CREATIVE METHOD FOR BAKED CLAY BEAMS DESIGN AND APPLICATION IN BUILDINGS

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ABSTRACT

For more than a century, reinforced cement concrete has gained widespread acceptance as a primary building material worldwide. However, as a result of rising steel and cement prices, especially the shipping costs associated with delivering these building supplies to remote locations with alluvial, clayey, or rich soil (plains Producing baked clay panels of structural components could be more advantageous and cost-effective for quick and affordable construction without compromising the buildings' strength and longevity. Many beam panels were cast, baked, post-reinforced, cured, and tested with this specific goal in mind. This was part of a systematic program of experimental investigation that imagined developments in rural areas in the future at relatively inexpensive and affordable costs for the poor masses. This paper presents the findings from the experimental investigation. Without the use of vertical reinforcement or anchorage steel, the shear and flexural strength of baked clay was evaluated on its own. The modulus of rupture, shear/flexural behavior, mode of failure, crack pattern, and ultimate load of baked clay beams were all studied. But experimental methods were also used to determine the material constants and basic structural characteristics, such as the modulus of elasticity, Poisson's ratio, and crushing strength of the material removed from the beams after testing. The outcomes are positive. Nonetheless, the results of these studies indicate that shear strength is the main influence. The ensuing sections contain all the information.

Keywords: Plate support, Roller support, Pit-sand, Beams, Clay, UDL, Point load

INTRODUCTION

One of the primary barriers to the socioeconomic development of third-world countries is the utilization of local natural resources by employing both empirical data from ancestral practices and modern exploration instruments for management and scientific elaboration of such materials.[1] . Clay is an affordable, widely available, and common substance. It doesn't require much alteration and is simple to extract. Another erratic substance with highly changeable physical characteristics is clay. During drying and fire, clay contracts. Numerous issues arise from this. Different clays shrink at different rates. When clay is cooled, its final products break. [2] The main reasons for supporting clay as the best material to use for rendering conventional wall systems, including straw bale walls, are its numerous health and environmental advantages. Earth has a great deal of technical and architectural potential, and the fact that it has been utilized to build both the most complex and the simplest structures worldwide attests to its significance in the modern construction industry. [3]. The Clay have a cohesive characteristics and this quality is enhanced if the clay is correctly mixed with water, then micro-finely ground. When there is enough water in the wet clay, it functions as a lubricant; when there is not enough water, it functions as a plastic body. It can be shaped into any shape with minimal pressure and won't rupture because it has no elastic limit. Clay has the ability to act as a binding agent. [4].Recently, International Resource Institute (IRI) has been engaged in Natural Composite Architecture, utilizing a wall and roofing system made of a mixture of straw bales, cellulose fiber, and bentonite clay. [5].Similar to ceramics, polymer clay has been used as a man-made modeling material. It is provided by a number of vendors under the FIMO brand. FIMO is a very versatile modeling clay based on plastic that is very easy to use. [6].A thorough analysis of numerous civil engineering journals, such as those published by the American Concrete Institute, American Society of Civil Engineers, and the British Institute of Civil Engineering, was conducted Prefabricated, post-reinforced baked clay structural panels, and the Journals had hundreds of professional publications about the characteristics and applications of clay. The whole booklet series published by the United Nations Economic and Social Commission for Asia and the Pacific Region in Bangkok does not have any investigation on the structural panels. The booklets provide details of research done on locally produced building materials and affordable housing. [7]. Cement concrete was made using baked clay brick pieces as coarse aggregate [8]. To lessen porosity and boost strength, a cement slurry treatment was applied to the same aggregate. [9].Numerous researchers, both ordinary and reinforced, spent many years studying different facets of concrete as a primary building material for bridges, buildings, and other structures. However, local building resources could be used to save money rather than having to carry bulky, costly items across great distances, such as cement, steel bars, coarse aggregate from rocks, and hill sand, especially in fertile plains across multiple nations. Due to preconceived notions that they are inferior and cannot be used for high-quality work, the most accessible and extensively used building materials pit sand, silt, and clay have not been used in construction.

In actuality, clay has been used from the dawn of civilization, dating back to Mesopotamia's Moen-jo-daro. [10] Automated devices have been developed to apply intense three-dimensional compression for compaction, resulting in bricks with a denser density more akin to concrete blocks. [11]. During the authors' initial experimental investigation [12]. It employed various clay to pit-sand ratios and compaction intensities to mold, compact, bake, and test so many cylinders of clay. It was evident from this that, with the right compaction, the strength characteristics of this specific type of material might be on par with cement concrete. Commonly, the Crushing strength of reinforced cement concrete used in construction industry is normally up to 20 N/mm^2 (3000psi). However, our research clearly showed that the strength could be enhanced much further than this limit under carefully controlled conditions and with a 70:30 clay: pit-sand ratio by raising the tamping force and lowering the water content.it mainly reduces the voids. All of these factors clearly point toward a future in which structural panels, rather than bricks, may be produced, baked, and utilized to quickly and affordably construct high-quality buildings at a lower cost than concrete.

It is possible to accomplish building economy.

(i) By employing inexpensive local resources like pit sand and clay.

(ii) The mass manufacture of structural member panels on a mechanized scale, with comparatively reduced production costs, and under strictly regulated conditions that mimic laboratory settings

(iii) Saving money on the expense of transporting bulky items across large distances.

(iv) Reduction of costs for finishing such as painting and plastering.

(iv) Building erected quickly and efficiently using pre-cast panels

PRESENT INVESTIGATIONS

Stiff steel molds were made in order to cast the beam panel models. Based on a stress analysis carried out with a computer-based numerical approach, these molds were designed. The outward force was the primary force for which these molds had to be constructed that was generated laterally as a result of applying vertical compression during compaction. Originally developed by Hinton and Owen, a Plate Bending, rectangular, eight-noded Elastic analysis was carried out using Finite Element, with a focus on maximum deflection at free edges whose thickness was first estimated. The ground supports the base slab firmly all around. This plate's thickness was also estimated, and its suitability in relation to produced stresses was subsequently verified. The top edge of the long walls was considered free, while the ends and bottom were determined to be fixed. Since the compressive load was supplied vertically downward for compaction and the clay was virtually in the plastic condition and the force was distributed uniformly. A unique setup for manually applying the pre-compression was created and manufactured in order to increase density and achieve the required level of compaction. It was noted that bulging occurred above allowable limits as a result of lateral displacement during the casting of the models. Thus, after experimenting with a few different approaches, a system for limiting the lateral deformation was created and put into service. The most effective and best layout among the ones the authors tried is shown in Fig. 1.The ideal ratios of clay and pit sand for material mixing were determined by previous research, which was presented in [13], Based on the results regarding the desired strength and workability, overall water content had retained 20 percent as of dry material.

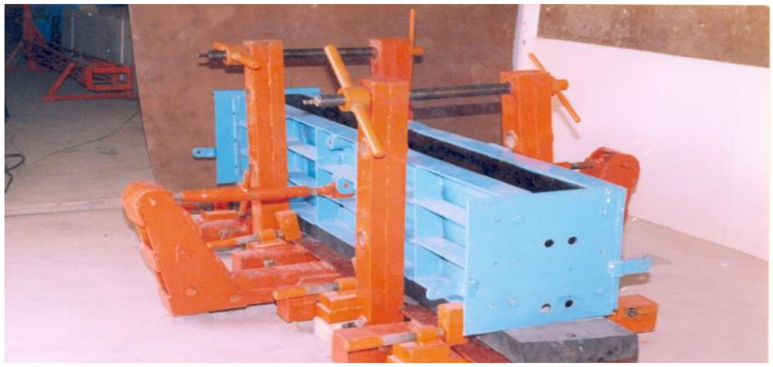

Figure1.Stiff steel mould for casting clay beam panels with lateral.

The clay was extracted at a depth of 4 feet from a variety of sources. For twenty-four hours, it was dried at 105 degrees Celsius. After then the clay was ground up to make it more refined. Then, in accordance with the authors' earlier research [13], 30% of pit sand was combined. Using an electrically powered pan mixer, the ingredients and water were combined. For every batch, there was a 10-minute mixing period. Following the material's transportation into the mold, a digital display amplifier system and electric load cells were used to apply and quantify the Compressive force of 3.5 N/mm2 for the first test series. As seen in Fig. 2.

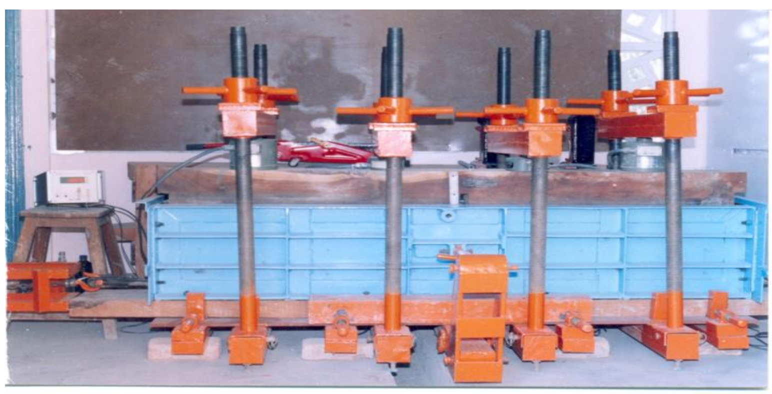

Figure 2. A mechanism for producing compression through wing nut tightening.

Numerous obstacles and challenges were encountered. For instance, during the drying process, there was a significant shrinkage that resulted in the beams breaking and becoming worthless. The issue was resolved by drying beneath cover made of thin plastic in the shade and away from the sun. In order to sustain the beam sample at the bottom during the drying process, a special scheme was used, which involved providing a hefty hardwood with a very smooth metallic sheet that had been appropriately greased; so that there was no cracking due to shrinkage and the ensuing deformation (i.e., shortening of the beams). Nevertheless, a technique of mild compression that made use of springs was also developed and put into service, as demonstrated in Fig: 3.

Figure 3. System of slight pre compression during drying to avoid cracking.

It should be noted that the beams used were originally 6 inches (150 mm) in width, 12 inches (300 mm) depth, and 6.5 feet (1950 mm) length. However, they underwent shrinkage in the following dimensions: the length decreased by 4 inches (100 mm), the breadth decreased by 0.3 inches (7.2 mm), and the depth showed a shrinkage of 0.6 inches (14.3 mm). The beams were exposed to sunlight after drying for a long enough period of time in the shade in order to remove as much moisture that had become trapped inside of them. Then place it inside the kiln, where Thermo-Couples were used to measure the temperature. For six hours at first, a lower temperature of 250 C^0 then the heat was progressively increased to 950 C^0 and held there for 22 hours. The fire was then put out, the temperature was gradually reduced, and the kiln was given the following two days to cool. Since beams are obviously much thicker than bricks, As a result, the complete baking of the beams could only be accomplished on the basis of experimental investigation. The beams had two one-inch-diameter pre-perforations near the bottom for the purpose of placing tensile reinforcement. For reinforcement, 3/8" and ½" dia. steel bars were utilized. Following casting, a puller similar to the one in Figure 4 was made to remove the steel shafts from the beams. By forcing cement slurry and fine aggregate into a 1:1 ratio, the steel bars were forced to connect with the surrounding baked clay. The apparatus made specifically for this use is displayed in Fig. 5.

Figure 4. Puller system to remove steel shafts from clay beams after casting.

Figure 5. Forced grouting of cement Slurry for baked clay beams.

Following grouting, 14 days of cure were spent. This established enough of a connection to prevent bars from slipping up to the maximum load. A specially made trolley was created to ensure the safe transportation of the beams from one location to another. As seen in Fig. 6, Plat-form Lift was created, produced and set up to safely lift clay beam models adjacent to the kiln.

Figure 6. A platform lift placed next to the kiln to safely raise clay beams.

Figure 7. Mobile lift for safe movement of baked clay beams.

The mobile lift seen in Figure 7 was created and produced with the purpose of transporting the beams to the testing laboratory so that the models could be mounted on the machine and tested. The beams, as depicted in Figs. 8 and 9, were tested using a Torsee testing machine. A digital display system and load cells were utilized to measure the load's intensity separately. The strain was measured at several points in relation to the neutral axis using Demec Gauge. Using a demec gauge, to measure the strain thirteen pairs of demec pads were adhered to the beam. After testing, specimens from the unbroken sections of the beams were removed in order to assess the material's basic structural qualities.

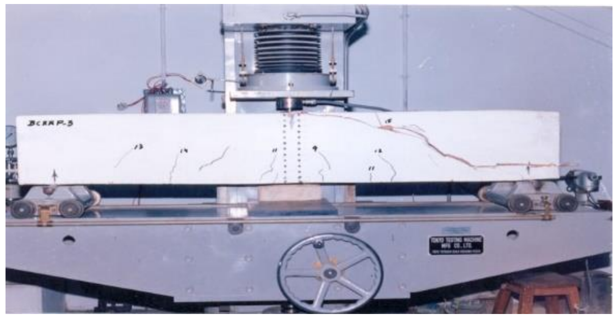

Figure 8. After failure point load is applied at the center to test the beam.

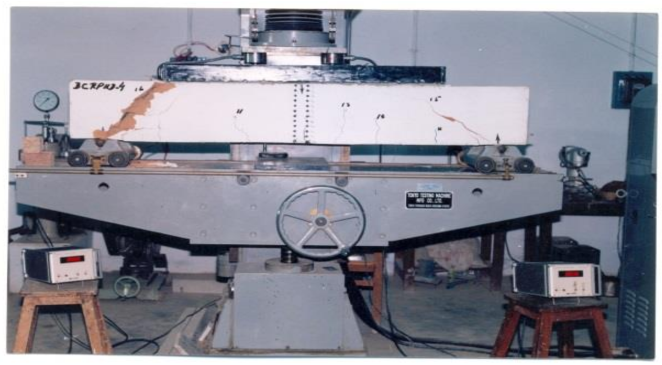

Figure 9. Beam tested by applying UDL after failure.

CRUSHING STRESS

The samples cut from the beams themselves had their cube crushing and cylinder crushing strengths measured; the specifics are shown in table 1 below. This table shows that the cube crushing strength can be attained up to 31.39 N/mm2 (4551 psi), which is a reasonable value.

Table 1 Specifications of Crushing Stress of Specimens Removed from Beam after Testing

Sr. No.	Description	Crube crushing strength fcu (N/mm^2)	Cylinder crushing strength fcy (N/mm^2)	%age of cube crushing strength (fcy/fcu)x100%
1.	BCRRP-1	31.30	24.82	79.29
2.	BCRRP-2	29.70	23.49	79.1
3.	BCRRP-3	31.10	24.84	79.3
4.	BCRRP-4	29.90	24.06	80.3
5.	BCRRP-5	27.40	21.27	78.8
6.	BCIRP-1	29.79	23.74	79.7
7.	BCIRP-2	31.39	25.18	80.2
8.	BCIRP-3	29.59	23.64	79.9
9.	BCIRP-4	29.77	23.60	79.3
10.	BCIRP-5	29.79	23.77	79.8
11.	BCRPUD-1	29.74	23.59	79.3

12.	BCRPUD-2	29.77	23.76	79.8
13.	BCRPUD-3	29.23	23.20	79.4
14.	BCRPUD-4	29.70	23.73	79.9
15.	BCRPUD-5	27.90	21.70	77.8
16.	BCIRUD-1	31.10	25.01	80.4
17.	BCIRUD-2	29.70	23.52	79.2
18.	BCIRUD-3	29.20	23.43	80.1
19.	BCIRUD-4	30.40	24.29	79.9
20.	BCRPUD-1	30.70	24.65	80.3
21.	BCRPUD-2	30.40	24.36	79.9
22.	BCRPUD-3	29.80	23.75	79.7
23.	BCRPUD-4	29.20	23.33	79.9
	AVERAGE	**29.80**	**23.77**	**79.6**

Legend: B = BAKED C = CLAY
R = RECTANGULAR I = I-SECTION
R = ROLLER SUPPORT P = PLATE SUPPORT
P = POINT LOAD
UD = UNIFORMLY DISTRIBUTED LOAD

MODULUS OF ELASTICITY AND POISSON'S RATIO

Table 2 displays the values of the modulus of elasticity and Poisson's ratio, which were calculated using the method suggested by B.S. CP 1881-1970. [14] Table 2 shows that the 0.189 value is the average Poisson's ratio, which is in line with typical concrete values. The modulus of elasticity average is 31.81 KN/mm2. It should be noted that the grade 20 concrete's modulus of elasticity, as stated in the reference [15] is taken as 25 KN/mm2. As a result, the modulus value is also appropriate.

MODULUS OF RUPTURE

A methodical experimental study was carried out to determine the material's modulus of rupture through the testing of unreinforced baked clay beams. Additionally, the material's tensile strength, crushing strength, and material constants like Poisson's ratio and modulus of elasticity were evaluated.

Table 2 Information after testing on the specimen's Modulus of Elasticity and Poisson's Ratio

Sr. No.	**Description**	**Poisson's Ratio "μ"**	**Modulus of Elasticity "E"**
1.	BCRRP-1	0.187	30.7
2.	BCRRP-2	0.183	32.4
3.	BCRRP-3	0.19	32.7
4.	BCRRP-4	0.24	31.2
5.	BCRRP-5	0.196	29.1
6.	BCIRP-1	0.183	32.7
7.	BCIRP-2	0.188	32.9
8.	BCIRP-3	0.22	32.1
9.	BCIRP-4	0.191	31.9
10.	BCIRP-5	0.197	32.1
11.	BCRPUD-1	0.193	32.4
12.	BCRPUD-2	0.185	31.7
13.	BCRPUD-3	0.164	31.4
14.	BCRPUD-4	0.193	31.7
15.	BCRPUD-5	0.197	30.1
16.	BCIRUD-1	0.221	32.7
17.	BCIRUD-2	0.199	31.1

18.	BCIRUD-3	0.174	31.4
19.	BCIRUD-4	0.185	31.9
20.	BCRPUD-1	0.189	31.7
21.	BCRPUD-2	0.165	32.2
22.	BCRPUD-3	0.167	32.7
23.	BCRPUD-4	0.177	32.9
	AVERAGE	**0.189**	**31.8**

The beam was exposed to two number point loads at one-third of the span. Gradually the loads were applied, and displacement was recorded for each load increase. This test was conducted using Forney's Universal Load Testing Machine from the United States of America and its flexural kit .The breakdown was abrupt, brittle, and came as no warning. The ultimate stress was determined to be 3.3 N/mm2 by using the well-known elastic equation for flexure to the ultimate load. This makes a lot of sense. This outcome suggests that this material cannot be deemed inferior to cement concrete, even if it isn't superior.

FLEXURAL AND SHEAR BEHAVIOUR

Numerous rectangular and I-section beams with dimensions of 143 x 286 x 1950 mm were put to the test using UDL and a single point load applied at the center, as seen in Figures 8. And 9. There was roller support at both ends. The I-section's flange measured 50 mm in thickness, while the web measured 100 mm. gradually, the stress was added in little steps of 4.6 KN. After deleting all partial safety factors, by using the B.S. CP 8110 and ACI-318 equations the flexural strength of the beam in terms of tension and compression was computed. According to the aforementioned codes, an estimate of the beams' shear strength was also made. Table 3 shows all of these numbers as well as the final experimental load. It was anticipated that the beams' shear strength would play a major role in the disaster. Shear was indeed the cause of the beams' failure. As seen in Figs. 8 and 9, diagonal cracks were the cause of the failure.

Table 3 Information on the Tested and Estimated Ultimate loads for Various Baked Clay Reinforced Beams.

S.NO	**Description**	**Flexural Strength " Steel" (N)**		**Flexural Strength " Baked Clay"**		**Shear Strength Calculated**		**Experi-mental load @ failure**	**Exp.load 2**	**Exp. Sher strength Calculated shear strength**				**Level of stress from measured strain**	**%age**	**Remarks**
		CP8110	**ACI**	**CP8110**	**ACI**	**CP110**	**ACI**			**CP8110**	**Av.**	**ACI**	**Av.**			
1.	BCRRP – 1	95523	107804	134347	103968	21261	27740	56595	28297	1.33	1.33	1.02	1.04	213	73.79	Roller supported rectangular beams subjected to point load at center
2.	BCRRP – 2	94282	106247	127480	103014	21261	26964	56595	28297	1.33		1.04		213	73.44	
3.	BCRRP – 3	95521	107175	133489	103777	21261	27740	56595	28297	1.33		1.02		221	76.73	
4.	BCRRP – 4	95523	106652	128338	103396	21261	27302	56595	28297	1.33		1.04		219	75.77	
5.	BCRRP – 5	91801	104466	117607	101488	21261	25682	56595	28297	1.33		1.10		263	89.15	
6.	BCIRP – 1	93042	100315	125290	101465	20832	26626	42795	21397	1.03	1.03	0.80	0.79	541	234.12	Roller supported I-Section beams subjected to point load at center
7.	BCIRP – 2	95523	102239	132019	102027	20832	27425	42795	21397	1.03		0.78		466	204.38	
8.	BCIRP – 3	93042	100817	124449	101091	20832	26560	42795	21397	1.03		0.80		550	237.1	
9.	BCIRP – 4	94282	100779	125206	101278	20832	26527	42795	21397	1.03		0.80		541	234.2	
10.	BCIRP – 5	93841	100944	125290	10465	20832	26626	42795	21397	1.03		0.80		499	215.1	

11.	BCRRUD – 1	100321	107960	196032	159290	17886	27032	114095	57047	3.18		2.11		604	135	Roller supported rectangular beams subjected to uniformly distributed load.
12.	BCRRUD – 2	99141	108032	196495	158703	17886	27133	114095	57047	3.18		2.10		600	134	
13.	BCRRUD – 3	101501	107791	192937	158117	17886	26829	114095	57047	3.18	3.19	2.12	2.13	634	141	
14.	BCRRUD – 4	97960	108019	196107	159290	17886	27133	115015	57047	3.21		2.10		596	132	
15.	BCRRUD – 5	99141	107084	184152	156357	17886	25952	114095	57047	3.18		2.19		621	137	
16.	BCIRUD – 1	100884	105096	201433	156893	17526	27322	79595	39797	2.27		1.45		487	152	Roller supporter I-Section beams subjected to uniformly distributed load.
17.	BCIRUD – 2	99967	104277	192373	155453	17526	26494	79595	39797	2.27		1.50		491	153.4	
18.	BCIRUD – 3	99769	104224	189134	159136	17526	26428	79595	39797	2.27	2.27	1.51	1.48	525	162	
19.	BCIRUD – 4	100489	104236	196907	156029	17526	26924	79595	39797	2.27		1.47		541	168	
20.	BCRPUD – 1	100911	108393	202633	159584	17886	27639	127435	63717	3.56		2.30		609	122	Rectangular beams supported on plate on both ends subjected to uniformly distributed load.
21.	BCRPUD – 2	100619	108278	200650	159290	17886	27470	127435	63717	3.56		2.32		600	120	
22.	BCRPUD – 3	100497	108028	196673	158703	17886	27133	127435	63717	3.56	3.55	2.34	2.33	592	118	
23.	BCRPUD – 4	100136	107848	192732	158117	17886	26863	126975	63717	3.56		2.36		617	123	

INVESTIGATION AND DISCUSSION OF THE BEAM TEST RESULTS

It is clear from the test results that the failure happened close to the predicted load. This is a blatant sign that, when compared to concrete, baked clay panels are excellent enough. The rectangular beams were first supported by rollers and had a point load applied to them in the middle. When all Codal factors of safety are eliminated, the load at failure is in the range where it is, on average, 1.33 times more than shear strength calculated using CP-8110 and 1.04 times greater than shear strength predicted using ACI. The connection between the final trial load and the estimated load, however, was only 1.03 and 0.79 for the I-section. When estimating the shear strength of beams, CP8110 seems to be more cautious than ACI As seen in Figs. 8 and 9, a significant improvement in the experimental load at failure was noted when a uniformly distributed load (UDL) was imposed on the central section of the beam that was 1.15 meters wide in place of a point load. UDL was only used in the center since the weight would have been directly passed to the supports in those areas, creating a deceptive impression of the beams' strength. It is found that there is a fairly excellent average ratio of 2.13 to the projected critical shear strength at failure, and 3.19 to the actual load. In terms of final load, the benefit is 100% (twice the load). But in terms of the center's bending moment, this increase is found to be 31%, of which some must have been caused by the loading system's resistance, the reduction of bending-related stress concentration relative to point load, and the steady increase in shear force from the center towards the supports. When plates were used in place of rollers, the kind of support had an approximate 12% impact on the final trial load. The maximum bending moment at the center did, however, only rise by 2%. Table 3 shows that, despite shear being the primary cause of failure, baked clay's strain at the flexural steel level indicates that the yielding point has already been reached. When uniformly distributed load was applied the compressive strength of the baked clay did not reach its ultimate crushing value. It is important to note that reinforcing steel bars are primarily made from scrap in Pakistan due to economic reasons. As a result, the batch of steel bars we purchased for our study did not exhibit the standard values. However, through experimentation, we were able to determine that, despite the lack of a clearly evident yield point, the average 0.2% proof stress was 554.2 N/mm2, and the average ultimate stress was 652 N/mm2. Comparing the percentage elongation to the codal value, it was rather low. Nevertheless, in the beams that underwent UDL testing, steel did not fracture or achieve its maximum value. Even if the support experiences the most shear, an increase in the ultimate load would not have been possible if shear alone was to blame for the collapse. It should be noted that the system applied the UDL in order to reduce friction and allow the baked clay material to compress. Initially, a load cell and digital display system were used to measure the load in DVM units. This load was calibrated to convert to Newtons. 460 N was equal to one DVM unit. As a result, the values for every beam in the same group became the same. Thus, it follows that this material can also effectively serve the local community at reasonable prices if buildings are to be built in rural locations where others constructive material is not present. As a result, we will keep to the original plan to produce structural panels on a massive scale using only locally and affordably available clay, pit, dune, and river bed sand instead of cement or aggregate from hills. The average ultimate load for rectangular beams supported on UDL steel plates is 3.55 and 2.3 (CP-8110 & ACI, respectively) times greater than the anticipated shear strength, which is rather commendable. The beams we examined had a length of just 1.95 meters However, because the slab passes the load to the beam along its whole span in real structures, beams may be quite lengthy and loads are more frequently dispersed. As a result, structures made with pre-perforated post-reinforced baked clay panels will perform even better. In addition to beams, panels, columns, or even slabs will be tested as part of the entire process of building with clay.

CONCLUSION

1. With a ratio of 70:30 percent clay to pit sand, baked clay panel's compressive strength shows promise in comparison to regular cement concrete, even with a moderate compression force of 3.5 N/mm2 for compaction. Crushing strength can reach a value of up to 31.39 N/mm2 (4551 psi).

2. Baked clay panels' Poisson's ratio and elasticity modulus are fairly close.

3. The baked clay materials show better performance in modulus of rupture with concrete.

4. The Investigation on application of this material's, especially in rural regions, shows promise for the construction of practically any kind of building that is both structurally sound and commercially successful.

5. Since shear, not flexure, is the primary cause of beam failure, shear strength needs to be increased to prevent ductile failure from steel yielding in the tensile zone.

6. There was no breakdown of the link between the surrounding material and the steel, no slipping of the bar, and no splitting of the bottom cover.

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