

## EXPERIMENTAL BENEFICIATION APPROACH TO IMPROVE PERFORMANCE OF BRICK RECYCLED AGGREGATE IN CEMENT MORTAR

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### ABSTRACT

*The increasing volume of construction and demolition waste (CDW) poses significant environmental challenges, necessitating effective recycling strategies to promote sustainable development in the construction sector in India. This paper examines the current state of CDW management, particularly focusing on brick waste, which is a major contributor to the overall waste generated in country. The study explores experimental techniques to enhance the properties of recycled aggregates, including water absorption and efflorescence tests, conducted according to established IS codes. From CDW, brick waste was derived as fine aggregates. Prior literature results indicated that brick aggregates (BA) exhibit higher water absorption due to their porous structure, highlighting the need for effective treatment methods. Different surface treatment slurries, such as cement, fly ash, and ground granulated blast-furnace slag (GGBS), were applied considering the Beneficiation approach to brick aggregates to improve their performance. Utilizing treated 3 types of aggregates, mortar cubes were casted, and results are then compared to cubes casted using conventional sand and brick aggregate without any coating. The compressive strength result of GGBS coated brick aggregates at 28 days compared with sand and BA shows 5.57 % and 29.17 % more respectively. Fly ash and cement-coated aggregated performed comparatively lesser results than GGBS coating. Similar results are observed for water absorption and GGBS aggregates as the findings underscore the potential of utilizing recycled materials in construction, contributing to resource conservation and environmental protection. This research advocates for a paradigm shift towards sustainable practices in the construction industry, emphasizing the importance of recycling and reusing materials to mitigate the adverse effects of CDW on the environment.*

*Keywords:* brick aggregates, slurry treatment, GGBS, fly ash, compressive strength.

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### INTRODUCTION

Recently, the growing quantities of construction and demolition concrete wastes have become deleterious to the environment. Recycling the construction and demolition of concrete wastes is essential for protecting the environment, saving limited natural resources, and realizing sustainable development in the construction works [1]. Nepal produces 5 billion pieces of bricks produced annually, Pakistan produces approximately 70 billion pieces of bricks annually, and India produces

more than 200 billion pieces of bricks annually [2]. Therefore, sustainable management of brick wastes will remain an outstanding environmental problem for the longer-term. Landfilling is now the predominant treatment option for CDW in many regions of the world. Worldwide, more than 35 % of CDW is disposed of in landfills [3].

To build an environment-friendly society, sorting, crushing and screening of construction solid waste have been done to get new green building materials which has gained wide international recognition. In recent

years, many scholars have carried out research on waste clay brick resource utilization, explored the technical means of effective utilization of waste clay bricks, and obtained many experimental, theoretical and applied research results. The urban population in India expected to reach 60 crores by 2030. Schemes like Pradhan Mantri Awas Yojana (PMAY), New Suraksha Yojana (NSY), Affordable Housing and other state government housing schemes will increase the possibility of the C&DW generation. Repair, restoration and construction of new housing and infrastructure will generate a large capacity of construction and demolition waste (C&DW). Brick waste, mortar and concrete waste are the significant waste contributing to C&DW. It is challenging to handle C&DW as it is a bulky, inert composite material [4]. Replacing natural aggregate with recycled coarse aggregate (RCA) and fine recycled concrete aggregate (FRCA) as fine aggregate to overcome the material shortage and achieve sustainability.

Fly ash and GGBS are widely used raw material which are easily available and contains appreciable amount of silica and alumina which is vital for construction material. Previous studies dealing with the research on construction materials have emphasised the use of Fly ash [5 - 8]. Recycling waste brick (WB) demonstrates significant environmental and social benefits, with versatile applications in construction and environmental materials. WB is effective for treating wastewater with contaminants like ammonia, fluorine, nitrogen, and phosphorus. It serves as a supplementary cementitious material in cement, mortar, and concrete, used either as fine or coarse aggregates [9]. Waste Red Brick Powder (WRBP) combined with fly ash in alkali-activated cement (AAC) binders improves reaction kinetics, compressive strength, and microstructure. This reduces energy consumption and CO<sub>2</sub> emissions, creating a sustainable low-carbon building material [10]. Concrete with Ceramic Waste Aggregate (CWA) and Clay Brick Waste Powder (CBWP) shows improved long-term strength, chloride ion permeability, and sulfate resistance, enabling full replacement of natural aggregates with CWA by optimizing CBWP ratios [11]. Brick Powder (BP) and Limestone Powder (LP), used as supplementary cementitious materials in Portland cement (PC), enhance strength, with ternary blends outperforming binary blends. These blends reduce CO<sub>2</sub> emissions and energy consumption while maintaining

performance [12]. Recycled Brick Powder (RBP) reduces fluidity but accelerates early hydration in cement pastes, supporting its use for recycling construction waste and reducing carbon emissions [13]. Incorporating WB and recycled concrete powder (RCP) in geopolymer technology improves mechanical strength and water resistance, achieving properties comparable to OPC mortar while conserving resources and reducing waste [14]. Up to 20 % of Concrete and Brick Waste Powder (CWP and BWP) can be used in cement mortar and concrete. BWP shows higher pozzolanic activity, while chemical activators like sodium silicate enhance their effectiveness [15]. Recycled Concrete Aggregate (RCA) treatment with fly ash and cement (FA&C) or nano-silica fume (NSF) improves density, reduces porosity and water absorption, and enhances mechanical strength [16]. Other methods, like nano-silica coating and calcium carbonate bio-deposition, enhance durability and mechanical properties of recycled aggregates [17]. Pressurized Carbonation with Nano-Silica (PCNS) treatment improves compressive strength by 20.7 % and matches the sorptivity of natural aggregate concrete [18]. Granulation of concrete slurry waste (CSW) and waste brick masonry powder (WBMP), with carbon dioxide curing, achieves improved water absorption, crushing strength, and CO<sub>2</sub> sequestration of about 3 %, offering sustainable benefits [19].

After reviewing the findings of earlier studies, it is discovered that most domestic and international research on waste clay bricks focusses on using them as coarse aggregate.

However, the concrete's mechanical and physical qualities particularly its compressive strength will suffer if leftover clay bricks are employed as coarse aggregate in its formulation [20 - 22]. This is because the waste clay brick's porous structure and particle size have an impact. Zong concluded that the coarse recycled aggregates from crushed bricks enhance the concrete's porosity and create a loose microstructure, which lowers the strength and concrete's resilience [23]. Nonetheless, Dudziak and Mechtcherine's studies showed that recycled concrete performs similarly to regular concrete and that the impact of coarse recycled aggregates from crushed bricks on concrete is minimal [24 - 26]. Given the variations in the use of waste clay brick aggregate in concrete as opposed to natural coarse aggregate, the quantity of waste clay brick aggregate is

restricted, and the utilisation Aggregation of discarded clay bricks is impeded. As a result, researchers have investigated using leftover clay brick in mortar and concrete rather than natural fine aggregate. It has been discovered that RCBA can partially replace natural fine aggregate to prepare mortar, and it has minimal impact on the mortar's durability, shrinkage, and compressive strength. However, it has a detrimental effect on mortar's flowability [27 - 30]. However, the investigation into recycled mortar lacks rigour and systematicity, and the macroscopic and microscopic studies on it is still necessary to determine how different RCBA parameters affect mortar performance. Several research studies dealt with brick waste as a replacement of fine aggregates, coarse aggregates. As per the change in the trend of use of types of brick, a recent study focuses on reutilizing the autoclaved aerated concrete block waste for mortar cubes [31]. Very few studies used the slurry soaking method to improve the quality of aggregate (Interfacial Transition Zone) which enhances the strength of aggregate [1].

In this paper, different types of slurries have been designed and used to treat brick aggregate the Beneficiation approach. The slurry ingredients that were selected are fly ash (FA), Ground granulated blast furnace slag (GGBS) and Ordinary Portland cement (OPC). The aggregate were soaked in different slurry to obtain the different coated aggregates. The results were compared to the non-coated aggregates of brick waste and sand. To test the physical and mechanical properties of coated brick aggregate before and after surface treatment, a series of laboratory tests such as water absorption, compressive test, fluorescence test was conducted. Also, surface characterization of coated brick aggregate was performed using a scanning electron microscope with energy dispersive spectroscopy (SEM-EDS) to examine the influence of the proposed technique on the morphology and mineralogy properties of brick aggregate surface.

## **EXPERIMENTAL**

For the experimentation, Ordinary Portland Cement Grade 43 of Ultratech brand is used. Fly ash and GGBS was supplied by Ashcon Energy Solution for experimental purpose. Manufactured sand of Grade I, II and III are used. Brick Aggregate (BA) is carefully sorted from the demolition site. The material is obtained from 40 years old construction and demolition building which is manually crushed to obtain the fine aggregate

and remove adhered mortar. The fine aggregate obtained are of two sizes passing from 4.75 mm and retrieved on 2.36 mm and passing from 2.36 mm and retrieved on 1.18 mm. The size of fine aggregate for the brick was determined according to a study of particle size distribution of natural sand. Raw materials were tested using X-ray fluorescence (XRF), X-ray diffraction (XRD) and scanning electron microscopy (SEM).

### **Surface treatment technique**

To strengthen aggregate three different types of slurries; (i) cement slurry (ii) fly ash slurry and (iii) GGBS slurry were used. One of the objectives of this study is to provide an effective and economic strengthening technique (the Beneficiation approach) for brick aggregate. The surface treatment process was illustrated in Fig. 1. In making slurries, the different types of strengthening material i.e cement, fly ash, GGBS were prepared by blending the materials with water for 3 min. Then, the brick aggregate was added into each slurry and soaked for 16 h at room temperature. After that, the brick aggregate was removed from the slurry bath and dried at the room temperature for 2 days. Finally, the coated aggregate was obtained as shown in Fig. 1 for different slurries as cement coated brick aggregate (CA), fly ash-coated brick aggregate (FA) and GGBS-coated brick aggregate (GA) for conducting the different laboratory tests.

### **Mix design**

To explore the effect of coating treatment compared to brick aggregates and sand, the mix developed according to the IS code 650. The percentage were 33.33 % for each component. The sand were of three types Grade 1 less than 2 mm and greater than 1mm, Grade 2 less than 1mm and greater than 0.5 mm, Grade 3 less than 0.5 mm and greater than 0.09 mm. The cement was as per 1:3 proportion contributing to 33.33 %. The next 33.33 % were for sand and other 33.33 % was of the derived aggregate. The derived aggregate was further divided into two types 1.18 mm and 2.45 mm contributing 16.66 % each. The percentage of water used was 0.3 to 0.5 % of cement content. The 33.33 % of sand was replaced by the derived aggregate. Table 1 shows the mix design proportion for the casting. For the performance evaluation of the derived brick aggregates from cement, fly ash and GGBS the compressive strength, water absorption and

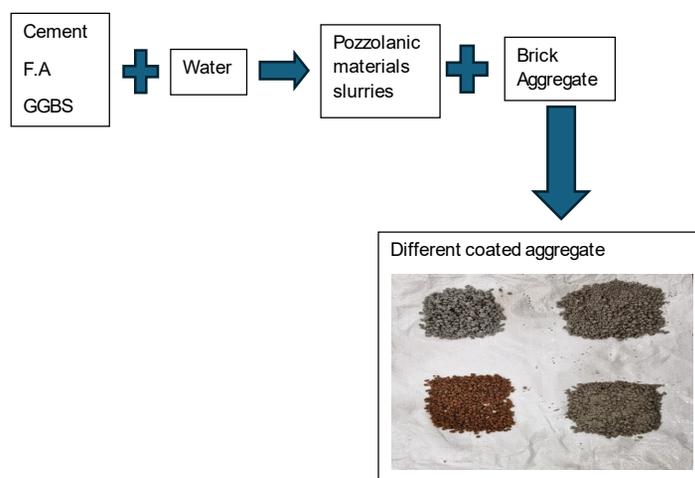


Fig. 1. Surface treatment process for BA with different pozzolanic materials.

Table 1. Mix design proportion prepared in this study.

Material	Abbreviation	Cement	Sand	Aggregate (1.18 mm + 2.36 mm)	Binder to water ratio
Sand	S	33.33 %	66.66 %	-	6:10
Brick aggregate	BA		33.33 %	33.33 %	6:10
Cement treated aggregate	CA				6:10
Fly ash treated aggregate	FA				6:10
GGBS treated aggregate	GA				6:10

efflorescence were performed and compared with results of conventional sand and brick aggregate.

### Physical testing

The mix were prepared as per Table 1. Five different pastes were made and poured into cube moulds of 50 mm × 50 mm × 50 mm. After 24 h, the paste cubes were demoulded and cured in a standard curing room (25°C). The sample were cured to the ages of 7 d, and 28 d. Cube specimens were tested for compressive strength by using a compressive testing machine. A set of three specimens for 7 d and 28 d of each sample were tested. The test was conducted according to the IS code 3495 Part 1 [32]. The compressive strength of the coated aggregate sample was compared to the base case i.e. sand and brick aggregate cube.

For water absorption test different cube for each sample were taken. The cube were put for curing for 24 h

after that the wet weight of each cube were recorded. After 24 h, the cubes were removed and put in oven for next 24 h at 105°C temperature. The dry weight of each cube where recorded. A set of 3 specimens of each sample were taken for data collection. The test was conducted according to the IS code 3495 Part 2 [32].

The efflorescence test of the different specimen of cubes was conducted according to IS code 3495 Part 3 [32]. The test measures the number of soluble salts that are deposited on the surface of the cube due to water evaporation. The cube sample where partially submerged in the water. The amount of water taken is 25 %. The water evaporated in the room temperature, after the water is completely evaporates again the same amount of water is added to the sample specimen which again evaporates, this procedure is repeated 2 to 3 times at the end the white powder patches are form on the surface of the cube.

## RESULTS AND DISCUSSION

### Test results

For determining the elemental composition XRF is done on cement, fly ash and GGBS. Class F fly ash contains more than 70 % of  $Al_2O_3 + Fe_2O_3 + SiO_2$  contents. In the current study, the type of fly ash comes under class F detected from the XRF results with the composition of 57.121 %  $SiO_2$ , 27.38 %  $Al_2O_3$  and 5.68 %  $Fe_2O_3$  as shown in Table 2. GGBS is found to have high amount of CaO as well as  $SiO_2$ .

Based on the Fig. 2 and 3, diffraction peaks shown on the spectrum, the main mineral composition identified by XRD in FA are found to be quartz ( $SiO_2$ ), mullite ( $2Al_2O_3SiO_2$ ) and GGBS primarily have Quartz and calcite. XRD pattern confirming the amorphous nature of GGBS will primarily exhibit a wide, low-intensity hump between roughly  $25^\circ$  and  $40^\circ 2\theta$ , potentially with minor sharp peaks indicating the presence of a small number of crystalline phases. The microstructure analysis done through scanning electron microscopy (SEM) in the

Fig. 4 showing presence of spherical particles in fly ash whereas in Fig. 5 GGBS abnormal shaped particles with distinct edges and angles were observed.

The Fig. 6 shows the compressive strength results of 7 and 28 days of all the casted samples. The sand and brick aggregate are the base case for the comparison between the coated aggregate. Percentage increase in the Compressive strength of cubes from 7 to 28 days was 2.57 %, 45.48 %, 19.90 %, 6.75 %, 22.06 % respectively for S, BA, CA, FA, GA. These results depict strength gain for the Sand on 7 days is faster as compared to others.

As compared with the brick aggregate the 28 days compressive strength of CA and GA 13.36 % and 29.17 % more. While for FA it was 6.61 % less to BA compared BA aggregate. As compared to the sand the 28 days compressive strength result of only GA coated aggregate cubes was more by 5.57 %, and for others it was showing decreasing trend. Overall, the GGBS coated aggregate sample cube shows maximum strength compared to brick aggregate and treated aggregates as well. The bulk density for the coated and uncoated aggregates cubes

Table 2. Chemical composition.

Raw material	Chemical compositions, %						Dry density, $kg\ m^{-3}$
	CaO	$Na_2O$	$SiO_2$	$Al_2O_3$	$Fe_2O_3$	$TiO_2$	
Cement	66.7	0.22	18.48	6.25	6.09	-	1650.00
Fly ash	0.43	0.42	57.12	27.38	5.68	1.89	1008.75
GGBS	37.2	0.27	33.84	14.28	1.2	0.53	1338.19

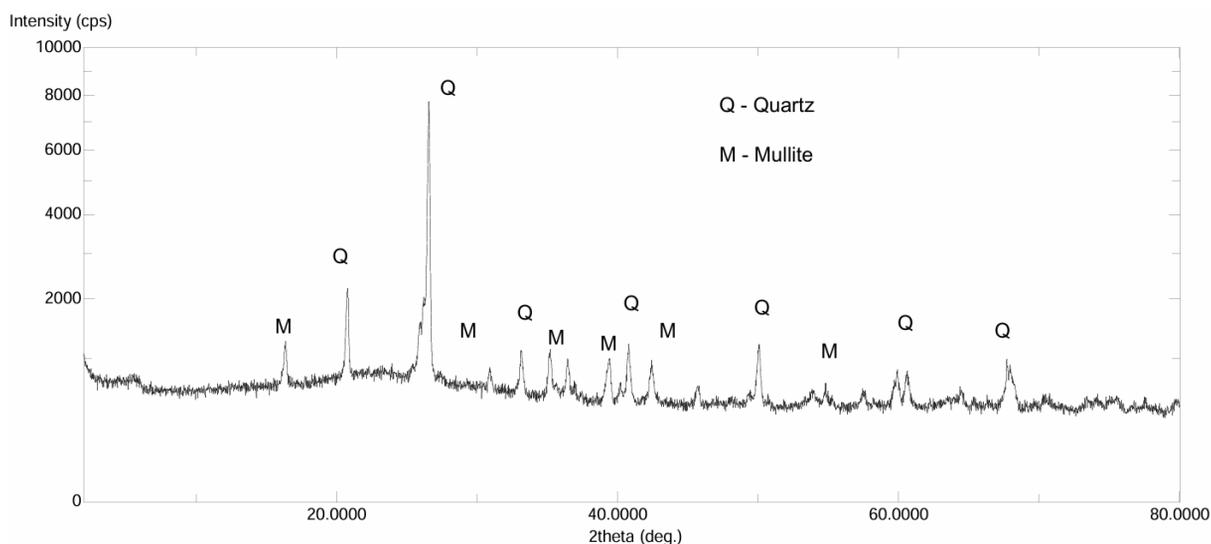


Fig. 2. XRD of fly ash.

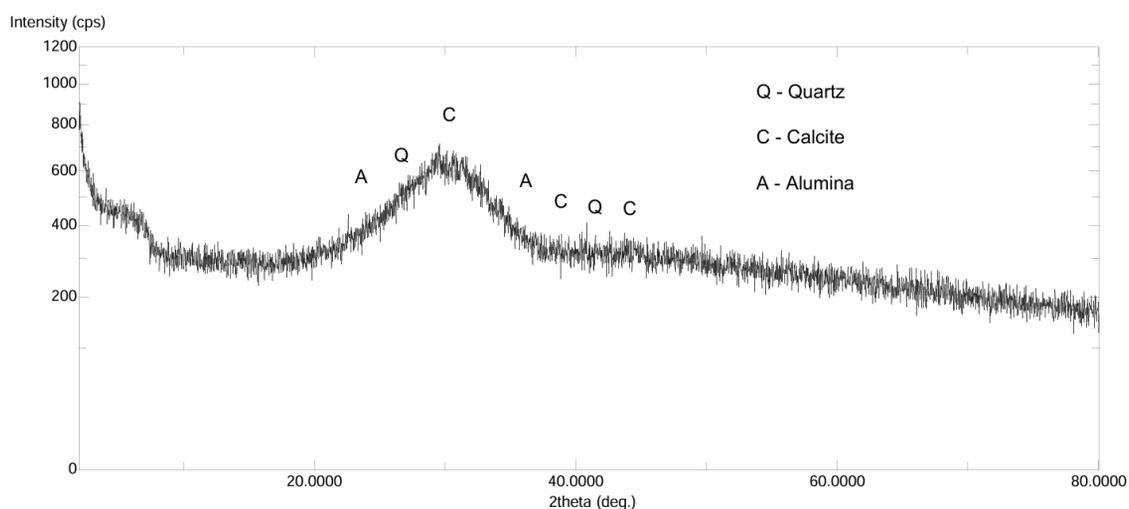


Fig. 3. XRD of GGBS.

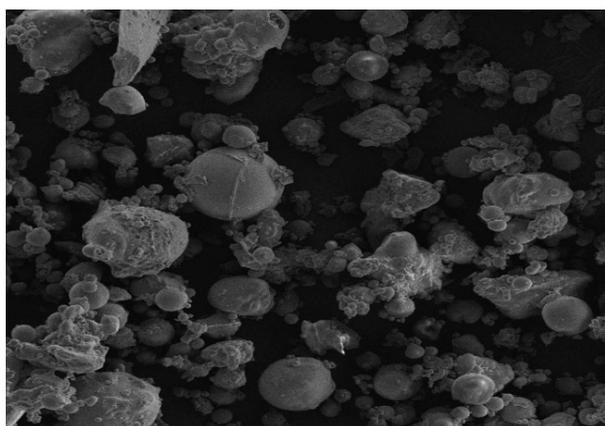


Fig. 4. SEM of fly ash.

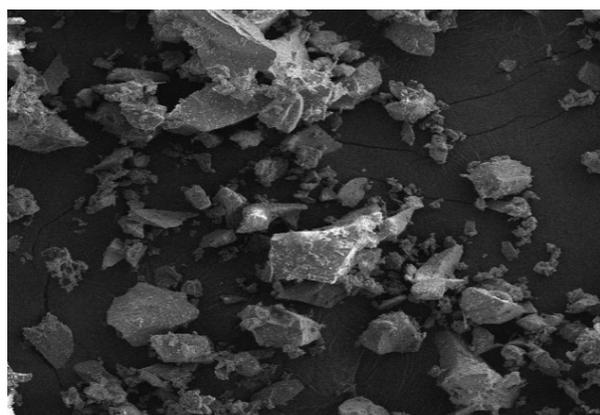


Fig. 5. SEM of GGBS.

was derived as given in Table 3. It was observed that density is higher for convention sand aggregate mortar wherein follows decreasing trend for GGBC, cement, fly ash and brick aggregate mortar.

Fig. 6 shows the percentage of water absorption of mortar cube. The water absorption of brick aggregate without coating is 12.71 % whereas the water absorption for GGBS coated aggregate is less i.e. 9.09 %. The brick aggregate shows maximum water absorption as brick aggregate are porous in structure compared to other aggregates which have the coating of different materials i.e cement, F.A, GGBS. Results depict the effectiveness of coating treatment done for the brick aggregate in saving the water absorption percentage. The efflorescence test was performed according to IS code 3495 Part 3. The results were nil/moderate for all the sample cubes tested.

### Microstructure analysis

To examine the morphologies of the treated samples SEM-EDS were conducted. Energy Dispersive Spectroscopy (EDS) test is carried out on using Bruker XFlash 6I30 which has an Excellent energy resolution (123 eV at Mn  $K\alpha$  and 45eV at C  $K\alpha$ ) & element detection range from 4 Be to 95Am. The software used for this is Espirit 1.9. EDS test is carried on casted samples at the 500 $\mu$ . The maximum number of major elements at the peak observed in GGBS aggregate are calcium (Ca), silicon (Si), oxygen (O) whereas in BA aggregate major elements at the peak are silicon (Si), calcium (Ca), oxygen (O), aluminium (Al) (Fig. 7 and Fig. 8).

SEM test is carried using FEI Nova NanoSEM 450, which has Ultra High-Resolution low voltage imaging and unique low vacuum capabilities. With Resolution,1.0

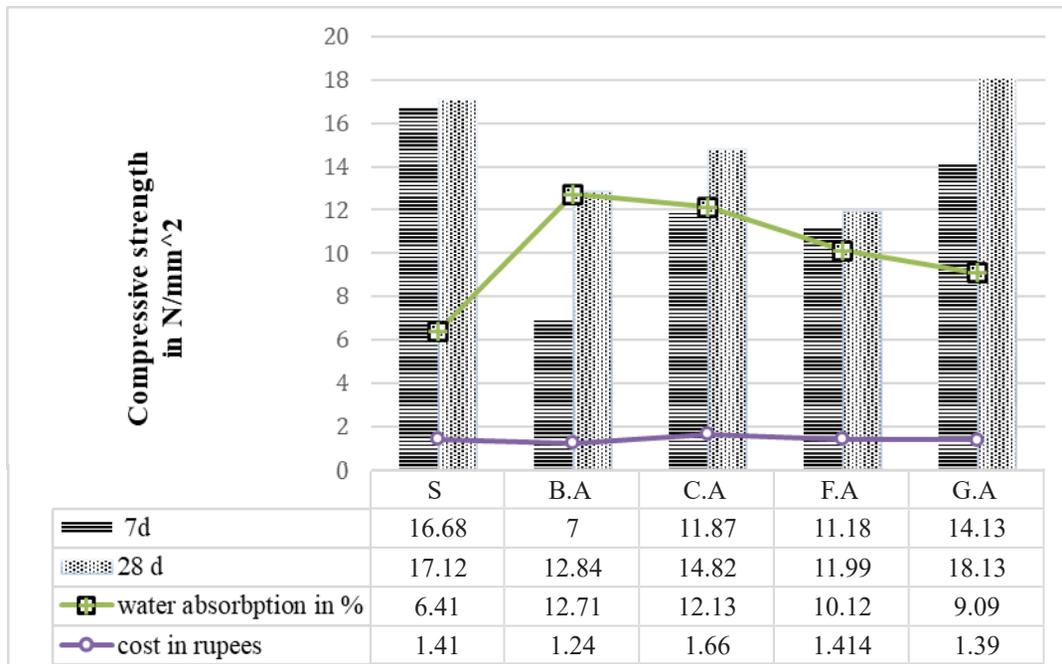


Fig. 6. Results of compressive test, water absorption and cost.

Table 3. Bulk density for mortar in kg m<sup>-3</sup>.

Material	Bulk density, kg m <sup>-3</sup>
S	2120
BA	1824
CA	1912
FA	1896
GA	2024

nm at 15kV, 1.4 nm at 1kV & 1.8 nm at 3kV and 30Pa. The software used for FESEM is xT microscope Control. The Fig. 9 and 10 show the SEM images of the prepared aggregate at 10µ. The SEM was adopted to study micro-morphology of aggregates.

The SEM images show the difference between brick aggregate without coating and brick aggregate with GGBS coating. In Fig. 9 the porous structure of brick aggregate is observed while in the Fig. 10 the coated structure of brick aggregate is observed. Through the surface treatment of aggregate coated with GGBS, the porous structure which was earlier observed in brick aggregate is properly coated with the slurry of GGBS which makes it more compact. Thus, justifying the results for compressive strength and water absorption.

### Cost

The cost was calculated excluding the transportation cost required for the materials only the cost of material is considered. The cost for brick aggregate is Rs. 2.678. The standard cost of rate is considered for other material. The cost is calculated in cubic metres. The cost required for cement cube is more compared to another cube. The cost required for GA cube is more than BA cube, but the compressive strength is more than BA and water absorption is also less of GA cube. In Fig. 6 the comparison of the costs of different cube are given.

### CONCLUSIONS

In this paper the study incorporates the Beneficiation approach by the slurry treatment process to improve the strength of brick waste material as a fine aggregate. The 28 days compressive strength of GGBS coated aggregate mortar cube is observed more than the sand mortar cube by 5.57 %. But the 7 days compressive strength of it is observed less than the sand mortar cube by 15.28 %. Whereas 7 days compressive strength of GGBS coated aggregate compared with brick aggregate is observed as 50.5 % increase and 28 days compressive strength of GGBS coated aggregate mortar cube as 29.17 %

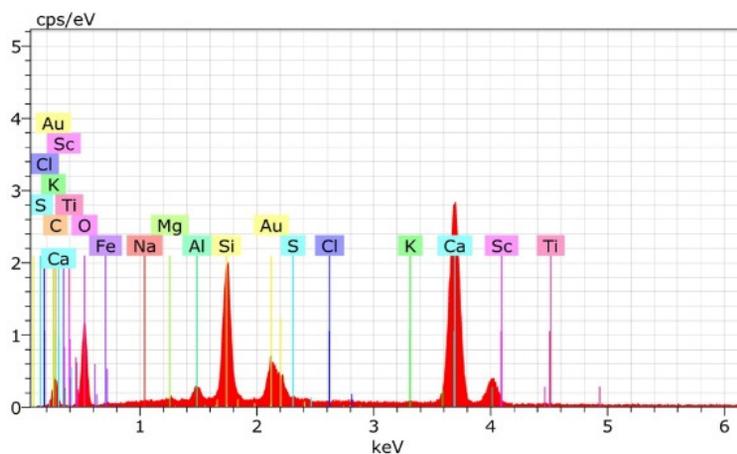


Fig. 7. EDS of GGBS aggregate.

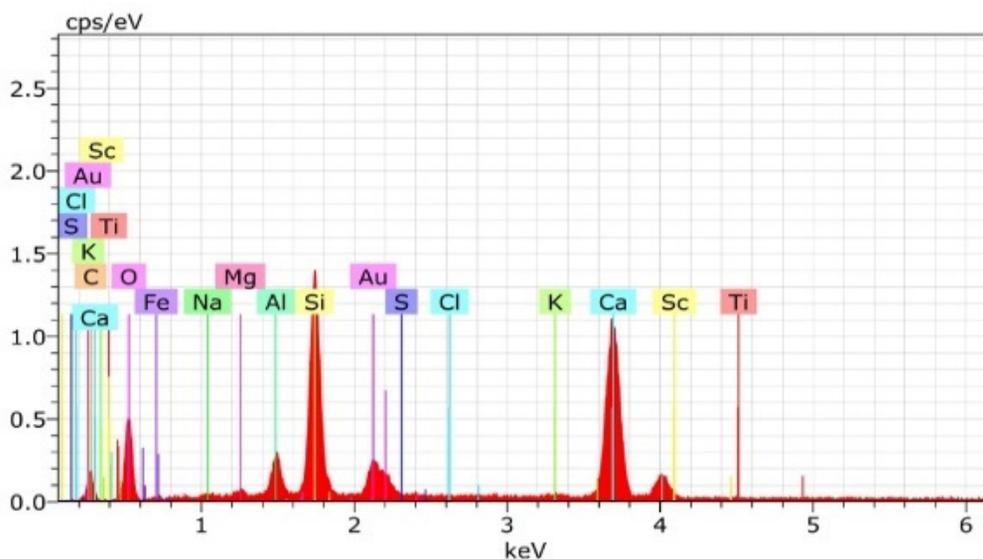


Fig. 8. EDS of brick aggregate.

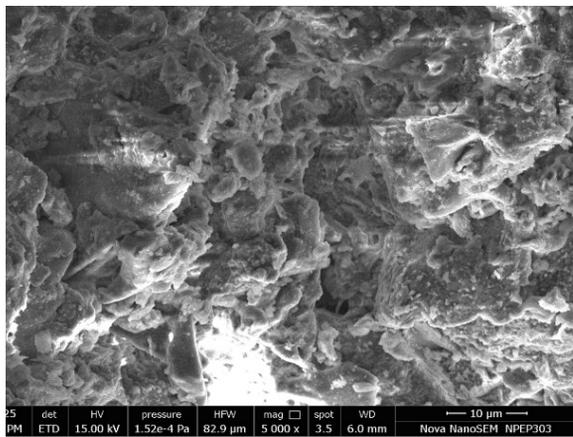


Fig. 9. Brick aggregate without coating.

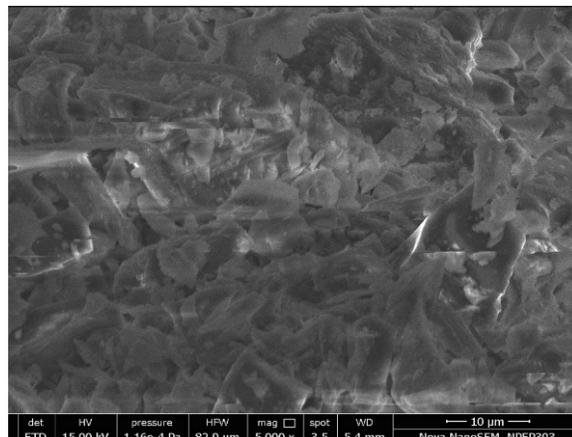


Fig. 10. Brick aggregate with GGBS coating.

increase. The water absorption for mortar cube of GGBS coated aggregate is decreased by 29 % as compared to the without coated brick aggregate. Through SEM and EDS microstructural analysis it is observed that the GGBS coated aggregate mortar cube are more compact as compared to the other coated aggregates. Different percentage variation in slurry and mix design can be studied further to explore the strength obtain by aggregate.

#### Author's contributions

N.K., S.M., V.S.: *Conceptualization*; N.K., S.M.: *Methodology*; N.K., S.M.: *Formal analysis and investigation*; N.K., S.M.: *Writing - original draft preparation*; S.M., V.S.: *Writing - review and editing*; N.A.: *Funding acquisition*; V.S.: *Resources and supervision*.

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