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Evaluating the Efficacy of Mortar Prepared by Replacing the Sand with Industrial Solid Waste like Quarry Dust and Foundry Sand in Varying Proportion

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Abstract—The purpose of this study is to evaluate the strength of the mortar that is prepared by replacing the fine aggregate i.e. sand with 0%, 25%, 50% and 100% of Quarry dust and Foundry sand respectively. These industrial by-products are generally dumped in landfills in huge quantities which disturbs the Ecology. In this study, an attempt is made to evaluate the efficacy of the waste products when used in mortar for brick masonry. The experimental program was conducted in 2-phases. In the first phase, all the characteristic properties were determined for both the basic constituent's i.e. Foundry sand and Quarry dust. The preliminary test included the chemical analysis, Sieve analysis, Bulk density, Specific gravity, Water absorption and Moisture content. Two proportions of the mortar were selected for the study i.e. 1:4 and 1:6. A set of 3 cubes for each proportion and combination i.e. mortar prepared using 0%, 25%, 50% and 100% of Foundry sand; Quarry dust were prepared respectively. In all 84 specimens of mortar cubes with mortar ratio of 1:4 and 1:6 were casted and tested to obtain the 7 days and 28 days compressive strength. In the second phase of test program, the mechanical properties of the final end product i.e. Brick masonry were determined. The tests included the Compressive strength of the brick prisms, Bond strength of the mortar in brick prism under flexure and in shear.

Keywords-Quarry dust, Foundry sand, Compressive strength of Mortar, Compressive strength of Masonry Prism, Masonry bond strength in Shear and Flexure

I. INTRODUCTION

Now days the growth of the construction industry globally has resulted into dearth of the virgin materials used in the construction work. These materials include natural river sand, aggregates and water. The incessant use of these materials has resulted into shortage, eventually that will lead to a yawning gap between the supply and demand. Non-renewable resources takes millions of years to be produced, once used they are not replaceable in human time frame. And also industrial solid wastes like Quarry stone dust and Foundry sand are generated abundantly, creates disposal problem due to the lack of landfill sites for these waste disposal.

II. SCOPE OF THE WORK

The main objective of the study is to evaluate the efficacy of the mortar prepared replacing the fine aggregate in mortar with 0%, 25% ,50% and 100% by weight of Natural sand with Quarry dust and Foundry sand respectively. To this aim, the following tests were performed:

1. Characteristics like Grading of fine material obtained, specific gravity, Bulk density were determined
2. Mortar mixture prepared using the quarry dust and foundry sand
   (i) Flow / Workability, Water retention and Compressive strength of the mortar
3. Brick Prisms prepared using the test mortar mixture

(i) Compressive strength, water absorption of bricks
(ii) Compressive strength of the Brick Masonry using the designed mortar mixture
(iii) Bond strength in shear using triplet bond test
(iv) Bond strength in flexure using the modified Bond wrench test set-up

III. EXPERIMENTAL PROGRAM

3.1. Phase - 1

All the basic tests were carried out to characterise the ingredients that were used in preparing the test mortar i.e. Natural river sand, Quarry dust powder and Foundry sand. Quarry dust was collected from the Vasavad, near Rajkot. Foundry sand was taken from Rajkot. The basic tests included the Chemical analysis, Sieve analysis, Bulk density, Specific gravity. All the tests were carried out in accordance with the relevant Indian standards. The results of the tests are listed below:

The results of the Quarry dust powder (QD), Foundry sand (FS) and the Natural sand (NS) using the sieve analysis as per the IS: 2116-1980 Standard Specification for sand for Masonry mortars is shown in Table -1. Chemical analysis is listed in Table-2, Bulk density, Specific gravity are listed in Table-3

Table 1.Sieve analysis of the fine aggregate ***Table 2.Chemical analysis of the fine aggregate***

Sr. No	*Sieve size*	*% passing for QD*	*% passing for FS*	*% passing for NS*	*Specification , % passing*
1	4.75 mm	100	100	99.75	100
2	2.36 mm	89.20	92.50	91.55	90-100
3	1.18 mm	71.35	83.20	81.20	70 -100
4	0.600 mm	41.60	65.85	60.30	40 -100
5	0.300 mm	21.05	31.90	25.10	5 -70
6	0.150 mm	10.09	10.70	06.20	0 -15
7	< 0.150mm	-	-	-	

Sr. No	*Test*	*Sample: QD*	*Sample: FS*
1	SiO2	51.99	85.68
2	Fe2O3	8.34	5.50
3	Al2O3	22.10	1.18
4	CaO	14.28	5.93
5	MgO	1.07	0.13
6	K2O	Absent	0.01
7	Na2O	Absent	0.10
8	DOC	0.41	0.62

Table 3.Properties of the fine aggregate

Properties	*Quarry Dust*	*Foundry Sand*	*Natural Sand*
Specific gravity	2.64	2.58	2.62
Bulk density	15.53 kN/m^3	14.35 kN/m^3	14.71 kN/m^3
Water absorption	5.8%	2.4%	2.0%
Moisture content	-	-	1.4%

Figure1. Texture of Natural sand, Quarry dust and Foundry sand respectively

3.1.1. Properties of the Mortar

Mortar mixtures thus prepared were tested for its important properties like Flow / Workability, Water retention and Compressive strength. Mortar proportion of 1:4 and 1:6 are selected for the present study. The w/c ratio was decided based on the amount of water that helped to achieve the required flow values between 110 to115 for a mortar paste with better consistency. Good workability of mortar helps to achieve a good extent of bond. Extent of bond refers to the amount

of intimate contact between the mortar and brick. Good extend of bond provides durability and resistance to water penetration.And alsowater retention of a mortar is a measure of the mortar's ability to retain its plasticity when subjected to the atmosphere or the absorptive forces of the masonry units.Water retentivity of mortar should not be less than 70% as per IS: 2250-1981.The following symbols are used to designate the Mix of mortar in study.**M1**- Cement: Natural River Sand (control mix), **M2**- Cement: 25% Quarry Stone Dust + 75% Natural River Sand, **M3**- Cement: 25% Foundry Sand + 75% Natural River Sand, **M4**- Cement: 50% Quarry Stone Dust + 50% Natural River Sand, **M5**- Cement: 50% Foundry Sand + 50% Natural River Sand, **M6**- Cement: 100% Quarry Stone Dust and **M7**- Cement: 100% Foundry Sand.The flow values and water retention values are indicated in the Table 4 and shown in Fig. 2. Flow test results shows that the flow values of M1, M2 and M3 do not vary much, which proves the designed mortar mixture to be workable enough for brick masonry works.

3.1.2.Compressive Strength of the Mortar

Compressive strength of the mortars is a very important property. Strength development of the mortar is an important requirement before the masonry is loaded to the full extent. 7^{th} and 28^{th} day compressive strength of the Mix-M1 to MixM7 with the mortar proportion of 1:4 and 1:6 were found as per the guidelines laid in IS: 2250-1981.The values of the compressive strength of 50x50x50 mm cubes were mentioned in Table4 represent a mean of three specimens. The results shows that the mortarprepared using the QD and FS (i.e. Mix-M2 and M3)gives higher values of compressive strength in comparison to the mortar prepared using Natural sand (Mix-M1).

Table4. Properties of the mortar

Mortar Proportion by weight	*Mortar mix designation*	*w/c ratio*	*Flow values in %*	*Water retentivity in %*	*7^{th} days Avg. Compressive strength in MPa*	*28^{th} days Avg. Compressive strength in MPa*
1:4	M1	0.633	111	72.3	7.6	13.5
	M2	0.76	114	80.75	8.10	14.45
	M3	0.66	110	74.89	7.73	13.89
	M4	0.91	112	76.3	7.93	12.73
	M5	0.96	111	71.4	6.33	11.27
	M6	1.09	110	68.5	6.73	11.87
	M7	1.26	113	75.3	4.80	7.26
1:6	M1	0.76	112	71.58	3.05	6.24
	M2	0.85	112	74.9	4.76	7.87
	M3	0.80	110	70.3	3.16	6.64
	M4	1.05	112	73.21	3.67	6.07
	M5	1.25	112	69.1	2.98	5.20
	M6	1.20	111	65.8	2.93	5.53
	M7	1.55	113	71.5	2.05	4.93

Figure2. Flow of Natural sand, Quarry dust andFoundry sand Mortar respectively

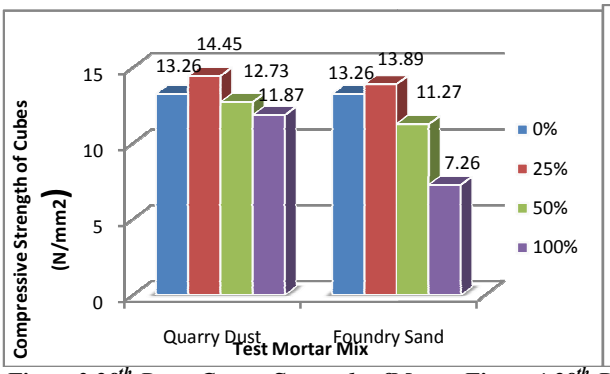

Figure3.28th Days Comp. Strength ofMortar Cubes vs. Test Mortar Mix 1:4

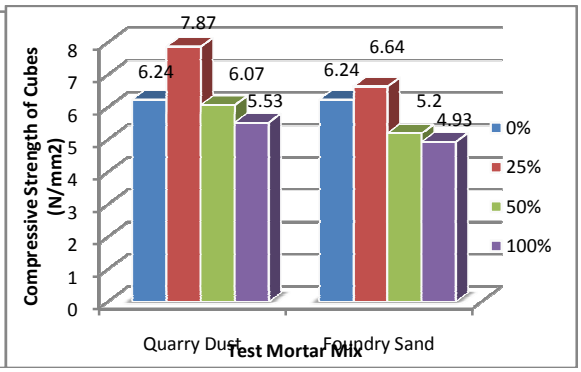

Figure4.28th Days Comp. Strength of Mortar Cubes vs. Test Mortar Mix 1:6

3.2 Phase – 2

3.2.1 Compressive Strength of the Brick Masonry

The brick prisms were built in accordance with IS: 1905-1987. Brick prisms of size 215 mm x 215 mm x 415 mm,having height to width ratio of 2.0 were prepared using bricks with compressive value of 5.88MPa. Water absorption of the bricks was found to 11.67 % respectively. Brick masonry prisms were casted and cured for a period of 28 days.3 set of prisms were casted and tested for each type of mix. Compressive strength values as obtained from the prism tests were multiplied by the correction factor as given in Table 12 of IS: 1905-1987.The mean value of the set of prisms are shown in Table 5. Also fig. 5 shows failure patterns of brick prisms made from three types of mortar.

Figure5. Failure pattern of brick prisms made from three different types of mortar

Table5. Compressive strength of brick masonry prism

Mix proportion by weight	*28th days Average Compressive Strength (MPa)*						
	M1	M2	M3	M4	M5	M6	M7
1:4	0.247	0.320	0.296	0.238	0.198	0.228	0.177
1:6	0.167	0.189	0.178	0.165	0.143	0.161	0.142

3.2.2. Bond Strength in Shear

The bond shear strength is determined by testing a triplet specimen such that only shear stresses develop in between the mortar and the masonry unit contact planes as shown in Figure 4. [1] Shear bond strength of brick triplet size240 x 215 x 100 mm was casted using prepared design mortar and tested at 28 days. 3 numbers of specimens for each type of mix were tested in shear. Average shear bond strength values are shown in Table 6.Shear bond strength (N/mm^2)was

calculated using the below equation: **Shear Bond Stress,** $\boldsymbol{\tau = \frac{P}{2A}}$ Where, P = Vertical compressive load in N; A = c/s area of the brick triplet; in mm^2.

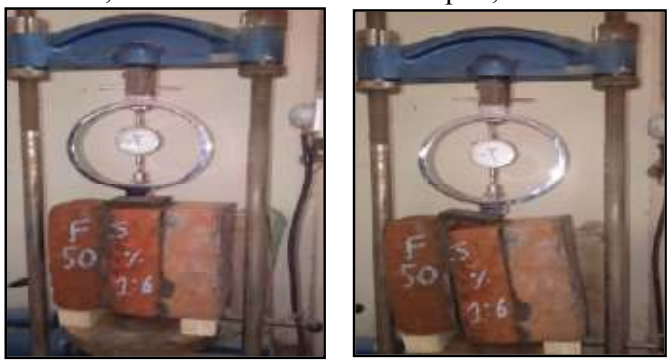

Figure6. Before and after failure pattern of brick triplet

3.2.3. Bond Strength in Flexure: Modified Bond Wrench Test set-up

Figure7 Shows the details of the modified bond wrench test setup [2]. The prism was supported on a rigid bottom. The bottom most brick of the prism was fully clamped. The load was applied to the top-most brick of the prism through a cantilevered arm with a hook connector installed at the end of the arm. An empty container was attached to the hook and then gradually filled using sand to apply load to the mortar joint until flexural bond failure occurred. This load causes a moment in the prism, which will further cause a flexure failure between the masonry unit and the mortar. Flexural bond strength of brick masonry prisms size215 x 490 x 100 mm were casted using prepared test mortar and tested at 28 days. 3 numbers of specimens for each type of mix were tested in flexure. Average flexural bond strength values are shown in Table 6.

$$\mathbf{f = \frac{M}{Z} = \frac{PL + P1\ L1}{Z}}$$

Where, P = maximum applied load (N),L = distance from center of prism to loading point = 780 mm, P1 = weight of loading arm and brick unit (N) = 27.47 N,L1 = distance from center of prism to centroid of loading arm = 280 mm, and Z = section modulus of section (mm^3).

Figure7.Modified bond-wrench test setup

Table6.Bond strength in Shear and Flexure

Mix Proportion by weight	*28th days Average Bond Strength in Shear (MPa)*							*28th days Average Bond Strength in Flexure (MPa)*						
	M1	M2	M3	M4	M5	M6	M7	M1	M2	M3	M4	M5	M6	M7
1:4	0.209	0.290	0.244	0.158	0.169	0.11	0.157	0.23	0.28	0.24	0.21	0.26	0.20	0.22
1:6	0.106	0.161	0.136	0.078	0.08	0.065	0.070	0.20	0.23	0.205	0.18	0.17	0.15	0.19

IV. CONCLUSION

- 7^{th} daysand 28^{th} days Compressive strength of the mortar mixture prepared using 25% Quarry Dust and Foundry Sand is found to be higher in comparison to the mortar prepared using Natural River Sand.
- The Compressive strength test results confirm that the performance of the Quarry Dust (25%) and Foundry Sand (25%) as fine aggregate in brick work, increases compare to that obtained for the prisms made from Natural River Sand.
- Bond strength in Shear and Flexure for Mortar Mix 1: 4 and 1:6 made from 25% replacement of Natural sand with QD, FS increases compared to Natural sand.
- 25% replacement of Natural river sand with Quarry dust and Foundry sand gives a workable mortar mixture without compromising of the strength in Compression, Flexure and Shear.

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