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PERFORMANCE OF FLYASH BRICKS FABRICATED USING WASTE MATERIALS

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Highlights-

- The performance of bricks constructed using industrial wastes is investigated and the outcomes are discussed in this paper.
- In this study, bricks were produced using an innovative self-compacting technique.

Abstract-

Waste-industrial by product from the thermal electrical/power plants known as fly-ash, that is used as a type of raw material to make bricks. In order to lessen the strain on an exhaustible resource that jeopardises the sustainability of the surrounding environment, bricks made by fly-ash are suggested as an alternative to traditional burnt-clay bricks. However, fly-ash is a substance with its own set of issues. Additionally, excessive strain on one material may eventually impact demand, which could have an impact on the construction sector. In order to counter this possibility, a number of environmentally friendly industrial waste materials are selected to partially replace fly-ash in fly-ash bricks, including bottom ash (BA), granite powder (GP), foundry sand (FS), quarry dust (QD), ground granulated blast-furnace slag (GGBS), steel slag (SS), bagasse-ash (BHA), and rice-husk ash (RHA). This would undoubtedly result in less fly-ash being consumed and conservation. Replacement rates for the chosen industrial waste materials are 25%, 50%, 75%, and 100%, respectively. The measured parameters are efflorescence, water absorption, and compressive strength of the cast specimen in comparison to a control specimen. Since bricks are often compressive materials, their moisture content has an impact on their strength and longevity. Salts are shown by efflorescence, while the brick's moisture content is revealed by water absorption. As a result, the brick specimens undergo the aforementioned tests, and the outcomes are documented. Using the different mixes FS, QD GP, GGBS, BHA and SS for secure waste-disposal and utilization of significant different minerals in waste-materials in view of characteristics compressive strength; it is possible to replace such waste-materials in fly-ash bricks to 100%. The IS code's maximum water absorption was exceeded by the average for all waste-material mixtures in construction bricks. Bricks that have had SBA and RHA replaced show zero and minimal efflorescence, respectively. Since the percentages of ferric-oxide and calcium-oxide in foundry sand are significantly lesser than in fly-ash bricks, the efflorescence in foundry sand mixing bricks is zero for any % replacement. The results of this study may improve the efficacy of fly-ash bricks and expand the scope for their replacement.

keywords: Fly-ash bricks, Granite powder (GP), Bottom ash (BA), Foundry sand (FS), Steel slag (SS), Bagasse-ash (BHA), Rice husk ash (RHA), Quarry dust (QD), Ground Granulated Blast-Furnace Slag (GGBS), Compressive Strength Test.

1. INTRODUCTION

For about 5000 years of human history, bricks have been a significant building material. Bricks are classified as Masonry constructions and are still a popular and affordable building-material today. Like stones, bricks maintained their value as building materials. Burning dry, hardened clay blocks produces bricks. Bricks made of burned clay continued to be the major building material used by all ancient civilizations. Because of its many advantageous qualities, including ease of construction, great durability, ease of production (whereas, clay is readily available in market for brick making), thermal attributes, etc., brick masonry was seen as significant. In the past, clay was a readily available raw material. However, our society's population explosion has led to a high demand, which has prompted the resource's exploitation. In addition, burning is a step in the brick-making process that has a significant carbon footprint and has raised concerns as global carbon emissions have increased and begun to have a significant influence on people's day-to-day lives.

Although there have been many proposals and uses of alternatives to bricks over the years, clay bricks remained the most popular choice for masonry construction. However, pulverized fuel ash, or fly-ash, has brought about a significant change in comparison to all other substitutes. Fly-ash, which is a waste by-product from the combustion of coal in thermal electrical/power plants. Fly-ash gets its name from the residue left over after burning coal that is carried away in smoke and ends up in chimney stacks [1]. Fly ash is a fine material that can be substituted for cement since it emits little heat when it is hydrated. Consequently, fly-ash was utilized to make bricks that were marketed as fly-ash bricks.

However, fly-ash also had several drawbacks, such as a low initial mechanical strength comparable to bricks and a low heat absorption rate, which made it an unsuitable construction material in tropical climates. The primary issue is that fly ash is completely useless for making bricks. Given that fly-ash bricks are a waste product with intrinsic quality variations, it becomes crucial to take into account the possibility that improper manufacturing could render them unusable as building materials. Marble powder is one of several waste products, particularly industrial wastes, which are known to strengthen fly-ash bricks. Examining alternative industrial waste materials to substitute fly-ash in bricks is crucial for enhancing fly-ash brick masonry and optimizing waste-management in the current environmental context, where the way of life is growing increasingly dependent on energy and resources [2]. Materials from industrial waste streams, such as granite powder, rice husk ash, quarry dust, bottom ash, foundry sand, steel slag, bagasse-ash, and GGBS (ground granulated blast-furnace slag), can be used in place of certain fly-ash in fly-ash bricks. Since these materials are being investigated/examined for use in the production of construction bricks or are being investigated as fly-ash substitutes in other materials or industries, they make sense as replacements. These materials are all waste products from industry that are already being used for different purposes in the building sector. Fly-ash is used in place of these industrial wastes in conventional amounts of 25%, 50%, 75%, and 100%. Here, the water absorption, compressive strength and efflorescence of the fly-ash bricks are examined with appropriate replacement. This allows us to investigate these materials' characteristics in connection to fly-ash as well as how fly-ash blocks react to the addition of foreign substances, and this is the main potential of current research/experimental study.

2. DIFFERENT MATERIALS AND METHODS

2.1 Fly-ash Bricks

Fly-ash is primarily composed of aluminum-oxide, silicon dioxide, and iron-oxide, with additional chemicals present as minor constituents or impurities. As was previously discussed, fly-ash is produced when coal is burned. Aside from that, fly-ash contains pozzolanic properties that make it valuable in the building sector. Due to fly-ash's pozzolanic properties, some research has also been done on replacing cement with the material. Returning to our area of expertise, fly-ash bricks are compressed bricks made of fly-ash, lime, and a small amount of accelerator [3]. Fly-ash bricks typically include mostly of fly-ash, cement, water, and M-sand with an accelerator acting as a catalyst. Because fly-ash is pozzolanic, it reacts with lime content when combined with water, and the accelerator guarantees the degree of reaction. The curing step is the next step in order to dry the mixture. The wet mix is dried at various temperatures and compressed at various pressures prior to curing. The kind and degree of curing determine the curing temperatures.

The pozzolanic-reaction results in the creation of calcium-silicon hydrate, a binding material in its gel state. However, the use of cement or lime, which has lime as a main component, renders the product non-sustainable in terms of the environment. Fly-ash is a waste product, but using it in place of burned clay makes fly-ash bricks appear more environmentally benign [4]. However, the fact that lime and fly-ash are waste products of highly polluting processes raises concerns. Fly-ash could be replaced in fly-ash bricks with other waste materials to combat this issue.

Although the replacement research notion is not new, more studies in this area may lead to the standardization of fly-ash brick production as an environmentally beneficial building material. Additionally, it might eventually lead to the promotion of fly-ash brick use in the building sector.

2.2 Materials for Replacement

The substitute materials ought to possess pozzolanic properties and be of a higher quality. The following materials have been investigated for the individual partial replacement of fly-ash in different proportions which are 25%, 50%, 75%, and 100%:

- Granite powder (GP),
- Bottom ash (BA),
- Foundry sand (FS),
- Steel slag (SS),
- Bagasse-ash (BHA),
- Rice husk ash (RHA)
- Quarry dust (QD),
- Ground Granulated Blast-Furnace Slag (GGBS)

2.2.1. Ground Granulated Blast-Furnace slag (GGBS)

The powdered slag is also known as GGBS or ground granulated blast-furnace slag, is produced as waste-slag material during the production process of steel in the iron industry. When steel is carbonated, or roasted, or iron is melted, slag is created at the bottom of the furnace. After cooling down (quenching), the slag is ground into fine-particles and used to make GGBS, or ground granulated blast furnace slag. It has a glassy, granular appearance and is quenched in steam or water. As a cementitious substance, GGBS absorbs sulphur from hydrated-lime to create more calcium-silicate hydrates, which are a great kind of binder. As a result, this substance is already used in concrete to partially replace cement. Because of its glassy nature and ability to polymerize with cement, GGBS is utilized in conjunction with cement. We can think of using it in place of fly-ash in fly-ash bricks by taking into account its application in the cement industry (figure 1).

Figure 1 Ground Granulated Blast-Furnace slag (GGBS)

2.2.2. Granite powder (GP)

Granite powder is a waste-product of the granite industry. Granite is a common rock used in construction. It is a member of the family of igneous rocks [5]. Granite is renowned for both its extreme strength and its smooth, shiny surface. Granular granite particles are released as dust during the cutting or polishing of granite rocks in quarries [6]. When the cut rocks have a desirable shape, these particles are also created. Granite powder is produced by using mechanical-cutters or water-jet, which produce finely GGD (granular granite-dust). Because of its extreme fineness, this granite powder has the potential to fly like cement. Because of its fineness, it can be used to substitute fly-ash in fly-ash bricks (figure 2).

Figure 2 Granite powder (GP)

2.2.3. Foundry sand (FS)

It is well recognized for being cooling and thermally insulating. As a result, foundries employ it to cast metal. A well-known and renowned technology for its smooth and efficient forging process is sand-casting. Thus, the sand that is utilized needs to have consistent ingredients and not react with the metal that is going to be cast. It is recommended to have sand with homogeneous physical qualities and a high silica concentration. Since some of the sand has already heated up or burned, it is typically thrown away at that point [7]. In foundries, it is not recommended to reuse sand. As a result, this sand—also known as foundry sand—is disposed of as garbage right away after being used to cast both non-ferrous and ferrous metals [8]. This foundry sand is highly homogeneous, rich in silica, and contains a metallic content. Because of its high silica percentage, it can react during hydration with calcium-oxide to produce CSH gel, which can be used as a binder. Thus, in fly-ash bricks, foundry sand is thought to substitute fly-ash to some extent (figure 3).

Figure 3 Foundry sand (FS)

2.2.4. Bottom ash (BA)

The production process is the same as that of fly ash; among the various materials considered, bottom ash is an obvious choice. Bottom ash is exactly what its name suggests-ash that builds up at the furnace's base. Ash is the residue that coal leaves in the furnace's bottom after burning in it. Bottom ash is the term for this [9]. It may be deduced from the aforementioned process that bottom-ash would have highly similar-composition to fly-ash but only with heavier particles (figure 4).

Figure 4 Bottom ash (BA)

2.2.5. Bagasse-ash (BHA)

The waste byproduct of the sugar production is bagasse. The significance of the sugar-industry and the process of sugar extraction do not need to be discussed. Bagasse is a by-product of the sugar extraction process and is generated in a highly sought-after industry. The leftover pulpy waste is burned to power the boilers in the sugar-factory, which melt raw-sugar to produce the extensively used crystallized sugar. However, burning bagasse is not a waste-friendly practice. Bagasse ash is the ash that is produced when bagasse is burned. Although its widespread application is debatable, this waste material is purported to be used as manure on farms. The disposal of this ash otherwise is undoubtedly harmful to the environment. Bagasse-ash has very high silica percentage along with other contaminants in its chemical composition. Additionally, pozzolanic properties are discovered to make it a competitive contender for fly-ash replacement in fly-ash bricks (figure 5).

Figure 5 Bagasse-ash (BHA)

2.2.6. Steel slag (SS)

A waste by-product of the steel producing sector is steel-slag. Iron ore, which is the raw material that becomes steel, must be extracted from its impurities and carbonated to produce steel. Some of the molten steel remains as a solid slag after the steel are purified. Steel slag is the term for this material. The kind of iron utilized or the method used to purify the steel affect the composition of steel-slag. Steel slag is mostly composed of silica, with trace amounts of carbon and magnesium. It is chosen to replace fly-ash because of its high silica concentration (figure 6).

Figure 6 Steel slag (SS)

2.2.7. Quarry dust (QD)

Dust is produced at quarries when the rocks are broken into tiny pieces or small sizes. Quarry dust is the name given to this dust [10]. All quarries produce this dust, although the raw-materials utilized in the quarry have an impact on the dust's chemical makeup. Quarry dust is typically categorized as fine aggregate and is suggested as a substitute for sand in concrete. Since sand is a necessary ingredient for fly-ash bricks, it makes sense to utilize quarry dust in its stead

[11]. Therefore, fly-ash might be substituted with quarry dust, increasing the amount of fine-aggregate in fly-ash bricks (figure 7).

Figure 7 Quarry dust (QD)

2.2.8. Rice-husk-ash (RHA)

One waste product from the manufacture of rice is rice husk. In the rice mills, rice-husk is burned in the open until it turns to ash [12]. However, this procedure produces two different kinds of ashes: one is carbonized ash and second white ash. The top layer of burned RHA is called carbonized ash, and because of its prolonged exposure to heat during the open burning process, it contains a high concentration of carbon. White ash, the interior layers of burned ash, has a high silica concentration since it is comparatively less burned and has not oxidized. Because of this quality, white ash—also known as rice husk ash, or RHA—is suitable for use in construction [13]. Concrete with a high silica concentration forms CSH gel and is useful for binding. The similar idea can be used to fly-ash bricks by substituting rice-husk ash for fly-ash (figure 8).

Figure 8 Rice-husk-ash (RHA)

2.3 Cement

As a very common building-material or used as binder, it needs no introduction in depth. For about 300 years, cement has been employed in construction, and for at least 2000 years, it has been utilized as lime. The term "binder material" refers to cement combined with a solvent (often water) that it hydrates to create the binding-content. As the finest aggregate in the concrete-mix, cement also serves as filler in the concrete-matrix. Lime makes up around 60% of the overall makeup of cement, plus silica and other ingredients. When lime and water come into contact, the lime becomes hydrated and forms Calcium-Silicate Hydrate (CSH) gel. To keep all the aggregates together, this gel serves as a binder [14]. Some scholars believe that the hydration reaction is an endless process. The extra silica component stays as the finer particles to fill in the fine spaces left by the coarse and fine aggregates. In this investigation, OPC 53-grade of this binding materials or cement that complies with IS code: 12269-1987 is utilized.

2.4 M-Sand

Manufactured sand is referred to as M-Sand. Although river sand is an exhaustible resource, its utilization is restricted when it comes to fine aggregate. Waste aggregates from breaking rocks are cleaned, sieved, and washed to obtain M-sand. Because they contain more silica, igneous rock fragments are typically favoured. It could occasionally be required to cleanse the particles before sifting. M-sand that complies with IS 383:1970 requirements is employed in this study.

2.5 Mix proportions

The study's criteria are derived from IS 12894:2002, clause 12.5. A number of experimental mixes were tested before the final blend was created. The ultimate split that was decided upon was fly ash at 60%, M-Sand at 30%, and cement at 10%. In accordance with IS 12894:2002, 230 mm × 110 mm · 70 mm was determined to be the modular size. Flyash can be substituted with other materials in the following standard ratios: 25%, 50%, 75%, and 100% individually. No substitute combinations were attempted. Every replacement is done separately using just fly-ash.

2.6 Experimental Methods

2.6.1. Casting of Fly-ash Brick Specimens

The aforementioned replacements for each industrial-waste are cast into the fly-ash bricks as a distinct substitute for the fly-ash content alone. A total of 33 mixes were received, consisting of a reference mix that had no replacement and four replacement levels for each replacing industrial waste. The casting process is as follows: fly ash and M-sand are added after cement and replacement materials have been combined [15]. Fly ash, M-sand, and cement are combined by hand in the reference mix. Following this, the dry mix is well combined for around two minutes. After that, enough water is added to the mixture to make it workable enough to fill the 230 mm by 110 mm by 75 mm mould. The mixture is allowed to dry in the mould for thirty minutes. After that, the dry mix is left out in the shade to dry for a day, and the prepared block is placed in an open tank filled with water to cure after drying [16]. Before being evaluated, the specimens are removed to allow for drying (figure 9).

2.6.2. Compressive-Strength Test

Since bricks are typically thought of as compressive structural components, the specimens were evaluated for compressive strength. In compliance with IS 3495 (Part 1): 1992 [17], the tests were conducted. For the experiment, a precision-calibrated Compression testing apparatus is employed. Two plywood sides were used for the specimens in accordance with the IS code. In order to create compressive stress, 14 N/mm^2/minute axial-load is applied, and each specimen's failure load (P) is suitably reported, adhering to IS 3495 (Part 1): 1992 regulations [17, 18].

Characteristics compressive-strength is determined using given equation,

$$\text{Compressive-Strength of Specimen} = \frac{P}{A}$$

where,

P stands for load at failure point in Newton (N), and

A stands for area of prepared specimens in mm^2, (figure 10 a)).

2.6.3. Water-Absorption Test

Bricks are tested for moisture content or for degree of compactness using a process called water absorption. The test for the cast specimen is conducted in the same way as the previously stated test, demonstrating compliance with IS 3495 (Part 2): 1992 [17]. The specimens were initially dried at the temperature between 104°C and 114°C in a ventilated oven. Following the specimen's cooling to room temperature, its weight is determined. The specimen is totally chilled and feels chilly to the touch. The balance that is being utilised for this function can weigh down to a minimum of 0.1. M_1 is the recorded weight after measurement. After that, the specimen spends a day fully submerged in fresh water at the temperature of about 27°C. The specimen is then removed, cleaned of any remaining water, and accurately weighed after three minutes in accordance with IS code 3495 (Part 2): 1992 [17]. This mass is noted as M_2.

The value from water-absorption test for brick specimens per mass is determined by,

$$\text{Water Absorption (\%)} = \frac{(M2-M1)}{M1} \times 100$$

Water absorption varies inversely with brick quality. Less water absorption equals a higher quality brick, and the bricks with water absorption value less than 20% are considered to be of acceptable or good quality (figure. 10 b)).

2.6.4. Efflorescence Test

Efflorescence, or the accumulation of salts on the outside brick layer, is primarily a sign that moisture is present within the brick, which could compromise its endurance. Following the guidelines in IS 3495 (Part 3): 1992 [17], the experiment is carried out. In accordance with IS 3495 (Part 3): 1992 [17], the brick specimens are immersed to a depth of 25 mm in a dish filled with distilled water. Until the fresh water is either absorbed by specimens or evaporates entirely, the entire arrangement is kept at ambient temperature (20 to 30 degrees Celsius). Complete covering of the arrangement is used to prevent further evaporation. A comparable amount of distilled/fresh water is added once the brick has dried, and the specimens are checked for efflorescence.

The extent to which salt deposits form on the brick specimen's surface indicates the degree of efflorescence, as follows,

- Nil – When there isn't a noticeable salt buildup
- Slight – When a thin layer of salts covers no more than 10% of the brick's visible surface
- Moderate – When the brick surface is covered in a layer that is heavier than 10% and covers up to 50% of its visible surface but shows no signs of flaking or powdering
- Heavy – When there is a substantial salt buildup that covers more than 50% of the brick's visible surface but the surface shows no signs of flaking or powdering
- Serious – When there is a significant salt buildup and the exposed surfaces are flaking, powdering, or both (figure 11).

a)

b)

c)

Figure 9 a) Mixing of Brick Specimens, b) Casting of Specimens and c) Curing in Fresh Water

a) **b)**

Figure 10 a) Compressive Strength Test, and b) Water Absorption Test

Figure 11 Efflorescence Test

3. DISCUSSION ON FINDINGS

3.1 Compressive-Strength

Table 1 shows the compressive-strength of waste based fly-ash brick specimens and getting the same of 12.7 MPa, which is comparable to 12.5 class according to IS code 12894:2002 [19].

Even the strength of other bricks made from different waste-products appears to have somewhat dropped in comparison to class 12.5. Mixtures FS25, FS50, FS75, GGBS25, GP50, GP75, SS25, SS50, and QD25 have compressive strengths that are higher than or equal to fly-ash 12.5 class mix. Because there is less silica in SS mix bricks, their compressive strength is lower. The compressive-strength of 15 MPa for clay based brick with a 30% replacement of quarry dust is indicated by Kadir et al. [20]. The compressive-strength decreases as replacement percentage rises further as shown in figure 12 as well using graph. Mixes SBA25, BA25 and RHA25 have slightly lower compressive strengths than mixes in class 12.5. Because GP100 brick is less porous and more crystalline than FA100 brick, it has a higher compressive strength. FS25 mix bricks have a compressive strength that is 64% more than FA100 bricks. According to Siva Kumar et al. [21,22], cement-filled FA/BA bricks have a compressive strength that is higher than that of regular clay bricks. A slight drop in compressive strength results from the RHA mix's higher amount of silicon and higher percentage of voids than the FA mix. According to Kazmia et al. [23], an increase in the amount of rice hush ash and sugarcane bagasse ash lowered the compressive strength of clay brick [24]. Class 3.5 is the lower mix that IS 12894:2002 [19] specifies. According to the experimental investigation, it is therefore possible to replace most of the waste-products in fly-ash bricks by 100% using the different mixes GP, GGBS, BHA, FS, QD, and SS. This ensures safe disposal of waste-materials and the utilization of vital minerals in waste-products considering compressive-strength.

3.2 Water Absorption Test

The table shows the findings of the water absorption tests for the various combinations. Up to 12.5 class, the average value of water-absorption shall not exceed 20% of mass, according to IS code 12894:2002 [19]. The average water-absorption in this investigation was less than the IS code's limit for all waste-products mixtures in brick specimens as shown in figure 13 as well using graph. Because the inclusion of GGBS reduces the brick's porosity, the water absorption percentage for GGBS mix specimens decreases as the percentage replacement rises. The water absorption percentage of GP mix bricks increases progressively as partial replacement increases because the inclusion of granite powder increases porosity. Because FS mix bricks are crystalline, they have reduced porosity and a lower water absorption percentage as replacement % increases. Because of their high porosity, bricks containing organic wastes like SBA and RHA absorb more water than bricks made of other waste mixes. The same information is presented by Kazmi et al. [23], who state that the high porosity features of SBA and RHA result in a significantly higher water absorption percentage. High water absorption value is a direct result of bricks having a higher percentage of RHA, according to Subhasi et al. [15]. Therefore, it has been decided that, in order to dispose of these wastes in a way that promotes sustainability, up to 75% substitution of RHA and SBA in FA bricks may be deemed acceptable. Because steel slag has less porosity than other materials, bricks with SS replacement absorb less water as the amount of SS increases. Because of the hollow spherical particles that cause porosity, the finding from water-absorption test of the BA mix specimens is slightly higher/more than that of FA brick specimens.

3.3 Efflorescence test

Luminescence Table 1 displays test results for fly ash bricks that are replaced with varying percentages of waste materials. Calcium oxide found in waste products has been shown by Netinger et al. to be a significant factor in the development of efflorescence. Ferric oxide (Fe2O3) has been found by Velasco et al. [14] to likewise cause efflorescence, with a weight-based tolerable limit of less than 10%. The same fact is also supported by the research outcomes of this study. Because the quantity of ferric-oxide and calcium-oxide in RHA and SBA brick specimens is lesser than control mix of fly-ash brick, these bricks, respectively, indicate negligible and mild efflorescence. Because GGBS100 mix bricks have a high percentage of calcium-oxide than FA-100 mix brick specimens, its efflorescence is mild. Because GP mix bricks have a higher amount of ferric oxide than FA100 bricks, they exhibit a minor efflorescence. The quantity of ferric-oxide and calcium-oxide in SS mix brick samples is significantly higher than in FA-100 bricks. As a result, there is a modest efflorescence. Since BA mix bricks have a larger ferric oxide concentration than FA bricks, there is less efflorescence in them at 75% and 100% replacement. Because the percentages of both calcium-oxide as well as ferric-oxide in foundry sand are significantly lesser than fly-ash bricks, and the efflorescence of such bricks is zero for all % replacement.

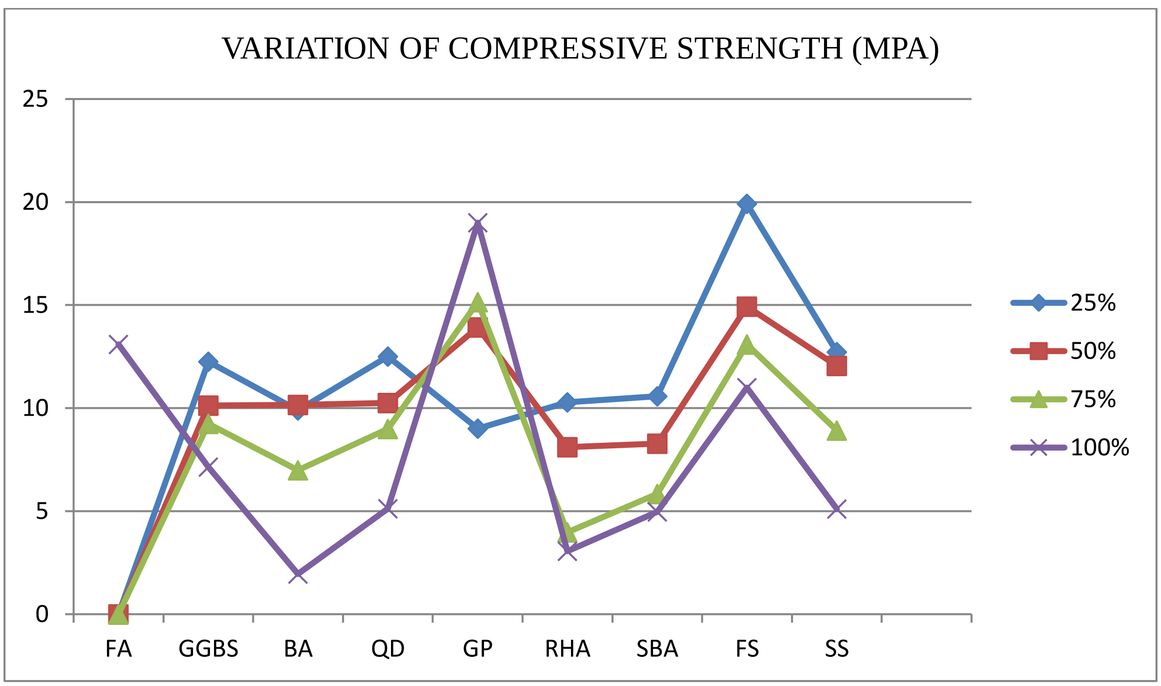

Figure 12 Variation of Compressive Strength (MPa)

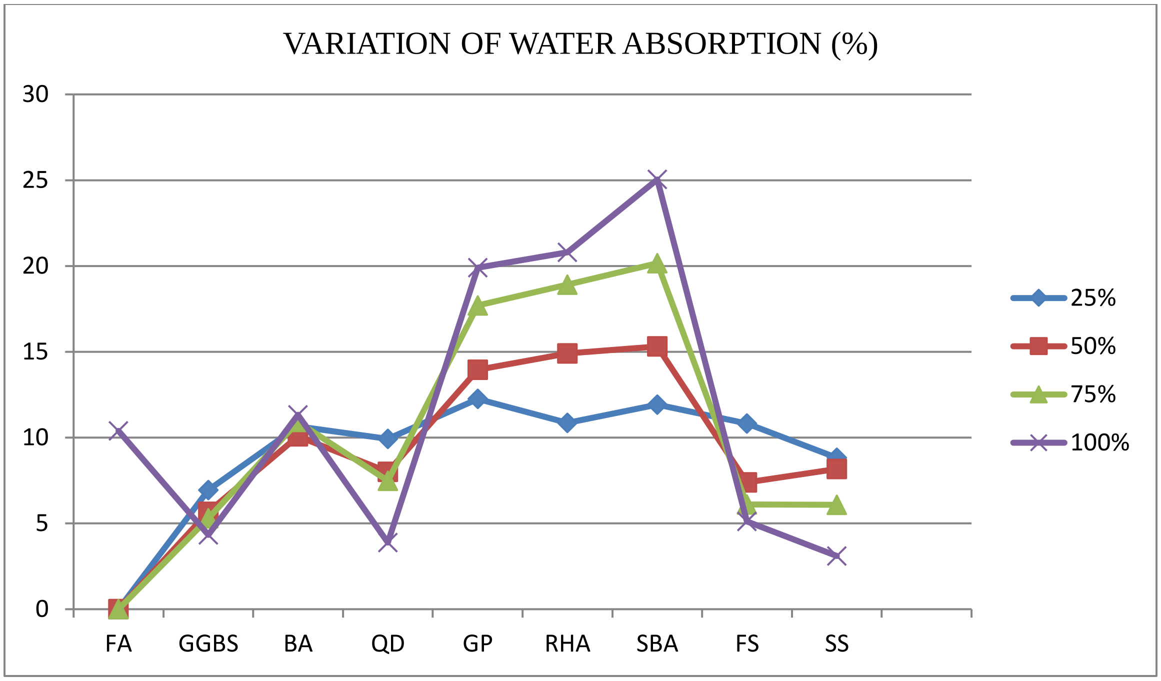

Figure 13 Variation of Water Absorption (%)

4. CONCLUSION

The following conclusion is suggested based on the data that were acquired and the conversations that were conducted with the aid of literature. This paper's only goal is to promote and enhance the use of such industrial wastes listed previously, in place of fly-ash while making fly-ash bricks. Consequently, the conclusions drawn from such viewpoint are,

- Using the different mixes GP, GGBS, BHA, FS, QD, and SS for secure waste-disposal and utilization of significant products in waste-products in view of compressive-strength, it is possible to replace all of the waste-products in fly-ash brick samples to 100%.
- Mixtures FS25, FS50, FS75, GGBS25, GP50, GP75, SS25, SS50, and QD25 have compressive strengths that are higher than or equal to fly-ash 12.5 class mix.
- FS25 mix bricks have a compressive strength that is 64% more than FA100 bricks.
- The IS code's maximum water absorption was exceeded by the average for all waste-material mixtures in bricks.
- When compared to other waste based bricks, brick containing organic wastes like SBA and RHA has a higher water absorption rate.
- It has been decided that replacing RHA and SBA in fly-ash bricks by up to 75% is acceptable in order to dispose of these waste products in a sustainable manner.
- Bricks that have had SBA and RHA replaced show zero and minimal efflorescence, respectively.

- Since the percentages of both ferric-oxide and calcium-oxide in foundry sand (FS) are significantly lesser than in fly-ash brick, even the efflorescence is zero for any % replacement.

Table 1 Detailed Test Results

Mix	Compressive Strength (MPa)				Water Absorption (%)				Efflorescence (N-Nil, S-Slight, M-Moderate)			
	Waste Materials (%)											
	25	50	75	100	25	50	75	100	25	50	75	100
FA	---	---	---	13.10	---	---	---	10.40	---	---	---	N
GGBS	12.26	10.12	9.24	7.15	6.94	5.67	5.30	4.34	S	S	M	M
BA	9.89	10.15	6.98	1.95	10.65	10.08	10.91	11.32	N	N	S	S
QD	12.5	10.25	8.99	5.13	9.92	8.0	7.48	3.88	S	S	S	S
GP	9.01	13.92	15.15	19.0	12.25	13.95	17.70	19.90	S	S	S	S
RHA	10.28	8.10	3.97	3.05	10.85	14.90	18.91	20.80	N	N	N	S
SBA	10.58	8.28	5.84	4.97	11.93	15.31	20.16	25.04	N	N	N	N
FS	19.91	14.93	13.10	11.0	10.82	7.39	6.11	5.12	N	N	N	N
SS	12.72	12.05	8.92	5.10	8.83	8.17	6.09	3.10	M	M	M	M

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