EMERGENCE OF NEW ERA FOR REINFORCED BAKED CLAY CONSTRUCTION

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ABSTRACT

Persistent pursuit for cheaper and reasonably durable buildings led to the construction of relatively new form of erection of pre-cast buildings consisting of pre-perforated post-reinforced baked clay panels of structural members. These panels are reinforced after baking with the help of grouting by using cement slurry. Although the uses of baked and sundried bricks have remained in use for construction of buildings since immemorial times; the concept of baked clay beams, column and slabs is new one. In this paper the authors present the details of systematic research which has been carried out to prove that if pre-perforated post-reinforced baked clay beams are employed for pre-cast construction, the economy could be achieved by up to 30% without sacrificing strength, durability and stability of construction. This is particularly important because of high rate of inflation and ever increasing cost of construction. Full details of this mode of construction are presented in the following section.

1. INTRODUCTION

Clay is a local material which are extensively used in construction of cob and adobe houses in Pakistan and across the Globe; however, no attempt had previously been made to determine quantitatively their fundamental structural / strength properties and material constants of it and therefore, no much information is available in the technical literature. The local skilled masons used their proportions only on the basis of experience and intuition.

Apart from that a variety of waste materials were just thrown away instead of trying to find their use as major ingredient in construction work. Therefore a systematic study was carried out on local clay to be used as construction material and subsequently results were presented.

The authors conducted a number of studies on the mechanical properties of clay in the past [1-14] which in turn suggest that by no means clay is an inferior material for construction; however, it has gone through negligence in the research community and could not receive proper attention.

In order to reduce the cost of construction and make use of materials locally available, the over-escalating cost of construction materials such as reinforcement steel, cement, coarse aggregate of hill origin, led to the idea of using local materials which are relatively cheaper but can successfully be used without sacrificing the quality of the work.

Pre-stressed baked clay blocks were prepared with an approach to enable them with an improved tensile performance [12-14].

2. AIMS AND OBJECTIVES OF PRESENT STUDY

The main objective of this research investigation is to manufacture and study the behaviour and properties of pre-perforated post - reinforced baked clay panels of beams. To achieve the above mentioned aim the related objectives associated are identifies as follows.

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(i) To develop RBC as replacement of RCC as chief material of construction for multistory buildings.

(ii) To check the suitability of baked clay structural panels for construction of multistory buildings without sacrificing the strength & durability of buildings.

(iii) To achieve the strength of this material at a reasonable level with concrete by applying various levels of pre-compression.

(iv) To achieve economy by applying

  (a) Very cheap local materials i.e. clay and pit-sand.

  (b) Saving in terms of cost of transportation of heavy materials over long distance.

  (c) Minimization of expenditure for finishing like plastering or applying paints and distempers etc with proper and uniform burning giving it a naturally good appearance, colour and texture.

(v) Step towards the mechanized system (manufacture & developed of equipment in order to pave the way for;

  (a) Mechanized mass scale production of the panels of structural members with relatively lower cost of production under very controlled conditions emulating those of laboratory.

  (b) Quick and speedy erection of building by making use of pre-cast panels

3. MATERIALS, METHODOLOGY AND BAKING SYSTEM

3.1 MATERIALS

3.1.1 Clay and pit-sand

The clay was obtained from 25 different sources at a depth of 100mm (4 ft) from the ground level. It was dried at a temperature of 105 ^{O}C for 24 hours. Then all the samples were sent for chemical analysis to detect the presence and quantity of various salts. The clay was then pulverized and pit-sand was mixed with it. Initially the ratio of pit-sand was a variable to find the best composition.

3.1.2 Mixing Water

Potable water was mixed in the mixture of clay and pit sand to the extent of 18% to 20%. In fact samples of underground water from a large number of sites were tested for various properties and salts.

3.1.3 Cement slurry

Ordinary Portland Cement and fine hill sand passing through standard sieve No 16 were mixed in the ratio 1:1 and the slurry was produced by adding water five times the weight of cement. The process of making the holes is shown in Fig 1, while the slurry was forced in to the holes where steel bars had been housed as shown in Fig 2. The slurry was developed during this study based on experimentation in terms of proper flow, complete filling of the space in the holes and proper bond between steel and surrounding baked clay.

Fig. 1: The system to pullout the shaft placed to form holes for pre-perforation

Fig. 2: Grouting System

3.1.4 Reinforcement

Tor-steel bars of 9.53 mm (3/8 inch) diameter, 12.7 mm (½ inch) diameter and 15.87 mm (5/8 inch) diameter were used. In Pakistan for the sake of economy 74% of reinforcing steel bars is produced from scrap. The manu-facturing processes also vary considerably. There-fore, their strength properties are not uniform. These bars showed limited ductility. The batch of steel bars procured for our research did not show distinct yield point therefore the average 0.2% proof stress was calculated for these bars and was found to be 554.2 N/mm^2 (80360psi) and average ultimate stress was 652 N/mm^2 (94540 psi).

3.1.5 Concrete

Four concrete beams were cast, cured and tested for the sake of comparison of results. The concrete ingredients were mixed by weight for the characteristic strength of 20 N/mm^2 (3000 psi) at 28 days. The size of coarse aggregates was 10 mm (0.375inch). The value of slump was in the range of 10-30mm.

3.2 METHODOLOGY

Initially pH value, Electric Conductivity, Exchangeable Sodium and Gypsm, Total salts content in solution

(PPM), Moisture Contents, Specific Gravity, Liquid Limit, Plastic Limit, Density of wet and dry soil are to obtain from twenty five different sites is determined. Preliminary studies are performed in terms of shrinkage, specific gravity, compressive strength, tensile strength, Poisson's ratio and modulus of elasticity of baked clay specimens consisting of hundreds of specimens including cubes, cylinders and briquettes. The major parameter is clay and pit-sand ratio.

A large number of baked clay specimens is compacted by applying compacting force of 6 N/mm^2 to improve the structural properties. Substantial equipment and testing arrangements required are also fabricated. Stiff steel mould are fabricated for casting the models of beam panels.

The clay was obtained from various sources at a depth of 1220 mm (4 ft) from the ground level. It was dried at a temperature of 105 ^{O}C for 24 hours. The clay was then pulverized for micro-fining it. Then as per previous research conducted by the author [2] 30% of pit-sand, was mixed. Mixing of the materials and the water was done with the electrically operated Pan mixer. Mixing was done for approximately 10 minutes for each batch. After delivery of the material in the mould, compressive force was applied and measured with the help of electric load cells and digital display amplifier system. Compression was applied by tightening the wing nuts as shown in Fig 1. The compression force for compaction is the major factor to achieve required strength of baked clay. Several impediments and hurdles were experienced. For example enormous shrinkage occurred during drying which caused cracking of the beams rendering them useless. The drying under the shade without exposure to sunshine with a thin plastic wrapper solved the problem. Special scheme was resorted by providing a heavy wooden plank fitted with a very smooth surfaced metallic sheet properly oiled to support the beam specimen at the bottom during its drying period; so that shrinkage and consequent deformation (i.e. shortening of the beams) did not cause any cracking. However, a system of slight compression with the help of springs was also devised and used as shown in Fig 3.

Figure 3: Photograph of the system used to avoid the cracking in the clay beams due to shrinkage.

It must be mentioned here that the beams cast, dried, baked and tested during this experimental investigation were 150 mm (6 inches) wide 300 mm (12 inches) deep and 1950 mm (6.5 ft) long initially but were reduced in length by 100 mm (4 inches), breadth decreased by 7.2 mm (0.3 inches) while the depth showed a shrinkage of 14.3 mm (0.6 inches).

After drying for sufficient time under the shade the beams were exposed to sunshine to exclude as much moisture as possible which was trapped deep inside them. The beams were then placed in the Kiln where the temperature was measured with the help of Thermo-Couples. The temperature and time periods were selected after trying a large number of temperature and duration combinations to achieve the best possible results because the thickness of beams is obviously much more than bricks and therefore the complete baking of the beams could be possible only on the basis of experimental investigation. The beams were pre-perforated near the bottom with two holes of one inch diameter for placement of tensile reinforcement. However, a few beams were reinforced both at top and bottom hence there were two holes near top and two near the bottom in these beams. A few beams contained vertical holes at 6 inch centre to centre for shear reinforcement. The steel bars of 3/8", ½" and 5/8 inch diameter were used as longitudinal reinforcement. A puller was manufactured to pull out the steel shafts from the beams after their casting as shown in Fig 1. The bond between steel bars and the surrounding baked clay was achieved through forced grouting of cement slurry with fine aggregate in the ratio 1:1 as shown in Fig 2.

After grouting curing was done for 14 days as shown in Fig 4. This created sufficient bond to avoid the problem of slipping of bars up to the ultimate load.

Figure 4: The tube to cure the baked clay beam after grouting

3.3 BAKING SYSTEM

For baking the cubes, cylinders and beams during this experimental work, a kiln as shown in Fig. 5 & 6, was constructed. The kiln was heated by burning fire wood.

Fig. 5: Photograph showing the Isometric view of the kiln

Fig. 6: Photograph showing back view of the kiln

Each time for complete cycle of burning, approximately 800 to 900 kg of fire wood is consumed. The temperature was controlled and maintained carefully. Initially the lower temperature of 250^{o}C was maintained for six hours. The temperature was then raised gradually to 950 ^{o}C and was maintained at this level for 16 hours. Then the temperature was lowered slowly and the fire was stopped and the kiln was allowed to cool down over next two days. The inner space of the kiln was enough to burn six beams at a time. The beams were placed inside through rectangular opening on the opposite side of the burning wood. There is an opening at the top which is covered at the time of burning. The cover itself is made up of clay. After the burning is over, the cover is partly removed for gradual cooling of the baked items. The temperature was maintained and measured with the help of thermo-couple. Four flues were provided opposite to each other to create draught.

4. EQUIPMENTS & MACHINERY

Since the use of reinforced baked clay panels was a new idea. It was not possible to find standard equipment and machinery in the market. This is invention of new gadgets which are not available in the market and lot of thinking and experimentation has gone in to it. First of all, the requirements were assessed.

Then ideas were conceived, strategy was devised, systems were envisaged, appropriate design was accomplished, bits and pieces were procured and in the end the required equipment and machinery were fabricated. They were used experimentally. Their behaviour was studied carefully and after satisfactory performance they were employed for the actual project. Two years' hard work along with considerable expenditure has been labeled as fabrication. Therefore these equipment and machinery were designed according to the design specifications. The details of the sample preparation and testing procedure are given in Ansari A. A. 2007 [5].

5. PRE-TENSIONING AND POST-TENSIONING

In pre tensioning, high tensile wires and strands are stretched to the required tension and anchored to bulk-heads. Photograph showing the system of baked clay pre-compression in Fig 7 & 8, testing process of pre-compression baked clay beam in Fig 9 and cracking pattern of pre-compression baked clay beam in fig 10. The tendons that are used for pre-tensioning and post-tensioning may consist of high tensile wires. The wire may be plain, crimped or dented. In both pre-tensioning and post-tensioning, the tendons need to be stretched to the required tension.

Fig. 7: System for applying pre compression to increase the strength of baked clay beams

Fig. 8: A bulkhead system fabricated for pre compression

Fig. 9: Pre-compression baked clay beam is testing on Torsee Testing Machine

Fig. 10: Photographs showing the cracks after testing the beam

6. DEVELOPMENT OF EXPERIMENTAL SET-UP

Torsee Testing Machine was used to test the beams. Load cells were used together with digital display system to measure intensity of the load independently. Demec Gauge was used to measure the strain at various locations with reference to the neutral axis. Thirteen pairs of demec pads were stuck on the beam to measure the strain with the help of demec gauge. To test the fundamental structural properties of the beam material itself specimens were cut from the intact portions of beams after testing. The flexural strength of all the beams in terms of steel and baked clay was estimated by using the recommendations of BS CP-8110 [15] and ACI-318 [16] after removal of partial safety factors. The shear strength was also estimated. This experimental study was carried out with the intention to develop design criteria for baked clay buildings and other types of structures by using clay as the chief material.

However, it must be mentioned here that the failure was not caused by the exhaustion of the strength in any terms but due to failure of the system which was designed to apply pre-compression. Actually not only the threads on the steel bars yielded but even the additional constraint provided by the welding also failed. Several different ways and means were adopted to strengthen the junction at both the ends of the beams.

The intensity of the load was measured by using the "Proving Ring'. It is surprising to note that failure occurred when the design load of the end support connections was not even reached.

Here we are more concerned about the difficulties faced to provide shear reinforcement. Hence ways and means must be devised to eliminate the use of reinforcement as far as possible. The longitudinal reinforcement can always be accommodated after the structural sections are moulded, dried and baked by inserting the steel and then by grouting to accomplish the bonding but the shear reinforcement is hard to be accommodated after baking. Under these circumstances the only options left for us is to avoid any reinforcement except longitudinal one and this can best be achieved if we strengthen the structural members to an extent that any failure which is sudden, brittle and without impending warning. Therefore the baked clay must be pre-compressed to a level that there could not be any tensile stresses to produce cracking or causing a diagonal failure [14]. With these motives in the sight the work has been under taken the details of which is presented in this paper.

7. DISCUSSIONS

The ultimate stage in terms of flexural or shear could not be reached because of the premature destruction of the anchorage, the failure loads exceeded from those which were attained in case of un-pre-compressed systems. Experimentally it has been proved that the shear strength could be increased from 5 to 50 percent if pre-compression is applied [17]. This was expected an increase which could comfortably be had in the building when they are constructed using baked clay without vertical reinforcement. The other purpose was to seek the possibility of using the baked clay for pre-stressed construction. When rectangular beams simply supported on rollers were tested by applying a point load the maximum benefit which could be achieved in terms of shear strength is of the order of 9 % (Table 1).

However, when UDL was applied this figure touched a

TABLE 1: EFFECT OF INTENSITY OF PRE-COMPRESSION FOR VARIOUS TYPES OF BEAMS

Description	RECTANGULAR SECTION											
	POINT LOAD						UNIFORMLY DISTRIBUTED LOAD					
	CP-8110			ACI			CP-8110			ACI		
	BCRRP	BCRRPPC	%age Diff.	BCRRP	BCRRPPC	%age Diff.	BCRRUD	BCRRUDPC	%age diff.	BCRRUD	BCRRUDPC	%age diff.
Flexural Strength (British steel)	89688	94103	4.7	101198	103766	2.47	92402	146467	36.91	101543	160458	36.7
Flexural Strength (Pak steel)	94530	103586	8.7	106469	109906	3.13	99613	160244	37.8	107777	170043	36.6
Flexural Strength (Baked Clay)	128312	159565	19.5	103128	105827	2.56	193145	252796	23.5	158349	106163	32.9
Shear Strength Calculated	38977	21261	20	27086	29833	9.21	30373	20832	14.14	26816	30248	11.34
Experimental load.	56595	63495	10.8	56595	62575	9.56	114095	115015	0.79	114279	115237	0.83
Exp.shear strength Cal. Shear strength	0.71	1.46	8.9	1.04	1.05	0.95	1.88	3.70	13.78	2.12	1.91	9.90
Experimental Displacement	8.4	7.7	9	8.4	7.7	8.33	9.7	8.12	16.3	9.8	8.12	17.14
Strain at the Level of steel	1700	1300	23.5	1700	1300	23.5	2300	1800	21.7	2300	1800	21.74
Level of stress from measured strain	226	490	53	226	419	53..9	611	491	19.6	611	492	19..47

BCRRP : Roller supported rectangular subjected to point load at center.

BCRRPPC : With proving ring without grouting, roller supported rectangular subjected to point load at center.

BCRRUD : Roller supported rectangular subjected to uniformly distributed load.

BCRRUDPC : With providing ring without grouting, roller supported rectangular subjected to uniformly distributed load.

Note: All the values are expressed in N/mm^2.

level of approximately 14 %. As usual the displacement maintained its lowest level with maximum value of 9.7mm. This is only 3.4 % of the depth of the beams. A ductile failure is needed rather than sudden due to crushing of baked clay or the diagonal failure. Therefore we tried to discover the best solution for resisting any brittle failure which must be avoided in all circumstances. Table 2, gives the details of experimental load at failure, experimental strain at the level of steel in baked clay, maximum experimental strain in compression zone and experimental displacement of the beams subjected to pre-compression of 20 as well as 30 kN pre-compression force. Here it can be seen that maximum strain in baked clay never exceeded the limit of 2400 micro-strain which is a clear manifestation that flexural limit was not crossed; rather everything was within the safe limit.

TABLE 2: VARIOUS EXPERIMENTAL DATA OF BEAMS TESTED FOR DIFFERENT COMPRESSION FORCES

S#	Description	Exp. load at failure (N)	Exp: Strain at the level of steel	Experimental displacement mm	Experimental Max. strain in compression zone	Maximum Bending Moment (F.E)	REMARKS
1.	BCRRPPC-1	63020	0.0013	7.72	0.0021	229100	BCRRPC: With proving ring without grouting, Roller supported rectangular subjected to point load at centre BCRRUDPC With proving ring without grouting, Roller supported Rectangular subjected to UDL BCRRPPCG$_{20}$: With 20 kN pre-compression force BCRRPPCG$_{30}$: With 30 kN Pre-compression force
2.	BCRRPPC-2	61180	0.0012	7.68	0.0020	222300	
3.	BCRRUDPC-1	67620	0.0018	8.13	0.0023	160200	
4.	BCRRUDPC-2	68080	0.0018	8.11	0.0023	160267	
5.	BCRRPPCG$_{20}$-1	55200	0.0017	8.89	0.0023	198900	
6.	BCRRPPCG$_{20}$-2	54740	0.0017	8.64	0.0024	198900	
7.	BCRRPPCG$_{30}$-1	55200	0.0017	8.28	0.0024	198900	
8.	BCRRPPCG$_{30}$-2	55200	0.0017	8.94	0.0024	198900	

TABLE 3: COMPARATIVE STRENGTH ANALYSIS OF BAKED CLAY & CONCRETE

S #	Boundary conditions	Flexural strength (steel)						Flexural strength (concrete)						Shear strength (calculated)					
		CP8110		% age	ACI		% age	CP8110		% age	ACI		% age	CP8110		% age	ACI		% age
		Baked clay N	Conc-rete N		Baked clay N	Conc-rete N		Baked clay N	Conc-rete N		Baked clay N	Conc-rete N		Baked clay N	Conc-rete N		Baked clay N	Conc-rete N	
1	Roller (Single reinforcement)	106034	118166	10	113402	125991	9.9	246856	256860	3.9	163220	188234	13	16539	18304	9.6	30103	31230	3.6
2	Roller (double reinforcement)	117929	119524	1.3	126119	126962	0.6	240916	286160	15	174251	190848	9	16907	18304	7.6	29563	33540	11
3	Fixed (double reinforcement)	202064	203362	0.6	216977	217846	0.4	238275	260320	8.4	192720	198309	2.8	16874	18304	7.8	29529	32887	10.2
4	Fixed (double reinforcement)	205913	201025	2.3	220549	217649	1.3	237376	256816	7.5	192862	195056	3.3	16982	18304	7.2	29874	32743	11.4
	Average			**3.5**			**3.05**			**8.7**			**7.02**			**8.5**			**9.05**

Otherwise properties studied so far allude to the conclusion that this material holds the promise for future; if properly handled and properly designed. Therefore, it can be safely concluded that such an application of pre-compression would hopefully show a drastic beneficial effect if only the anchorage systems are fully operative. It must be mentioned here that for the sake of comparison four concrete beams were also cast and tested. Table 3, shows the comparative analysis of strength of baked clay and concrete. The percentage difference of experimental displacement of concrete is somewhat higher than that of baked clay. Averagely the displacement of concrete beam is 27 % higher than the baked clay. Therefore it can safely be deduced that lesser the displacement, lesser shall be the cracking and ultimately behaviour of baked clay could be regarded as more favourable than concrete.

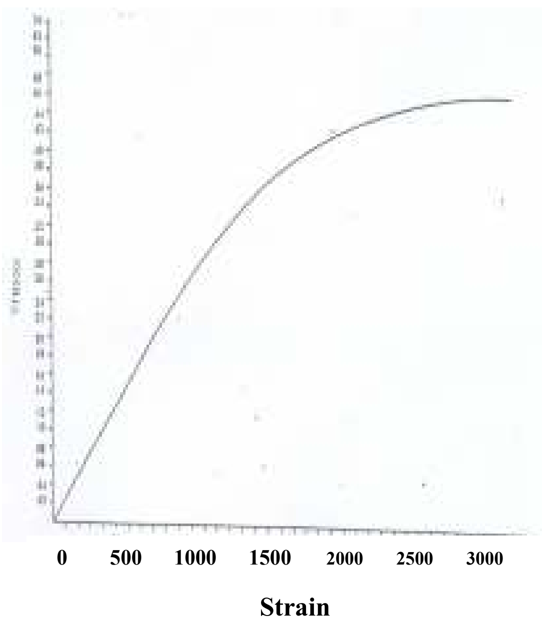

Figure 11: Graph showing the stress-strain relationship of baked clay beam.

Results are satisfactory we are to find that baked clay is not an inferior material than concrete. Depending upon the boundary conditions, estimated flexural strength in terms of steel and concrete together with two estimations on the basis of BS CP-8110 [15] and ACI-318 [16], results are presented in Table 3.

It is apparent that the difference is only of the order of 0.6 to 10 % and 0.4 to 9.9% and to 8.4 to 3.9% and to 2.8 to 13 % finally 10.2 to 11%. This all can be regarded as negligible. Therefore, it can safely be concluded that baked clay is equally good if not better than concrete.

The strain in baked clay beams at the level of steel in tensile zone just one stage before failure has been converted into stress by using the Fig. 11. The figure is based on the behaviour of baked clay specimens subjected to direct axial compressive stress tested in the laboratory. This level of stress is so high that micro-cracking invisible by naked eye must have occurred. However, this could not be detected.

8. CONCLUSIONS

1. Experimentally it has been proved that the shear strength could be increased from 5 to 50 percent if pre-compression is applied.
2. Here it can be seen that maximum strain in baked
   clay never exceeded the limit of 2400 micro-strain which is a clear manifestation that flexural limit was not crossed; rather everything was within the safe limit.
3. Pre-compression would hopefully show a drastic beneficial effect if only the anchorage systems are fully operative.
4. The percentage difference of experimental displacement of concrete is somewhat higher than that of baked clay. Therefore it can safely be deduced that lesser the displacement, lesser shall be the cracking and ultimately behaviour of baked clay could be regarded as more favourable than concrete.
5. Pre-perforated and post-reinforced system of construction consisting of pre-cast panels of baked clay holds promise as an alternative of cement concrete at a reduced cost without compromising on the quality, durability and elegance of multistory buildings.

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