Sustainable Pond Ash Masonry Mortar for Fly Ash and Pond Ash Masonry Units – Assessment of Properties

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Abstract— Coal dependent power plants are the fundamental source of power production units in India. The primary by-product of this power plant is fly Ash. The fly Ash can be utilized as a cementitious material or mineral admixture replacing cement partially in concretes, for providing numerous benefits to concrete. The experiment is carried out to assess mortar behavior in fresh and hardened state and also the behavior of Masonry Block bonded with CM with fly ash and Pond ash as constituents The strength development of masonry cement mortar of grades CM1:4, CM1:6 and CM1:8 containing various proportions of fly ash replacing cement and pond ash replacing fine aggregates under normal curing as per IS 2250-1981.The study is extended to understand the behavior of masonry mortar in masonry block -masonry triplets and masonry quadruplets.

Key words: Fly Ash, Pond Ash, Fa-Pa bricks, Brick masonry, Compressive strength, Shear Bond Strength

I. INTRODUCTION

The Thermal Power Plants depends on Coal as main source of production in India. The primary by-product of the Thermal power plant is Coal Ashes consisting of Fly Ash, Bottom ash and Pond Ash. Fly ashes are a finely divided particles, generated due to the ignition of finely powdered coal, transported by the flue gasses and gathered by electrostatic precipitators. Fly Ash is the most broadly utilized Pozzolanic material throughout the world. In dry disposal, the fly ash is transported by truck, chute or conveyor at the site and disposed off by constructing a dry embankment (dyke). In wet disposal, the fly ash is transported as slurry through pipe and disposed off in impoundment called "Ash Pond".

Bottom Ash — Pulverized fuel ash collected from the bottom of boilers by any suitable process (Cl. 3.1:IS3812, Par I, 2003)

Fly Ash — Pulverized fuel ash extracted from flue gases by any suitable process such as by cyclone separator or electro-static precipitator (Cl. 3.3:IS3812, Par I, 2003).

Pond Ash — Fly ash or bottom ash or both mixed in any proportion and conveyed in the form of water slurry and deposited in pond or lagoon (Cl. 3.5:IS3812, Par I, 2003).

Pulverized Fuel Ash — Ash generated by burning of ground or pulverized or crushed coal or lignite fired boilers. It can be fly ash, bottom ash, pond ash or mound ash (Cl. 3.6:IS3812, Par I, 2003).

Historical review: The conversion of waste into useful resources is an age old practice of civilization. In the year 1930 in USA, the fly ash became easily accessible in coal based thermal power plants. For encouraging the utilization of Fly ash, scientist started research works and in the year 1937, R.E Davis and his associates published research details that are carried out in University of California to use fly ash as cement replacement material in cement concrete. This research work serves as a foundation for specification, testing and usages of Fly ash.

The pozzolanic property is defined as “a property of siliceous and aluminous material which is in finely divided form, in presence of moisture, reacts with calcium hydroxide to form a compound which possesses cementitious property”. In India, Bureau of Indian Standard (BIS) has published Indian specifications: 3812 in the year 1996 for fly ash as pozzolana and admixture. It mainly has 3 parts. Part 1 deals with the use of fly ash as pozzolana, part 2 deals with the use of fly ash as admixture and part 3 deals with the use of fly ash as fine aggregates. But in the year 1981 these specification have been revised and use of fly ash has been covered in single specification. There was a further revision is issued in the year 2003 into two parts.

Part-1 deals with the use of fly ash as pozzolana in cement, cement mortar and concrete.

Part-2 deals with the use of fly ash as admixture in cement mortar and concrete.

II. MATERIAL PROPERTIES

A. *Cement:*

In thevpresent investigation, ordinary Portlandvcement of grade 43 confirming to the specification as per IS 8112-2013 was used and the results obtained are as follows, Normal Consistency 28.6%, Initial setting time 145 minutes, Finalisetting time 330 minute, Soundness 0.5mm Compressive strength for 7,14 and 28 days curing is 34 MPa, 41.5 MPa and 56 MPa.

B. *Fly Ash:*

Physical properties of typical sample of Fly ash are as follows and it satisfy the requirement as per IS: 3812:2013. Specific gravity 2.08 , Fineness 349 ,Compressive strength at 28 days in MPa for test sample 31.0 and for Plain cement mortar cube 33.5, Soundness in percent 0.031 and Residue on 45 micron sieve in percent 15.7.Fly Ash satisfies the Chemical Properties requirement as per IS: 3812:2013

C. *Natural River Sand:*

The maximum size of the fine aggregate was taken to be 4.75mm.The testing of sand was done as per Indian standard specification IS 383-1970. Physical Properties of Sand are as follows, Fineness modulus 3.58, Specific Gravity 2.60, Zone II and Water absorption (%) 1.9.

D. *Pond Ash:*

Physical Properties of Pond Ash are as follows, Specific Gravity 2.06, FinenessvModulus 1.764, LBD 921Kg/m3, RBD 1048Kg/m3, Zone IV and Water absorption (Frying Pan method) 20.6%. Pond ash satisfies the Chemical requirements as per IS: 3812:2013

III. MIX PROPORTIONS OF CEMENT MORTAR

The design mix for three grades of Cement Mortar (CM) 1:4, 1:6 and 1:8 are presented as follows.

A. Grade of Cement Mortar Mixes CM1:4, CM1:6 and CM1:8:

Water content depends on the percentage of flow required from flow table test.

Sl. No.	Materials	Details for Compressive Strength Test		
		CM1:4	CM 1:6	CM1:8
1	Specimen	50mm Cube		
2	Cementitious Material Cement+Fly ash	612gm	437 gm	340 gm
3	50% Sand+ 50% Pond Ash	2448gm	2623 gm	2720 gm

Table 1: Material Calculation for Conventional Cement Mortar CM1:4, CM1:6 and CM1:8

B. Details of Specimens Cast For Various Tests:

The size, shape and quantity of specimens cast for different tests are presented in Table 2.

Test	Dimension of the specimen in (mm)	Shape of the specimen
Compressive Strength	Mortar Unit - 50*50*50	Cube
Shear Bond Strength	Masonry Block - Varies with mortar thickness	Prism

Table 2: Details of Specimens Required - Various Tests

IV. TEST PROCEDURES AND METHODOLOGY

A. Flow Table Test:

The flow table test is performed in accordance with the procedure as per IS 2259-1981. The different trials are conducted and the final mixes are arrived. The flow of 110 to 115 is considered for the mortar to be intended to use as masonry mortar. The mix of mortar is prepared as per the table 1, to test the flow characteristics. The top surface of the flow table is carefully cleaned and is allowed to dry. The mould of the flow table is placed exactly at the centre of Flow Table. A layer of mortar of nearly 25mm thick is placed in the mould and tamping is done 20 times by using a tamping rod. The mould is filled to overflow and the top surface is leveled by trowel. The surroundings of mould is removed and cleaned. Then the mould is lifted and flow table is immediately dropped from a height of 12.5mm.The number of blows given is 25 in 15 seconds. The procedure is repeated with different dosage of admixture till the required flow rate is achieved. The flow is measured as increase in average base diameter measured on four diameters at equal equispaced intervals. The flow is expressed in percentage. The result of the Flow Test is recorded.

B. Compressivevstrength of Cement Mortar:

The compressive strength of masonry mortar is carried out as per IS 2250-1981. The inner sides of the moulds are properly oiled and then mortar satisfying the workability from flow table test is placed in the moulds about half of its height and is properly compacted with tamping rod. The moulds are filled fully and the upper layer is leveled with trowel. The specimens are placed at vibration free place at a temperature of 27±2oc for 24 hours. The specimens are properly marked for further identification after demoulding and are taken for curing. The specimens after a curing period of 28 days, are tested in a dry state. The surface of the machine is cleaned properly. The specimen is placed on the platens of CTM and the load at the rate of 2 MPa to 6 MPa per minute is applied till the specimen fails. The load at failure is recorded nearest to 0.05 N/mm2.

$$Compressive\ strength = \frac{Load\ at\ failure\ N}{Cross\ sectional\ area\ (mm2)}$$

C. CompressivevStrength of Masonry Prism

The compressive strength test of masonry prism is conducted as per IS 1905-1987. It is hard to decide the quality and flexible characteristics of the masonry on the premise of known characteristics of the constituent materials. The expectation of the conduct of the masonry assemblage on the premise of its constituent materials is excessively complex. Therefore, the strength and elastic characteristics of integral masonry prisms are estimated by making of masonry prism and test under vertical loading, which are summarized as follows.

In case of compressive strength of masonry, the prisms are built using similar materials under the same condition with same bounding arrangements as for the structure. During the casting of prism it is noted that the consistency of mortar, workmanship, the thickness of the mortar joint must of constant and accurate. The assembled prisms must have height to thickness ratio of at least 2 but not more than 5. The correction factor for brick work and block work for height to thickness ratio more than 2 and less than 5 is given in table below. The strength value recorded in such cases should be multiplied by the correction factor mentioned in Table 3.

Ratio of Height to Thickness(h/t)	2	2.5	3	3.5	4	5
Correction Factor for Brick Work	0.73	0.8	0.86	0.91	0.95	1.00
Correction Factor for Block Work	1.00	-	1.20	-	1.30	1.37
Intermediate values are found out by interpolation						

Table 3: Correction Factor for Brick Work and Block Work

Prisms are tested after 28 days of curing between the mid steel sheets of nominal thickness of about 4mm, comparatively longer than the bed area of the prism, in testing machine having upper platform spherically seated. The uniform rate of loading applied is 350 to 700 kN/m. The load at failure is noted.

During casting of masonry prism, the partially saturated masonry units are used to prevent the flow of water from mortar to the bricks. The cement mortar used in the masonry are of grade CM1:4,1:6 and 1:8 in which cement is replaced with fly ash in varying percentage of 0%, 25% and 50%, and sand is replaced by pond ash in varying percentage of 0%, 25% and 50% using known water cement ratio obtained using flow table test, mixes are mixed. The mortar layer of uniform thickness of 8mm and 10mm is used. The specimens are cured using wet gunny bags for a period of 28 days.

The prisms are tested after 28 days of curing and the specimen is placed in between sheets of nominal thickness of 4mm steel plate, having length comparatively longer than the bed area of the prism and tested in CTM, the upper platform of which is spherically seated. The load is allowed to be distributed uniformly at the rate of 350 to750 kN/m. The load at failure is recorded.

Failure may be of following types;

CF1=Failure by crushing, CF2=Failure by splitting

D. *Shear Bond Strength:*

The masonry prisms of Triplet and Quadruplet are constructed using partially pre wetted bricks to prevent movement of water from mortar to the bricks. Cement Mortar of grades CM1:4, 1:6 and 1:8 used consisted of cement and fly ash in the percentage of replacement of 0%, 25% and 50% and M-Sand as fine aggregates, replacing partially with pond ash at percentage of replacement of 0%, 25% and 50%. The water cement ratio obtained by flow table test is used to mix the mortar and to prepare masonry blocks. The thickness of mortar is varied from 8mm to 10mm. The specimens are cured in water 28 days using wet gunny bags.

Specimens are tested after 28 days of curing. The loading arrangement is made in such a way that that parallel motion of the top and base bricks is arrested and only the center brick is allowed to move freely in parallel direction. Shear load is applied steadily utilizing the hydraulic jack till the bond amongst brick and mortar joint fizzled and subsequently giving shear bond strength of the given specimen.

The shear failure can be classified as follows

Type I: Bond failure i.e., failure will take place at brick-mortar interface. (SF1)

Type II: Brick failure i.e., failure of brick take place not at brick-mortar interface. (SF2)

Type III: a combination of I and II.

V. RESULTS AND DISCUSSION

A. *Results of Fresh Properties of Mortar - Flow Table Test:*

Grade of mortar	Sl.No	Designation	Water Cement ratio	Flow (%)
CM(1:4)	1	$4A_{0,0}$	0.75	110
	2	$4A_{25,25}$	1.00	110
	3	$4A_{50,50}$	1.55	112
	4	$4A_{50,75}$	1.85	115
	5	$4A_{50,100}$	2.2	110
CM(1:6)	1	$6A_{0,0}$	0.9	110
	2	$6A_{25,25}$	1.65	108
	3	$6A_{50,50}$	2.3	112
	4	$6A_{50,75}$	3.15	110
	5	$6A_{50,100}$	3.9	114
CM(1:8)	1	$8A_{0,0}$	1.25	112
	2	$8A_{25,25}$	2.4	114
	3	$8A_{50,50}$	3.45	110
	4	$8A_{50,75}$	4.1	115
	5	$8A_{50,100}$	5.9	110

Table 4: Flow Table Test

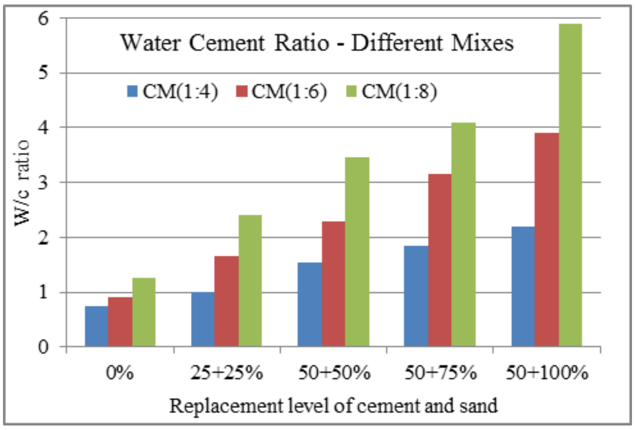

Fig. 1: Variation of W/C ratio of Different mixes of Cement Mortar CM 1:4, CM1:6 and CM1:8

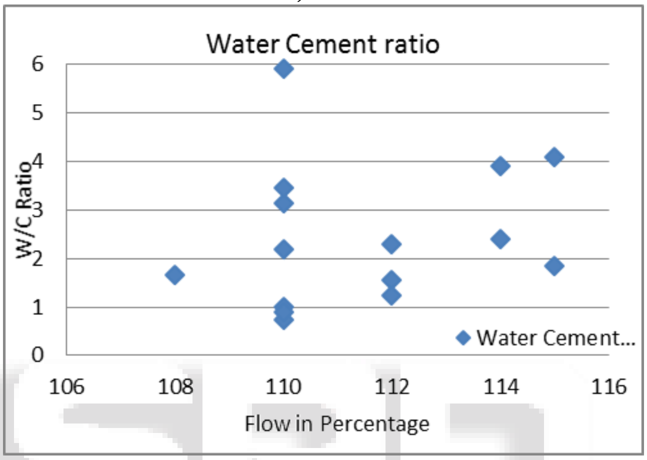

Fig. 2: Range of Flow measured using Flow Table Test

The observations made from the results are as follows.

- As the grade of mortar is changed from higher grade of 1:4 to lower grades of 1:6 and 1:8, water and admixture requirement of mortar is also increased to get the required flow of 110 – 115. Except mix CM6A25,25 with flow percentage of 108, all other mixes have satisfied the intended flow rate as per the standard specifications. This behaviour is attributed to the higher percentage of fine aggregates in the lower grades of concrete and vice versa.
- It was observed that at higher replacement levels of pond ash in the mortar mixes, the mortar mix exhibited harshness of the mixes.

B. *Results of Compressive Strength of Cement Mortar:*

Grade of mortar	Sl.No.	Designation	Compressive Strength in N/mm² at Curing Period of		
			7 Days	14 Days	28 Days
CM(1:4)	1	$4A_{0,0}$	7.20	12.00	22.90
	2	$4A_{25,25}$	4.50	8.53	12.67
	3	$4A_{50,50}$	2.00	2.10	7.06
	4	$4A_{50,75}$	0.95	0.92	4.13
	5	$4A_{50,100}$	0.85	0.80	1.90
CM(1:6)	1	$6A_{0,0}$	5.10	10.12	14.80
	2	$6A_{25,25}$	2.90	2.92	8.40
	3	$6A_{50,50}$	1.85	2.40	3.90
	4	$6A_{50,75}$	1.20	1.80	2.26

	5	$6A_{50,100}$	0.80	0.85	1.06
CM(1:8)	1	$8A_{0,0}$	3.15	4.80	10.00
	2	$8A_{25,25}$	1.90	2.95	5.90
	3	$8A_{50,50}$	1.15	1.80	3.33
	4	$8A_{50,75}$	0.80	1.10	1.20
	5	$8A_{50,100}$	0.40	0.80	0.80

Table 5: Compressive Strength of Cement Mortar

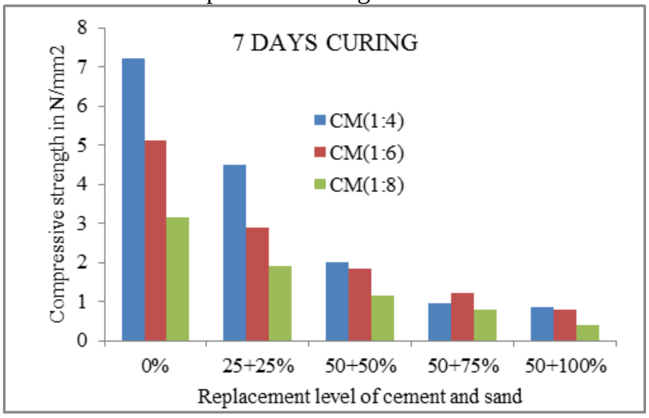

Fig. 3: Compressive Strength of Cement Mortar Mixes at 7 Days Curing Period.

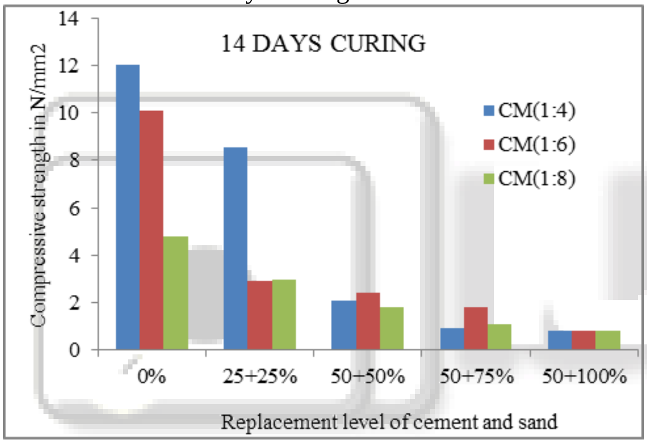

Fig. 4: Development of Compressive Strength of CM mixes at a Curing Period of 14 days

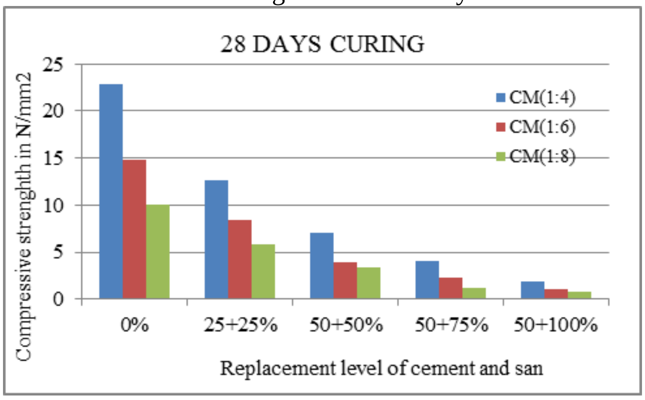

Fig. 5: Compressive Strength of Mortar Mixes at 28 days of Curing Period

The observations made from the results are as follows.

- The compressive strength assessed after 28 days of curing period of normal mortar with no replacement for grade of CM (1:4), CM (1:6) and CM (1:8) was 22.9, 14.8 and 10 N/mm2.
- The compressive strength of mortar mixes with different levels of replacement of fly ash and pond ash as alternative materials to cement and fine aggregates respectively, investigated at the end of 28 days of curing are of the range mentioned as follows. The strength ranges from 12.67 to 1.9 MPa for CM (1:4), 8.4 to 1.06 MPa for CM (1:6) and 5.90 to 0.8 MPa for CM (1:8). The results are within the specified range of values specified as per IS 1905 – 1987, satisfying the minimum compressive strength requirement of mortar mixes.

C. Results of Compressive strength of Masonry Prism

Grade of CM	Designation of Specimen			Failure Load (kN)	Compressive Strength (N/mm^2)	Corrected compressive strength (N/mm^2)	Mode of failure
CM(1:4)	Triplet	8mm	$4A_0$	65	2.56	1.94	CF1
			$4A_{25,25}$	55	2.173	1.65	CF2
			$4A_{25,50}$	46	1.81	1.37	CF1
		10mm	$4A_0$	98	3.87	2.97	CF1
			$4A_{25,25}$	87	3.438	2.64	CF2
			$4A_{25,50}$	61	2.41	1.85	CF2
	Quadruplet	8mm	$4A_0$	75	2.96	2.516	CF1
			$4A_{25,25}$	68	2.68	2.27	CF1
			$4A_{25,50}$	64	2.52	2.142	CF1
		10mm	$4A_0$	111	4.38	3.76	CF2
			$4A_{25,25}$	98	3.87	3.32	CF1
			$4A_{25,50}$	78	3.08	2.64	CF2

Table 6: Results of compressive strength of masonry prism for CM (1:4)

	Designation of Specimen			Failure load (KN)	Compressive strength(N/mm^2)	Corrected compressive (N/mm^2)	Mode of failure
CM(1:6)	Triplet	8mm	$6A_0$	63	2.49	1.89	CF2
			$6A_{25,25}$	48	1.89	1.44	CF1
			$6A_{25,50}$	42	1.66	1.26	CF1
		10mm	$6A_0$	97	3.83	2.91	CF1
			$6A_{25,25}$	82	3.24	2.49	CF2
			$6A_{25,50}$	58	2.29	1.76	CF2
	Quadruplet	8mm	$6A_0$	82	3.24	2.75	CF1
			$6A_{25,25}$	61	2.41	2.05	CF1
			$6A_{25,50}$	53	2.09	1.77	CF1
		10mm	$6A_0$	107	4.22	3.62	CF1
			$6A_{25,25}$	95	3.75	3.225	CF2
			$6A_{25,50}$	72	2.84	2.44	CF1

Table 7: Results of compressive strength of masonry prism for CM (1:6)

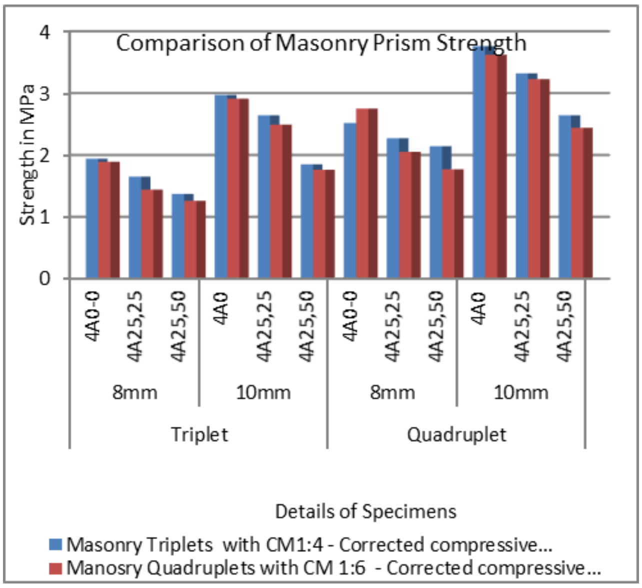

Fig. 6: Comparison of Compressive Strength – Masonry Triplets and Quadruplets

The observations made from the results are as follows.

- The Compressive strength of masonry Triplet with control mortar of grade CM (1:4) for mortar layer thickness of 8mm and 10mm is 1.94 MPa and 2.97 MPa respectively. The masonry triplets take more load, in turn show higher strength at 10mm thick mortar layer.
- The reduction in compressive strength is observed in masonry blocks with mortar having higher content of pond ash. The reduction in strength of masonry block with 8mm thick mortar with replacement of 25% cement with fly ash and and 25% of M-sand with Pond ash is 14.9% (23.8% for triplets with 10mm thick mortar of CM1:6), where in reduction is 29.3% (33.3% for triplets with 10mm thick mortar of CM1:6) when the replacement of M-Sand by pond ash is increased to 50%.
- When the mortar thickness is increased to 10mm the reduction in compressive strength observed is 11.1% (14.4% for triplets with 10mm thick mortar of CM1:6) and 37.7% (39.5% for triplets with 10mm thick mortar of CM1:6) for the above conditions.
- This shows that 10mm thick mortar layer provides higher strength and optimum replacement level is 25% for cement with fly ash and 25% for M-sand with pond ash.
- The rate of reduction of strength observed for richer grade of CM1:4 is lesser compared to that of CM1:6 as expected

D. Results of Shear Bond Strength of Masonry;

Grade of mortar			Designation of Specimen	Failure load (KN)	Shear bond strength (N/mm2)	Mode of failure
CM(1:4)	Triplet	8mm	$4A_0$	14	0.525	SF1
			$4A_{25}$	12	0.45	SF1
			$4A_{50}$	8	0.30	SF2
		10mm	$4A_0$	22	0.79	SF1
			$4A_{25}$	17	0.61	SF1
			$4A_{50}$	9	0.32	SF2
	Q	8	$4A_0$	18	0.51	SF1
			$4A_{25}$	16	0.45	SF1
			$4A_{50}$	10	0.28	SF2
		10mm	$4A_0$	25	0.68	SF1
			$4A_{25}$	17	0.46	SF1
			$4A_{50}$	11	0.30	SF1

Table 8: Results of Shear Bond Strength of masonry prism with CM 1:4

Grade of mortar			Designation of Specimen	Failure load (KN)	Shear bond strength (N/mm2)	Mode of failure
CM(1:6)	Triplet	8mm	$6A_0$	14	0.52	SF1
			$6A_{25}$	11	0.41	SF1
			$6A_{50}$	6	0.22	SF2
		10mm	$6A_0$	18	0.64	SF2
			$6A_{25}$	14	0.50	SF1
			$6A_{50}$	9	0.32	SF2
	Quadruplet	8mm	$6A_0$	14	0.39	SF1
			$6A_{25}$	13	0.36	SF1
			$6A_{50}$	10	0.28	SF2
		10mm	$6A_0$	21	0.58	SF1
			$6A_{25}$	16	0.44	SF2
			$6A_{50}$	8	0.22	SF1

Table 9: Results of Shear Bond Strength of masonry prism with CM 1:6

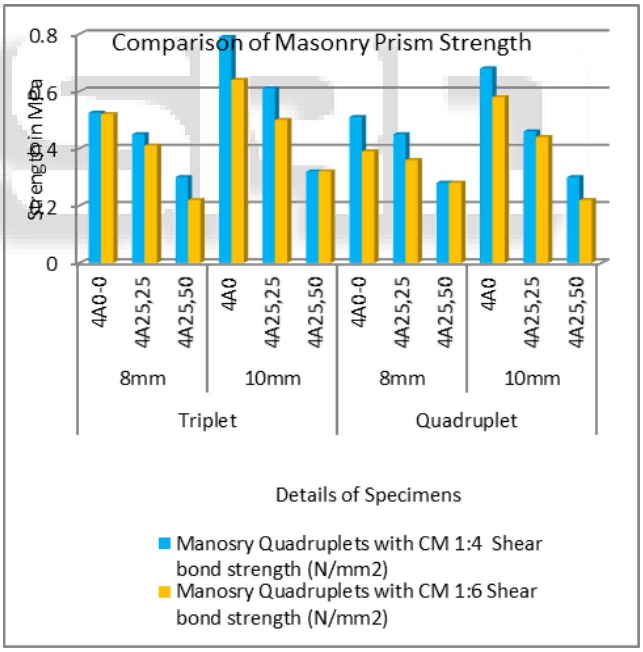

Fig. 7: Comparison of Shear Bond Strength – Comparison of Behavior of Masonry Triplets and Quadruplets

The observations made from the results of shear bond strength are as follows.

- The Shear Bond strengths of masonry Triplets with normal mortar of grade CM (1:4) for mortar layer thickness of about 8mm and 10mm are 0.563 MPa and 0.703 MPa respectively. The reduction in Shear Bond strength of different mixes with replacement level 25% for both cement and Fine aggregates is least and the same can be considered as optimum replacement level for mortar mixes.

- The reduction in the shear bond strength is more for higher thickness of 10mm and for 8mm, indicating that 8mm mortar layer of CM1:6 is better for building walls.
- As the grade of mortar changes from lighter to richer, the thickness of the mortar layer required decreases.
- The masonry triplets with 8mm thick mortar later is resisting more shear load than the quadruplets having same thickness of mortar of same grade. Similar result is observed even with 10mm thick layer of mortar of Cm1:4 indicating that lesser thickness is better in resisting shear in case of mortar of grade 1:4.
- The resistance of masonry triples to shear bond of CM1:6 is more with 10mm thick mortar layer than that of quadruplets with mortar layer of 8mm for the same grade of mortar.

VI. Conclusions

1) Pond ash is lighter than Natural River Sand and has lower specific gravity.
2) The presence of fly ash makes the mixes of mortar more workable and presence of pond ash makes the mixes slightly harsh.
3) The compressive strength of mortar at different replacement level satisfy the minimum compressive strength requirements as per IS 1905-1987 for different grade of mortar.
4) The particles of pond ash are porous and hence make the Fa-Pa Bricks lighter at higher replacement levels.
5) Masonry triplets of Fa-Pa blocks with mortar of CM1:6 of 10mm thick layer and Fa-Pa Block with 8 mm thick layer of CM1:4 provide the strength comparable to each other and are slightly lesser than that of normal mixes.
6) The reduction in the shear bond strength is more for higher thickness of 10mm and for 8mm, indicating that 8mm mortar layer of CM1:6 is better for building walls.

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