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STRENGTH AND DURABILITY PROPERTIES OF CONCRETE CONTAINING QUARRY ROCK DUST AS FINE AGGREGATE

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ABSTRACT

Common river sand is expensive due to excessive cost of transportation from natural sources. Also large-scale depletion of these sources creates environmental problems. As environmental transportation and other constraints make the availability and use of river sand less attractive, a substitute or replacement product for concrete industry needs to be found. River sand is most commonly used fine aggregate in the production of concrete poses the problem of acute shortage in many areas. Whose continued use has started posing serious problems with respect to its availability, cost and environmental impact.

In such a situation the Quarry rock dust can be an economic alternative to the river sand. Quarry Rock Dust can be defined as residue, tailing or other non-voluble waste material after the extraction and processing of rocks to form fine particles less than 4.75mm. Usually, Quarry Rock Dust is used in large scale in the highways as a surface finishing material and also used for manufacturing of hollow blocks and lightweight concrete prefabricated Elements. Use of Quarry rock dust as a fine aggregate in concrete draws serious attention of researchers and investigators.

This paper presents the feasibility of the usage of Quarry Rock Dust as hundred percent substitutes for Natural Sand in concrete. Mix design has been developed for three grades using design an approach IS, ACI, USBR, RN.No.4 and BRITISH for both conventional concrete and quarry dust concrete. Tests were conducted on cubes and beams to study the strength of concrete made of Quarry Rock Dust and the results were compared with the Natural Sand Concrete. An attempt has also been made to durability studies on Quarry Rock Dust when compared with the Natural Sand concrete. It is found that the compressive, flexural strength and Durability Studies of concrete made of Quarry Rock Dust are nearly 10% more than the conventional concrete.

Keywords: concrete, quarry rock dust, river sand, strength, properties, shrinkage.

INTRODUCTION

Currently India has taken a major initiative on developing the infrastructures such as express highways, power projects and industrial structures etc., to meet the requirements of globalization, in the construction of buildings and other structures concrete plays the rightful role and a large quantum of concrete is being utilized. River sand, which is one of the constituents used in the production of conventional concrete, has become highly expensive and also scarce. In the backdrop of such a bleak atmosphere, there is large demand for alternative materials from industrial waste.

The consumption of cement content, workability, compressive strength and cost of concrete made with Quarry Rock Dust were studied by researchers Babu K.K. *et al.* [1], Nagaraj T.S. *et al.* [11] and Narasimahan *et al.* [13]. The mix design proposed by Nagaraj *et al.* [12] shows the possibilities of ensuring the workability by wise combination of rock dust and sand, use of super plasticizer and optimum water content using generalized lyse Rule. Sahu A.K. *et al.* [17] reported significant increase in compressive strength, modulus of rupture and split tensile strength when 40 percent of sand is replaced by Quarry Rock Dust in concrete. Ilangovan and Nagamani [18,19] reported that Natural Sand with Quarry Dust as full replacement in concrete as possible with proper treatment of Quarry Dust before utilization.

The utilization of Quarry rock dust which can be called as manufactured sand has been accepted as a building material in the industrially advanced countries of the west for the past three decades [15]. As a result of sustained research and developmental works undertaken with respect to increasing application of this industrial waste, the level of utilization of Quarry Rock Dust in the industrialized nations like Australia, France, Germany and UK has been reached more than 60% of its total production. The use of manufactured sand in India has not been much, when compared to some advanced countries [2].

This paper presents the feasibility of the usage of Quarry Rock Dust as hundred percent substitutes for Conventional Concrete. Tests were conducted on cubes and beams to study the compressive, flexural strengths of concrete made of Quarry Rock Dust for three different proportions and five different methods. Durability Studies were done for concrete with Quarry Rock Dust and compared with the Conventional Concrete.

MATERIALS AND METHODS

Cement

Ordinary Portland Cement (43 Grade) with 28 percent normal consistency Conforming to IS: 8112-1989 [3] was used.

Quarry rock dust

The Quarry Rock Dust obtained from local resource AMC Crushers (P) Ltd., Dindigul was used in concrete to cast test cubes and beams. The physical and chemical properties of Quarry Rock Dust obtained by testing the samples as per Indian Standards are listed in Tables 1 and 2, respectively.

Table-1. Physical properties of quarry rock dust and natural sand.

Property	Quarry rock dust	Natural sand	Test method
Specific gravity	2.54-2.60	2.60	[5] IS 2386 (Part III) 1963
Bulk relative density (kg/m^3)	1720-1810	1460	IS 2386 (Part III) 1963
Absorption (%)	1.20-1.50	Nil	IS 2386 (Part III) 1963
Moisture content (%)	Nil	1.50	IS 2386 (Part III) 1963
Fine particles less than 0.075mm (%)	12-15	06	[5] IS 2386 (Part I) 1963
Sieve analysis	Zone II	Zone II	[4]IS 383 - 1970

Table-2. Typical chemical composition of quarry rock dust and natural sand.

Constituent	Quarry rock dust (%)	Natural sand (%)	Test method
SiO_2	62.48	80.78	[10]IS: 4032-1968
Al_2O_3	18.72	10.52	
Fe_2O_3	06.54	01.75	
CaO	04.83	03.21	
MgO	02.56	00.77	
Na_2O	Nil	01.37	
K_2O	03.18	01.23	
TiO_2	01.21	Nil	
Loss of ignition	00.48	00.37	

Fine aggregate (Natural river sand)

River sand having density of 1460 kg/m^3 and fineness Modulus (FM) of 2.51 was used. The specific gravity was found to be 2.6.

Coarse aggregate

Natural granite aggregate having density of 2700kg/m^3 and fineness modules (FM) of 6.80 was used. The specific gravity was found to be 2.60 and water absorption as 0.45%.

Admixture

Commercially available Super-plasticiser has been used to enhance the workability of fresh concrete for selected proportions of ingredients.

MIX DESIGN

Since there is No standard method of designing concrete mixes incorporating Quarry Rock Dust as fine Aggregate. The method mix design proposed by IS [8], ACI, USBR, RN No.4, BS were first employed to design the Conventional Concrete mixes and finally natural sand was fully replaced by Quarry Rock Dust to obtain Quarry Rock Dust concrete mixes. The purpose of mix proportioning is to produce the required properties in both plastic and hardened concrete by working out a combination of available materials, with various economic and practical standards.

TEST SPECIMENS AND TEST PROCEDURE

The 150 mm size concrete cubes, concrete beams of size 100 mm x 100 mm x 500 mm were used as test specimens to determine the compressive strength and flexural strength respectively. The specimens were cast for M20, M30 and M40 grade and for coarse aggregates of size 20 mm was used. The workability of fresh concrete was measured in terms of slump values, V-B time and compaction factor. To obtain the required slump value, V-B time and equivalent compacting factor superplasticiser (0.7 to 2.4 % of weight of cement) were added. The properties of fresh concrete were measured according to IS: 1199-1959 [6]. The ingredients of concrete were thoroughly mixed in mixer machine till uniform consistency was achieved. The cubes were compacted on a vibrating table while the beams were compacted using

needle vibrator. Compressive strength and flexural strength were obtained as per IS: 516-1959 [7].

DURABILITY STUDIES

For Durability Studies the Indian Standard mix Proportion (by weight) use in the mixes of Conventional Concrete and Quarry Rock Dust concrete were fixed as 1:0.99:1.56 and 1:0.91:1.56 after several trials. The water/cement ratio for both two mixes was 0.35 and 0.38 by weight. Water reducing admixture was used to improve the workability and its dose was fixed as 275 m1/50kg of cement. The objective of this durability study was to investigate the drying and shrinkage studies, deterioration, and water absorption studies for both Conventional Concrete and Quarry Rock Dust concrete as per codel provisions.

Drying shrinkage

This study presents the drying shrinkage measurement on conventional concrete as well as Quarry Rock Dust concrete. Shrinkage - measuring device (length comparator) conforming to the specification of IS: 4031-1988 [9] was used for measuring length changes of concrete specimens. The prismatic test specimens of size 75 x 75 x 305mm with the gauge length between the stainless steel gauge studs, as 250mm were prepared. Figure-1 shows the drying shrinkage strain plotted against the age, in days. The shrinkage strain has been calculated by dividing the change in length of the test specimen (250mm). The change in length of the test specimens at the end of a particular time has been calculated by multiplying the difference in a dial gauge records between the first reading and the reading at the end of the chosen interval, with the sensitivity of the dial gauge (0.002mm).

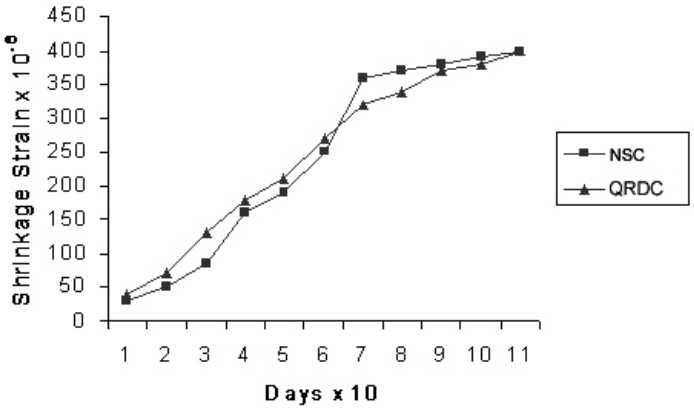
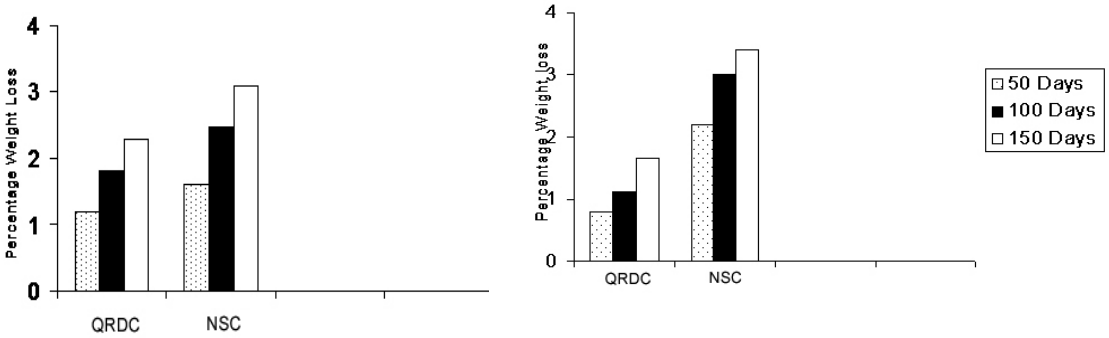


Figure-1. Plot showing drying shrinkage against age for two mixes.

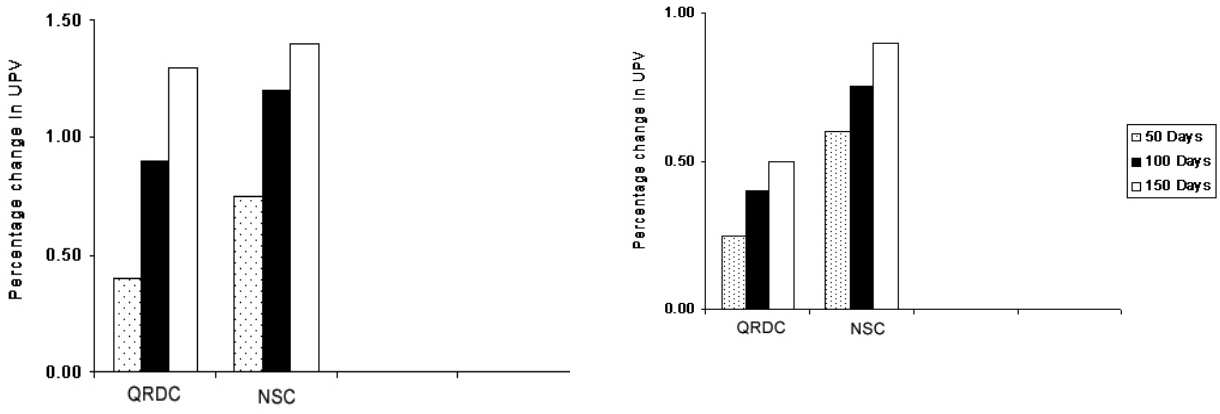
Deterioration studies

In order to evaluate the degree of deterioration of two concrete mixes against accelerated sulphate and acid attack, standard prism specimens were immersed in testing baths (one containing 7.5 percent $MgSO_4$ and 7.5 percent Na_2SO_4 by weight of water and other containing H_2SO_4 of pH value 2). After 28 days of water curing the change in weight and direct emission of Ultrasonic pulse velocity (UPV) with age of different mixes subjected to above solutions are shown in Figures 2 and 3. It indicates that the durability of Quarry Rock Dust concrete under sulphate and acid action is higher to that of conventional concrete.



(a) H2SO4 solution. **(b)** Sulphate solution.

Figure-2. Percentage weight loss for two mixes.



(a) H_2SO_4 solution. **(b)** Sulphate solution.

Figure-3. Percentage change in UPV of two mixes.

QRDC-Quarry Rock Dust Concrete
NSC-Natural Sand Concrete (conventional concrete)
UPV-Ultrasonic Pulse velocity

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.

Permeability

The permeability test was carried out as shown in Figure-4. 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. Water pressure of 0.1Mpa was applied for 48 hours, and then pressure of 0.30Mpa and 0.70Mpa, each for 24 hours, was applied. Immediately after this, 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 greatest penetration depth of (average of greatest penetration depth of three similar samples) of four Mixes was measured.

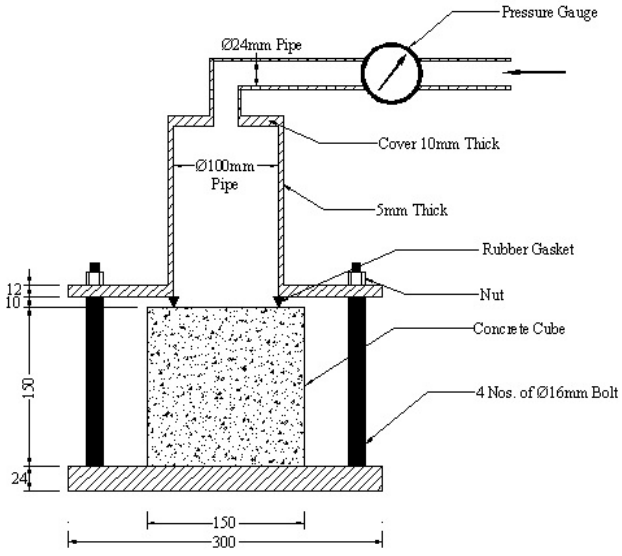


Figure-4. Test setup of water permeability test.

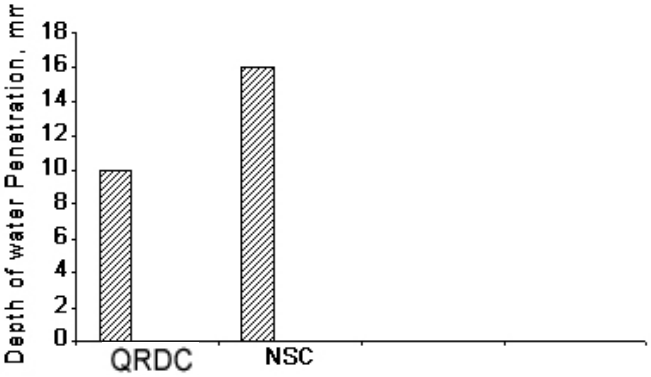


Figure-5. Depth of water penetration of two different mixes.

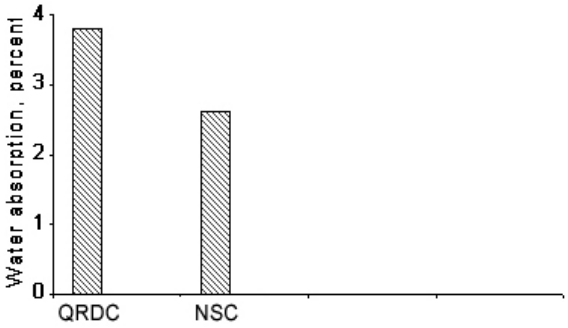


Figure-6. Water absorption studies of two Mixes.

QRDC-Quarry Rock Dust Concrete
NSC-Natural Sand Concrete (conventional concrete)

RESULTS AND DISCUSSIONS

Water/cement ratio

The variation of compressive strength with water/cement ratio is shown in Tables 3 and 4 for the Mixes designed by the various methods for Natural Sand and Quarry Rock Dust. For a given grade of concrete the I.S. method required the least water/cement ratio while the British Method resulted in the highest water/cement ratio. In general British and Road Note No. 4 methods resulted in higher water/cement ratio compared to Indian, ACI and USBR methods.

Details of concrete Mix, results of workability and strength test.

Table-3. Fine aggregate (Natural sand).

Grade of concrete	**Mix design method**	**Mix proportions** (by weight)	**W/C ratio**	**A/C ratio**	**Workability**			**Compressive strength** (Mpa)		**Flexural strength** (Mpa) 28days
					Slump (mm)	**V-B time** (Sec)	**Compaction factor**	7 days	28 days	
M-20	Indian	1:1.54:2.95	0.49	4.50	60	9	0.87	19.00	31.00	5.10
	ACI	1:2.37:3.33	0.57	5.70	70	6	0.88	16.00	22.00	3.79
	USBR	1:2.44:3.31	0.50	5.75	80	5	0.88	10.00	24.50	3.37
	RN No.4	1:2.98:2.92	0.58	4.90	80	5	0.89	9.00	21.00	3.05
	British	1:3.29:4.30	0.62	7.59	90	3	0.90	12.00	24.00	4.62
M-30	Indian	1:0.99:1.56	0.35	3.00	20	34	0.82	27.00	44.00	7.40
	ACI	1:1.42:2.34	0.43	3.76	40	27	0.85	19.50	31.00	5.96
	USBR	1:2.26:3.07	0.44	5.33	50	29	0.86	18.50	30.00	6.05
	RN No.4	1:1.75:3.41	0.49	5.16	50	23	0.89	19.00	31.00	6.05
	British	1:2.43:3.92	0.50	6.35	60	26	0.90	18.00	32.00	5.40
M-40	Indian	1:0.60:1.95	0.31	2.55	10	50	0.72	33.00	55.00	8.80
	ACI	1:1.01:1.92	0.36	2.93	30	44	0.79	30.00	44.00	7.06
	USBR	1:1.87:2.55	0.37	4.42	30	46	0.80	26.00	41.00	7.60
	RN No.4	1:1.18:1.74	0.36	2.92	40	34	0.83	24.00	42.00	8.40
	British	1:2.58:3.24	0.46	5.82	40	36	0.88	26.00	46.00	7.50

Details of concrete Mix, results of workability and strength test.

Table-4. Fine aggregate (Quarry Rock Dust).

Grade of concrete	Mix design method	Mix proportions (by weight)	W/C ratio	A/C ratio	Workability			Compressive strength (Mpa)		Flexural strength (Mpa) 28days
					Slump (mm)	V-B time (Sec)	Compaction factor	7 days	28 days	
M-20	Indian	1:1.42:2.95	0.53	4.32	70	6	0.80	21.00	34.50	6.40
	ACI	1:2.37:3.11	0.68	5.48	80	5	0.82	12.50	24.60	3.90
	USBR	1:2.24:3.46	0.54	5.70	60	4	0.84	12.00	28.00	3.80
	RN No.4	1:1.90:2.92	0.66	4.82	75	3	0.85	10.00	23.70	3.45
	British	1:3.43:4.05	0.69	7.48	80	2	0.88	13.50	26.50	5.10
M-30	Indian	1:0.91:1.56	0.38	2.77	40	30	0.78	28.00	49.00	8.12
	ACI	1:1.29:2.04	0.45	3.33	60	24	0.80	20.00	34.00	6.56
	USBR	1:2.13:2.79	0.49	4.92	50	25	0.82	21.00	32.50	6.90
	RN No.4	1:1.54:2.32	0.51	3.86	60	20	0.84	21.50	31.00	6.40
	British	1:3.15:4.05	0.66	7.20	70	21	0.86	19.50	36.00	6.00
M-40	Indian	1:0.55:1.96	0.32	2.51	30	43	0.24	35.00	57.00	9.70
	ACI	1:1.05:1.80	0.39	2.13	40	38	0.76	31.50	46.50	7.80
	USBR	1:1.72:2.54	0.43	4.26	30	32	0.80	28.50	43.50	8.12
	RN No.4	1:1.38:2.09	0.47	3.47	25	30	0.80	25.00	42.50	9.40
	British	1:2.63:3.37	0.57	6.00	30	28	0.78	27.50	49.50	8.60

Aggregate/cement ratio

The lowest aggregate/cement ratio corresponding to the richest mixes were indicated in the IS method while the highest aggregate/cement ratio corresponding to leanest Mixes were obtained for Mixes designed by the British method for both conventional concrete Mixes and Quarry Rock Dust concrete Mixes. The aggregate/cement ratio resulting from the different methods varied from 4.50 to 7.59, 3.0 to 6.35and 2.55 to 5.82 for the M-20, M-30 and M-40 grades of conventional concrete and 4.32 to 7.48,2.77 to 7.20 and 2.51 to 6.00 for M-20, M-30 and M-40 grades of Quarry Rock Dust concrete. The Indian standard method consistently resulted in the richest Mix for all five methods of both concretes.

Workability

The variation of workability of fresh concrete is measured in terms of slump, compaction factor and V-B time with water/cement ratio and reported in Tables 3 and 4, respectively. For the given water/cement ratio, the highest slumps and compaction factor were recorded for the mixes designed by British method. The overall workability value of Quarry Rock Dust concrete is less compared to conventional concrete.

Compressive and flexural strength

The compressive and flexural strength results of standard cubes and beams are compiled in Tables 3 and 4. The Indian standard method resulted in highly conservative results of compressive and Flexural strengths for all the three grades of concrete mainly due to high cement content used in conjunction with low aggregate/cement and water/cement ratio in comparison with other advanced by other countries methods in both cases. The overall strength reported 10 to 15 percent increases for five methods of concrete mixes of Natural sand when fully replaced by Quarry Rock Dust.

CONCLUSIONS

Based on the above discussions, following conclusions are drawn:

- The Physical and chemical properties of quarry rock dust is satisfied the requirements of [3]code provision in properties studies (Tables 1 and 2). Natural river sand, if replaced by hundred percent Quarry Rock Dust from quarries, may some times give equal or better than the reference concrete made with Natural Sand, in terms of compressive and flexural strength studies (Tables 3 and 4).
- Studies reported here and elsewhere have shown that the strength of Quarry Rock Dust concrete is comparatively 10-12 percent more than that of similar mix of Conventional Concrete [1,2 and 11 to 19]. Also the result of this investigation shows that drying shrinkage strains of Quarry Rock Dust concrete are quite large to the shrinkage strain of Conventional Concrete. However, at the later age, they have shown equal strain than Conventional Concrete (Figure-1). The Durability of Quarry Rock Dust concrete under sulphate and acid action is higher inferior to the Conventional Concrete (Figures 2 and 3). Permeability Test results (Figure-5) clearly demonstrates that the permeability of Quarry Rock Dust concrete is less compared to that of conventional concrete. The water absorption of Quarry Rock Dust concrete is slightly higher than Conventional Concrete (Figure-6). Therefore, the results of this study provide

a strong support for the use of Quarry Rock Dust as fine aggregate in Concrete Manufacturing.

- Thus, it can be concluded that the replacement of natural sand with Quarry Rock Dust, as full replacement in concrete is possible. However, it is advisable to carry out trial casting with Quarry Rock Dust proposed to be used, in order to arrive at the water content and mix proportion to suit the required workability levels and strength requirement. However, more research studies are being made on Quarry Rock Dust concrete necessary for the practical application of Quarry Rock Dust as Fine Aggregate.

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