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INTERLOCKING BRICKS AND PRISMS USING WASTE GLASS AGGREGATES BY INTEGRATING GEOPOLYMER TECHNOLOGY

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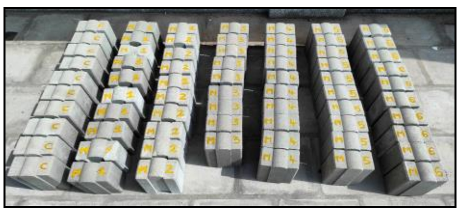
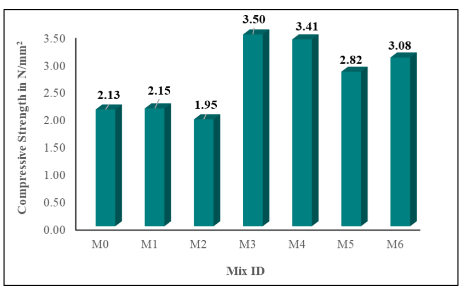
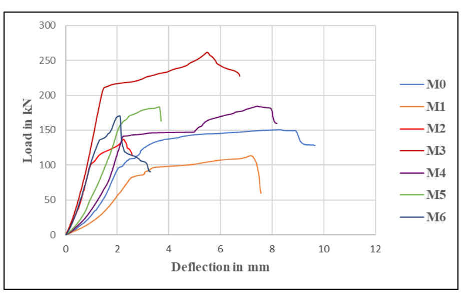
Graphical abstract







Abstract

An attempt has been made to develop sustainable and low-cost geopolymer interlocking bricks using the binders namely Ground Granulated Blast Furnace Slag (GGBS) and fly ash by activating them with hydroxides and silicates of sodium. M-Sand is used in combination with waste glass as fine aggregates. Seven mix ratios adopted are : Bricks with 100% M-Sand, 90% M-Sand and 10% waste glass, 80% M-Sand and 20% waste glass, 70% M-Sand and 30% waste glass, 60% M-Sand and 40% waste glass, 50% M-Sand and 50% waste glass and 40% M-Sand and 60% waste glass. Physical tests were conducted for all the materials used. In total, eighty-four interlocking bricks of size 300 mm x 200mm x 125mm were cast and the bricks were kept in room temperature for 28 days. Interlocking bricks were then tested for density, compressive strength and water absorption. Prisms of length 600 mm, height 375 mm and width 200 mm were constructed using three layers of interlocking bricks and subjected to compressive load. Interlocking bricks with 70% M-Sand and 30% Waste glass exhibited maximum compressive strength and low water absorption. Prisms with 70% M-Sand and 30% waste glass has maximum ultimate load carrying capacity and energy Absorption.

Keywords: Interlocking Bricks, Fly ash, GGBS, Waste Glass, Prism

1.0 INTRODUCTION

Consumption of materials and time are inevitable during the entire process of construction. Improving the quality of construction, reducing the quantity of raw materials and reducing the construction time are the prime challenges that are faced in the construction industry. Lot of developments are happening across the globe to address the above challenges. Interlocking bricks are the one of the developments of conventional type of bricks which are designed in such a way that they are connected to the surrounding bricks with the shear key and locking mechanism thereby the use of mortar for bonding of bricks in the same layer and between the adjacent layers is avoided.

In the market interlocking bricks are available in different sizes and shapes with appropriate self-locking systems. Conventionally interlocking bricks were made of sand and stone dust with the primary binding material being Ordinary Portland Cement (OPC). Due to an enormous increase in price and due to the diminishing reserves of natural river sand, there develops an urge for replacement of natural river sand with other waste materials which provides similar physical and mechanical properties. Waste glass is one of such materials which has been explored by many researchers for its suitability to be used in concrete and mortar. Waste glass below 30% could be considered for practice in making concrete with suitable addition of admixture for desired workability and air content [1]. The optimum percentage of glass particles that could be used as aggregates in concrete is 50% [2]. Waste glass also has a potential to be considered as a cement replacing material in the order of 20% without any compromise in the mechanical properties and for replacement of fine aggregates up to 20% as the mixes with 20% waste glass as aggregates have mechanical properties similar to that of the conventional mixes [3]. Another investigation also confirmed that the use of waste glass powder could replace cement up to 20% whereas, if used combinedly with crushed glass as aggregates, the mechanical properties were good till certain limit and after that the workability decreases. Hence for replacement of both cement and aggregates, 10% is optimum due to better workability and greater strength [4]. A mix of clay brick powder and waste glass with cement at an optimum level of 15% can be used in cement mortar [5]. When partial replacement of waste glass as fine aggregates with fly ash and perlite, geopolymer mortar with a compressive strength from 44 N/mm^2 to 51 N/mm^2 could be synthesized [6].

On the other side the manufacturing process of cement poses severe threats to the environment by releasing greenhouse gases thereby contributing significantly to the global warming. Hence the researchers are experimenting on alternate materials for OPC which are eco-friendlier and more sustainable. Industrial waste materials and by products were explored for their appropriateness to be used a replacement for cement. GGBS, Micro silica, Fly ash, and other pozzolanic materials were used along with OPC partially to study their effects on the mechanical and long term properties of mortar and concrete and found that each one of them have their own merits and demerits when used with cement. Also, the above said materials were found to be effective when used only in limited percentages. Use of fly ash in the interlocking bricks has a negative effect on the porosity, density, water absorption, density and compressive strength whereas it has high resistance to alkali silica reaction [7].

Later on, focus was more towards research on geopolymer technology in which activated fly ash was used for 100% replacement of cement which required heat curing for achieving the targeted strength. Even in geopolymer technology, different pozzolanic materials were tried in combinations and activated using activators to get optimum mixes. Even geopolymer interlocking bricks were made using crumb rubber as the fine aggregates which could be used for non-load bearing applications [8]. In order to lessen the pollution and also to reduce dumping of waste on landfills, bricks of interlocking nature were also produced using plastic bottles comprising of Polyethylene Terephthalate and Polyurethane binder in a ratio of 60 and 40 which was found to be ideal for partition walls and non-load bearing masonry [9]. Waste glass powder based geopolymers in waste glass aggregate pavement bases could pave the way for the probable collaboration with the pavement industry as they serve as the greener substitutes [10].

Alkali-activated bricks appears to be gainful as they could include high quantity of wastes and industrial byproducts like fly ash, rice husk ash, bottom ash, GGBS, Kaolinitic clay, cement kiln dust etc. and could be an alternative masonry choice for sustainable construction [11]. It is claimed that geopolymer bricks are energy efficient and economical as compared with clay bricks [12]. Paver blocks of required properties could be made by introducing recycled asphalt aggregates into a matrix of geopolymer thereby managing the excessive waste and helping the decision makers of the paving industry to utilize the recycled asphalt pavement in an environment-friendly way [13].

The real viability for the recovery and reuse of waste brick in the making of a new geopolymer brick by activation by alkaline solutions along with blast furnace slag in the matrix improves the mechanical and physical properties of the geopolymer brick [14]. Fly ash could be replaced partially with residues like waste glass and red mud for the synthesis of geopolymer as they show the properties within the ranges fit for construction. The flexural strength and fracture toughness values are superior due to the adding of red mud as related to waste glass [15]. Geopolymer bricks prepared from the ceramic wall fine dust waste consisting of limestone, kaolin clay, bentonite, potash, quartz and feldspar with Sodium hydroxide and Calcium hydroxide is about 30% cheaper than the traditional clay bricks [16].

Although extensive research has been done on interlocking bricks and prisms using different substitute materials for cement as well as fine aggregates, no work has been done in investigating the properties of the interlocking bricks and the wall prisms made with fly ash, GGBS, M sand and waste glass fine aggregates. Hence a try has been made through this investigation to find out the structural behaviour of prisms constructed out of the interlocking bricks developed.

2.0 EXPERIMENTAL PROGRAM

2.1 Materials

The binders employed for the interlocking bricks are fly ash consistent with IS 3812-2003[17] and GGBS as per BS 6699:1992 [18]. Chemicals used for the activation of the above binders are a mixture of silicates and hydroxides of Sodium (8M) and they are 0.4 times the binder quantity. Silicates and Hydroxides of sodium are in the proportion of 2.5:1 Aggregates are M sand mixed with waste glass in various percentages with a maximum size of 4.75mm and chips are of size 4mm. From the particle size analysis test as per IS 2386 – Part 1 1963 [19], the fineness modulus of M sand and waste glass are 3.12 and 3.38, both belonging to Zone 1 of IS 383-1970 [20]. The specific gravity and compacted bulk density are found to be 1722 kg/m^3 and 2.36 for M sand and 1655 kg/m^3 and 2.06 for waste glass. For chips, aggregate impact and crushing values are determined to be 18% and 28% respectively. The compacted density and water absorption are 1450 kg/m^3 and 0.9% correspondingly. The fly ash and GGBS are possessing specific gravity values of 2.18 and 2.89. For the desired consistency of molding interlocking bricks, the requirement of water by trial-and-error process was obtained as 17.5% which is the extra water required. The materials used are shown in Figure 1a to Figure 1h.

2.2 Mix Design and Proportions

The material quantities were arrived based on the density of concrete (2400 kg/m^3). The mix is assumed to have 80% of aggregates (70% chips and 30% fine aggregate) which occupies 1920 kg/m^3 and 20% of binder and alkaline solutions (480 kg/m^3). The binder comprises of fly ash and GGBS out of which fly ash occupies 80%. Six mix ratios were considered that are designated as M0, M1, M2, M3, M4, M5 and M6 (100% M sand, 90% M sand and 10% waste glass, 80% M sand and 20% waste glass, 70% M sand and 30% waste glass, 60% M sand and 40% waste glass, 50% M sand and 50% waste glass and 40% M sand and 60% waste glass respectively) by altering the proportions of M sand and waste glass as fine aggregates. The quantities of fine aggregates were arrived for different percentages of M sand and waste glass on volume basis considering their specific gravities. The individual quantities of materials arrived for the different mixes are enumerated in Table 1.

Figure. 1a. Fly ash

Figure.1b. GGBS

Figure. 1c. Chips

Figure. 1d. M sand

Figure. 1e. Waste glass before processing

Figure. 1f. Waste glass after processing

Figure. 1g. NaOH pellets

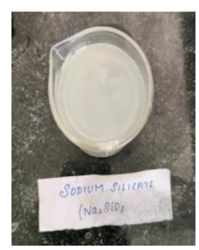


Figure. 1h. Na_2SiO_3 Solution

Table 1 Mix Details

Mix ID	Fly ash (kg/m^3)	GGBS (kg/m^3)	Chips (kg/m^3)	M sand (kg/m^3)	Waste glass (kg/m^3)	NaOH (kg/m^3)	Na_2SiO_3 (kg/m^3)	Water (kg/m^3)
M0	272.28	68.57	1344	566.4	-	39.18	97.95	59.99
M1	272.28	68.57	1344	509.76	49.44	39.18	97.95	59.99
M2	272.28	68.57	1344	453.12	98.88	39.18	97.95	59.99
M3	272.28	68.57	1344	396.48	148.32	39.18	97.95	59.99
M4	272.28	68.57	1344	339.84	197.76	39.18	97.95	59.99
M5	272.28	68.57	1344	283.2	247.2	39.18	97.95	59.99
M6	272.28	68.57	1344	226.56	296.64	39.18	97.95	59.99

2.3 Preparation and Testing of Bricks and Prisms

NaOH solution of 8 molar concentration was prepared one day before molding of bricks and the same was mixed with 2.5 times of Na_2SiO_3 solution. Firstly, all the dry powder and aggregate materials were added and mixed homogenously in a mixer. Then alkaline liquid and water are mixed and added to the dry materials. The mix was then placed in the die part for the casting in the interlocking brick making machine which works by hydraulic power. After removing the specimen from the die interlocking bricks were kept in the shed in the room temperature for 28 days curing. The dye used for casting and the brick after casting are given away in Figure 2a and Figure 2b respectively.

Figure 2a Die

Figure 2b Casting Process

84 bricks were cast, with 12 bricks for each ratio out which 3 bricks were tested under compression, 3 bricks were subjected to water absorption test and 6 bricks were used to construct the interlocking wall prisms which were then tested for compression. The bricks that were ready for the test are shown in Figure 3. Density was also estimated by weighing the bricks before compression test. The water absorption was also determined which is the moisture absorption of the oven dried specimen after immersed in water for 24 hours as shown in Figure 4 as a percentage of its dry weight. The compression test on interlocking Bricks was performed due to applied crushing load in the Compression Testing machine.

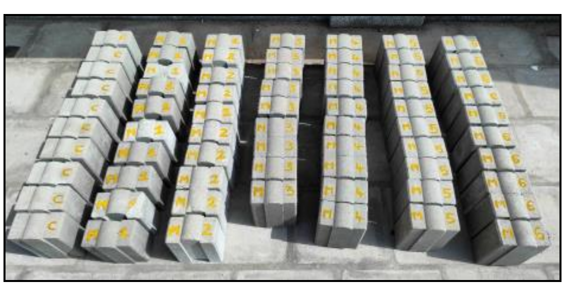


Figure 3 Interlocking Bricks

Figure 4 Water absorption test

In addition to the tests on bricks, compression test on prisms was also executed. The total length of the interlocking brick prism is 600 mm, height is 375mm and width of the prism is 200 mm. The three layers of interlocking prism were constructed without mortar as shown in Figure 5 and tested in Universal testing machine with system interface. Steel plate was placed at the top surface to apply the load uniformly on the prism. The load was gradually applied at 2.5 kN/sec till the failure of the prism. The ultimate load, breaking load and maximum displacement of the prisms were noted.

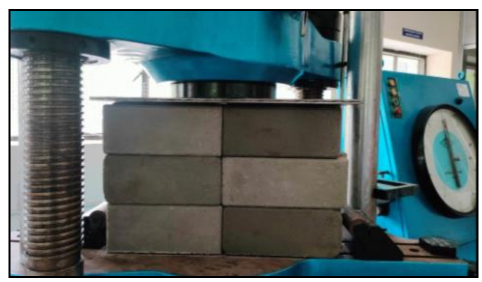


Figure 5 Test setup for prism

3.0 RESULTS AND DISCUSSION

3.1 Density

Bricks were weighed and the densities were calculated by dividing the masses by their volumes. For each of the mix ratios, three bricks were weighed and the individual weights are recorded. The average densities are presented in Figure 6 that ranges from 1908 kg/m^3 to 2047 kg/m^3. The density of brick with 100% M sand is 1955 kg/m^3. As the M sand is replaced with waste glass by 10% and 20%, there is a drop in the average density values. But beyond 20% of waste glass content there is a rise in density of the specimens as compared with M0 samples. Density is maximum for M3 bricks having 70% M sand and 30% waste glass as fine aggregates. Variation in density among M4, M5 and M6 samples are not that much substantial. As per IS 2185:2005 (Part I), for a solid concrete block (Grade C) to be used in load bearing structure, density should be atleast 1800 kg/m^3. Geopolymer bricks made from fly ash, GGBS, M sand and waste glass met out the requirements to be used as load bearing units from density aspects.

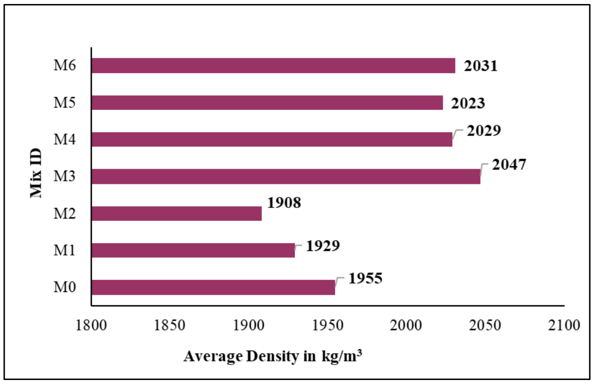


Figure 6 Density

3.2 Compressive Strength

The average compression test results of all tested samples are offered in Figure 7. For every mix proportion, three bricks were tested and the ultimate load was recorded. From the experimental values obtained, it could be noticed that the M0 samples were having an average strength of 2.13 N/mm^2 due to compression whereas the average strength is 1.95 N/mm^2 for M2 mix which is the least among all the mixes. Also, M2 is the only mix among all other mixes, that had a lesser compressive strength than M0. The highest compressive strength is for M3 ratio with a compressive strength of 3.5 N/mm^2 at 28 days. M4 mix with 60% M sand and 40% waste glass has almost comparable compressive strength as that of M3. Likewise, M0 and M1 mixes have almost similar strengths. As per IS 2185:2005 (Part I), for a solid load bearing unit Grade C(4.0), for individual units, compressive strength should not be less than 3.2 N/mm^2 and for Grade C(5.0), compressive strength should have a minimum value of 4 N/mm^2 [21]. For M1 mix, two blocks satisfied the Grade C (4.0). Similarly, all the bricks made with M3 and M4 mixes namely 70% M sand & 30% waste glass, 60% M sand & 40% waste glass respectively have a compressive strength more than 3.2 N/mm^2 and hence falls under Grade C (4.0). All other mixes did not meet out the compressive strength requirements of IS 2185:2005 (Part I). Mixes could be made by increasing the percentage of GGBS and by increasing the molarity of NaOH solution further to overcome this shortfall in strengths. Also, it could be seen from the strength values that, when compared with bricks with M1 mix, all other mixes revealed higher compressive strengths except M2. In M2 also, this decrease in strength is due to the lower value of strength exhibited by one of the bricks which have reduced the average compressive strength of that mix. Patterns of failure of the bricks are depicted in Figure 8a to Figure 8g and in all the bricks, failure is seen by the development of vertical cracks along the depth of the brick and the crushing is prominently visible in the M1 brick.

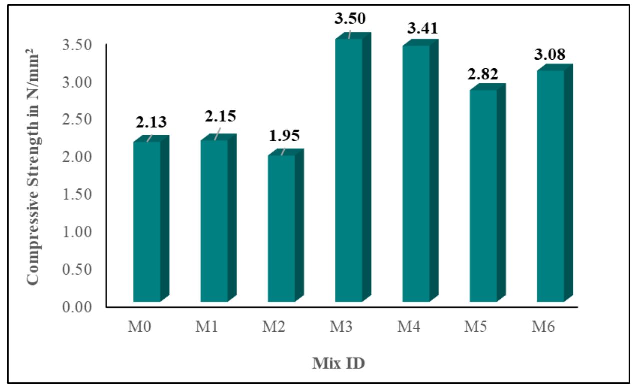


Figure 7 Compressive strength

Figure 8a Failure of M0 brick

Figure 8b Failure of M1 brick

Figure 8c Failure of M2 brick

Figure 8d Failure of M3 brick

Figure 8e Failure of M4 brick

Figure 8f Failure of M5 brick

Figure 8g Failure of M6 brick

3.3 Water Absorption

The initial weights and the weights after immersion were documented and the average water absorption values are plotted in Figure 9. The average water absorption of three units shall not be more than 10 percent by mass according to IS 2185:2005 (Part I). M0 samples have an average value of 10.6% that is slightly more than the limit specified by the Indian Standard. All other specimens have the absorption less than 10%. M3 has the low absorption and the next least value is for M4 mix. Hence the bricks are suitable for applications as they comply with the norms of IS 2185:2005 (Part I). The results are promising as the interlocking bricks developed in this work with 80% of fly ash have less water absorption against the use of fly ash in the interlocking bricks having a negative effect water absorption that is exposed through previous studies by researchers. The least water absorption of M3 indicates that the mix is dense and there is minimum voids or pores in the specimens.

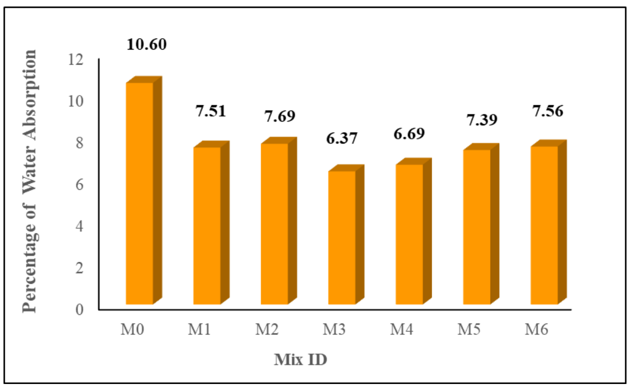


Figure 9 Water absorption

3.4 Behaviour of Prisms

The wall prisms were tested under compression till failure. The ultimate and breaking loads along with displacements at ultimate load and the maximum displacements are recorded for all the prisms as portrayed in Table 2. The trends of displacement with loads are plotted through graphs as shown in Figure 10. The load-deflection relationships of the masonry prism follow a linear trend in the initial loading stages. After cracking initiated, there is an inelastic behavior in the prisms. In all the prisms, the strength degradation is very sudden with slight increase in deformation after the peak stress. The prisms M2, M5 and M6 have not experienced much deformation before they reach the ultimate load whereas M0, M1, M3 and M4 prisms shows considerable deflection before reaching its maximum compressive strength.

Table 2 Load and Deflection values

Mix ID	Load linear till (kN)	Ultimate Load (kN)	Compressive Strength (N/mm²)	Displacement at Ultimate Load (mm)	Breaking Load (kN)	Maximum Displacement (mm)
M_0	95.51	150.899	1.26	8.31	128.188	9.65
M_1	80.6	113.548	0.95	7.158	59.574	7.577
M_2	92.14	136.778	1.14	2.235	113.389	2.584
M_3	209.85	261.428	2.18	5.482	227.325	6.739
M_4	139.76	184.124	1.53	7.437	159.729	8.188
M_5	153.46	183.387	1.53	3.631	162.92	3.701
M_6	133.03	170.79	1.42	2.095	90.448	3.299

M0 prism has capacity of 150.899 kN. The M3 prism with 30% waste glass has the highest load carrying ability which withstood a load of 261.428 kN. M4 prism has the next maximum load carrying capacity followed by M5 and M6. The least load of 113.548 kN is noted for M1 prism which has 90% M sand and 10% waste glass and the next lower value 136.778 kN is for M2 with 80% M sand and 20% waste glass. The maximum compressive stress of the M3 prism is 2.18 N/mm². The prism M0 samples was having maximum compressive stress of 1.26 N/mm² whereas the maximum stresses are lesser for M1 and M2 prisms that are 0.95 N/mm² and 1.14 N/mm² respectively. In all other prisms, the compressive stresses are higher than M0.

The trend of maximum compressive strength of interlocking prism and brick is almost analogous. Figure 11 shows the relationship among the maximum compressive stress of the bricks and the maximum compressive strengths of the prisms together with the respective linear regression [22, 23]. The compressive strength of the brick unit (f_{cbr}) and the prism (f_{cwp}) is related as $f_{br} = 0.5248\ f_{wp}$.

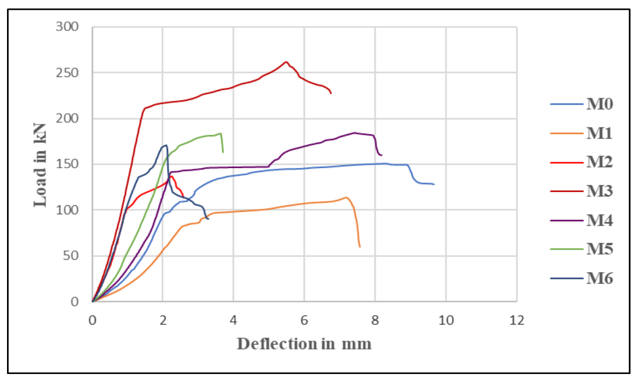


Figure 10 Load Vs Displacement

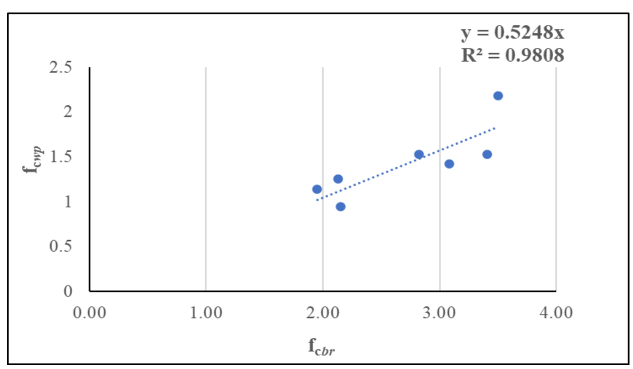


Figure 11 Relation between f_{cwp} and f_{cbr}

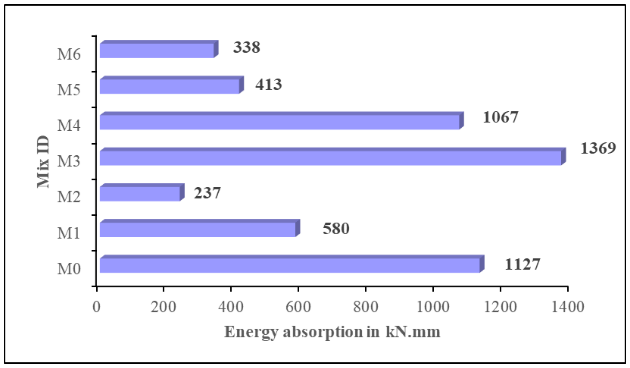


Figure 12 Energy Absorption

The area enclosed by the load-displacement graphs were calculated which provide the energy absorption capacity or toughness of the prisms as revealed in Figure 12. Out of all the prisms tested, M3 has the highest capacity to absorb energy and the next highest toughness is for M0 prism with 100% of M sand. The difference in energy absorption capacities between M4 and M0 is very meagre. M2 prism with 80% M sand and 20% waste glass has the lowest toughness value of 237 kN.mm. The failure modes of all the prisms tested Figure.13a to Figure 13g. All the prisms failed by compression with vertical and splitting type of cracks in the front sides. The cracks initiated in the top layer of the brick, propagating slowly to the bottom layers as the load intensifies. Cracks were seen in all the three layers of the bricks ensuring the monolithic failure of the prism.

Figure 13a Failure of M0 prism

Figure 13b Failure of M1 prism

Figure 13c Failure of M2 prism

Figure 13d Failure of M3 prism

Figure 13e Failure of M4 prism

Figure 13f Failure of M5 prism

Figure 13g Failure of M6 prism

4.0 CONCLUSION

The findings of the experimental program undertaken are summarized here. Geopolymer bricks made from fly ash, GGBS, M sand and waste glass satisfy the density requirements as per IS 2185:2005 (Part I) to be used as load bearing units. Interlocking bricks with 70% M-Sand and 30% Waste glass exhibited maximum compressive strength and low water absorption. Bricks made with M3 and M4 mixes namely 70% M sand & 30% waste glass, 60% M sand & 40% waste glass respectively have a compressive strength more than 3.2 N/mm^2 and hence falls under Grade C (4.0) as per the compressive strength requirements of IS 2185:2005 (Part I). Interlocking brick prisms with 70% M-Sand and 30% Waste glass has maximum ultimate load carrying capacity and energy Absorption. The trend of maximum compressive strength of interlocking prism and individual brick is almost analogous.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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