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A Comparative Study of Fly Ash Bricks Made with Blend of Clay Brick Waste and Stone Dust

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Abstract

The growing environmental concerns and proper disposal of brick waste is a challenge for construction industry. Many research articles support the use of brick waste in construction materials as aggregates. Production of bricks using waste brick aggregate has environmental benefits by lowering the disposal problem and at the same time saving conventional resources. The present work focuses on the utilization of brick waste as a partial replacement of conventional aggregates in the mix of fly ash bricks. The technical properties of brick samples made were compared with each other. Stone dust was replaced by waste brick aggregates in different percentages. These bricks were tested after 14 days of curing in the material testing laboratory. The study was conducted to observe the changes in its properties, i.e. compressive strength, water absorption etc. The results showed that the compressive strength decreases with increase in amount of brick aggregates added and the water absorption increases.

***Keywords**: Construction, waste utilization, eco-friendly bricks, sustainable construction, building materials*

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INTRODUCTION

There are huge problems of environmental pollution and disposal occurring from improper treatment and handling of waste materials, instigating a need to recycle or reuse them incorporating into building materials. There have been numerous attempts to incorporate wastes into the production of bricks for example, saw dust ash, fly ash, rice husk ash, sludge, limestone dust etc. Most of these experiments were performed by utilizing different waste products in the production of bricks yielding positive results.

The earliest sun dried brick were discovered thousands of years ago and not much has changed since then in this sector. There are vast technological advancements that are needed in this segment as fired clay bricks not only consume natural resources but also produce huge amounts of wastes. The production of these bricks not only consumes natural resources but is also a significant source of air pollution. Also a huge amount of wastage occurs in material handling and kiln firing, leading to broken, under-burnt, over-burnt and deformed bricks. It is estimated that nearly 8–10% of the total production of clay bricks is discarded and thus there is a need to use this waste resourcefully.

Presently, India is witnessing tremendous growth in the infrastructure sector leading to a high rate of urbanisation and with the increase in urban population the rate of infrastructure development is bound to grow. It is estimated that Indian construction industry generates nearly 10–12 million tonnes of waste annually. Most of these wastes presently are dumped through landfills or used as base work in road construction. Therefore, there arises a need to utilize these waste products efficiently. In Rajasthan, there are a huge number of brick kilns producing huge amount of brick waste. Recently, China has partially constrained the use of traditional clay bricks owing to the limitation of clay resources. The definitive worldwide aim nowadays is to find raw materials, which can be utilized to produce masonry units to replace conventional fired clay bricks. Frequent studies have been directed on making of fired brick of fly ash. FA bricks show better mechanical and physicochemical properties [1]. In terms of compressive strength, these FA bricks are thrice as resilient as and stronger than traditional bricks while ensuring long life of the structure. The present study focuses on the pressed fly ash bricks.

LITERATURE REVIEW

Poon *et al.* researched the manufacturing of concrete bricks and paving blocks by the usage of recycled aggregates found from construction and demolition (C&D) waste along with OPC and/or fly ash [2]. To find out the properties of these bricks, a series of tests conforming to ASTM were carried out on the bricks and blocks formulated with recycled aggregates and without recycled aggregates. The experimentation exhibited that the substitution of coarse and fine natural aggregates by recycled aggregates at the percentages of 25 and 50% had limited outcome on the compressive strength of the brick and block samples, but greater concentration of substitution decreased the compressive strength.

At the percentage of up to 100% recycled aggregates as the substitution of natural aggregates, concrete paving blocks with a 28 day compressive strength of more than 49 MPa can be manufactured without the addition of fly ash, whereas paving blocks for footway uses, with a reduced compressive strength of about 30 MPa and masonry bricks can be manufactured with the inclusion of fly ash.

Demir and Orhan explored the outcome of reusing of waste brick material on the durability and mechanical qualities of the bricks [3]. After crushing, the samples were separated in two classes; one passing through a 4.75 mm sieve (Sample A) and other passing through 600 µm sieve (Sample B). Different ratios of the waste (0, 10, 20 and 30% by mass) were utilized to the raw-brick clay and the samples were thus divided into A10, A20, A30 and B10, B20, B30 respectively. Standard tests such as compressive strength, shrinkage, and water absorption etc. were carried out to establish the mechanical qualities of these bricks at 900, 1000 and 1100°C with a heating rate of 150°C/h for duration of 30 min each. The physical and chemical properties of the samples were tested and compared with ASTM and TS (Turkish Standard Code). The findings indicate that at a mass of 30% fine-waste material additive, sintered at 900°C, the test specimen has an adequate compressive strength of 7.85 MPa and water absorption of 18.4%.

Cicek and Tanrverdi observed the making of light weight bricks by the usage of class F fly ash alongside sand and hydrated lime [4]. Samples of bricks were made under diverse conditions to find out the outcome of variety of factors. A combination of 68% fly ash, 12% hydrated lime and 20% sand was found to be the optimum raw material combination. The water absorption, unit volume weight, thermal conductivity and compressive strength of the fly ash-sand-lime bricks achieved under ideal test circumstances are; 40.5%, 1.14 g/cm^3, 0.34 W/mK and 10.25 MPa respectively. The outcomes concluded that it is feasible to manufacture good quality light weight bricks from fly ash.

Cultrone and Sebastian evaluated the practical qualities of clay bricks (solid moulded or 800 and 1000°C) pure or combined with 5% by weight of fly ash [5]. The improvement in the durability and a decline in the density (2.53 g/cm^3) of bricks was a direct outcome of combination of fly ash particles. SEM indicated vitrification effects which were less apparent in integrated bricks with excessive carbonate content. There was no change in the texture of bricks whether fly ash was added or not. Moreover, the amount of decay caused by salt crystallization in the structural pores was found to be very less. At the end it was determined that this combination of fly ash with clay could have useful effects and can be used as a mode of reusing fly ash and attaining low cost in production of bricks.

Tabin *et al.* examines the water absorption and strength characteristic of fly ash bricks made of local soil (S), fly ash (FA) and lime (L) [6]. Different ratios of fly ash bricks (both on Hand moulded and pressure moulded) were tested according to Indian standard code. It was found out that none of the L-S-FA bricks placate all the limitations of standard codes. While some of the bricks placate the necessities in respect of strength only the L-FA (40: 60) bricks fill in the limitations of Indian standard code with a water absorption physiognomies with 20% water absorption after 28 days of curing as well as strength of 6.2 N/mm^2 after 28 days of curing. It also concluded that with increase in the lime content, the compressive strength of the bricks increases. With respect to strength only, most of these L-S-FA bricks fit in to class 3.5 and 5 while in accordance to standard code, the water absorption characteristics of all L-S-FA bricks fail. The only brick that is in accordance with all the conditions of class 3.5 with respect to both strength and water absorption is L-FA (40: 60) brick.

Shakir *et al.*, accounts the results of an exploration done on bricks manufactured with the usage of fly ash (FA), quarry dust (QD), and billet scale (BS) by non-conventional method [7]. This non-conventional method has a different procedure for manufacturing the bricks which comprises combining the components accompanied by cement and water, and then composing the bricks within the moulds but no pressure is administered over these moulds. This traditional method of brick manufacturing has extraordinary environmental and ecological effect as this novel method neither uses clay or shale nor necessitates extreme pressure on moulds or high sintering temperature kiln. Different proportions were made by varying cement (OPC) by 10 to 15%, quarry dust by 50 to 60%, fly ash and billet scale from 0 to 40%. The physical and chemical properties of the samples were tested and compared with ASTM. The compressive strength fluctuated in (6.2–26.3) MPa and water absorption reduced with the increment of FA+BS and rises with the escalation of (BS+QD) but it was below 20% in all the cases. The best performance with respect to mechanical qualities was shown by an optimum proportion of fly ash and billet scale, quarry dust and billet scale to be 1:1. Production of bricks with the usage of mixture of a billet scale, quarry dust and fly ash is quite feasible.
Yadav *et al.*, experimentally defines the reusing of the waste products like STP sludge and fly ash by including them into bricks [8]. The chemical composition of STP sludge and fly ash is very similar to brick clay in chemical characteristics; so, it could be a viable replacement for clay bricks. Sludge and fly ash were mixed in different proportions with sludge + fly ash percentages as follows: 20+80%, 30+70%, 50+50%, 80+20%, 90+10% and 100% sludge. Sintering of these sludge-fly ash bricks is done in a muffle furnace at 1000°C. The testing and comparison of qualities of these bricks conform to Indian standard codes. The most productive brick configuration is sludge:fly ash=80:20 with a crushing strength of 6.4 N/mm^2 and water absorption of 19.4%. The cost of manufacturing these bricks is Rs. 0.64 only and thus is quite feasible.

EXPERIMENTAL WORK

Material Properties

Fly ash, hydrated lime, sand, waste brick aggregates and water are used for present study. Various properties related to the study are discussed in the next part of the paper.

Fly Ash

Large quantities of fly ash are generated as an unwanted secondary product in thermal power stations which use pulverized coal as a fuel source. The foremost sources of fly ash in India are the 150 odd thermal power plants which account for greater than 51% of India's commercial energy demand. The current formation of fly ash is around 140 million tons every year and with the commissioning of super thermal power plants and with the expanding utilization of poor quality coal of high ash substance, the fly ash production is probable to stretch to around 170 million tons by 2020 AD. This has represented a genuine dumping and environmental issue not withstanding possessing an extensive tract of rare tillable area. The pulverized fly ash used in the present study was acquired from local thermal power plant. The fly ash used conforms to the Indian standard 3812 [9].

Stone Dust

All plants use locally available sand/stone dust. Deleterious materials such as clay and silt in the material shall not be more than five percent. The sand used for the experimental works is locally procured. In case of stone dust the permissible limit for 150 μm sieve is increased to 20% with an extra 5% allowance permitted.

Sludge Lime
Calcium hydroxide (Lime) is an mineral compound with the chemical formulation containing Ca(OH)2. It is also known as hydrated lime. It is a colourless crystal or white powder and when calcium oxide (CaO) is mixed or slaked with water, hydrated lime is attained. This sample of sludge lime is adequate for construction of fly ash bricks. As hydrated lime is much costlier as compared to sludge lime whereas there isn't much difference in the strength of fly ash bricks, sludge lime is used in the present investigation. There are some recommendations for the use of lime sludge i.e. it should be free from extraneous materials, lumps etc. to the degree imaginable.

Waste Brick Aggregates
The waste bricks used in this study were taken from the brick kilns where bricks are broken during handling, drying and transportation. To turn these bricks into aggregates, these bricks were broken down using a jaw crusher as shown in Figure 1. After passing through jaw crusher then the material was passed through a roll crusher as shown in Figures 1 and 2. This provides us with fine-waste aggregates as shown and thus can be used as a replacement of sand in the present analysis.

Water
Water is a significant component of fly ash brick making mixture as it vigorously contributes in the chemical reaction. Water is also used for curing the brick for 14 days after the brick has been made. Potable water, i.e. tap water is usually considered suitable and thus in the present investigation, tap water is used both in mixing and curing purposes.

Mix Combination
A total of four mix combination were considered (Table 1) and tested in the present investigation. These bricks were produced according to standard guidelines for manufacturing quality fly ash bricks [10].

These guidelines can be consistently obeyed to yield fly ash bricks conforming to IS: 12894 [11].

Making Process
The process of making these bricks starts with grinding lime with optimum amount of water in the pan-mixer till it becomes a paste without any lumps. Required quantity of ash and sand/stone dust are then added to the pan-mixture and mixed until it forms a homogenous mixture. The raw materials are thoroughly mixed in the pan-mixture for at least 3–5 min to ensure uniform and homogenous composition with consistency in colour too. If small lumps of lime are left in the bricks, they start hydrating after the curing period is over and cause cracks in the bricks, thus weakening the bricks.

This mixture is then transferred to the moulding machinery which is then compacted through a hydraulic press (Figure 3). A conveyor belt is used to transport the materials from the pan-mixer to the hydraulic rotary press where the moulds are mechanically filled in. Bricks are formed at a pressure of 150 MPa. These compacted bricks are manually laid on a wooden pallet in four to five layers. The brick laden pallets are transported to the stack yard using a hydraulic trolley.

Finished bricks are dried for about 1–2 days. Water curing is then done for a minimum period of 14 days to allow the required strength to be achieved. Curing is done by sprinkling water either physically or mechanically.


Fig. 1: *Jaw Crusher.*


Fig. 2: *Roll Crusher.*


Fig. 3: *Fly Ash Brick m/c.*

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Table 1: *Combination of Various Materials Used in Making Bricks.*

Designation	Waste Brick Aggregates (%)	Fly Ash (%)	Stone Dust (%)	Lime
CB	0	60	30	10
BA10S20	10	60	20	10
BA20S10	20	60	10	10
BA30S0	30	60	0	10

Bricks named CB, BA10S20, BA20S10 and BA30S0 were manufactured with a constant 60% fly ash and 10% lime. Stone dust (S) in CB is replaced by brick aggregates, 10% at a time and thus forming BA10S20, BA20S10 and BA30S0. In BA30S0, 100% replacement of stone dust by waste brick aggregates was performed and studied.

RESULTS AND DISCUSSIONS

Compressive Test

The bricks incorporating different amounts of fly ash were immersed in water for three days and then tested in compression testing machine (Figure 4).

Table 2 shows the results of this test i.e. average compressive strength of different mixes. The data is further represented in the form of graphs (Figure 5).

Fig. 4: *Compression Test being carried out on Bricks Using a Compression Testing Machine.*

Table 2: *Compressive Strength of Various Bricks.*

Brick Designation	Average Compressive Strength of Bricks (N/mm^2)
CB	4.88
BA10S20	3.87
BA20S10	2.74
BA30S0	2.24

The minimum strength needed in these bricks is 3.5 N/mm^2. The compressive strength decreases as we increase the percentage of brick aggregates i.e. brick dust into the mix. After replacing 10% of stone dust with brick aggregates there is a decrease of 15.8% of compressive strength in the brick specimen BA10S20 with respect to CB. As we increase the amount of brick aggregates in the mix i.e. making BA20S10 and BA30S0 (100% replacement), the strength decreases considerably. The strength decreases drastically when the amount of brick aggregates is increased from 10 to 20% with the percentage decrease being 63.5%. While the change in compressive strength is less when the amount of brick aggregates are increased from 20 to 30%, i.e. total replacement of sand in the mix with the decrease being 100% with respect to CB.

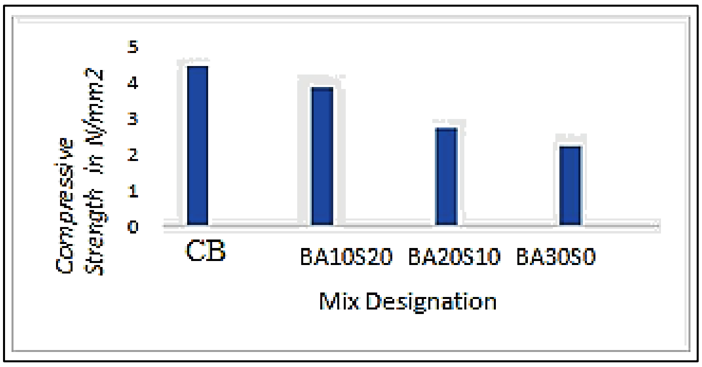

Fig. 5: *Variation of Compressive Strength of Brick Specimens*

Table 3: *Average Water Absorption Percentage of Various Brick Specimens.*

Brick Designation	Average Water Absorption of Bricks (%)
CB	17.59
BA10S20	19.75
BA20S10	21.57
BA30S0	21.75

Water Absorption Test

The bricks utilizing varying amounts of fly ash were tested for weight before and after immersing them in water for 24 h (Figure 6). The average change in percentage was noted down in Table 3 and Figure 7. These tests conform the Indian standard.

The maximum water absorption permitted through Indian standard is 20%, therefore only two brick specimens qualify this condition. With BA10S20 having its average value very near to the boundary condition. There is an increase in water absorption from CB to BA10S20, i.e. when we decrease the amount of stone dust and increase the amount of brick aggregates by 10%, which is 2.16%. When we increase the amount of brick aggregates further replacing stone dust by another 10%, the brick specimen BA20S10 fails the IS code requirement of maximum water absorption of 20% by a percentage value of 1.57%.

The percentage increase from CB to BA20S10 is 3.98%. After total replacement of stone dust by brick aggregates the BA30S0 brick specimen's water absorption further increases by 4.16%. This change is very less as compared to the previous increments owing to majority of brick aggregates already present.

Fig. 6: *Water Absorption.*

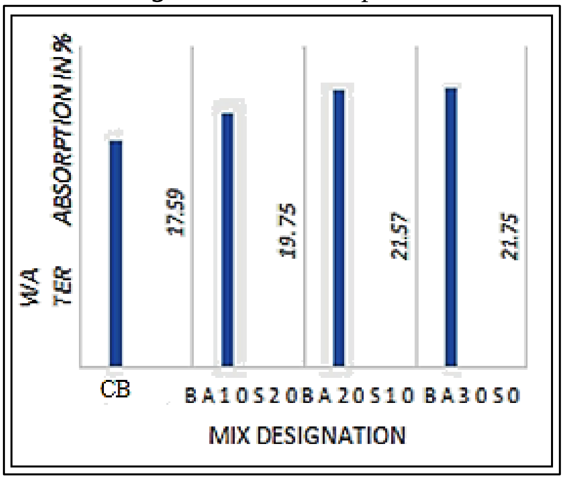

Fig. 7: *Variation of Water Absorption.*

Efflorescence Test

The brick specimens were tested for efflorescence by measuring the salt deposits over the samples which were immersed in water with the depth of immersion being 25 mm. This process was repeated twice and after the water was evaporated, the white deposits were observed and are mentioned in Table 4.

Table 4: *Amount of Efflorescence in the Brick Specimens.*

Brick Designation	Average Efflorescence of Bricks
CB	Nil
BA10S20	Nil
BA20S10	Nil
BA30S0	Slight

The maximum efflorescence permitted by IS-1375 shall not be more than moderate up to class 12.5 [12]. Therefore, all the bricks qualify this requirement set by the Indian standard. Only two brick specimens namely, BA30S0 and BA65FA25 show only slight efflorescence while the other bricks do not show any white deposits over the surface of the bricks. Therefore, we conclude that the brick aggregates cause slight efflorescence in these fly ash brick specimens and that too with only after 100% replacement of stone dust.

Warpage Test

The brick specimens were tested for warpage after cleaning the brick to remove any dirt or impurities. Both convex and concave warpage were tested for all the brick specimens present in the study. The results are tabulated as follows (Tables 5 and 6).

Table 5: *Concave Warpage Present in the Brick Specimens.*

Brick Designation	Average Concave Warpage of Bricks
CB	Nil
BA10S20	Nil
BA20S10	Nil
BA30S0	Nil

Table 6: *Convex Warpage Present in the Brick Specimens.*

Brick Designation	Average Convex Warpage of Bricks
CB	Nil
BA10S20	Nil
BA20S10	Nil
BA30S0	Nil

The tests show that there was not any convex or concave warpage for the brick specimens tested to the IS code requirements. The bricks were flat without any undulations or curvature thus qualifying this test.

Shape and Size Test

According to the Indian Standard-1375, the brick made from fly ash should have a dimension of 230 mm×110 mm×70 mm with a margin of error being ±2 mm [12]. The average dimension of 20 bricks was taken and is stated in the following Table 7.

Table 7: *Average Brick Dimension of All the Brick Specimens.*

Brick Designation	Average Brick Dimension of Brick Specimens (mm)
CB	230×110×70
BA10S20	232×108×68
BA20S10	232×110×70
BA30S0	232×110×68

The maximum margin stated in IS 1375 is ±2 mm; therefore all the brick specimens qualify in this requirement of the Indian standard.

CONCLUSIONS

- The control brick gave a compressive strength of 4.88 N/mm^2. After replacing 10% stone dust by waste brick aggregates there is a decrease of 15.8% of compressive strength with respect to control brick.
- As we increase the percentage of waste brick aggregates replaced by stone dust to 20 and 30%, the compressive strength decreases 63.5 and 100% respectively.

- As we increase the amount of brick aggregates, the compressive strength decreases.
- The control brick had water absorption of 17.59%. After replacing 10% stone dust by waste brick aggregates there is an increase in water absorption by a marginal amount of 2.16%. Water absorption for 10% replacement of brick aggregates is still below the permissible limit set by Indian standard.
- As we increase the percentage of waste brick aggregates replaced by stone dust to 20 and 30%, the water absorption crosses the permissible limit mark and fails in this test. The percentage increase for 20 and 30% replacement amounts to 3.18 and 4.16% respectively.
- The increased water absorption in this case is due to the fact that brick aggregates absorb more moisture as compared to the stone dust.
- All the brick samples qualify this requirement set by the India standard as the bricks made had a maximum efflorescence as, slight efflorescence.
- Slight efflorescence occurred in bricks with 30% brick aggregates and the sample with 25% fly ash and 65% brick aggregates confirmed our conclusion that increased amount of brick aggregates cause efflorescence.
- In all the brick samples tested, there was neither convex nor concave warpage present.

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