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VALORIZATION OF CRUSHED GLASS AS A POTENTIAL REPLACEMENT FOR SAND IN CEMENT STABILIZED FLY ASH BRICKS

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Abstract

The present study involved the utilization of crushed glass as an auxiliary additive in the manufacture of cement stabilized fly ash (CSF) bricks. The bricks were made with 1:1 proportion of fly ash and sand stabilized with 20 % cement. Crushed glass was used as replacement for the fine aggregate in increments of 10 % up to 40 % wherein the sand was completely replaced with crushed glass. The various mix proportions were then moulded into bricks with the addition of water by hand moulding method of forming the bricks and sun dried followed by sprinkle curing over a period of 21 days. The bricks were then subjected to compressive strength, water absorption and efflorescence tests to gauge its performance. The investigation revealed that the addition of crushed glass to the brick mix resulted in an increase in strength of the bricks, however, the maximum strength achieved could not achieve the strength of the control specimen. But the strength was higher than the minimum strength recommended by Bureau of Indian Standards (BIS) for stabilized blocks as well as burnt bricks. It also reduced the water absorption marginally while no efflorescence was seen in any of the combinations. A cost comparison revealed that the optimal combination with crushed glass was able reduce the cost of the brick by 20 %.

Keywords:

Low cost bricks;
Fly ash;
Cement;
Sand;
Crushed glass.

1 Introduction

Bricks are one of the basic building units for construction of buildings. Traditionally fired bricks are used for construction of walls and enclosures. However, the increasing scarcity of natural resources like soil and huge consumption of energy in the manufacture of fired bricks has forced Civil engineers to look for other environment friendly alternatives. In the recent times, waste materials have been adopted increasingly in the manufacture of bricks and blocks. A lot of waste materials have been investigated for their potential beneficial use in manufacture of bricks and blocks. Fly ash [1], red mud [2], bagasse ash [3], cement kiln dust [4], phosphogypsum [5], egg shell powder [6] and quarry dust [7] are some of the waste materials that have been investigated in manufacture of stabilized blocks and bricks. However, fly ash is one of the most common and widely generated wastes around the world. The worldwide production of coal combustion ashes is around 780 million tonnes [8]. In India, the fly ash production was 184.14 million tonnes in the year 2014 - 15 [9]. Thus, this investigation has been focused on the performance of fly ash bricks. Cement Stabilized Fly Ash (CSF) bricks are modern masonry units of various sizes to be used for walling. Use of such bricks is more appropriate in regions where clay bricks are costly, not available or of insufficient strength. Depending upon the structural requirements of masonry units, the mix can be designed using suitable ingredients and proportioning.

These bricks can be cast to desired shape and size to facilitate construction of wall of requisite thickness and appearance. CSF bricks are gaining popularity in the construction at present. One of the greatest advantages of stabilized bricks and blocks is they consume very less energy when compared to traditional fired bricks [10]. However, fly ash brick manufacture involves the utilization of fly ash and sand instead of soil. Utilization of sand in the manufacture of stabilized soil bricks with solid wastes have been recorded earlier [1, 11]. But, the use of river sand as fine aggregate leads to exploitation of natural resources, lowering of water table, sinking of bridge piers and erosion of river bed. If fine aggregate is replaced in specific percentage and in specific size range, it will decrease the utilization of natural fine aggregate, thereby reducing the ill effects of river dredging and making concrete and fly ash brick manufacture sustainable. Thus, potential alternatives need to be explored to ensure sustainability of the available natural resources. Sand is a granular material that provides frictional resistance. A potential replacement for sand should exhibit similar properties to ensure that the replacement performs similar to sand if not better. Steel slag is one waste material that can exhibit granular nature similar to sand on crushing, so much so that there have been investigations involving steel slag as replacement for sand [12]. Another waste material that can be used as potential replacement for sand is crushed glass. In 1994, United States discarded 9.2 million metric tonnes of post-consumer glass waste in landfills [13]. An enormous quantity of waste glass is generated all around the world. According to 2010 data, the global generation of municipal solid waste was 1.3 billion tonnes, out of which glass accounted for 5 % of the wastes. In India, which lies in South Asian Region, 1 % of total urban waste generated comprises of glass wastes [14]. Thus, glass is a mounting problem that can be managed by proper collection and recycling systems. Figure 1 shows the collection rate for recycling in various countries.

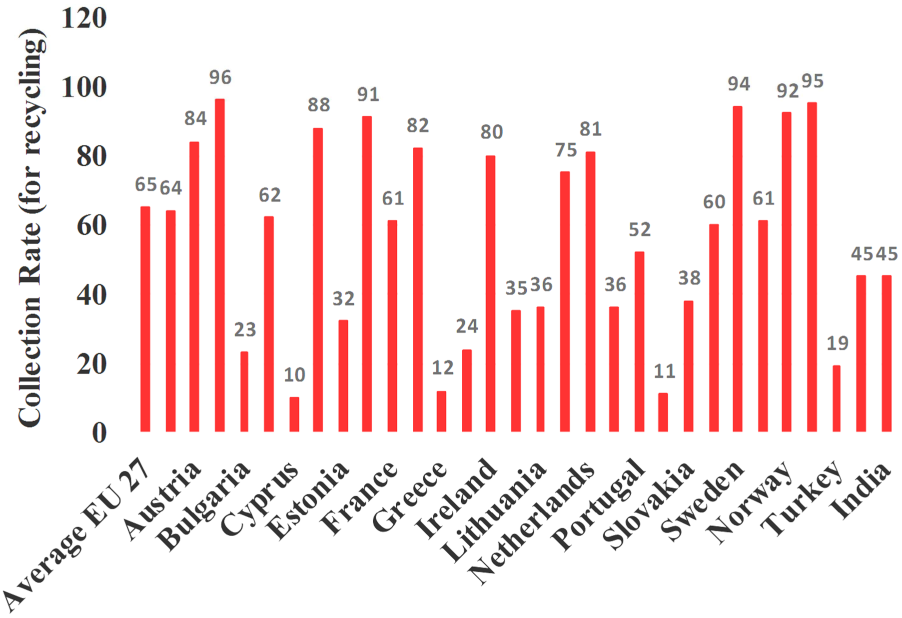

Fig. 1: Glass recycling rates in various countries [15].

Majority of the glass collected for recycling finds its way back to glass manufacturing units. However, other avenues for effective reuse and recycling of waste glass are also available. There have been investigations where crushed glass has been used as replacement for aggregate [16, 17]. There has been utilization of glass in the field of soil engineering. Utilization of glass along with biosolids to be used as fill material has been investigated [18, 19]. Glass waste utilization in soil improvement has also been attempted [20]. Glass wastes utilization also been attempted in the manufacture of tiles [21] as well as bricks. The amount of waste glass produced has gradually increased over the years due to an ever-growing use of glass products. The primary objective of this investigation is to investigate the performance of crushed glass as a potential replacement for sand in the manufacture of CSF bricks.

2 Materials

The various raw materials selected for the study includes fly ash, cement, river sand, waste glass.

2.1 Cement

Cement adopted for the manufacture of the blocks in ordinary Portland cement purchased from a local dealer. The cement was used ‘as is’ from the bag supplied by the supplier. The cement was subjected to specific gravity test in the laboratory, which came out to be 3.12.

2.2 Fly ash

The fly ash used in this investigation was class F fly ash. The fly ash was procured from a fly ash block manufacturer in Vengambakkam in Kanchipuram District of Tamil Nadu. The fly ash was subjected to specific gravity test, which came out to be 2.3. Typical composition of fly ash along with that of cement is shown in Table 1.

Table 1: Composition of ordinary Portland cement [22] and class F fly ash [23].

% of	SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	Na_2O	P_2O_5	TiO_2	SO_3
Cement	21.45	4.45	63.81	3.07	0.83	2.42	0.20	0.11	0.22	2.46
Fly ash	48.0	24.3	3.2	15.6	DNR	--	0.8	DNR	DNR	0.4

DNR – Data Not Reported

2.3 Sand

Good quality river sand was procured from a fly ash block manufacturer in Vengambakkam for utilization in this investigation. The sand was subjected to specific gravity and sieve analysis tests. The specific gravity of the sand came out to be 2.68. The grain size distribution of the sand used is shown in Figure 2.

2.4 Crushed glass

Glass is formed by melting of silica, soda ash and lime followed by supercooling to achieve solid which does not crystallize but rather retains the amorphous structure of the molten liquid. Silicate glasses, rich in silica are commonly referred to as “glass” in the industry. The main types of glass are soda glass, lead crystal glass, borosilicate glass and electric glass. Broken glass or waste glass is usually referred to as ‘cullet’. Cullet can be either internal cullet or external cullet. Internal cullet is not considered as waste because they are usually rejects within the industry that do not meet the quality control and are absorbed as raw materials in the manufacturing process. External cullet is the waste glass that is collected and reprocessed for the purpose of recycling. External cullet is further classified as pre-consumer and post-consumer cullet depending upon whether the cullet is generated in the industry using glass as a component or is generated after use by the consumer [24]. The specific gravity of fine crushed glass is in the range of 2.49 to 2.52 [13]. Crushed glass used in this work was sourced from a waste glass crushing and recycling unit located in Korukkupet, Chennai. Various types of glass were crushed and ground for use in this work. A sieve analysis was carried out on the ground glass aggregates to determine their particle size composition which is shown in Figure 2 along with that of sand.

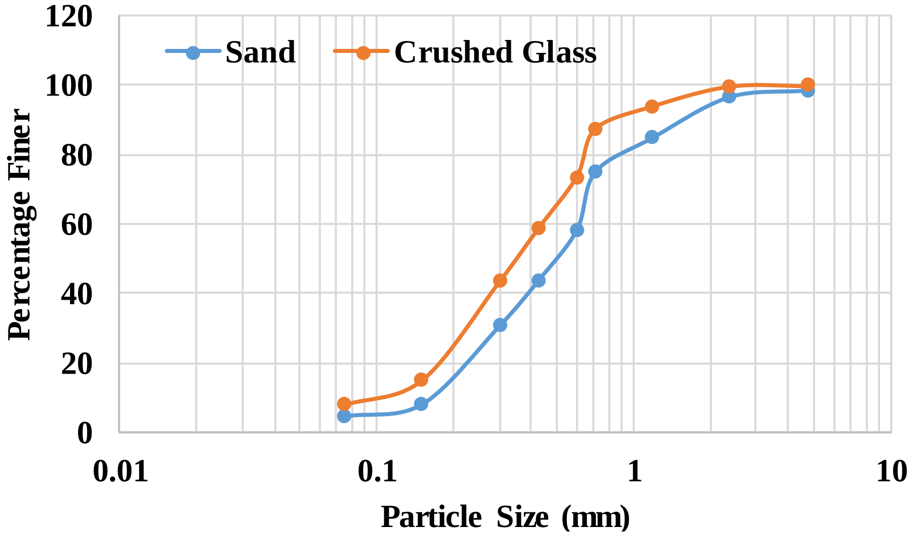

Fig. 2: Particle size distribution of fine aggregate and crushed glass.

3 Methodology

The methodology adopted in this investigation involved the selection of mix proportions, preparation of mix, casting of bricks, curing and testing. The methodology developed was based on the work done by Vijayaraghavan et al. [25] in valorization of slag and quarry waste in the manufacture of bricks.

3.1 Mix proportions

The mix proportions were selected such a way that fly ash to sand had a proportion of 1 : 1 with the remaining being made up of the binder or cement. The cement content was fixed at 20 % and the remaining 80 % was equally split between sand and fly ash to achieve 1 : 1 proportion. Earlier investigators have also adopted 1 : 1 mix with sand in their utilization of waste materials in block manufacture [1, 11]. The sand adopted in the mix proportion was replaced by crushed glass in stages of 10 % until complete replacement of sand with crushed glass. Thus, the crushed glass replaces sand by 25 %, 50 %, 75 % and 100 % in the four replacement stages along with the control specimen. Table 2 shows the mix proportions adopted in this investigation.

3.2 Preparation of mix and moulding

The different quantities of the materials where weighed according to proportion and the requisite quantity of water was added to the mix and thoroughly mixed manually to achieve a plastic mix. The prepared mix was immediately used to mould the bricks manually by hand. The samples were mixed with sufficient quantity of water to obtain working consistency for moulding. The clean mould was filled with the mixture taking care to avoid formation of any large voids in within the matrix of the brick. The surplus mix was then removed and top surface was levelled. Like traditional hand moulded clay bricks, no hydraulic pressure was applied for moulding of the bricks.

Table 2: Mix proportion of crushed glass amended CSF blocks.

Combination	Cement, %	Fly ash, %	Sand, %	Glass, %
1	20	40	40	0
2	20	40	30	10
3	20	40	20	20
4	20	40	10	30
5	20	40	0	40

3.3 Curing

The bricks were de-moulded after a period of 24 hours and allowed to dry in Sunlight for 2 hours. Finally, the sundried blocks were taken for curing, which was done by sprinkle curing for a period of 21 days. Kulkarni et al. [26] had also adopted a curing period of 21 days for lime stabilized fly ash bricks with bagasse ash.

3.4 Testing

According to BIS code, [27], stabilized bricks should be evaluated for their compressive strength, water absorption and abrasion test. In this investigation, CSF bricks were subjected to compressive strength test, water absorption test and one other test viz. efflorescence test, all done in accordance with BIS code [28]. A similar test programme was also adopted by James et al. [29] for cement stabilized blocks with bagasse ash. The moulding and testing of bricks is shown in Figure 3.

3.5 Cost comparison

A cost comparison analysis was also performed on the various combinations of the bricks evaluated to determine the effect of cost savings achieved due to the valorisation of the crushed glass in the manufacture of CSF bricks. The various types of cost like transportation cost, cost of materials, cost of labour is taken from Tamil Nadu Public Works Department Schedule of Rates.

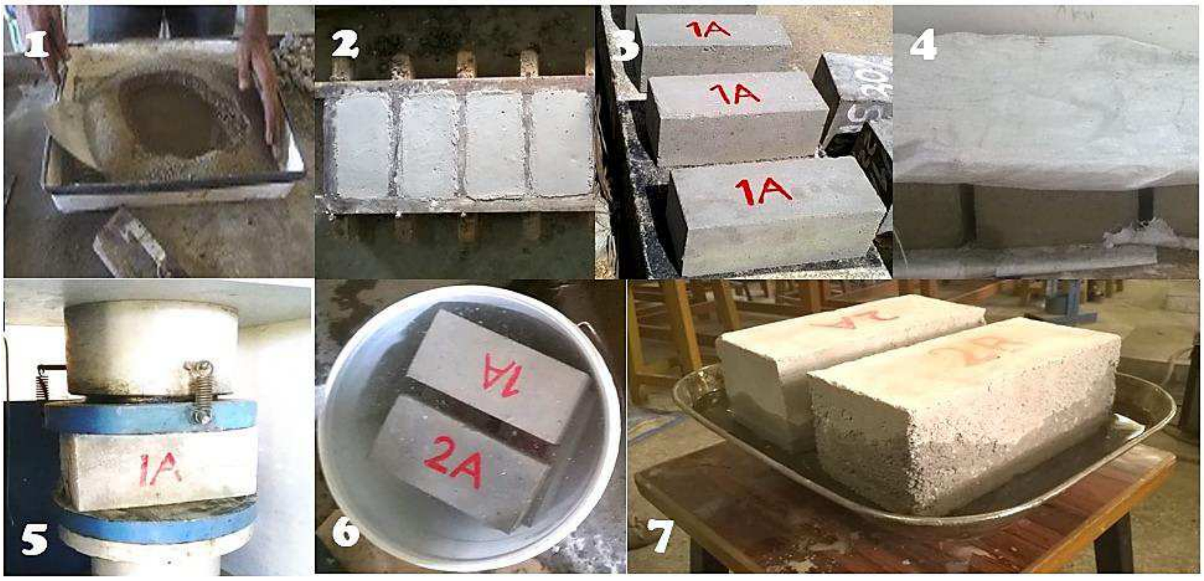

Fig. 3: Moulding and testing of bricks. (1 - proportioning and mixing; 2 - hand moulding; 3 - sun drying; 4 - curing; 5 - compressive strength; 6 - water absorption; 7 - efflorescence).

4 Results

The results of the various tests on the CSF bricks have been discussed in the following sub-sections.

4.1 Compressive strength

The compressive strength of the CSF bricks was evaluated in accordance with BIS code and the results are shown in Figure 4. The minimum required strength of a class I burnt brick as well as class 20 and 30 stabilized blocks have also been included in the figure for reference.

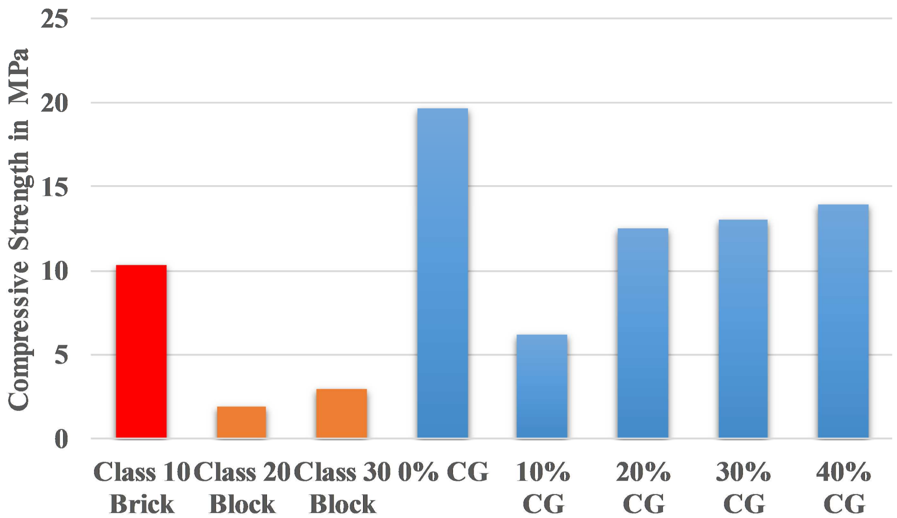

Fig. 4: Compressive strength of CSF bricks amended with % crushed glass (CG).

It can be seen that the addition of crushed glass as replacement for sand in the manufacture of bricks has resulted in an increase in strength with increase in proportion of crushed glass in lieu of sand; however, the compressive strength is still lower than that achieved by the control specimen. However, the strength achieved by the stabilized bricks are significantly higher than the minimum strength of class 20 and 30 stabilized blocks as well as class 10 burnt bricks recommended by BIS. The minimum recommended strength of a class 10 brick is 10 MPa, whereas the minimum recommended strengths of a class 20 and class 30 stabilized blocks are 1.96 and 2.94 MPa respectively. In comparison, 40 % crushed glass amended CSF bricks produced strength of 13.93 MPa. Though, this is lesser than the strength of the control specimen (19.68 MPa), it is still higher than the minimum strength of a class 10 burnt brick. It is significantly higher than the minimum strengths of stabilized blocks. Greepala and Parichartpreecha [1] found that replacement of cement with fly ash in cement stabilized lateritic interlocking blocks produced strength of 15.2 MPa. Thus, it can be seen that valorization of crushed glass in the manufacture of CSF can achieve strength higher than the minimum recommended standards.

Figure 5 shows the percentage strength difference of the crushed glass amended specimens when compared to the control specimens as well as when compared to the minimum recommended strength of a burnt brick. The strengths were not compared with that of the minimum recommended strength of stabilized blocks as strength of the amended CSF bricks were significantly higher. The figure clearly reveals that when compared to the control specimen the crushed glass amended specimens have negative percentage difference in strength, but there is a recovery in negative difference with increase in the % crushed glass content. The negative strength difference steadily improves from 68.29 % for 10 % crushed glass to 29.22 % for 40 % crushed glass.

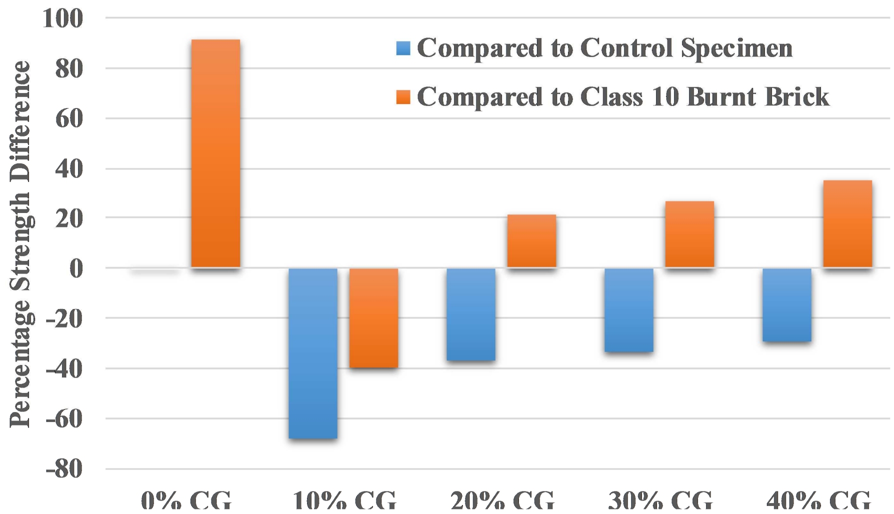

Fig. 5: % Strength difference of crushed glass (CG) amended blocks.

When compared to the strength of a class I burnt brick, it can be seen that the control specimen has a huge strength gain of 91.07 %. Replacement of one fourth of san by crushed glass has resulted in a reduction in strength of 39.42 %. However, further increase in the crushed glass content has resulted in an increase in the percentage strength gain with a complete replacement of sand by crushed glass has resulted in a strength gain of 35.24 %. Though, this is significantly less than the strength gain of control specimen, it is still a major gain when compared to burnt clay brick. The cost analysis of the bricks will determine the beneficial effect of crushed glass replacement when compared to control specimen.

In order to analyze the effectiveness of the crushed glass amendment of CSF bricks, a comparison was made with a few earlier works in fly ash bricks. Figure 6 shows the comparison of the strength results of the present work with the work done by Vijayaraghavan et al. [25] who worked on CSF bricks amended with slag and with Kulkarni et al. [26] who worked on lime stabilized fly ash (LSF) bricks amended with bagasse ash (BA). Since the works adopted different proportions of cement/lime and fly ash contents in their works, the authors have attempted to bring everything on to a comparable platform by reducing the proportions of cement/lime, fly ash and the additive as the ratio of cementitious material (cement/lime + fly ash) to auxiliary additive which was plotted on the *x*-axis whereas the compressive strength of the bricks was plotted on the *y*-axis. A similar comparison was earlier attempted by James et al. [29] in comparing cement stabilized soil blocks amended with bagasse ash. In order to reduce the variations of the plot points and obtain a smooth curve, the *x*-axis and *y*-axis were reduced to logarithmic scales. This comparison still has the demerits of not taking into account the variations in curing period and moulding processes. It is only a mere attempt to determine the standing of the strength of CG amended CSF bricks among existing literature.

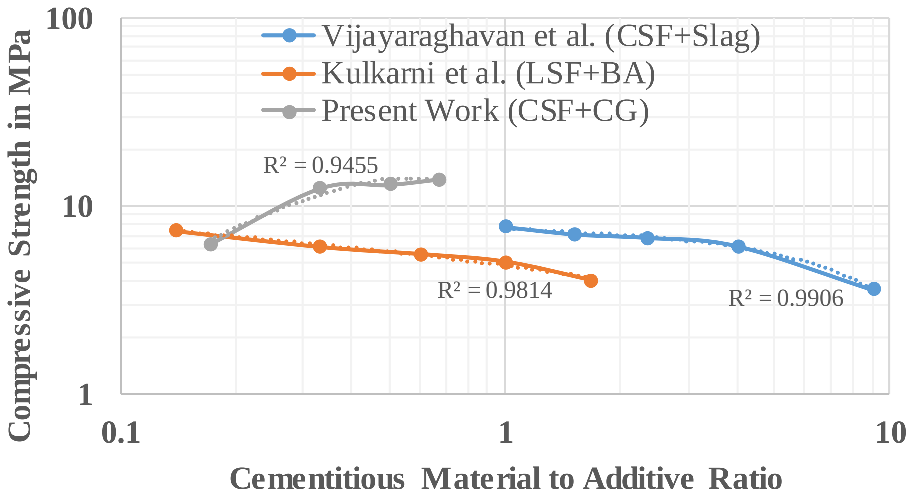

Fig. 6: Comparison of present work with earlier works.

From the figure, it can be seen that in both cases of earlier works, the compressive strength of the bricks reduced with an increase in the cementitious material to auxiliary additive (CMA) ratio, whereas in the present work, the compressive strength increased with the increase in the same. CMA ratios of Vijayaraghavan et al. [25] were higher when compared to Kulkarni et al. [26] and the present work. CMA ratios of Kulkarni et al. [26] were comparable to those of the present work; however, their work involved lime as the stabilizer whereas the present work adopted cement as the stabilizer. The present work showed the highest strength of bricks when compared to both the earlier works. The present work showed higher strength at lower CMA ratios when compared to Vijayaraghavan et al. [25], whereas against Kulkarni et al. [26] the strength was higher at comparable CMA ratios. But it must be noted that in the case of Vijayaraghavan et al. [25] as well as Kulkarni et al. [26], the increase in auxiliary additive resulted in a reduction in the proportion of the binder in the composition of cementitious material, which may be the reason for the reduction in strength with increase in the CMA ratio. In the present work however, the cement content of the brick was maintained constant, which may have been the reason for no reduction in strength. In both earlier works, the auxiliary additives were reactive materials with pozzolanic benefits whereas in the present work, crushed glass is an inert material. As the auxiliary additives adopted in the earlier works replaced a proportion of the cementitious composition, the pozzolanic benefits achieved were offset by the loss in cementitious material. In the present case, the addition of crushed glass which did not replace the cementitious composition may have resulted in a better packing of the material during moulding. Moreover, the crushed glass being more angular in nature when compared to sand which it replaced, it must have developed increased strength due to frictional interaction with the matrix of the brick. This may have been the reason for the increase in strength of the bricks with increase in the proportion of crushed glass. Comparing the trends of all three works, the R^2 value of the present work, though good, is still the lowest. This may be due to the effect of variable quality workmanship introduced due to hand moulding method of brick forming. However, it should be noted that Vijayaraghavan et al. [25] also had adopted hand moulding method for forming the bricks which itself is a testament to the variation in brick quality in hand moulding method.

4.2 Water absorption

The water absorption of the CSF blocks amended with crushed glass has been discussed in the following sections. Figure 7 shows the water absorption of the crushed glass amended CSF blocks. It can be clearly seen that the water absorption of the CSF blocks is very low when compared to the minimum requirements as required by BIS codes. The maximum permissible water absorption for a class 10 brick is 20 % whereas the corresponding allowed for stabilized soil block is 15 %.

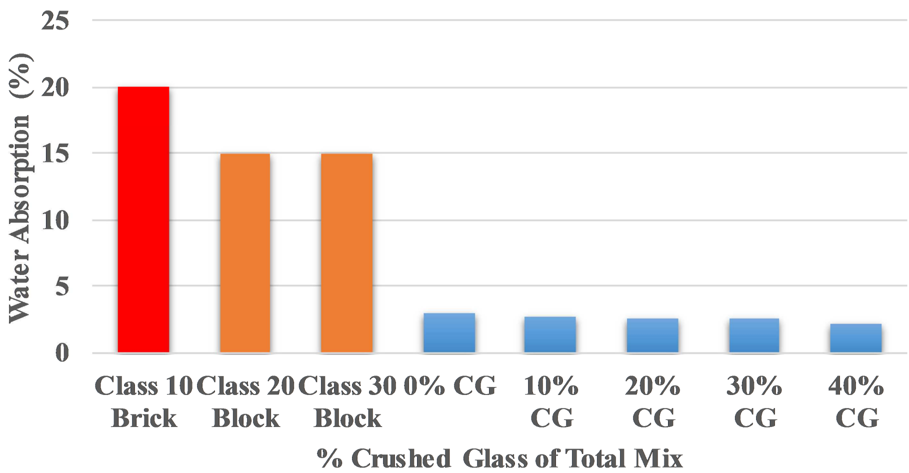

Fig. 7: Water absorption of CSF bricks amended with crushed glass (CG).

The water absorption values of CSF bricks vary from 3.03 % for the control specimen to 2.18 % for the 40 % crushed glass amended specimen. The water absorption values are less than one fifth of that of stabilized soil blocks. However, it is evident that addition of crushed glass does not have any significant effect on the water absorption of the CSF bricks with the water absorption reducing by only a mere 0.85 % for complete replacement of sand by crushed glass. Madurwar et al. [30] reported the water absorption of 10 % for commercially available CSF brick. However, it should be noted that commercially available fly ash brick reported in his work used only 10 % cement which may be the reason for higher water absorption when compared to the current study.

4.3 Efflorescence

The effect of crushed glass amendment on the efflorescence of the CSF bricks is shown in Table 3. It can be seen that the addition of crushed glass to CSF bricks has not produced any efflorescence in the bricks. However, it should be also noted that no efflorescence was produced even in the control specimen. Thus, addition of crushed glass to CSF brick manufacture has not resulted in any detrimental effects on bricks from the point of view of salt deposition.

Table 3: Efflorescence of CG amended CSF bricks.

Combination	Glass, %	Efflorescence
1	0	Nil
2	10	Nil
3	20	Nil
4	30	Nil
5	40	Nil

4.4 Cost comparison

Cost estimation of alternative building materials play a crucial role in increasing the acceptability of such materials in the actual field practice, especially in developing countries like India. Cost estimation makes such alternative materials attractive to the lay man who cannot afford the conventional building materials whose costs have started to skyrocket in recent times. Rajkumar et al. [31] found that utilization of bagasse ash in the manufacture of cement concrete paver blocks resulted in cost savings of up to 24.15 % in pavement construction using the modified paver blocks. From the results of the various aforementioned tests, it can be seen that 40 % CG amendment of CSF bricks has resulted in an acceptable performance on all counts. Thus, the cost analysis has been performed for the said combination. The gist of the cost analysis is shown in Table 4. For a clearer understanding of the cost analysis, the comparative statement has been shown in currencies of ₹ (Indian Rupee), $ (American Dollar) and € (Euro), considering the exchange rate as ₹ 70.51 to a dollar and ₹ 80.05 to a euro.

Table 4: Gist of cost analysis of CSF bricks.

Raw materials and labour	Cost per 1000 bricks					
	CSF brick			CG amended CSF brick		
	(₹)	($)	(€)	(₹)	($)	(€)
Cement	3270	46.37	40.86	3270	46.37	40.86
Fly ash	1260	17.87	15.74	1260	17.87	15.74
Sand	3400	48.21	42.48	-	-	-
CG	-	-	-	1700	24.10	21.24
Labour	500	7.09	6.25	500	7.09	6.25
Total	8430	119.54	105.33	6730	95.43	84.09

Based on the results of the cost analysis performed it was found that the production of 40 % CG amended CSF bricks were cheaper than plain CSF bricks. The cost of the above brick combination was ₹6730 ($95.43 or €84.09) per 1000 bricks which was ₹1700 ($24.10 or €21.24) cheaper than the control specimen which costs ₹8430 ($119.54 or €105.33) per 1000 bricks. This amounts to a savings of 20.17 % in material cost. Kulkarni et al.[26] reported a reduction of ₹0.11 ($0.0016 or €0.0014) amounting to 3.27 % savings in cost due to bagasse ash amendment of lime stabilized fly ash bricks. Thus, it can be seen that CG amendment of CSF bricks can be significantly cost effective with one-fifth savings in cost.

5 Conclusion

Based on the results of the experimental investigation wherein CG was adopted as replacement for fine aggregate in the manufacture of CSF bricks, the following conclusions were obtained.

1. Replacement of fine aggregate with CG resulted in a general increase in the compressive strength of the CSF bricks, but where not as strong as the control specimen. 40 % CG amended CSF bricks were stronger than class 10 bricks recommended by BIS and hence, can be recommended for use in field practice for non-load bearing walls and lightly loaded structures. Addition of CG to CSF

bricks may have improved the packing of the brick during moulding along with improved frictional interlocking leading to enhanced strength.

2. Amendment of CSF bricks with CG resulted in a reduction in the water absorption of the bricks. However, it was found that dependence of the water absorption of the bricks on the quantum of CG amendment was insignificant. CG amendment of CSF bricks did not produce any efflorescence in any of the combinations investigated. Thus, it can be concluded that CG amendment results in improved water resistance.

3. It was found that CG amendment up to 40 % resulted in a reduction in the cost of the material by up to 20 %. Thus, it can be concluded that CG amended CSF bricks can be recommended as a low-cost alternative for conventional fly ash bricks for lightly loaded and non-load bearing structures.

The CG amended CSF bricks were more resistant to water absorption, however, its durability to extended periods of wetting or alternate cycles of wetting and drying were not investigated in this investigation, which can be taken up in future investigations to fully reveal the potential of reusing CG in such applications.

Conflict of interest statement

The authors declare that there is no conflict of interest in the publication of this article.

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