VOL. 4, NO. 4, JUNE 2009 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

PROPERTIES OF GREEN CONCRETE CONTAINING QUARRY ROCK DUST AND MARBLE SLUDGE POWDER AS FINE AGGREGATE

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ABSTRACT

Green concrete capable for sustainable development is characterized by application of industrial wastes to reduce consumption of natural resources and energy and pollution of the environment. Marble sludge powder can be used as filler and helps to reduce the total voids content in concrete. Natural sand in many parts of the country is not graded properly and has excessive silt on other hand quarry rock dust does not contain silt or organic impurities and can be produced to meet desired gradation and fineness as per requirement. Consequently, this contributes to improve the strength of concrete. Through reaction with the concrete admixture, Marble sludge powder and quarry rock dust improved pozzolanic reaction, micro-aggregate filling, and concrete durability. This paper presents the feasibility of the usage of quarry rock dust and marble sludge powder as hundred percent substitutes for natural sand in concrete. An attempt has been made to durability studies on green concrete compared with the natural sand concrete. It is found that the compressive, split tensile strength and durability studies of concrete made of quarry rock dust are nearly 14 % more than the conventional concrete. The concrete resistance to sulphate attack was enhanced greatly. Application of green concrete is an effective way to reduce environment pollution and improve durability of concrete under severe conditions.

Keywords: green concrete**,** marble sludge powder, quarry rock dust, mechanical properties, durability.

INTRODUCTION

Green concrete has nothing to do with color. It is a concept of thinking environment into concrete considering every aspect from raw materials manufacture over mixture design to structural design, construction, and service life. Green concrete is very often also cheap to produce, because, for example, waste products are used as a partial substitute for cement, charges for the disposal of waste are avoided, energy consumption in production is lower, and durability is greater.

Waste can be used to produce new products or can be used as admixtures so that natural sources are used more efficiency and the environment is protected from waste deposits [1].

In India the extractive activity of decorative sedimentary carbonate rocks, commercially indicated as Marbles and "Granites", is one of the most thriving industry. Marble sludge powder is an industrial waste containing heavy metals in its constitutes. Stone slurry generated during processing corresponds to around 40%of the dimension stone industry final product. This is relevant because dimension stone industry presents an annual output of 68 million tons of processed product [2]. Pravin Kumar et al used quarry rock dust along with fly ash and micro silica in self compacting concrete (SCC) and reported satisfactory strength gain [3].

A. E. Ahmed *et al.* studied the influence of natural and crushed stone very fine sand (finer than 75 micron) on the performance of fresh and hardened concrete [4]. The ordinary stone dust obtained from crushers does not comply with IS: 383-1979. The presence of flaky, badly graded and rough textured particles result in hash concrete for given design parameters [5]. Use of quarry rock dust as a fine aggregate in concrete draws serious attention of researchers and investigators. Marble powder has a very high Blaine fineness value of about 1.5 m^2/g with 90% of particles passing 50 μm sieves and 50% under 7 μm [6]. The maximum compressive and flexural strengths were observed for specimens containing a 6% waste sludge when compared with control and it was also found that waste sludge up to 9% could effectively be used as an additive material in cement [7]. To avoid the pollution and reuse the waste material, the present study is carried out. As the properties are as good as the sand, the marble sludge powder and quarry dust is used as fine aggregate in the cement concrete.

Characterization of waste

The physical characteristics of the waste are furnished in Table-1. The fineness modulus of marble sludge powder and quarry rock dust is comparable to that of fine sand of 2.2 to 2.6. The coefficient of uniformity for fine sand is generally should be less than 6. Similarly the coefficient of gradation should be between 1 and 3 for fine sand. The chemical characteristics of the river sand, marble sludge powder and quarry rock dust are furnished in Table-2. The chemical characteristics are compared with the oxide composition of ordinary Portland cement.

VOL. 4, NO. 4, JUNE 2009 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Table-1. Physical characteristics of marble sludge powder, quarry rock dust and river sand.

Sample code	Moisture content (%)		Bulk density (kg/m^3)	Fineness modulus	Effective size (mm)	Coefficient of uniformity	Coefficient of gradation
	Wet	Dry					
Marble sludge powder	23.35	1.59	1118	2.04	0.17	1.58	1.37
Quarry rock dust	24.25	2.10	1750	2.35	0.22	4.50	2.20
River Sand	25.00	2.50	1430	2.20	0.20	6.00	2.00

Table-2. Chemical characteristics of marble sludge powder, quarry rock dust, river sand and Portland cement.

Sample	Fe_2O_3 % Wt.	MnO % Wt.	Na_2O % Wt.	MgO % Wt.	K_2O % Wt.	Al_2O_3 % Wt.	CaO % Wt.	SiO_2 % Wt.	Test method
Marble sludge powder	11.99	0.08	2.08	8.74	2.33	4.45	1.58	64.86	IS: 4032-1968
Quarry rock dust	1.22	0.07	3.0	0.33	5.34	13.63	1.28	75.25	
River Sand	1.75	0.03	1.37	00.77	1.23	10.52	3.21	80.78	
Portland cement	0.55	0.85	0.85	2.15	0.85	5.50	63.50	21.50	

HEAVY METAL LEACHABILITY OF THE WASTE

The waste is of inorganic type with heavy metal concentration in the TCLP extract of the marble sludge powder and quarry rock dusts are as shown in Table-3. The heavy metals concentration of As, Ba, Cd, Cr, Hg, Pb and Ag are within the acceptable limits as specified by USEPA. The results indicate that there won't be any impact on the leachability of waste.

Table-3. Heavy metal leachability of marble sludge powder and quarry rock dust by TCLP test.

Industry code	Heavy metal concentration (mg/L)						
	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Silver
Marble sludge powder (Avg of 3samples)	0.770	16.320	0.675	0.780	0.370	BDL*	0.180
Quarry rock dust (Avg of 3samples)	0.553	12.450	0.320	1.220	0.885	BDL*	0.210
TCLP Limits	5.0	100	1.0	5.0	5.0	0.2	5.0

* BDL - Below Detectable Limit.

RAW MATERIALS AND TEST METHODS

Cement

Ordinary Portland Cement (43 Grade) with 28 percent normal consistency with specific surface 3300 cm^2/g conforming to IS: 8112-1989 [8] was used.

Marble sludge powder

Marble sludge powder was obtained in wet form directly taken from deposits of marble factories. Wet marble sludge powder must be dried before the sample preparation. Marble dust was sieved from 1mm sieve. The high content of CaO confirmed that the original stones were Marble and limestone. The dust was also tested (NP 85) to identify the absence of organic matter, thus confirming that it could be used in concrete mixtures. Particle size distribution of marble sludge powder using hydrometer analysis is shown in Figure-1 and Table-4.

VOL. 4, NO. 4, JUNE 2009 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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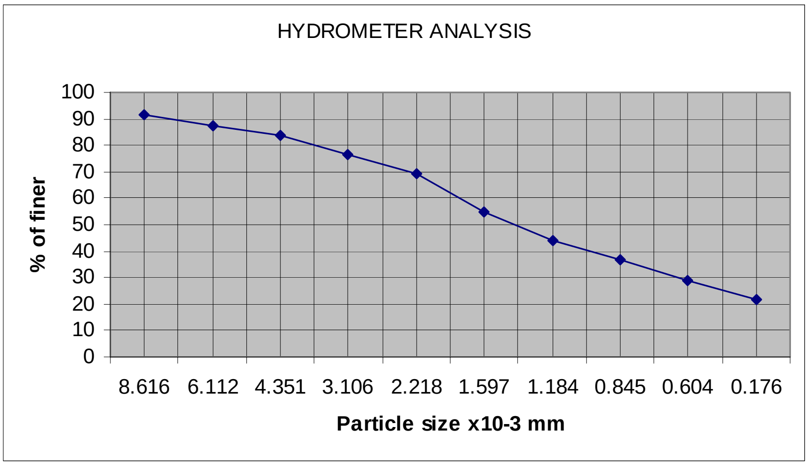

Figure-1.

$$\text{Factor } M = [0.3\eta/g(G-1)C_w]^{1/2}$$

where C_w = 1
G = 2.212
η = 9.81×10^{-3} poise
g = 9.81 m/sec^2
He = Effective Height, sec
T = Time taken for settlement
Particle Size D = M√(He/t)

Table-4. Particle size distribution.

S. No.	Elapsed time (t)	Hydrometer reading Rh	Corrected reading Rh	Height (cm)	Reading R	Factor M x10^{-3} m	Particle size D x10^{-3} mm	% of finer
1	0.5 min	25	3	15	25	1.573	8.616	91.3
2	1 min	24	2	15.1	24	1.573	6.112	87.6
3	2 min	23	1	15.3	23	1.573	4.351	84
4	4 min	21	-1	15.6	21	1.573	3.106	76.7
5	8 min	19	-3	15.9	19	1.573	2.218	69.4
6	16 min	15	-7	16.5	15	1.573	1.597	54.8
7	30 min	12	-10	17	12	1.573	1.184	43.8
8	1 hour	10	-12	17.3	10	1.573	0.845	36.5
9	2 hours	8	-14	17.7	8	1.573	0.604	29.2
10	24 hours	6	-16	18	6	1.573	0.176	21.9

It can be observed that the marble sludge powder had a high specific surface area; this could mean that is addition should confer more cohesiveness to mortars and concrete. A known weight of slurry was put in an oven to dry at a temperature of 110±5°C. At fixed intervals (1 hour, 4 hours, 12 hours, 24 hours, 48 hours, and 72 hours) the weight loss was registered with the aim to reach the constant weight. Specific gravity of the marble sludge powder is 2.212.

Quarry rock dust

The quarry rock dust was obtained from local crusher at Kariapatti, Virudunagar District. The specific gravity of the quarry rock dust is 2.677. Moisture content and bulk density of waste are less than the sand properties.

Fine aggregate

Medium size sand from Madurai Vaigai river with a modulus of fineness = 2.20; Specific gravity 2.677, normal grading with the silt content 0.8%.

Course aggregate

Crushed stone from Madurai district with a size of 5-20 mm and normal continuous grading was used. The content of flaky and elongated particles is <3%, the crushing index ≤6% and the specific gravity 2.738.

Water

A tap water available in the concrete laboratory was used in manufacturing the concrete. The qualities of water samples are uniform and potable.

Super plasticizer

A superplasticizer based on refined lingo Sulphonates, 'Roff Superplast 320' was used to get and preserve the designed workability.

Mix proportion of concrete

For durability studies the Indian standard mix proportion (by weight) use in the mixes of conventional concrete and green concrete were fixed as 1:1.81:2.04, 1:1.73:2.04 after several trials. Based on properties of raw materials, two different mix proportions are taken and given in Table-5. Mix A is the controlled concrete using river sand and Mix B is the green concrete using industrial waste (50% quarry rock dust and 50% marble sludge powder) as fine aggregate. The water/cement ratio for both two mixes was 0.55% by weight. Water reducing admixture was used to improve the workability and its dose was fixed as 250 ml/50kg of cement.

Table-5. Mix proportion.

Material	**Mix A** (1:1.81:2.04)	**Mix B** (1:1.73:2.04)
Cement in kg	425	425
F.A.1 (River sand in kg)	770	0
F.A.2 (Quarry rock dust in kg)	0	368
F.A.3 (Marble sludge powder in kg)	0	368
Course aggregate (in kg)	868	868
Water in litres (W/C: 0.55%)	234	234
Super plasticizer 0.5%	2.125	2.125
Cement/Aggregate ratio	1:4.24	1:4.24
C.A./F.A ratio	0.887	0.887

RESULTS AND DISCUSSIONS

Freshly mixtures property

The workability of fresh concrete was measured in terms of slump, slump flow value and V- funnel time which are presented in Table-6. The properties of fresh concrete were measured according to IS: 1199-1959[9]. The ingredients of concrete were thoroughly mixed in mixer machine till uniform consistency was achieved. Slump for Mix A and Mix B mixes are 210 and 255 mm respectively. Slump flow for Mix A and Mix B mixes are 420, and 657 mm respectively. V-funnel time for Mix A and Mix B are 23 and 14 sec, respectively.

Table-6. Workability, average compressive strength and split tensile strength of concrete.

MIX	**Slump in mm**	**Slump flow in mm**	**V-funnel time in Sec**
Mix A	210	420	23
Mix B	255	657	14

Hardened mixture properties

i) Compressive and split tensile strength

The 150 mm size concrete cubes, concrete cylinder of size 150 mm dia and 300 mm height were used as test specimens to determine the compressive strength and split tensile strength respectively. The results of standard cubes and cylinders are compiled in Tables-7. The Indian standard method resulted in highly conservative results of compressive and split tensile strengths for the M20 grades of concrete. Compressive strength and split tensile strength were obtained as per IS: 516-1959 [10]. The 7 days and 28 days compressive strength of green concrete is 6.49% and 9.49% higher than controlled concrete respectively. Similarly the 7 days and 28 days split tensile strength of green concrete is 14.62 and 8.66% higher than controlled concrete respectively. The 3 days compressive and split tensile strengths of green concrete were decreasing 12.36% and 10.41% respectively when compared with controlled concrete. The authors suggest that a slightly less strength of concrete at early age, in some degree, is beneficial to the durability of the concrete.

Table-7. Average compressive strength and split tensile strength of concrete.

MIX	Average Compressive Strength in N/mm^2			Split Tensile Strength in N/mm^2		
	3 days	7 days	28 days	3 days	7 days	28 days
Mix A	15.45	18.33	36.85	2.40	2.60	4.62
Mix B	13.54	19.52	40.35	2.15	2.98	5.02

Durability studies

The objective of this durability study was to investigate the water absorption, permeability and resistance to sulphate attack for both conventional concrete and green concrete as per code provisions.

Water absorption

Six cubes of size 150mm were cast for two different mixes. All specimens were removed 24 hours after casting and subsequently water cured for 28 days. Samples were removed from water and wiped out any traces of water with damp cloth and difference in weight was measured and the results are shown in Table-8.

Table-8. Percentage of weight loss.

Mix	% of water absorption after 28 days	Percentage of weight loss					
		28 days		90 days		150 days	
		Na_2SO_4 and $MgSO_4$	H_2SO_4	Na_2SO_4 and $MgSO_4$	H_2SO_4	Na_2SO_4 and $MgSO_4$	H_2SO_4
Mix A	2.85	1.65	2.10	2.20	2.65	2.95	3.15
Mix B	3.74	1.15	0.80	1.95	1.10	2.10	1.80

Resistance to sulphate attack

The resistance to sulphate attack was studied by storage of standard prism specimens were immersed in standard condition for 28 and 90 days and 150 days in testing baths (containing 7.5 percent $MgSO_4$ and 7.5 percent Na_2SO_4 by weight of water). After 28 days of water curing the change in weight was determined and shown in Table-8. After 28 and 90 days corrosion the compressive strength of specimens results were compared with those of specimens stored in fresh water. It represents that the durability of Green concrete under sulphate is higher to that of conventional concrete. The mix proportions of mortar specimen are given in Table-9 and the results are given in Table-10. It can be seen from the test results with storage in 7.5% sodium sulphate solution and 7.5% magnesium sulphate solution for 28 days that the corrosion resistance of mortar specimen with green concrete is much better than that of control specimen, the effect is better for M4 mix (fine aggregate replaced with 50% marble powder and 50% with quarry rock dust). This is due to that the active SiO_2 in marble powder and quarry rock dust can react with the Ca $(OH)_2$ in concrete to form secondary calcium silicate hydrate and make it chemically stable and structurally dense, the impermeability of concrete is enhanced as well. In addition, the marble powder can reduce the content of calcium aluminate in cementitious material, leading to increase of sulphate resistance of concrete. From the results after 90-day immersion, the mortar specimens with green concrete in 7.5% sulphate solution have similar effect with those immersed for 28 days, but for those in 7.5% magnesium sulphate, the influence of addition on anticorrosion factor is not obvious.

VOL. 4, NO. 4, JUNE 2009 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Table-9. Mix proportions of mortar specimens.

Mix No.	**Cement** (OPC 43)	**River sand**	**Quarry rock dust**	**Marble sludge powder**	**Water**
M1	100	300	0	0	40
M2	100	0	0	300	41
M3	100	0	75	225	42
M4	100	0	150	150	42
M5	100	0	225	75	43
M6	100	0	300	0	42

Table-10. Compressive strength of mortar specimens.

Mix No.	**28-days Compressive strength** (MPa)					**90-days Compressive strength** (MPa)				
	Fresh water	Na_2SO_4	%	$MgSO_4$	%	Fresh water	Na_2SO_4	%	$MgSO_4$	%
M1	52.50	42.30	0.81	40.10	0.76	56.70	43.30	0.76	42.55	0.75
M2	53.20	55.18	1.04	50.75	0.95	55.45	58.15	1.05	52.62	0.95
M3	55.75	57.90	1.04	58.12	1.04	57.62	58.93	1.02	52.68	0.91
M4	58.85	63.45	1.08	61.95	1.05	63.24	66.95	1.06	65.25	1.03
M5	50.54	52.20	1.03	51.85	1.03	52.55	52.15	0.99	50.63	0.96
M6	48.73	48.82	1.00	48.46	0.99	50.72	48.95	0.97	47.66	0.94

Permeability

Test on permeability of the green concrete was carried out. Standard cube of specimen of size 150mm X 150mm X 150mm was installed with in the apparatus. At First the specimen was rubbed by sand paper to remove any oily layer on it. The pressure up to 2.0 MPa and kept for 10 hours, no leakage found. Then the specimen was split vertically in the middle applying compressive forces on two laid mild steel bars on the top and bottom surface of the cube specimen under compression testing Machine. The minimum and maximum penetration depths of two mixes were measured and given in Table-11. Due to the pozzolanic and filling effects of the marble powder and quarry rock dust, there is more cementitious material formed with dense structure, therefore, it is easy to prepare a high impermeable concrete.

Table-11. Test results of permeability of concrete specimen.

Mix	**Impermeable pressure** (MPa)	**Description**	**Depth of penetration**	
			Min (in cm)	**Max** (in cm)
Mix A	2.0	No leakage found	3.50	14.20
Mix B	2.0	No leakage found	3.30	11.50

CONCLUSIONS

All the experimental data shows that the addition of the industrial wastes improves the physical and mechanical properties. These results are of great importance because this kind of innovative concrete requires large amounts of fine particles. Due to its high fineness of the marble sludge powder it provided to be very effective in assuring very good cohesiveness of concrete. From the above study, it is concluded that the quarry rock dust and marble sludge powder may be used as a replacement material for fine aggregate.

- The chemical compositions of quarry rock dust and marble sludge powder such as Fe_2O_3, MnO, Na_2O, MgO, K_2O, Al_2O_3, CaO, and SiO_2 are comparable with that of cement.
- The replacement of fine aggregate with 50% marble sludge powder and 50% Quarry rock dust (Green concrete) gives an excellent result in strength aspect and quality aspect. The results showed that the M4 mix induced higher compressive strength, higher splitting tensile strength. Increase the marble sludge powder content by more than 50% improves the workability but affects the compressive and split tensile strength of concrete.
- Green concrete induced higher workability and it satisfy the self compacting concrete performance which is the slump flow is 657mm without affecting

the strength of concrete. Slump flow increases with the increase of marble sludge powder content. V-funnel time decreases with the increase of marble sludge powder content
- Test results show that these industrial wastes are capable of improving hardened concrete performance.
- Green concrete enhancing fresh concrete behavior and can be used in architectural concrete mixtures containing white cement.
- Permeability test results clearly demonstrate that the permeability of green concrete is less compared to that of conventional concrete.
- The water absorption of green concrete is slightly higher than conventional concrete.
- The durability of green concrete under sulphate is higher to that of conventional concrete. From the results after 90-day immersion, the mortar specimens with green concrete in 7.5% sulphate solution have similar effect with those immersed for 28 days, but for those in 7.5% magnesium sulphate, the influence of addition on anti corrosion factor is not obvious.

The combined use of quarry rock dust and marble sludge powder exhibited excellent performance due to efficient micro filling ability and pozzolanic activity. Therefore, the results of this study provide a strong recommendation for the use of quarry rock dust and marble sludge powder as fine aggregate in concrete manufacturing.

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