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To Study the Structural Properties of Clay and Fly Ash Brick Masonry

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ABSTRACT: Brick masonry, a composite of brick units bound together with mortar, is widely used for building construction in India. Burnt clay bricks are commonly used in construction of masonry structures since many years. But with growing environmental concern for conservation of natural resources and disposal of fly ash, bricks made with fly ash are emerging as a substitute to burnt clay bricks for construction of masonry structures. The behavior of masonry structure is dependent on the properties of its constituents such as brick units and mortar separately and together as a unified mass. Brick properties vary largely from region to region as bricks are made with locally available raw materials with inherent randomness. Therefore, the analysis and design of brick masonry structures considering the mean values of material properties may underestimate or overestimate the structural capacity. In order to design a safer structure it is necessary to take in to consideration the randomness and variability of the material properties of brick masonry. This requires mathematical description of the variability in different material properties of brick masonry. The variability of mechanical properties related to steel and concrete is well researched, while the same for brick masonry has not received proper attention. Shear bond strength of masonry plays an important role in dealing with in-plane forces. The soaking of bricks prior to construction is very essential to achieve good shear bond strength. Bricks with higher initial rate of absorption must be pre-wetted prior to use in construction else they absorb more water from mortar inhibiting its hydration. In present study, several experiments are carried out to determine mechanical properties such as initial rate of absorption, water absorption, dry density and compressive strength of brick units, compressive strength of mortar and masonry prism.

Keywords: *Brick masonry; water absorption; initial rate of absorption; compressive strength;*

Notations*CM1(Cement Mortar with Cement to Sand ratio 1:6) ;CM2 (Cement Mortar with Cement to Sand ratio 1:4.5); CM3(Cement Mortar with Cement to Sand ratio 1:3) ; COV(Coefficient of Variation); FAB-I (Fly Ash Brick with Fly Ash from Source-I); FAB-II(Fly Ash Brick with Fly Ash from Source-II) ;IRA(Initial Rate of Absorption); IS (Indian Standard); SD(Standard Deviation);WA(Water Absorption)*

I. INTRODUCTION

Housing is one of the basic requirements for human survival. Masonry is an inevitable component of housing. Among different types of masonries, brick masonry is one of the most widely used in our country and elsewhere because of low cost, easy availability of raw materials, good strength, easy construction with less supervision, good sound and heat insulation properties, and availability of manpower. Brick masonry is a composite material of systematic arrangement of brick units and mortar joints. The behavior of masonry is dependent on the properties of its constituents such as brick units and mortar separately and together as a unified mass. Burnt clay bricks are widely used around the globe but in recent years many other varieties of bricks have been developed. Among them fly ash bricks has gained much popularity because of its numerous advantages over burnt clay bricks. The performance of brick masonry depends on its compressive strength as well as on the bond strength at brick mortar joint. Brick properties vary largely from region to region as raw materials for brick production are locally available and do not come from the controlled industry environment.

Fly ash brick is a recent entrant to the class of bricks that is primarily made of fly ash which is abundantly produced from different coal based plants, lime or cement and sand [1]. These bricks can be used in all construction fields where fired clay bricks are used [2]. In the present study three brick variants are considered. Hand-mounded burnt clay bricks used in the present study are procured from a kiln near Sirsa, India. Two types of fly ash cement bricks are used in the study which differs on the basis of their composition and the source of fly ash used. These two varieties are widely used in construction of buildings in the regions surrounding Sirsa (Haryana) and Ludhiana (Punjab). The bricks considered in the present study have non-modular size of approximately 235×110×75 mm. Three different mixes of mortar are considered in the present study (Cement: Sand = 1:3, 2:9 and 1:6) and the mortar cube of size 70×70×70 mm is used. The thickness of the mortar joint is maintained 8 to 10 mm for all masonry assemblages used in the present study.

II. MATERIALS AND METHODS

Brick is one of the primary materials used in this study. Three variants of brick are considered, out of which one is clay brick and other two are fly ash bricks. Burnt clay bricks used in the present study are procured from a kiln near Sirsa. The clay bricks used are of good quality and falls under the class designation of 7.5 as per Indian Standard IS 1077:1992 classification. The clay bricks are hand-molded and have non-modular size. Fig. 3.1 depicts a typical burnt clay brick used in the study. The bricks which are uniform in color with sharp corners and smooth faces are selected for the study. Two types of fly ash cement bricks are used in the study which differs on the basis of their composition and the source of fly ash used. Fig. 3.2 shows two varieties of Class F fly ash considered: (a) grey colored fly ash with high silica plus alumina which is collected from source-I and (b) brown colored fly ash with silica plus alumina and significant amount of iron oxide which is collected from source-II. Source I and II are coal based plants located at Panipat (Haryana) and Ludhiana (Punjab). The changes in the color and properties of fly ash are probably because of variations in method of production of fly ash, loss of ignition and coal properties.

Fig. 1. (a) Source-I and (b) Source-II.

Table 1: Mix proportions and dimensions of brick specimens.

Designation	Mix Proportions (Fly Ash: Sand: Cement)	Dimensions in mm (Length×Breadth×Height)
CB	Clay constituents	235×110×75
FAB-I	60:30:10	235×110×75
FAB-II	50:40:10	235×110×75

Sand The locally available river sand is used for making mortars conforming to the specifications of Indian Standard IS: 2116:1980[13].

Cement Ordinary Portland Cement (OPC-43) of ACC brand is used confirming to IS 8112-1989 in the present study for preparing mortar.

Mortar. Mortar is used as a binding material to combine brick units and together they form masonry. Mortar is a mixture of sand, a binder and water. The binder may be lime or cement, in this study, cement is used as the binder so the mortar is called cement mortar [1]. Three grades of cement mortar are prepared by changing the ratios of cement and sand. The three mortar grades are designated as CM1, CM2 and CM3. Table 1 presents the designation, mix proportion and characteristic of the mortar.

Table 2: Designation and mix proportions of different grades of mortar.

Designation	Mix Proportions (Cement: Sand)	Characteristic
CM1	1:6	Weak Mortar
CM2	1:4.5	Intermediate Mortar
CM3	1:3	Strong Mortar

Tests For MechanicalProperties

Initial Rate of Absorption. IRA test is essentially a measurement of the amount of water a unit brick absorbs when immersed in water at 3 mm depth for one minute. It is measured in kg/m^2/min or gm/30 in^2/min. The IRA value gives the in-hand knowledge about the absorptive capacity of bricks. The test is done as specified in ASTM C67-14 [5]. First, the bricks are oven dried for not less than 24 hours or until two consecutive readings show no variations in weight. Then the bricks are cooled for 4 hours or till the surface is not hot to touch. The testing tray is filled with water with its level kept at 3 mm above the supports. The dimension of the brick specimen is noted and its dry weight is determined. It is then placed on the supports and the water level is maintained by adding additional water when found necessary. After one minute the brick unit is taken out of testing tray, wiped with wet cloth and its weight is found. The gain in weight within one minute divided by its surface area gives the IRA value.

Water Absorption and Dry Density. Water absorption is the measure of the amount of water the brick unit absorbs when placed in water for 24 hours. It is a commonly followed test and is conducted as per Indian Standard IS 3495:1992.The brick specimen is oven dried for not less than 24 hours or until two consecutive readings show no variations in weight. The dry weight of sample is found and it then immersed in water bath for 24 hours. Then the sample is taken out, wiped with wet cloth and its wet weight is found. The WA is calculated by dividing the gain in weight by dry weight of brick. The dry density of the brick is determined by dividing the dry weight of brick by its volume.

Compressive Strength. The strength of the specimen under compression is determined by testing in compression testing machine. In this study, specimens of brick units, mortar cubes and masonry prisms are tested under compressive loading. The brick and prism specimens are tested with frog filled face towards loading surface between two plywood sheets (soft capping). The compression test of brick, mortar cube and prism are conducted as per specification in Indian Standards IS 3495:1992[12], IS 2250:1981[14] and ASTM C1314-14[6] respectively.

III. RESULTS AND DISCUSSION

Several experimental tests are conducted on brick units to determine four mechanical properties such as IRA, WA, dry density and compressive strength. The casting and testing of samples are done in the Material testing lab of Campus under the observation of Lab technician. A total of 30 brick units comprising of 10 numbers each for CB, FAB-I, FAB-II are tested. The brick units of each variant collected randomly from a single-batch-made brick lot are tested. The values of each property obtained for all the 30 samples of the brick along with mean, standard deviation and coefficient of variation (COV) are tabulated in Table 3.

Variation in IRA. It can be seen from the Table 4 that the IRA for the CB specimens used in this study is found to vary from 3.25 to 3.96kg/m^2/min (with a COV of 0.07), that for FAB-I is found to vary from 4.47 to 4.91 kg/m^2/min (with a COV of 0.04) and similarly for FAB-II the values varied from 2.35 to 2.66 kg/m^2/min (with a COV of 0.04). If IRA is higher than 1.5 kg/m^2/min, brick units are highly absorptive and should be wetted prior to lying to achieve better bond strength.

Variation in WA. Like IRA, WA affect the bond strength and durability of brick masonry. In addition to that, higher value of WA causes cracks on plasters as well as damage to the wall finish. Table shows that the WA for CB is ranged from 16.6% to 17.16% (with a COV of 0.08), for FAB-I from 17.02% to 17.7% (with a COV of 0.012) and similarly for FAB-II from 16.32% to 16.79% (with a COV of 0.009).

This satisfies the criteria of maximum limit of 20% specified in Indian Standard IS 12894:2002. The WA value for fly ash bricks was reported to vary from 12.5 to 37%. The mean values of WA are depicted in Fig. 4.2. It has been observed that the fly ash is highly water absorbent material so fly ash brick tends to have higher WA value. This is probably the reason for higher WA in fly ash bricks than clay bricks.

Table 3: Values of IRA, WA, dry density and compressive strength for brick specimens.

Sl. No.	IRA(kg/m^2/min)			WA (%)			Dry density (kN/m^3)			Compressive strength (MPa)		
	CB	**FAB-I**	**FAB-II**	**CB**	**FAB-I**	**FAB-II**	**CB**	**FAB-I**	**FAB-II**	**CB**	**FAB-I**	**FAB-II**
1	3.25	4.47	2.35	16.68	17.02	16.32	15.08	15.02	16.27	7.09	4.74	8.85
2	3.29	4.51	2.38	16.75	17.11	16.34	15.11	15.06	16.33	7.09	4.74	9.15
3	3.42	4.59	2.41	16.75	17.14	16.36	15.11	15.08	16.35	7.22	4.74	9.27
4	3.45	4.63	2.44	16.86	17.23	16.46	15.16	15.11	16.42	7.28	4.79	9.28
5	3.53	4.67	2.44	16.91	17.34	16.46	15.2	15.12	16.48	7.31	5.05	9.4
6	3.61	4.72	2.49	16.95	17.45	16.46	15.35	15.13	16.5	7.31	5.14	9.45
7	3.7	4.74	2.54	16.99	17.58	16.53	15.36	15.13	16.5	7.38	5.23	9.56
8	3.77	4.78	2.56	17	17.58	16.58	15.39	15.16	16.56	7.7	5.3	9.63
9	3.83	4.79	2.6	17.03	17.68	16.66	15.4	15.2	16.62	7.73	5.38	9.9
10	3.96	4.91	2.66	17.16	17.7	16.79	15.45	15.23	16.65	7.74	5.58	9.96
Mean	3.581	4.681	2.487	16.908	17.383	16.496	15.261	15.12	16.468	7.385	5.069	9.445
SD	0.23	0.14	0.1	0.15	0.25	0.15	0.14	0.062	0.11	0.25	0.3	0.33
COV	0.07	0.03	0.04	0.008	0.012	0.009	0.009	0.004	0.006	0.03	0.05	0.04

Variation in dry density. The dry density of CB is found to vary from 15.08 to 15.45 kN/m^3 (with a COV of 0.09), for FAB-I it is 15.02 to 1523 kN/m^3 (with a COV of 0.009) and for FAB-II it is found to vary from 16.27 to 16.65 kN/m^3 (with a COV of 0.004) as shown in Table . However, the variation among FAB-II is least followed by CB and FAB-I. It is observed that FAB-II bricks have higher amount of sand and lower amount of fly ash as compared to FAB-I, [10] hence its weight is slightly higher. It could be said that higher amount of fly ash in bricks makes the bricks lighter as dry density of FAB-I is lower than FAB-II.

Variation in compressive strength of brick units. As seen from Table 4, the compressive strength value for CB is found to vary from7.09 to 7.74 MPa (with a COV of 0.03), for FAB-I the values ranged from4.74 to 5.58 MPa (with a COV of 0.05) and similarly, the compressive strength of FAB-II varied from 8.85 to 9.96 MPa (with a COV of 0.04). The compressive strength of clay brick (CB) and fly ash brick specimens (FAB-I and FAB-II) is found to be in good agreement with the studies carried out by many past researchers [11] in which the values reported to vary from 4.3 to 8.0 MPa for fly ash bricks and 3.2 to 18.0 MPa for clay bricks.

Variation in Compressive Strength of Masonry Prisms. It could be witnessed from Table that the compressive strength in clay brick prisms varies from 1.49 to 3.88 MPa for CB-CM1 prism (with a COV of 0.37), 2.33 to 3.8 MPa for CB-CM2 prism (with a COV of 0.2) and 3.00 to 4.65 MPa for CB-CM3 prism (with a COV of 0.17). The compressive strength for first variety of fly ash bricks varies from 1.36 to 2.52 MPa for FAB-I-CM1 prism (with a COV of 0.23), 2.30 to 3.49 MPa for FAB-I-CM2 prism (with a COV of 0.15) and2.91 to 4.46 MPa for FAB-I-CM1 prism (with a COV of 0.13). Similarly the compressive strength for second variety of fly ash bricks ranges from 1.55 to 3.49 MPa for FAB-II-CM1 prism (with a COV of 0.29), 3.49 to 5.04 MPa for FAB-II-CM2 prism (with a COV of 0.14) and 4.65 to 5.62 MPa for FAB-II-CM3 prism (with a COV of 0.06).

Table 4: Compressive strength (MPa) for masonry prisms.

Brick Type	CB			FAB-I			FAB-II		
	CM1	CM2	CM3	CM1	CM2	CM3	CM1	CM2	CM3
1	1.49	2.33	3	1.36	2.3	2.91	1.55	3.49	4.65
2	1.56	2.35	3.2	1.45	2.46	3.1	1.94	3.49	5.04
3	2.33	3.1	3.96	1.94	2.91	3.88	1.94	3.88	5.04
4	2.91	3.15	4.3	2.13	3.1	4.18	2.71	3.88	5.23
5	3.1	3.49	4.58	2.27	3.3	4.46	2.71	4.27	5.43
6	3.88	3.88	4.65	2.52	3.49	4.46	3.49	5.04	5.62
Mean	2.5	3.05	3.9	1.94	2.9	3.8	2.39	4	5.16
SD	0.93	0.61	0.7	0.45	0.46	0.67	0.71	0.58	0.34
COV	0.37	0.2	0.17	0.23	0.15	0.17	0.29	0.14	0.06

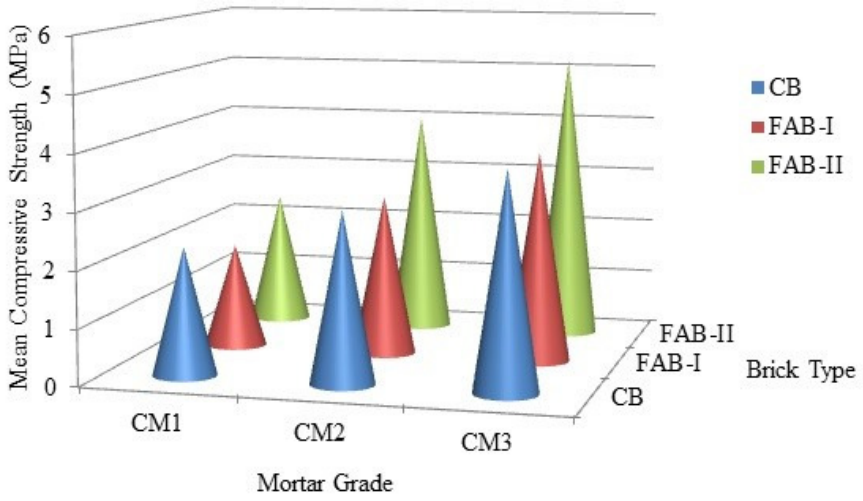

Fig. 1. Mean compressive strength of the masonry prisms.

IV. CONCLUSION OF THE WORK

1. The IRA is more for the FAB-1 as compare to clay bricks and FAB-II.
2. WA is more in the fly ash brick as compare to clay bricks because FAB-1 has more percentage of fly ash as compare to FAB-II.
3. FAB-II has more dry density as compare to FAB-1 and clay bricks. This is due to that FAB-II has more sand and less sand.
4. The mean compressive strength of FAB-II is highest as compare to FAB-1.
5. The compressive strength of prism made using FAB-II is highest followed by CB and least by FAB-I. It is to be noted that FAB-II brick unit has highest mean strength followed by CB and least by FAB-I. The similar trend is followed for all mortar grades which signify that high strength of brick unit is also responsible for increasing the compressive strength of masonry.
6. COV of compressive strength of fly ash brick prisms is less than clay brick prisms. This may be due to the fact that fly ash brick being made from pozzolanic material [15], (fly ash) reacts better with mortar and forms good bond and reduces the variation in masonry of fly ash bricks are identified.

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