTICLE SIZE**	**CURING TIME**
1	28% + 9% + 54% + 3%	50nm/1cm	450	9
2	33% + 18% + 37% + 6%	100nm/2cm	650	18
3	38% + 21% + 26% + 9%	150nm/3cm	850	27

Table Number 2. *Details of Matrix Chart of L9 Orthogonal Array*

EXPERIMENT NO.	P1	P2	P3	P4	LEVEL
1.	1 (a)	1 (a)	1 (a)	1 (a)	L1
2.	1 (a)	2 (b)	2 (b)	2 (b)	L1
3.	1 (a)	3 (c)	3 (c)	3 (c)	L1
4.	2 (b)	1 (a)	2 (b)	3 (c)	L2
5.	2 (b)	2 (b)	3 (c)	1 (a)	L2
6.	2 (b)	3 (c)	1 (a)	2 (b)	L2
7.	3 (c)	1 (a)	3 (c)	2 (b)	L3
8.	3 (c)	2 (b)	1 (a)	3 (c)	L3
9.	3 (c)	3 (c)	2 (b)	1 (a)	L3

Table Number 3. *Details of Material % Composition as per Matrix Chart of L9 Orthogonal Array*

CEMENT (%) + FLY-ASH (%) + COARSE AGGREGATE (%) + GLASS POWDER (%)	GLASS POWDER/FIBER SIZE AND PERCENTAGE	PARTICLE SIZE OF COARSE AGGREGATE	GYPSUM
28% + 9% + 54% + 3%	50nm/1cm	425	6%
28% + 9% + 54% + 3%	100nm/2cm	600	6%
28% + 9% + 54% + 3%	150nm/3cm	825	6%
33% + 18% + 37% + 6%	50nm/1cm	825	6%
33% + 18% + 37% + 6%	100nm/2cm	425	6%
33% + 18% + 37% + 6%	150nm/3cm	600	6%
38% + 21% + 26% + 9%	50nm/1cm	600	6%
38% + 21% + 26% + 9%	100nm/2cm	825	6%
38% + 21% + 26% + 9%	150nm/3cm	425	6%

Table Number 4. *Details of Material % Ratio Composition in Grams for 01 Kilogram.*

CEMENT (%)	FLY ASH (%)	COARSE AGGREGATE (%)	GLASS POWDER (%)	GYPSUM (%)
280	90	540	30	60
330	180	370	60	60
380	210	260	90	60

III. Result and Discussion

Using fly ash building bricks of various particle sizes mixed with cement, gypsum, and coarse aggregate dust, an experimentally based inquiry was conducted to determine the ideal combination % for compressive and tensile force application. Diverse sets of experiments has been performed for testing compressive and tensile strength after producing samples from diverse materials and percentage (like cement, fly-ash, coarse aggregate, glass powder, glass fiber, gypsum) with varying particle, fiber size and curing time parameters. Fly ash building bricks were cast from the various variable material compositions through mould. Bricks were subjected to the following tests: efflorescence, water absorption, and compressive strength.

A. Compressive-Tensile Strength Test

Fly ash construction brick has a compressive strength of five times more than typical clay brick. Brick has a minimum compressive strength of 0.95 N/mm^2 and tensile strength of 3.8 N/mm^2. Consequently, the compressive strength and tensile strength of fly ash masonry bricks ranges from 7.12 to 47.5 N/mm^2 and 23.75 to 190 N /mm^2. Bricks used for various projects shouldn't have compressive strengths that are less than those listed above. In this study, we examined the compressive strength of bricks using a computerized universal testing apparatus is lower as compared to tensile strength. Building bricks are put for further dry heating under solar radiation after the wet curing period for three separate dry curing durations, namely 9, 18, and 27 days. Brick samples are ready for testing after solar drying for construction bricks has been completed. Building bricks are placed in a calibrated compression testing machine with a 3000 KN load capacity to test the samples as shown in figure number 8, providing consistent stress at a rate of 2.9 N/mm^2. The maximum load at which a particular sample fails is known as a load of failure, and it is recorded in the indicator reading on the testing machine, as illustrated in tables 5, 6. 7 and 8.

From figure number 6 and 7, it is clearly represented the response to Mean and SN Ratio Curves for Compressive-Tensile Test. The graph indicates the optimum factor and level which has been selected before doing experimentation, results reveals that the composition factor, curing time and particle size were most effected parameter compared with glass powder size and fiber. These parameters or factor plays important role for building up the strength.

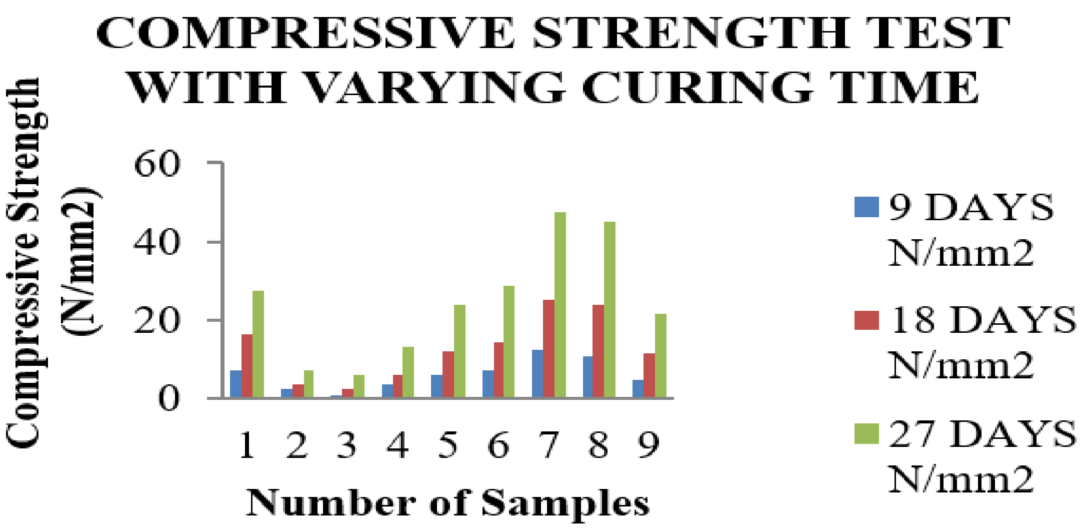

Figure 4. *Graphical Differences of Strength (Compressive) with diverse Samples and Curing Parameter*

Table Number 5. *Details of Compressive Strength of Diverse Samples.*

EX NO.	CEMENT (%) + FLY-ASH (%) + COARSE AGGREGATE (%) + GLASS POWDER (%)	GLASS POWDER SIZE	PARTICLE SIZE OF COARSE AGGREGATE	GYPSUM (%)	COMPRESIVE TEST
1	28% + 9% + 54% + 3%	50nm	425	6%	27.3125
2	28% + 9% + 54% + 3%	100nm	600	6%	7.125
3	28% + 9% + 54% + 3%	150nm	825	6%	5.9375
4	33% + 18% + 37% + 6%	50nm	825	6%	13.0625
5	33% + 18% + 37% + 6%	100nm	425	6%	23.75
6	33% + 18% + 37% + 6%	150nm	600	6%	28.5
7	38% + 21% + 26% + 9%	50nm	600	6%	47.5
8	38% + 21% + 26% + 9%	100nm	825	6%	45.125
9	38% + 21% + 26% + 9%	150nm	425	6%	21.375

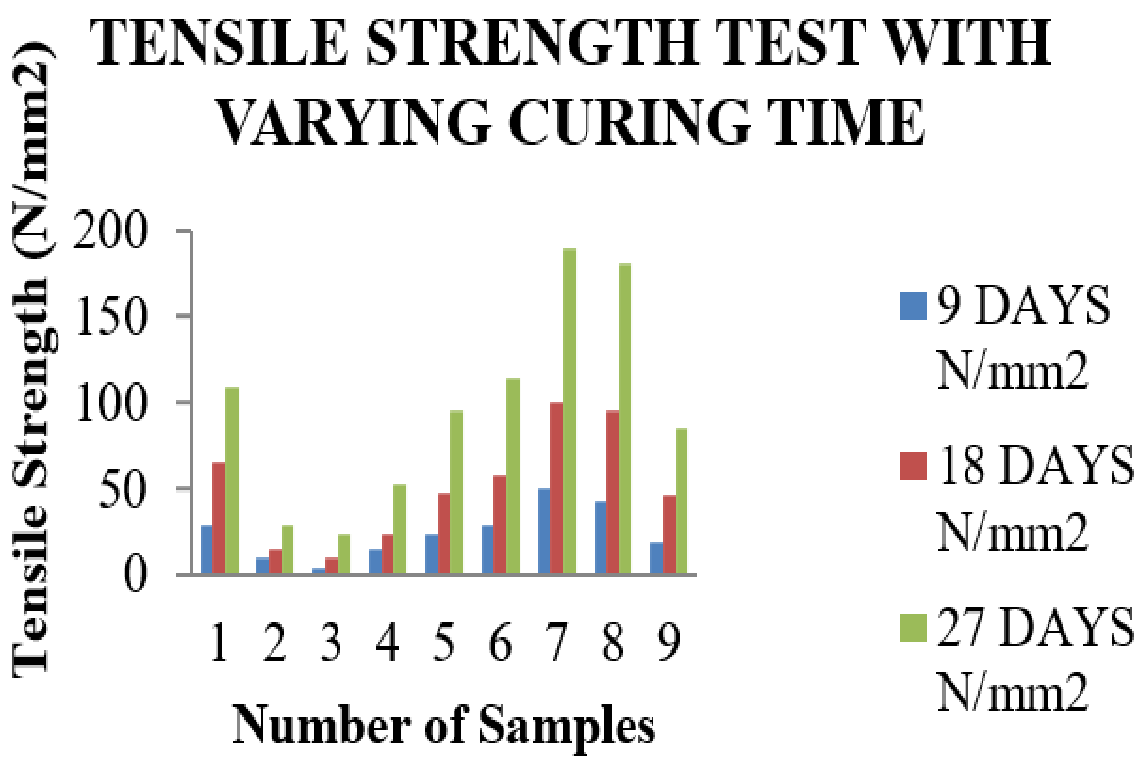

Figure 5. *Graphical Differences of Strength (Tensile) with diverse Samples and Curing Parameter*

Table Number 6. *Details of Tensile Strength of Diverse Samples.*

EX. NO.	CEMENT (%) + FLY-ASH (%) + COARSE AGGREGATE (%) + GLASS FIBER (%)	GLASS FIBER SIZE	PARTICLE SIZE OF COARSE AGGREGATE	GYPSUM (%)	TENSILE TEST
1	28% + 9% + 54% + 3%	1cm	425	6%	109.25
2	28% + 9% + 54% + 3%	2cm	600	6%	28.5
3	28% + 9% + 54% + 3%	3cm	825	6%	23.75
4	33% + 18% + 37% + 6%	1cm	825	6%	52.25
5	33% + 18% + 37% + 6%	2cm	425	6%	95
6	33% + 18% + 37% + 6%	3cm	600	6%	114
7	38% + 21% + 26% + 9%	1cm	600	6%	190
8	38% + 21% + 26% + 9%	2cm	825	6%	180.5
9	38% + 21% + 26% + 9%	3cm	425	6%	85.5

Table Number 7. *Details of Strength (Compression) with Varying Curing Time/Period.*

SET OF EXPERIMENT	CURING TIME/DAY		
	9 DAYS N/mm^2	18 DAYS N/mm^2	27 DAYS N/mm^2
1	7.125	16.15	27.3125
2	2.375	3.5625	7.125
3	0.95	2.375	5.9375
4	3.5625	5.9375	13.0625
5	5.9375	11.875	23.75
6	7.125	14.25	28.5
7	12.35	24.9375	47.5
8	10.6875	23.75	45.125
9	4.75	11.4	21.375

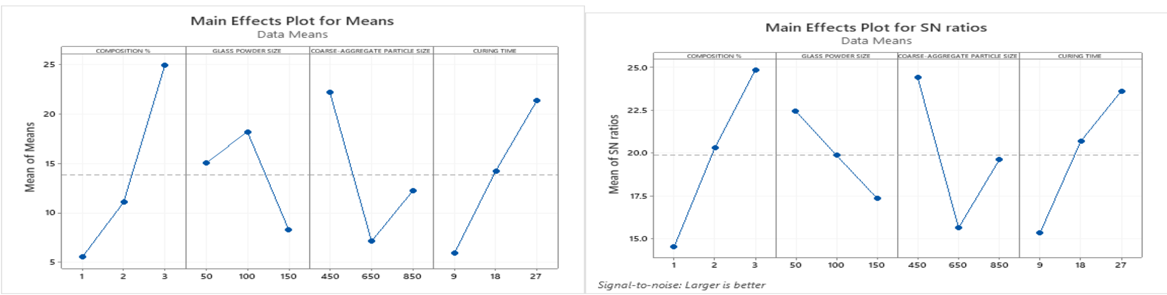

Figure 6. *Detailed representation of response to Mean and SN Ratio Curves for Compressive Test*

Table Number 8. *Details of Strength (Tensile) with Varying Curing Time/Period.*

SET OF EXPERIMENT	CURING TIME/DAY		
	9 DAYS N/mm^2	18 DAYS N/mm^2	27 DAYS N/mm^2
1	28.5	64.6	109.25
2	9.5	14.25	28.5
3	3.8	9.5	23.75
4	14.25	23.75	52.25
5	23.75	47.5	95
6	28.5	57	114
7	49.4	99.75	190
8	42.75	95	180.5
9	19	45.6	85.5

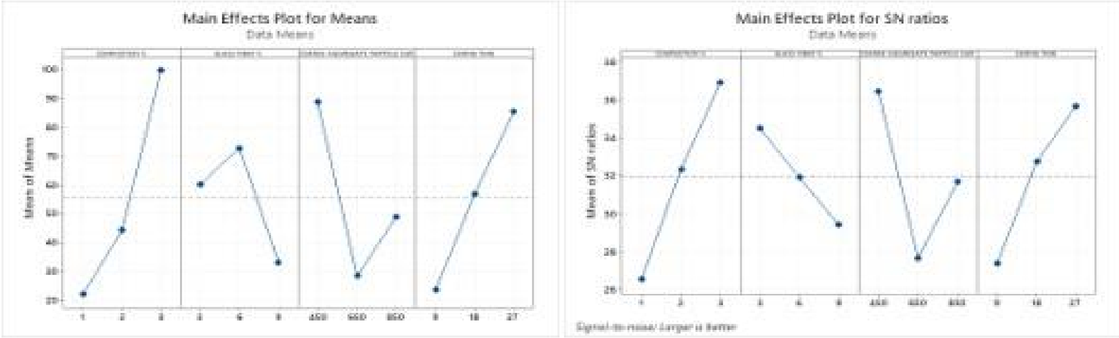

Figure 7. *Detailed representation of response to Mean and SN Ratio Curves for Tensile Test*

Figure 8. *Compressive-Tensile Testing M/c*

B. Water Absorption Test

In the water absorption test, we first weigh all of the samples before submerging them, following the measurement of weight W1.

After immersing each sample in water for 24 hours, we remove each individually and weigh them to determine their W2 weight. After reading every line, we put the entire sample into an oven set at 105 to 115 degrees Celsius temperature until the bricks reached a steady weight. We then let the bricks cool to room temperature and weighed them (W1). It has been shown that the samples only absorbed around 15% of the water. We use the calculation W% = (W2 - W1/W1) x 100 to determine the water absorption percentage by weight after removing all the bricks from the oven.

Table Number 9. *Test Details of Absorption % of Water with Diverse Sample having Glass Fiber good for Compressive Strength*

EX. NO.	W1 (kg)	W2 (kg)	(W2-W1)	(W2-W1)/W1	(W2-W1)/W1X100 %
1	1.44	1.53	0.09	0.06	6.23
2	1.67	1.82	0.15	0.09	8.96
3	2.23	2.48	0.25	0.11	11.27
4	1.84	1.98	0.14	0.08	7.67
5	2.24	2.44	0.21	0.09	9.20
6	1.90	2.09	0.19	0.10	9.98
7	2.06	2.21	0.15	0.07	7.44
8	2.15	2.32	0.17	0.08	7.66
9	2.15	2.36	0.21	0.10	9.95

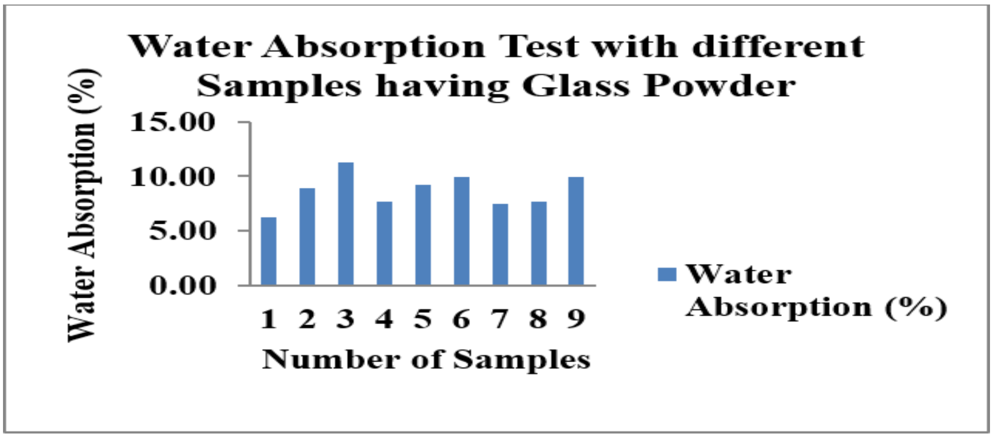

Figure 9. *Graphical Differences between % of Water Absorption with Diverse Samples having Glass Powder*

Table.Number 10. *Test Details of Absorption % of Water with Diverse Sample having Glass Fiber good for Tensile Strength*

EX. NO.	W1 (kg)	W2 (kg)	(W2-W1)	(W2-W1)/W1	(W2-W1)/W1X100 %
1	1.77	2.07	0.31	0.17	17.31
2	2.00	2.36	0.37	0.18	18.32
3	2.55	3.02	0.47	0.18	18.30
4	2.16	2.52	0.36	0.17	16.51
5	2.56	2.98	0.42	0.16	16.47
6	2.23	2.63	0.41	0.18	18.22
7	2.38	2.75	0.37	0.16	15.50
8	2.48	2.86	0.38	0.15	15.38
9	2.47	2.90	0.43	0.17	17.38

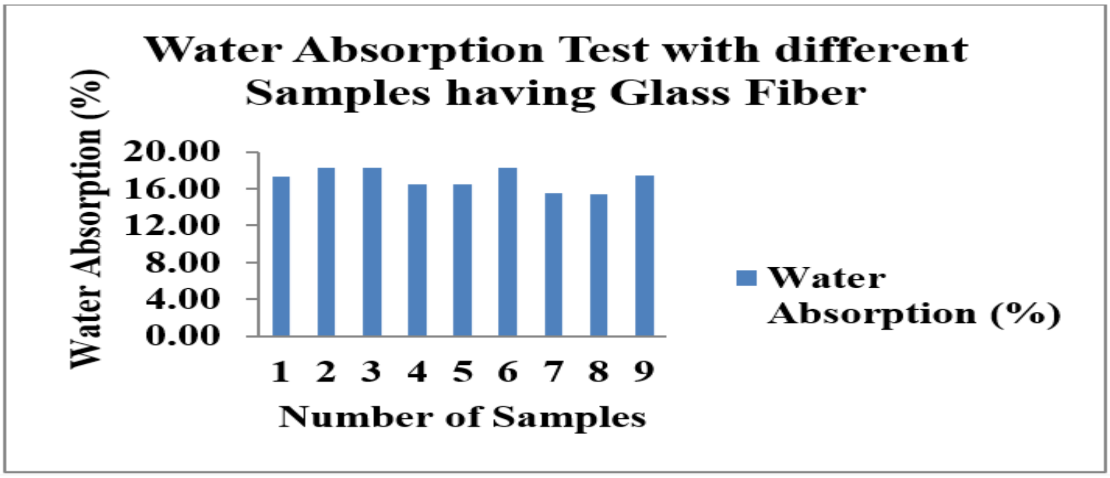

Figure 10. *Graphical Differences between % of Water Absorption with Diverse Samples having Glass Fiber*

C. Efflorescence Test

First, we submerged one end of a brick vertically in water for the efflorescence test. Fly ash construction bricks were submerged in water to a depth of 2.5 cm, and all the arrangements were then placed in a warm, well-ventilated chamber between 25 and 35 0C until all the water had evaporated. The water in the dish was completely absorbed and evaporated by the fly ash building brick, so we added more water to the dish and let it absorb and evaporate as before. Following this procedure, we analyze each sample of fly ash construction bricks to determine the appropriate amount of white spots on their surface. After observation, the report is classified as effloresced if the presence of salt deposits causes a difference and not effloresced if there is no change.

According to the findings of our current study, there are no white spots in any of the fly ash **construction bricks**

V. Conclusion

With three different fly ash and coarse aggregate dust particle sizes, including 425-micron, 600 micron, and 825 microns, prepared at three different curing times under solar radiation, including 9 days, 18 days, and 27 days, we are attempting to determine the optimal mixture percentage of fly ash building bricks for varying material composition. Sample 17 exhibits the greatest results of all samples for the Compressive-Tensile Strength Test and Water Absorption Test, with a value of 47.5 N/mm2 and 190 N/mm2, as shown in Table Number 5 and 6. According to Indian standards, several combination percentages of fly ash (9 to 21%), gypsum (6%), cement (28-38%), glass powder (3%-9%), glass fiber (1cm-3cm) and coarse aggregate (26-54%) with three distinct coarse-aggregate particle sizes (450 nm, 650 nm, and 850 nm), glass powder size (50 nm, 100 nm, and 150 nm) were tested for various mix proportions. The most optimal combination percentage for high compressive-Tensile strength (particle size 600 micron, 27-day curing). From the findings above, it is also inferred that the lengthy curing period required to prepare to fly ash construction bricks causes their superior compression-tensile strength and smaller particle size of coarse aggregate, fly-ash. By employing the combination above composition percentage, we may produce bricks without baking them, saving fuel costs as baking is a necessary step in preparing and producing regular clay bricks. This experiment has demonstrated this. For baking clay bricks, a temperature range of 1701 K to 3786 K must be maintained constantly for five days. This involves spending a lot of money on the baking process. The investigation results show that we reduce baking costs, which makes our product very cost-effective, and we achieve five times better results compared to other fly ash bricks currently on the market, normal high-strength clay building bricks. The evaluated compressive-tensile strength results during experiments for various fly ash bricks ranged from 0.95-12.35 and 3.8-49.4 N/mm^2 for 9 days, 2.37-24.93, 9.5-99.75 N/mm^2 for 18 days and 5.93-47.5, 23.75-190 N/mm^2 for 21 days of curing time, while for typical best strength clay bricks, it was 47.5 and 190 N/mm^2 which makes our product very cost-effective. Therefore, it is clear that the results of our research on the composition of fly ash construction bricks with variable percentages of different materials are promising.

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