EFFECT ON PHYSICAL AND MECHANICAL PROPERTIES OF CEMENT MORTAR PREPARED WITH WASTE GRANITE POWDER AS SECONDARY AGGREGATE

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ABSTRACT. The main objective of this paper is to provide an alternative to conventional fine aggregate for the production of cement mortars. Two widely used mortar mix proportions (1:4 and 1:6) were selected for this experimental study, where granite powder of fineness modulus of 0.9 was used as fine aggregate. The experimental study was performed in two stages. In the first stage, fine sand of fineness modulus of 1.65 was replaced in the range of 0% to 100% by granite powder. Workability, fresh bulk density, compressive strength and water absorption were evaluated and their results were compared with those of control mortar. Results showed that on complete substitution of river sand by granite powder, w/c required to achieve necessary workability increased from 1.2 to 2.3. Hence these mortar mixes showed a fall in compressive strength by 41% and increase in water absorption by 56%. In the second stage, granite powder was used as a replacement of 30% and 40% volume of fine aggregate. The remaining volume of fine aggregate constituted of coarse sand of fineness modulus of 2.65. This was done in order to achieve required gradation as per BIS specifications. Parameters mentioned above were evaluated again. On studying the results, it was found that compressive strength for blended mixes increased by 11% as compared to that of the control mix with no change in water absorption properties. It was concluded that a sustainable mortar can be produced by replacing 30% to 40% of volume of fine aggregate by granite powder.

Keywords: Cement mortar, Granite powder, Gradation, Fineness modulus, Workability.

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INTRODUCTION

The Indian state of Rajasthan has about 20% of total granite reserves of the country [23]. To obtain a finished product of granite dimensional stone, the extracted granite block is processed by sawing and polishing using advanced tools. However the by–product generated in the form of fine granite dust with water (granite slurry) during this industrial processing is very large. On dumping, the water in the granite slurry (GS) evaporates and only fine dust of granite remains. This granite powder (GP) is lifted up by air and moves with the wind to create environmental and health problems. In humans, GP can cause breathing disorders and lung diseases. GP being fine in nature, clogs the space between the particles of soil which reduce its fertility and stop percolation of water into the ground. When GS is discharged haphazardly near river beds and lakes, it can reduce the quality of open source of fresh water and cause significant damage to aquatic life also. Hence controlled disposal of GS is very crucial for the granite dimension stone industry to be sustainable.

On the other side, economic growth of the country needs a robust infrastructure which can in turn help improve the quality of life of its citizens. For construction of infrastructure, the building materials industry needs natural resources which are only limited. Cement composite based building materials need significant amount of natural stones in the form of fine aggregate. Given the prevailing nature of environmental problems, access to good quality fine aggregate is also a big challenge. A report prepared by a German company with the title “Material Consumption Patterns in India” revealed that by the year 2020, India will require 1.4 billion tonnes of fine aggregate for construction every year. Also, the fine aggregate requirement for mortar preparation alone will be 248 million tonnes/annum [9]. Sand from river beds is the main source for the above huge requirement of fine aggregates. Apart from this, there are other industrial by – products which can be used to partially replace river sand as fine aggregate. However the availability of such waste materials is limited and region based. Hence for a state like Rajasthan which is plagued by problems associated with GP waste from granite processing, utilization of the same as fine aggregate appears to be a lucrative option. Such utilization will help resolve the problems associated with disposal for GP and also reduce the need of natural fine aggregate for construction.

There are several studies which have evaluated the effect of GP as fine aggregate [18, 21, 22, 24, 26] and alternative binder [1, 8, 10, 20] in concrete and brick manufacturing [19, 25]. Literature pertaining to the studies of mortars prepared with GP is very limited. The pioneer of such an evaluation were Bonavetti and Irassar (1994) who found out that 10% substitution of sand by granite dust increases the compressive and flexural strength of mortars [27]. Marmol et al. (2010) used granite cutting waste (up to 10% replacement of cement) for the preparation of coloured and masonry mortars without compromising compressive strength [11]. Ramos et al. (2013) concluded that usage of granite sludge waste as a replacement of cement by up to a level of 10%, enhances the durability of mortars [2]. A.O. Mashaly et al. (2018) revealed that up to 20% replacement of cement by granite sludge, there is no negative effect on physical, mechanical and durability properties of mortars [28].

The above short literature review on utilization of GP in concrete and mortar shows that GP has been tested to a lesser extent as a potential secondary aggregate for production of mortars. Hence, this paper represents a successful attempt in which sustainable mortars are prepared using waste GP as a replacement for valuable river sand.

MATERIAL INGREDIENTS

For the experimental program, pozzolanic Portland cement (PPC) was utilized conforming the specifications set by IS 1489 - Part 1 (1991) [13]. The specific gravity and loose bulk density was found to be 2.9 and 1100 kg/m^3 respectively.

River sand of two particle size distributions were procured from a local dealer in Rajasthan. Based on the particle size distribution, they were designated as coarse sand (CS) and fine sand (FS). CS and FS conformed to zone – II and zone – IV respectively as per IS 383 (2016) [12]. Physical properties of both the samples are enlisted in Table 1.

Table 1 Physical properties of fine aggregates

FINE AGGREGATE	SPECIFIC GRAVITY	WATER ABSORPTION (%)	LOOSE BULK DENSITY (KG/M^3)	FINENESS MODULUS
	IS 2386 Part 3 (1963)			ASTM C 33
Coarse river sand (CS)	2.68	7.05	1597	2.65
Fine river sand (FS)	2.65	8.83	1545	1.65
Granite Powder (GP)	2.46	15.29	1368	0.9

Granite powder (GP) used to replace sand in cement mortar was procured from Shahpura Stone Processing Industry, Shahpura, Jaipur, Rajasthan. GP was sun dried to remove the moisture before characterization and utilization in mortar production. On carrying out particle size analysis it was found that GP can be assigned to zone – IV category of IS 383 (2016) [12]. Physical properties of GP are detailed in Table 1.

The chemical analysis for all fine aggregates used (CS, FS and GP) was carried out using X – ray fluorescence (XRF) technique (Table. 2). From this table it can be seen that, the proportion of silica (SiO_2) was approximately similar in all of three fine aggregates. The quantity of Fe_2O_3 and CaO was nearly nil in GP. The amount of Al_2O_3 and Na_2O was slightly higher in GP than in both sand samples.

The microstructure of fine aggregates was analysed through SEM (Scanning Electron Microscopy) technique. The SEM images of CS, FS and GP are presented in Figure 1. The surface of both conventional sands is very smooth and rounded, but of granite powder is very rough and angular.

Table 2 Chemical composition of fine aggregates

OXIDES	COARSE SAND (%)	FINE SAND (%)	GRANITE POWDER (%)
SiO_2	75.82	73.46	74.39
Al_2O_3	10.17	10.78	13.5
Fe_2O_3	3.15	3.38	0.86
MgO	1.19	1.33	0.38
MnO	0.08	0.09	0.02
CaO	3.36	3.58	0.41
Na_2O	2.17	2.25	4.16
K_2O	1.9	2.06	4.79
TiO_2	0.42	0.45	0.17
P_2O_5	0.07	0.08	0.02

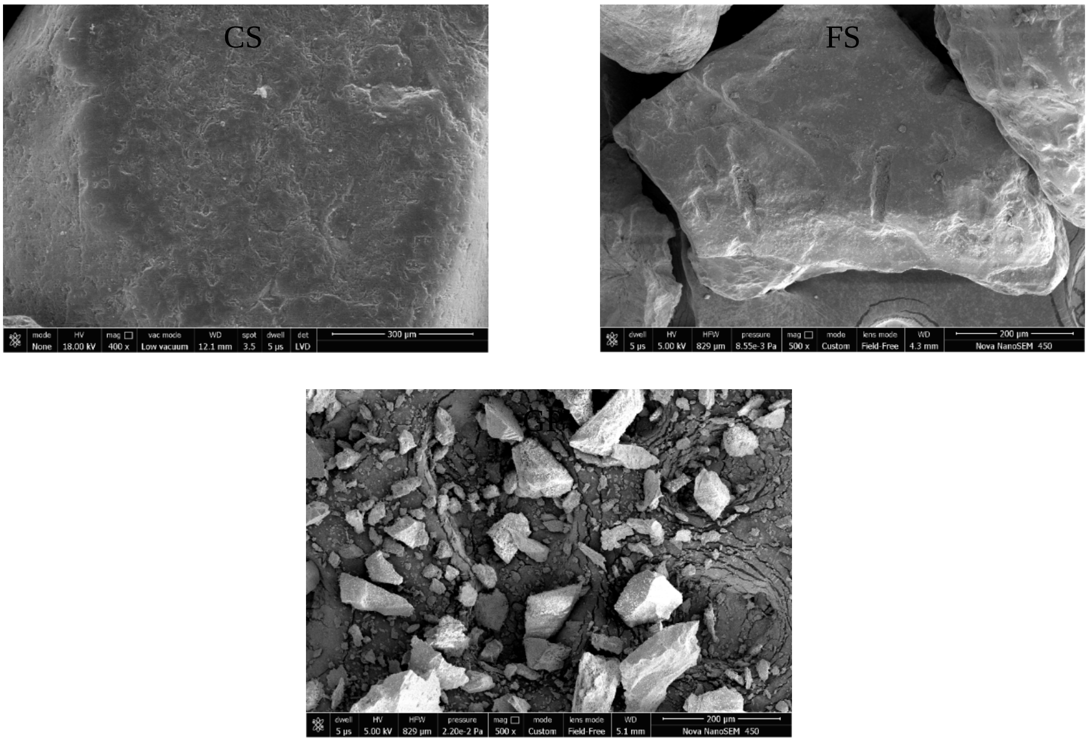

Figure 1   SEM images of fine aggregates

METHODOLOGY

In line with the set objectives, river sand was replaced in different proportions by GP for the production of cement mortars. The experimental study was carried out on mortars with mix proportions of 1:4 and 1:6. Two type of conventional fine aggregates were used in two stages of this investigation.

Stage I

In this stage, FS (zone – IV) was used for the preparation of control mortar. This fine sand also conformed to the particle size distribution requirements set by IS 2116 (1980) (specification for sand for masonry mortars) [3] and IS 1542 (1992) (specification for sand for plaster) [15]. FS was replaced from 0% to 100% in intervals of 10% by GP. Quantities of materials required to produce one m^3 of mortar is given in Table 3. Workability, fresh density, compressive strength and water absorption were evaluated and their results were compared with those of control mortar.

Table 3 Quantities of materials to prepare one cum of mortar mixes

% REPLACEMENT	1:4 MIX				1:6 MIX			
	Cement (kg)	FS (kg)	GP (kg)	Water (kg)	Cement (kg)	FS (kg)	GP (kg)	Water (kg)
0	273	1534	-	328	189	1591	-	337
10	269	1362	135	344	189	1432	141	344
20	266	1195	266	354	188	1268	281	348
30	268	1054	400	351	188	1108	420	351
40	271	913	539	347	187	948	559	354
50	271	760	674	349	186	784	694	361
60	270	607	804	354	185	624	829	366
70	268	453	933	359	183	464	958	374
80	265	297	1056	369	182	306	1085	382
90	261	146	1171	379	180	151	1206	391
100	258	-	1283	390	178	-	1331	398

Stage II

In this stage, CS (zone – II) and GP were combined such that the resulting composite fine aggregate mixture satisfied the gradation requirements stipulated by IS 2116 (1980) [3] and IS 1542 (1992) [15]. Based on trials, the required gradation was achieved when 30% to 40% of CS was replaced by GP. Hence mortar mixes of the same two proportions were prepared in which GP constituted 30% and 40% of fine aggregate volume. Quantities of materials required to produce one m^3 of mortar is given in Table 4. Parameters like workability, fresh density, compressive strength and water absorption by capillary (sorptivity test) were evaluated. These results were compared with those of control mortar prepared by fine sand in Stage I. The details of the specifications followed for conducting the tests on mortar mixes are tabulated in Table 5.

Table 4 Quantities of materials for one cum of mortar mixes

Mix	Cement (kg)	CS (kg)	FS (kg)	GP (kg)	Water (kg)
4FS	273	-	1534	-	328
4CS-30	279	1136	-	416	313
4CS-40	277	964	-	551	322
6FS	189	-	1591	-	337
6CS-30	192	1171	-	430	323
6CS-40	193	1009	-	575	327

Table 5 Details of the tests

S. NO.	TEST	SPECIFICATION
1.	Consistency of mortar (Flow)	ASTM C 1437 (2001)
2.	Fresh density	ASTM C 270 (2003)
3.	Compressive strength	IS 2250 (1981)
4.	Water absorption	ASTM C 642 (2006)
5.	Sorptivity	ASTM C 1403 (2000)

RESULTS AND DISCUSSIONS

Stage I

The workability of all the mortar mixes was fixed to a flow value of 110% to 115% using the flow table test. Water cement ratio (w/c) was varied in order to obtain the above requirement. As seen from Table 3, w/c had to be increased when the quantity of GP increased from 0% to 100% for both the mix proportions. At 40% replacement of FS by GP, water requirement increased by 6% (1:4 mix) and 5% (1:6 mix) only, whereas the increment in water content is about 19% (1:4 mix) and 18% (1:6 mix) when FS is completely replaced by GP. This increase in w/c was due to higher fineness of granite powder (Refer Table 1) when compared to FS in blended mortars.

The variations in fresh density with increase in replacement of FS by GP is shown in Figure 2. From this figure it can be seen that, the fresh density of mortars has reduced with increase in the substitution level of GP. This reduction can be because of lower specific gravity of granite powder (Refer Table 1) than fine sand. Additionally, presence of greater amount of water in mixes with GP has also contributed to reduction of the same parameter.

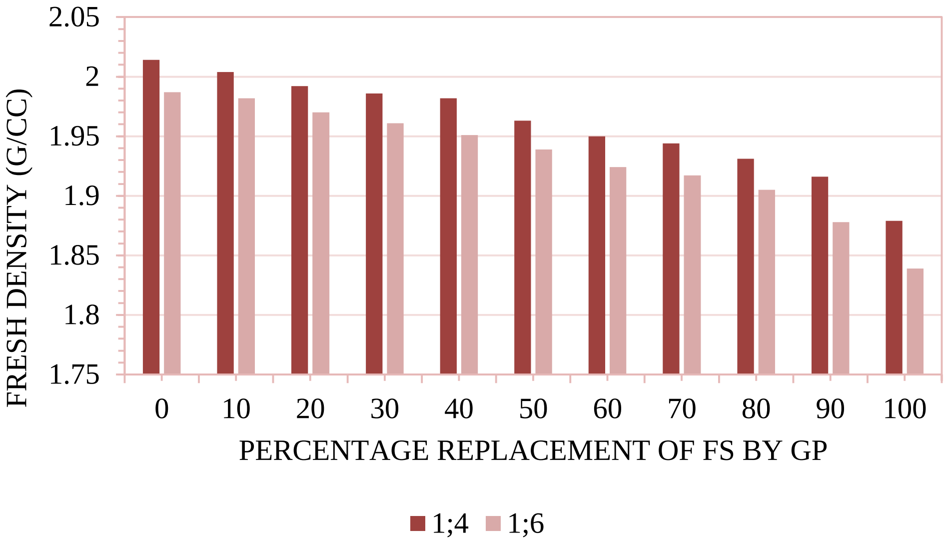

Figure 2 Fresh density of mortars prepared in Stage I

The changes in compressive strength on replacement of FS by GP after 7 days and 28 days of curing is graphically presented in Figure. 3. Like fresh bulk density, compressive strength also reduced with in GP quantity in mortars for both the mix proportions and both the curing periods. At complete substitution the reduction in compressive strength is 41% and 21% for 1:4 and 1:6 mix proportions respectively after 28 days of curing. This decrement in compressive strength can be directly linked to increment of w/c ratio of mixes with GP.

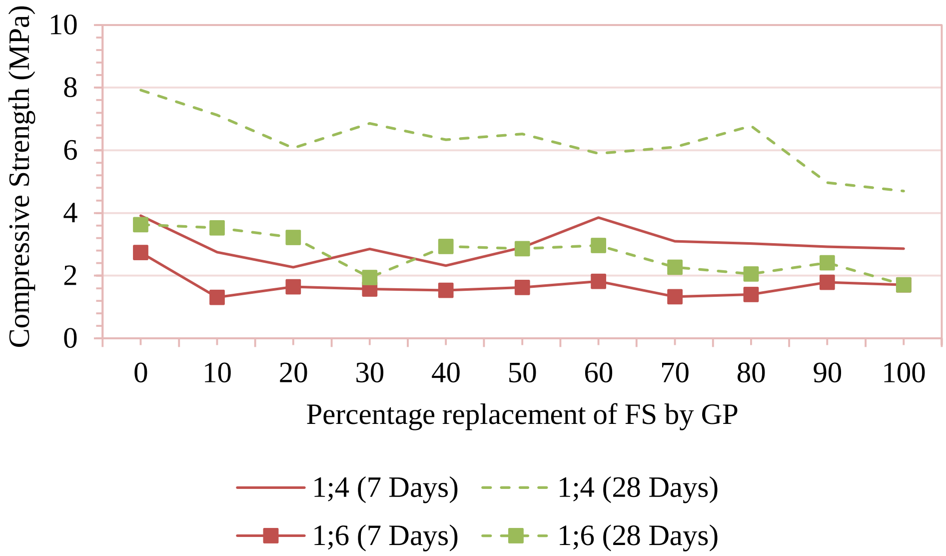

Figure 3 Compressive strength of mortars in Stage I

The variation in water absorption capacity of mixes with GP for both the mix proportions is shown in Figure 4. The pattern obtained here also confirms the role of w/c ratio for both mix proportions. The increment of w/c ratio in mortars with GP might have created more voids and these voids have been responsible for higher water absorption capacity of such mixes when compared to the corresponding control mortars. Therefore it can be concluded that on inclusion of GP in place of FS, the resulting mortars mixes require higher amount of water and hence such mixes have lesser compressive resistance and absorb more water.

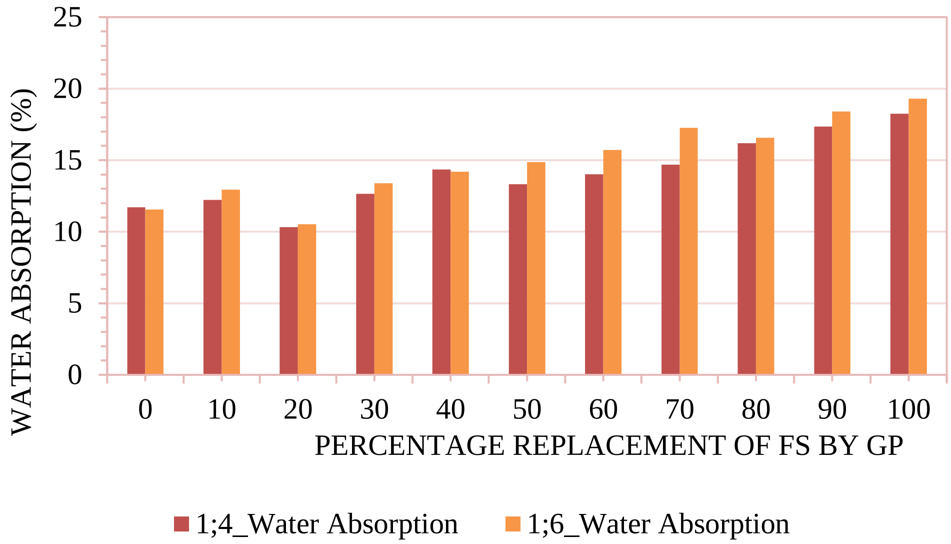

Figure 4 Water absorption of mortars prepared in Stage I

To reduce the fineness of the fine aggregates, sand which is slightly coarser in nature was used to combine with GP. Results obtained on evaluating their performance is given the following section.

Stage II

After the failure of blended mortars with FS, trials were conducted, where a coarser river sand sample (CS) was used instead of FS. During this stage of the study it was made sure that incorporation GP does not increase the net fineness of composite fine aggregate grading when compared to the stipulated FS alone. Hence stipulated gradations given in relevant standards were achieved with CS and GP when both of these were combined in the ratios of 70:30 & 60:40. The fineness modulus of these composite grading is given is 1.74 and 1.64 respectively. These values are very much similar to the fineness modulus of FS alone.

The results for blended mortars in Stage II were compared with control mortar prepared with fine sand in Stage I. On analysing the amount of water required (w/c) (Table 4) for mortar mixes to obtain the necessary workability, it can be seen that for blended mortars, w/c were lower than that of w/c ratio of control mortar prepared with FS only. This reduction in w/c ratio may be due to effect of pore filling of voids by granite powder which was earlier occupied by water. This pore filling effect reduces the plastic viscosity of mortar mixes which in turn helps in improving the workability. The pore filling effect can be confirmed by the increase in the fresh density values of blended mortar when compared to the control mortar as shown Figure 5.

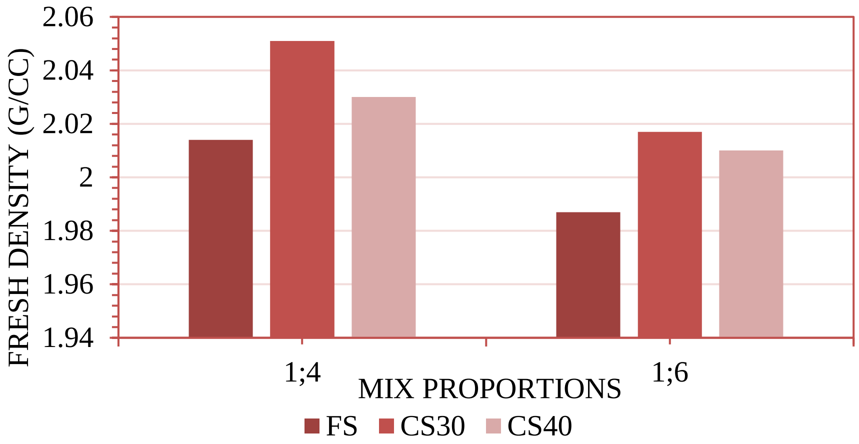

Figure 5 Fresh density of mortars prepared in Stage II

The variation in compressive strength of mortar mixes is shown in Figure 6. The compressive strength for blended mixes increased by 11% of the control mix. The increment in compressive strength of these mortars mixes can be due to lower w/c ratio and pore filling effect of granite powder. The rough texture and angularity of granite powder (Refer to Figure 1) might have also contributed to this gain in compressive strength.

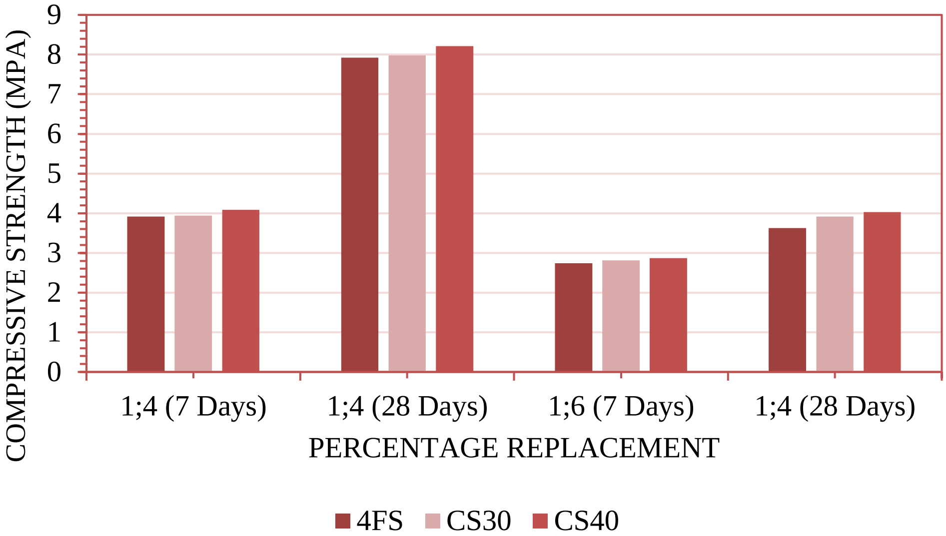

Figure 6 Compressive strength of mortars prepared in Stage II

The results obtained in water absorption by capillary (sorptivity test) are shown in Figure 7. The results indicate that there is reduction in capillary action with the incorporation of GP in cement mortar. This reduction in capillary action may be due to the rough and angular surface of GP which improved bond between cement and aggregate. The pore filling effect due to inclusion of GP is also reflected in the results achieved in this test.

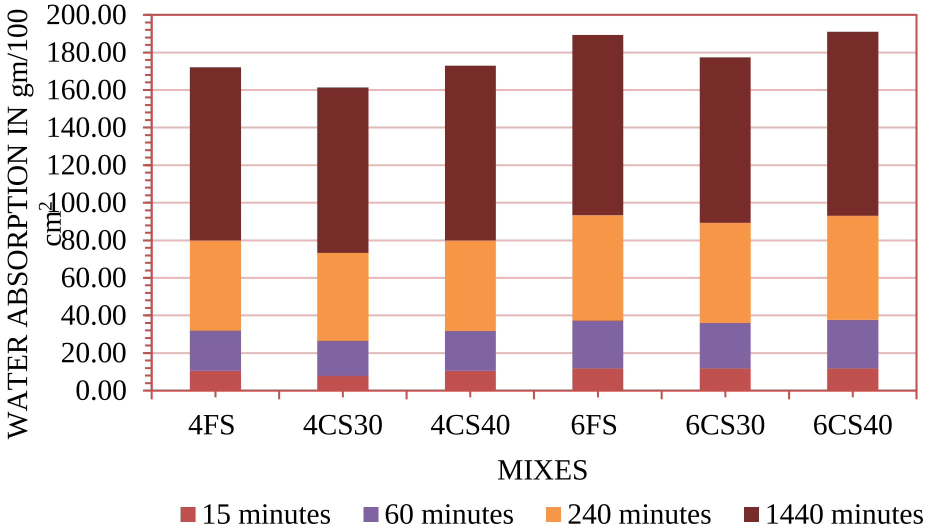

Figure 7 Water absorption due to capillary rise of mortars in Stage II

CONCLUSIONS

The nature of mortars prepared with fine sand, coarse sand and granite slurry is subjected with following observations:

- The incorporation of granite powder increased water-cement ratio for mortars with fine sand due to its fineness. This problem can solved when granite powder is properly graded with coarse sand.
- Fresh density reduced in blended mortars prepared with fine sand and granite powder due to lower bulk density of granite powder. This issue is also sorted out in mortars were granite powder is combined with coarse sand. The increase in this parameter is due to the ability of granite powder to fill the pores between coarse sand.
- There is no negative effect on the compressive strength of mortars prepared with coarse sand and granite powder (at 30% and 40% replacement level).
- The rate of water absorption (sorptivity) of mortar prepared with coarse sand and 30% granite powder is least as compared to other mortars.

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