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An Investigative Study to Incorporate Waste Glass Powder with Natural Clay to Manufacture Baked Glass Infused-Clay Bricks

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Abstract: Present work was focused on the effective use of waste glass powder alongside clay to prepare bricks. The bricks prepared from the waste glass powder will form a sustainable and innovative approach with certain advantages over the traditional clay bricks. This approach would help to divert the waste glasses from landfills and incinerators to be embedded in widely used construction materials. These waste glass embedded bricks require relatively less clay and energy for the preparation. Moreover, these bricks are significantly stronger, more durable, and less water-absorbent than the traditional clay bricks. Thus, the bricks of such kind have the potential to revolutionize the construction industry with sustainable waste management ideology. This work aims to investigate the behavioral aspects and physical properties of the bricks prepared with waste glass powder as a partial replacement of clay. In this study, the waste glasses were crushed/powdered and sieved with 1.18 mm, prior to its addition to clay in varied proportions (7%, 12%, 17% and 22%). The brick prepared by the addition of 17% of waste glass powder was qualitatively found better and had matched to class (II) brick properties.

Index Terms: Waste glass powder, Clay, Brick preparation, Porosity, Compression strength, Water absorption.
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1. Introduction

The world grapples with an immense challenge for the proper disposal, reuse and recycling of various waste materials. In this context, use of waste glass powder alongside natural clay for the brick preparation forms a promising methodology. The incorporation of waste glass powder as an additive to natural clay was found to address the issues related to solid waste management in a sustainable pathway [1]. More popularly, waste glass powder was used as a partial replacement of cement or sand to form sustainable concrete [2, 3]. With an increased global demand for various construction materials, the waste glass powder incorporated bricks can contribute to conserve the natural resources and also reduce the load on solid wastes [4-6]. The use of crushed waste glass/plastics in brick preparation had resulted in the development of a new type of building material known as glass/plastic-infused bricks [7]. These bricks can be prepared by mixing waste glass powder with clay and then firing the moulded brick in a kiln at relatively reduced temperature (800-900^{o}C). The added glass powder acts as a flux, hence the bricks would get baked at a lower temperature than the routine clay bricks. This enables the process to happen with a quantitative reduction in natural clay addition and reduced energy input for brick baking [8]. Under the similar context, numerous wastes are used to prepare various construction/building materials in recent past [9].

2. Overview Of Prior Arts

Many organizations/institutions and the associated researchers had worked on embedding variety of waste glasses along with natural clay in varied proportions to prepare fired clay bricks. A few of such research works are referred and the key factors are tabulated below.

Loryuenyong, V., *et al*, in 2009, had reported the addition of waste glass to clay (upto 45 % by weight) to prepare bricks. Upon their qualitative evaluation after baking at 1100^{o}C, a better compressive strength (26-41 MPa) and relatively low water absorption (2-3%) features were noted for those bricks prepared with waste glass addition in the range of 15-30% by weight. The bricks prepared by the higher input of waste glass (45% by weight) had interestingly displayed higher water absorption features due to the enhanced porosity [10]. Demir, I, in 2009, had illustrated the impact study of fired clay bricks formed by the addition of waste glass to clay. Collected waste glass was milled and added to clay in varied proportions (2.5/5/10 % by weight) to prepare bricks with a control sample brick (only clay). The brick variants are baked at 850, 950 and 1050^{o}C. Based on the qualitative analysis and SEM studies, the compressive strength of bricks had significantly improved due to the sintering action imposed by the addition of waste glass [11]. Dondi, M., *et al*, in 2009, had reported the use of waste of PC monitors and TV sets (having the glass composition to over 40% by weight) to prepare clay bricks and roof tiles. The partial replacement of natural clay by this additive to around 2-4% by weight had appeared to be productive. Beyond it (5% by weight), had imparted unacceptable qualitative variations in bricks. The work recommends the use of glass powder in around 1 mm size to achieve a proper add-mixture with clay [12]. Lee, J.-S., *et al*. in 2013, had illustrated the effective intrusion of crushed waste CRT glass as the partial replacement to clay in the preparation of bricks. Based on the analytical aspects, the bricks containing under 5% of crushed CRT glass had shown superior behaviors with regard to compressive strength and water absorption features [13]. Kazmi, S. M. S., *et al*, in 2017, had demonstrated the use of waste glass sludge as secondary raw material to prepare light weight clay bricks. The brick samples were prepared by the addition of varied input of waste glass sludge (5/10/15/20/25% by weight) to natural clay and baked in an industrial kiln. The glass sludge embedded bricks had exhibited better qualitative features contributing to more economical and sustainable construction ideology [14]. Asif, H., *et al*, in 2018, had demonstrated the use of waste glass in varied proportions (0-20% by weight) alongside clay to prepare low cost bricks. The bricks were baked at 900, 950 and 1000^{o}C by employing an electrical oven (for lab scale study) and industrial kiln (for large scale study) and tested for various qualitative parameters. An increase in the waste glass addition and burning temperature, had collectively led to the rise of compressive and flexural strengths of isolated bricks. Meanwhile, the water absorption and weight per unit area were significantly decreased [15]. Akinyele, J. O., *et al*, in 2020, had reported the intrusion of crushed glass (1/2/3/4/5%) as the partial replacement to clay. Similarly, plastic was also added to clay to prepare the bricks. The raw brick variants are baked at 800oC in electric kiln. In conclusion, the work recommends the use of crushed glass (5%) and plastic (not more than 3%) to clay for the preparation of waste infused burnt bricks [7]. Akinwumi, I. I., *et al*, in 2019, had disclosed the use and impact of waste glass powder in various particle sizes to prepare fired clay bricks. As per the qualitative tests, unit weight, firing shrinkage and compressive strength of the brick had decreased with an increasing particle size of the waste glass powder. The work concludes by recommending the use of waste glass powder with particle sizes of less than 75μm for the production of fired clay bricks [16]. Ramkumar, N., *et al*, in 2020, had reported the use of cigarette butts and waste glass as the additives to clay to prepare fired clay bricks. The isolated bricks were tested for various qualitative parameters like compressive strength, flexural strength, density, water absorption and thermal conductivity [17]. Ali, A., *et* *al*, in 2021, had illustrated the use of waste glass powder (upto 20% by weight) along with natural clay to prepare light weight bricks. The bricks with waste glass powder composition (20% by weight), had shown a significant decrease in density (14%) with superior qualitative aspects [18]. Hasan, M. R., *et al*, in 2021, had disclosed the use of waste soda lime glass as an effective partial replacement (2/4/10/16/30% by weight) of clay to prepare bricks. Various qualitative tests were performed on the isolated bricks, it was found that the bricks had satisfactorily matched to Grade-A and Grade-S category (as per Bangladeshi standard for conventional building clay brick-BDS 208) [19]. Xin, Y., *et al*, in 2021, had reported a comprehensive review work regarding the use of waste glass powder to prepare bricks. A special mention was done as per the past disclosures that the incorporation of glass powder in brick making would reduce the baking temperature but enhances the qualitative aspects. Notably, the input of glass powder with reduced particle size had significantly enhanced the brick quality. A better thermal conductivity was observed in the bricks prepared with the addition of glass powder than in the routine clay bricks. The SEM images reported in a few works had shown denser and uniform structure leading to better compressive strength and reduced water absorption features of glass powder induced bricks [19]. Tripathi, M., & Chauhan, V. B., in 2021, had demonstrated the use of waste glass powder in varied proportions with clay and baking the raw brick variants at 800-900^{o}C to prepare glass-infused bricks. Upon the analysis, the brick prepared by the addition of 20% waste glass powder had shown 77% rise in compressive strength and relatively low water absorption (8.6%) potential. The work concludes saying a significant saving (11.3%) in the manufacturing cost compared to routine clay based ones [8]. Zhang, Z., *et al*, in 2022, had illustrated the use of brick clay mill residue as the starting material to prepare alkali-activated bricks embedded with plastic and waste glass powder. By the qualitative evaluation, the bricks prepared by the addition of only waste glass powder had shown tolerance to the addition of glass powder to around 55% by weight. Meanwhile, the bricks prepared by the addition of only plastic had shown tolerance to the addition of plastic to only 2% by weight. When both the additives are used together, the maximum composite ratio was established having glass powder (25% by weight) and plastic (2% by weight). The SEM images were also studied to establish the bonding features, indicating the adverse impacts of higher plastic input on the micro-structure of bricks. Notably, the works reports the complete elimination of brick baking/firing at above 800^{o}C, thus contribute to energy conservation [21]. Krishnan, A. K., *et al*, in 2022, had demonstrated the preparation of masonry bricks using both recycled glass powder and recycled plastics as the partial replacements to natural clay. The alkaline activators were employed in varied proportions (5/10/15/20%) to bind the additives to clay and dried gradually in oven (50-155^{o}C). These alkaline activated bricks had exhibited better durability and higher compressive strength. This was more interestingly achieved by significantly low baking temperature [22]. Khan, F. A., *et al*, in 2022, had demonstrated the constructive utility of waste glass powder in varied proportions (upto 50% by weight) as a partial replacement to natural clay to prepare bricks. The qualitative analysis of these bricks had shown enhanced compressive strength and rupture modulus. Additionally, a drastic decrease was observed in the water absorption features and relative density of bricks [23]. Mejia, T., *et al*, in 2023, had demonstrated the preparation of bricks composing cement, coarse sand and recycled waste glass which are pre-crushed to the granulation of E.070 (as per Peruvian Technical Standard Masonry). Upon the analysis of numerous specimen bricks, the best results were obtained for the combination of 1:3:2 (cement, coarse sand and waste glass). Moreover, the work forms a significant platform for an environmentally sustainable architecture [24].

From the prior art disclosures, it was evident that the use of waste glass powder in optimum quantities as a partial replacement to natural clay had numerous benefits with regard to environment concerns and the brick performance. In the past disclosed works, natural clay was partially replaced by waste glass powder (upto 55% by weight) with satisfactory results. However, a precise tolerance limit of waste glass powder addition in the past innovative disclosures had shown a vast variation. The focus of this study was aimed at carefully crushing the waste glasses to form a fine powder and sieving it to gather the required size (approximately 1.18 mm) of glass powder to have the intended uniformity of it with the natural clay. It was then used as the partial replacement (upto 22% by weight) for natural clay to prepare the brick moulds and dried. The dried raw bricks were then baked at around 900-1000^{o}C, in utility kilns for a better heat transfer and thermal impact reproducibility.

3. METHODOLOGY

3.1 PREPARATION OF BRICK VARIANTS

The present initiative to prepare waste glass powder embedded bricks involves the processes like glass powder preparation, clay preparation, mixing, molding, drying and baking. The elaborate process details are tabulated as below. The process followed was a replication of those followed to achieve the routine clay bricks, which was followed to prepare the control samples [25].

Glass powder preparation: - Waste glasses were collected from different sources and crushed them carefully to get the fine powder. The glass powder mixture obtained was sieved to gather the uniform sized glass particles of approximately 1.18 mm. The left over bigger glass granules were taken along with another fresh lot of waste glasses for the crushing process.

Clay preparation: - Natural clay was collected and cleaned to eliminate the stones/other suspended debris. It was then subjected to the routine weathering process.

Mixing and Moulding: - Proportionate quantities of clay and glass powder were mixed well (**Fig. 1**). To the mixture optimum water was added, mixed and tempered using the pug-mill to get a proper pre-brick mixture (**Fig. 2**). A few variants were prepared separately in duplicates with varied input of glass powder to clay, **Table 1**. It was then pressed into the mould (190 x 90 x 90 mm), until it completely fills all the corners of the mould. The excess deposits were eliminated and later the mould was removed carefully to get the specimen raw bricks.

Fig. 1:- Addition of sieved glass powder to cleaned & weathered clay

Fig. 2:- Initiation of tempering process to form the lump for moulding

Table 1:- Brick variants prepared by the addition of waste glass powder in different proportions to natural clay.

Brick variants	Natural clay input (Kg)	Waste glass powder input (Kg)	Mix-proportion ratio
BV-1	5.58	0.42	93:7
BV-2	5.28	0.72	88:12
BV-3	4.98	1.02	83:17
BV-4	4.68	1.32	78:22

Drying and Baking: - The raw brick variants were allowed to dry in a well ventilated room for 10 days, by the end of exposure they will possibly retain around 5-7% of water. The bricks were then baked in a kiln for 48 hours at around 900-1000^{o}C.

3.2 PRE-BRICK MIXTURE AND BRICK ANALYSIS METHODS

Smearing test: - This test was conducted as per the guideline stated in IS: 2720 (Part-17)-1986 [26]. The tempered pre-brick paste was taken in hand and a ball was made from it. It was rolled in hand for some time, by then it starts to dry a bit. With the assistance of thumb finger, a small portion of the ball was pinched out carefully and quickly spread it on the thumb and index finger (**Fig. 3**).

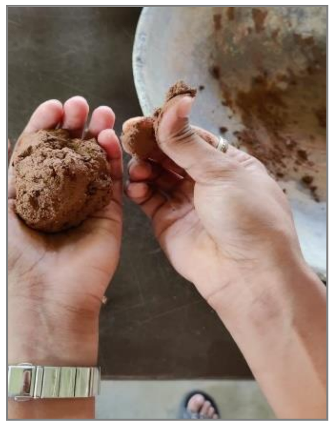

Fig. 3:-Smearing test conduction

Wet ball test: - This test was conducted as per the guidelines stated in IS: 2720 (Part-II)-1973 [27]. A ball had to be made using the hand from the tempered pre-brick paste. The ball should be dropped on to a clean and dry surface (concrete or any firm surface) from a height of atleast 1 meter or it can be dropped from the shoulder height. The nature of ball had to be observed after the impact for the deformation. The dry ball test can also be conducted with some mild modifications to wet ball test process. The ball must be dried and then it should be dropped on to the clean and dry surface. If the ball breaks-up into many pieces upon the impact, that indicates the presence of higher sand content in the pre-brick paste contributing to reduced cohesion (**Fig. 4**).

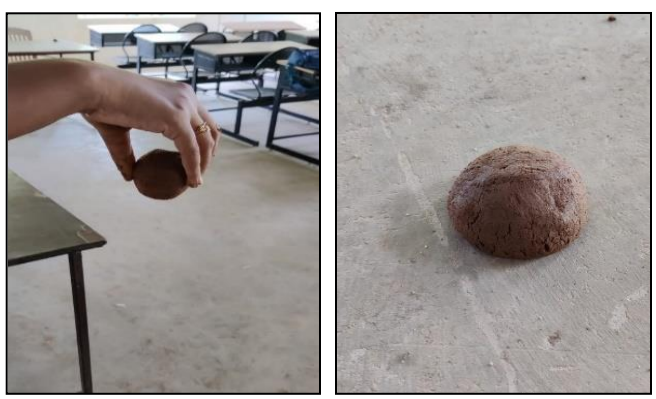

Fig. 4:-Wet ball test conduction

Sedimentation test: - This test was done as per the guidelines stated in IS: 2720 (Part-1)-1983 [28]. A beaker must be filled with pre-brick mixture (1/3rd), to the same added water (3/4th) and stirred for 5 minutes. It was left undisturbed for 24 h, later the percentage depth of settled clay or sand to the total depth should be calculated (**Fig. 5**).

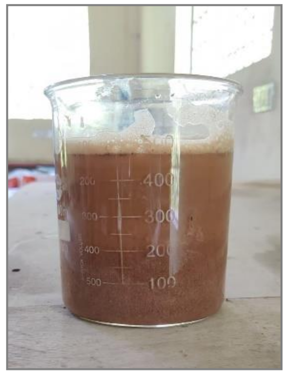

Fig. 5:-Sedimentation test conduction

Compressive strength test: - This test was performed as per the guidelines depicted in IS: 3495 (Part-1)-1992 [29]. The brick sample must be placed between the plates of compression test machine, with the flat face had to be placed horizontal and the mortar-filled face should be vertical. Once after the proper brick positioning, an axial load had to be applied at a uniform rate of 14 N/mm^2 per minute until the deformation occurs. The maximum load responsible for the deformation or failure had to be recorded. The compressive strength of common well-burnt clay bricks usually ranges from 5-10 N/mm^2, depending on the nature of natural clay (**Fig. 6**).

Fig. 6:-Compression strength estimation

Water absorption test: - This test was performed as per the guidelines narrated in IS: 3495 (Part- 2)1-992 [30]. The dried brick specimen had to be immersed in clean water at temperature of around 25-29^{o}C for 24 h. The brick specimen should be removed from water and the surface bound water had to be wiped away using the damp cloth. It should to be weighed within 3 minutes after its removal from the immersion. The percentage of water absorption can be calculated by recording the pre (W_1) and post (W_2) brick specimen weight (**Fig. 7**).

Fig. 7:- Water absorption potential estimation

4. RESULTS AND DISCUSSION

The pre-brick mixture/brick variants/control brick samples were subjected for a few essential qualitative tests like Smearing, Wet ball, Sedimentation, Compressive strength and Water absorption. The results obtained were furnished in detail as below, **Table 2**.

Table 2:- Data of the tests conducted with corresponding results and applicable remarks.

Evaluation type	**Sample information**	**Results and remarks**
Smearing test	Pre-brick paste of BV-1	Smooth waxy like texture
	Pre-brick paste of BV-2	Smooth waxy like texture
	Pre-brick paste of BV-3	Smooth waxy like texture
	Pre-brick paste of BV-4	Slightly rough texture was observed
Wet ball test	Pre-brick paste of BV-1	Shape deformed at the bottom only
	Pre-brick paste of BV-2	Shape deformed at the bottom only
	Pre-brick paste of BV-3	Shape deformed at the bottom only
	Pre-brick paste of BV-4	Shape deformed at the bottom only
Sedimentation test	Cleaned natural clay	Settled clay content was approximately 31%
	Pre-brick mixture of BV-1	Settled clay content was approximately 29%
	Pre-brick mixture of BV-2	Settled clay content was approximately 27%
	Pre-brick mixture of BV-3	Settled clay content was approximately 26%
	Pre-brick mixture of BV-4	Settled clay content was approximately 25%
Compressive strength (N/mm^2)	Control sample	3.99
	Average of (BV-1a & BV-1b)	4.05
	Average of (BV-2a & BV-2b)	4.55
	Average of (BV-3a & BV-3b)	4.88
	Average of (BV-4a & BV-4b)	4.59
Water absorption (%)	Control sample	9.96
	Average of (BV-1a & BV-1b)	9.45
	Average of (BV-2a & BV-2b)	9.33
	Average of (BV-3a & BV-3b)	9.04
	Average of (BV-4a & BV-4b)	9.24

Smearing test: - It was conducted for the pre-brick paste variants, for the three variants (BV-1, BV-2 and BV-3) a smooth waxy like texture was observed indicating the presence of good enough plasticity. In BV-4, a mild rough texture was observed due to higher input of waste glass granules.

Wet ball test: - It was conducted on all the pre-brick paste variants. All had exhibited the deformation of shape at the bottom impact area, indicating the presence of essential moisture content in the paste.
Sedimentation test: - It was conducted for the cleaned natural clay, which had shown the settlement of clay to around 31%. Similarly, the test results for the pre-brick mixture variants like BV-1, BV-2, BV-3 and BV-4 had shown the clay settlement to around 29%, 27%, 26% and 25% respectively. The clay composition in the pre-brick mixture variants had shown a gradual decrease with the increase in glass powder addition.
Compressive strength analysis: - It was performed on the baked brick variants in duplication and also for the control sample for the consistency of results. Interestingly, BV-4 with 22% of embedded glass powder has shown the initiation of decrease in compressive strength. BV-1, BV-2 and BV-3 had exhibited the increasing trend with BV-3 ended up with a maximum compressive strength (4.88 N/mm^2). In the context, the brick variant with 17% of glass powder composition had provided the maximum compressive strength. The control sample having only natural clay had recorded a compressive strength of 3.99 N/mm^2 during the testing process, **Fig. 8**.

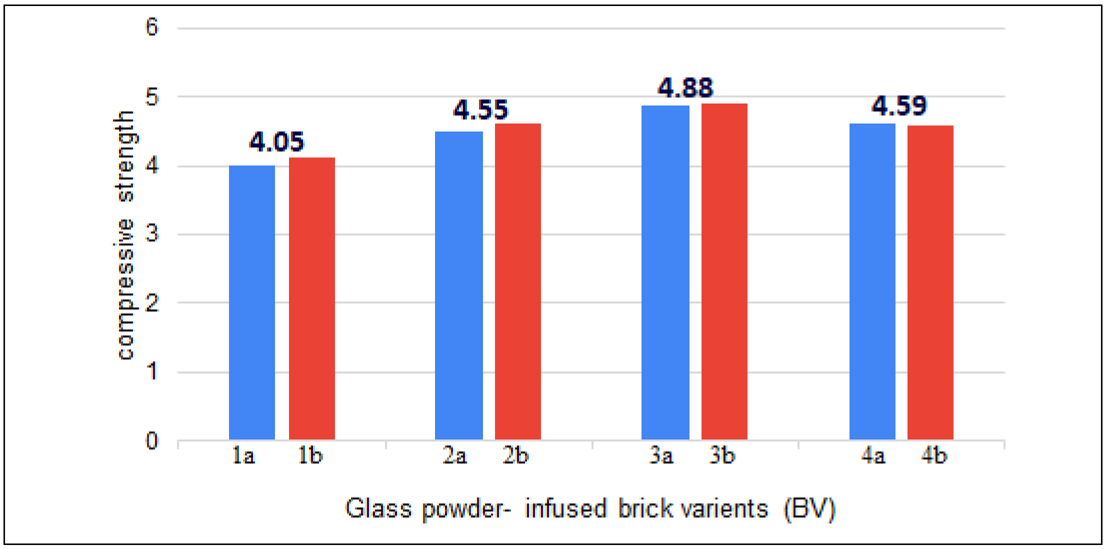

Fig. 8:- Graphical display of compressive strength displayed by the prepared brick variants

Water absorption estimation: - It was executed for all the fired brick variants (in duplicates) and also for the control sample. The required analysis criterion of below 20% water absorption was recorded for all the bricks exposed for the test. More importantly, least water absorption was recorded for BV-3, with 9.04%. A mild increasing trend in water absorption (9.24%) was observed for BV-4 indicating the increase in porosity, **Fig. 9**.

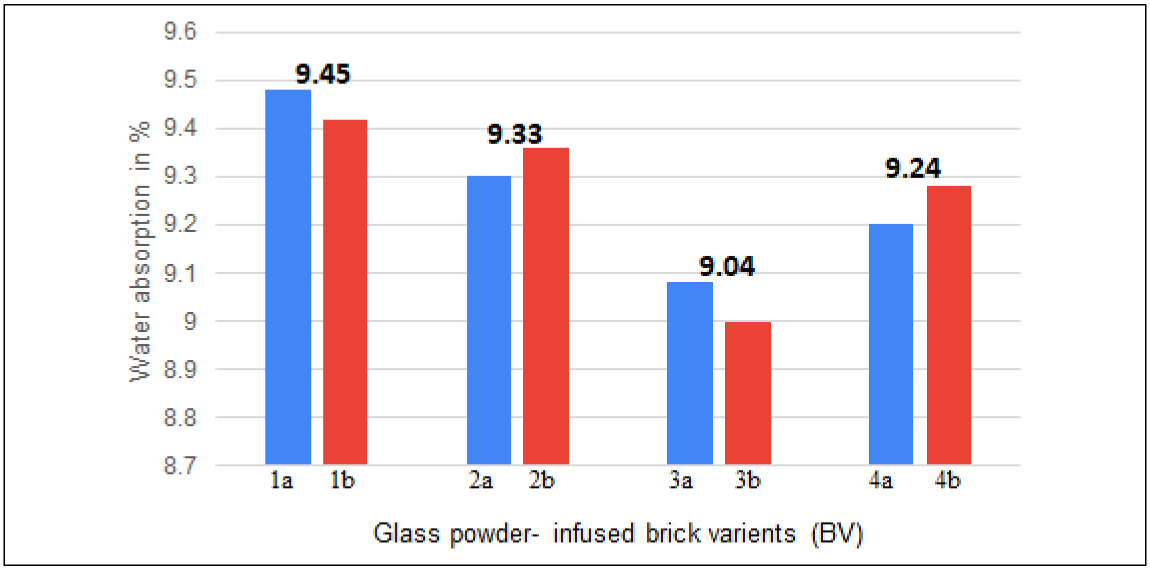

Fig. 9:- Graphical display of water absorption features exhibited by the prepared brick variants

5. CONCLUSION

This research initiative uplifts the use of 17% of waste glass powder addition (as partial replacement) to natural clay for the preparation of baked clay bricks. Based on the information gathered from the prior arts and also from this work, the type of natural clay and the granular size of glass powder will determine the qualitative superiority of glass-infused clay bricks. The type of natural clay used for this work can effectively tolerate the addition of 17% of waste glass powder to provide superior quality bricks with good compressive strength (4.88 Nmm^2) and very less water absorption (9.04%) potential. In the grand mosaic of sustainable construction, waste glass powder embedded bricks not only fortify structures but also provide a pathway towards the greener future. This methodology had turned the non-biodegradable waste (discarded glasses) to a useful construction material (fired clay bricks). Meanwhile, the work empowers the legacy of innovation and sustainability.

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