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Effects on the Properties of Concrete by Partial Replacement of Cement with Carbon Black and Natural Fine Aggregate with Robo Sand

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Abstract— The sustainability, strength and durability of any of the constituent material of concrete plays an important role in studying and determining the effects on the properties of concrete. Pores in concrete seem to be an immense problem ever since concrete was discovered. Pores attract water that leads to the ill effects such as acid intrusion, freezing and thawing, decrease in resistance to chloride ion, reduced compressive strength etc. Less permeability of concrete plays an important role in gaining the strength and reducing the corrosion of reinforcement in concrete. This paper reviews in studying the properties of concrete using quarry dust (robo sand) as a partial replacement of natural fine aggregate and carbon black as a partial replacement of cement in concrete by using different percentages of both the materials. Experiments have been conducted by introducing carbon black in concrete which is a waste of rubber industry to act as filler and which imparts the enhanced properties of concrete. In this present experimental study, various properties of concrete have been studied using quarry dust (robo sand, artificial sand, stone dust) as a replacement of natural fine aggregate and carbon black as a replacement of cement in concrete by using different percentages of both the materials. Based on the review of previous studies, it can be concluded that the improvement in the strength of concrete is attributed the hydration acceleration at the early ages due to the effect of the stone dust as microfillers. It was also found that the concrete porosity was lower than that of the corresponding concrete without robo sand at the same water/cement ratio. It was also found that at the percentage replacement of cement by carbon black (CB) (5%) and robo sand (RS) by natural sand (50%), the concrete becomes denser as both carbon black and stone dust act as micro fillers in the concrete due to their sizes with respect to cement and natural sand. Hence a study has been carried out using both the materials carbon black and robo sand simultaneously in the concrete. Moreover, the permeability of the concrete decreases which in turn would reduce the corrosion rate and in turn increase the durability and sustainability of concrete. Replacing a portion of cement with non-reactive waste material carbon black and natural sand with quarry dust and getting the increase in strength and durability at same w/c ratio is of utmost importance regarding the economy (sustainability).

Keywords— Compressive Strength Split Tensile Strength, Flexural Strength, Slump, Permeability.

I. INTRODUCTION

From early 1990s, the demand of the mineral admixtures has increased tremendously for the manufacturing of cement and concrete. Then after 1990s, the future demand for the mineral admixtures was expected to increase even more. Hence, in the building construction, the concrete which is manufactured with the help of constituent materials like cement, fine aggregate and coarse aggregate should be sustainable, and even stronger to withstand the loads and the weathering conditions during its age. Nowadays the building construction industry of India is facing a major problem that is natural fine aggregate. Due to restriction/ban executed on sand quarrying by government, result scarcity of river sand. The cost of river sand automatically increased due to huge material demand and substructure development in India. The shortage of natural sand will disturb the building industry. Maximum construction industries use natural river sand as fine aggregate. Researches are going on due to shoot up in the claim of robo sand and reduction of natural sand, besides constraints levied on the exploitation of the natural river sand. Hence there is a necessity to find a new alternative material to replace the natural fine aggregate, such that surplus river erosion and damage to surroundings is avoided. Investigators are finding alternate material to substitute the natural river sand, and one of the main material is quarry stone dust (Artificial Sand/Robo Sand).

A. *Robo Sand*

Robo Sand is obtained from crushing stones in a quarry. The sand used in concrete must have a proper gradation of 150 microns to 4.75 mm. The fineness modulus of robo sand is is 2.52. The uniformity coefficient is less than 6 and its specific gravity if 2.66.

B. *Carbon Black*

Carbon black is effectively pure carbon which is formed by incomplete burning/thermolysis the compounds made up of hydrogen and carbon. The appearance of carbon black is black, fine powder. It is an unwanted material obtained from the rubber manufacturing industries and hence it is difficult to dispose. Normally these wastes from rubber manufacturing industries are decomposed in the soil thereby causing soil contamination and pollution in water. By utilizing carbon black as filler, this problem can be reduced to a high degree. The specific gravity of carbon black is 1.33.

II. **LITERATURE REVIEW**

M.H.Kharita et al. (2009) [1] concluded by their experimental investigation that when carbon black is used as an additive in the hematite concrete (15% of weight of the cement), there is no significant effect on the shielding properties, but it enhances the mechanical properties of hematite concrete. It has been investigated that of 6% of carbon black powder in hematite concrete enhances the workability of fresh mix, and compressive strength of the concrete. Precautions should be taken when the carbon black powder is used as an additive at high temperatures, because it gets affected easily by heat.

M. Shahul Hameed et al (2009) [2] investigated the feasibility of using quarry dust and marble dust in the concrete as a replacement of natural sand. The results indicated that the compressive strength, split tensile strength and flexural strength were 14% more than that of conventional concrete at 50% replacement.

Dr. G. Chitra et al. (2014) [3] investigated the different tests regarding strength and durability. Carbon black was used as a filler to minimize the presence of pores. 18 cubes, 12 cylinders were cast at the percentage replacement of cement at 0%, 2%, 5%, 8%, 12% and 15%. Different tests like compressive strength test, water absorption and split tensile test were conducted during the research work. It was later found that at 5% replacement of cement with carbon black, there is 20.7% increase in compressive strength (for M25 grade, the compressive strength was found out to be 29.33 N/mm^2). Moreover, the split tensile strength at 5% was found out to be effective.

Sami Masadeh (2015) [4] examined the impact of carbon black as an additive in the concrete on deterioration of steel reinforcement. This was accomplished by embedding of steel bars in various cement concrete blends which contained 0.1, 0.2, 0.3, 0.4, and 0.5 carbon-black/concrete ratio. The test samples were cured and then drenched in chloride solution of 3.5% for a half year. After that the penetration of chloride ions and accordingly the rate of corrosions were measured. It was found that with the increase in carbon black powder content, the corrosion rate and chloride ion infiltration diminished. It was because of filling property of fines of carbon black (in the order less than 250 nm). At 7% substitution, increment in curing from 1 month to a half year prompted around 5.7% lessening in permeability than that of no carbon blend. It was likewise reasoned that as the chloride ion penetration decreases, rate of deterioration of steel reinforcement also decreases.

S.Rukmangadhara Rao et al. (2015) [5] studied two grades of concrete M25 and M35 at different replacements of natural sand by robo sand. The results were quite satisfying indicating when the 50% of natural river sand was replaced by robo sand, the compressive strength was found out to be maximum rather than 0%, 75% and 100% replacement. It was concluded that the compressive strength at 50% replacement was 36.15 N/mm^2 for grade M25 and 49.33 N/mm^2 grade M35.

K. Srinivas Reddy et al. (2016) [6] compared the results of the concrete containing different percentages of robo sand with a reference mix. Compressive strength of concrete (grade M25) was investigated at percentage replacement of 0%, 20%, 40%, and 60% of natural sand with robo sand or quarry dust. Results were matched with reference mix of 0% replacement. The compressive strength of cement concrete with 20%, 40%, 60% replacements were much more than that of reference mixes. According to price – service ratio the use of robo sand gives effective results; the cost of robo sand is 30-50% less in market which is good for production of economical concrete. The service of robo sand is also as good enough for as natural sand concrete.

III. DISCUSSION ON THE VARIOUS PROPERTIES OF CONCRETE

Carbon black and robo sand/quarry dust plays an important role in enhancing the mechanical and durability properties of concrete. It has been also found out that it helps in making the concrete denser than conventional concrete. Based on the literature review, some of the properties associated are discussed below;

1. *Compressive Strength and Split Tensile Strength*: - From the literature review of S. Rukmangadhara Rao, G. Himali Kumari, N. Vidya Sagar Lal (2015), we can conclude that with the increase in percentage of robo sand, compressive strength increases. It is because the particles of the robo sand are much lesser in size than the natural sand. Hence there is a sort of pore refinement which increases the compressive strength of concrete. Same is the case of carbon black. Hence blending the two materials will give appropriate results with accordance with compressive strength. The optimum percentage replacement of robo sand is 50% and as of carbon black is 5-6%. Beyond this replacement the trend gets reversed. The results are shown in table I.

TABLE I

Strength of Concrete with Robo sand in M-25 Grades

% age Replacement of Natural Sand with Robo Sand	Average Compressive Strength of Concrete at different ages (N/mm^2)	
	7 days	28 days
0	21.81	30.99
50	24.36	35.98
75	23.20	34.10
100	22.36	32.36

2. *Workability:* - An attempt was by W W J Chan, C M L Wu (2000) [10] made using carbon black as an additive filler in concrete and which imparts the enhanced properties of concrete Since the size of robo sand is very less than that of natural sand, hence during the mixing, the workability gets reduced. In contrast, carbon black is inert i.e. it has very less positive and negative charges and carbon black has less absorption rate with water creating a sort of repulsive force, which has a great advantage in workability. Hence blending of the two materials, on one hand the workability gets reduced, but on the other hand, carbon black nullifies the reduced workability. This can lessen the water/cement ratio and has a role to act as a superplasticizer.

3. *Durability Properties*: - As mentioned above, there is pore refinement of concrete when carbon black robo sand is added to concrete due to which permeability is reduced. As studied by Manjunatha M, Akshay N K, Jeevan H (2016), on decreasing the permeability, the water entering the concrete will be less than that of the water entering in conventional concrete. Hence there will be less corrosion of reinforcement when CB and RS are added to the concrete. Hence both the materials play an important role in sustaining the concrete for a long time.

4. *Impact Resistance*: - Fig.1 below shows the comparative quarry dust content and impact resistance of concrete. According to Tahir Celik and Khaled Marar (1996) in Fig. 1, at 5% of the dust content in the concrete mix, the number of blows reached the maximum (80 blows). However, as the quarry dust percentage is increased, the number of blows was found out to be minimum of 33 blows at 30% of the quarry dust content, which in turn indicated that the impact resistance decreases. Hence, 5% of dust increases the impact resistance in the concrete while the compressive strength is found out to be maximum at 10% dust content, but it was also observed that beyond the 5% replacement, impact strength may decrease due to the rise in the number of fines in the concrete.

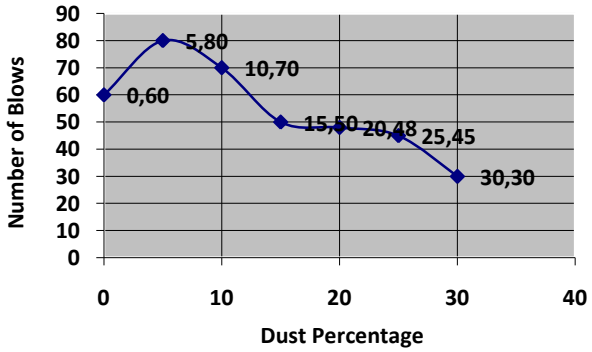

Fig.1. Impact Resistance in terms of dust % and number of blows

5. *Water Permeability:* - W Tahir Celik and Khaled Marar (1996) studied the water permeability results as graphically drawn in fig 2. Three concrete test cylinders were made using quarry dust (robo sand) and the average permeability coefficient (K) is represented in the same curve. The test results as drawn graphically indicate that the coefficient of permeability (K) decreases as the robo dust content increases. It can be reviewed that the peak value of coefficient of permeability at 0% dust (quarry dust) content is $6.59x10^{-10}$ cm/sec, and the least value for 30% dust (quarry dust) content is $1.93x\ 10^{-10}$ cm/sec. The adding of dust content to the concrete decreases the permeability of concrete because it blocks the passages and the water ways. Results are shown in Fig. 2.

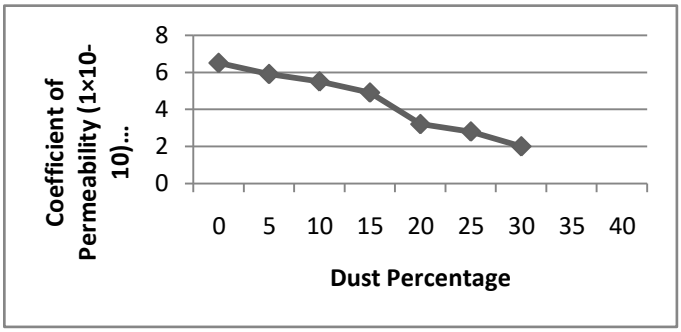

Fig.2. Dust Percentage vs Permeability

IV. METHODOLOGY

In this research work, M25 grade of concrete was used, made with OPC (grade 43) with water cement ratio as 0.5, natural fine aggregate and natural coarse aggregate of both 10mm and 20mm. Slump test was performed to check the workability of concrete. The Carbon Black was kept constant as 5% and the percentage of Robo Sand was changed as 10%, 20%, 30%, 40%, 45%, 50%, 55% and 60%. The work was carried out in nine batches. In this research work, 3 cubes, 3 cylinders and 3 beams were casted for each batch for 7 days and 28 days respectively. The tests like compressive strength test, split tensile test and flexural strength test were carried out for all the mixes.

V. RESULTS AND DISCUSSION

1. *Slump Test Results*

It was found that with the increase in robo sand content (keeping percentage of carbon black fixed as 5%), the slump value decreases from 78mm to 60mm. An attempt was made using carbon black as an additive filler in concrete and which imparts the enhanced properties of concrete Since the size of robo sand is very less than that of natural sand, hence during the mixing, the workability gets reduced. On the other hand, carbon black is inert i.e. it has very less positive and negative charges and carbon black has less absorption rate with water creating a sort of repulsive force, which has a great advantage in workability. Hence blending of the two materials, on one hand the workability gets reduced, but on the other hand, carbon black nullifies the reduced workability. This can lessen the water/cement ratio and has a role to act as a super plasticizer. The results are tabulated below in Table II.

TABLE II

Slump Values at Different Percentage Replacements

Percentage Replacements	Slump (mm)
Control Mix (0% CB + 0% RS)	78
5% CB + 10% RS	75
5% CB + 20% RS	72
5% CB + 30% RS	70
5% CB + 40% RS	68
5% CB + 45% RS	65
5% CB + 50% RS	63
5% CB + 55% RS	62
5% CB + 60% RS	60

2. Compressive Strength Test Results

From the compressive strength test results, we can conclude that with the increase in percentage of robo sand, compressive strength increases both at 7 days and 28 days. At 7 days, it has been found that there is only 2.45% increase in compressive strength at 5% replacement of carbon black and 50% replacement of robo sand. But at 28 days, there is 21.29% increase in compressive strength at 5% replacement of carbon black and 50% replacement of robo sand. It is because the particles of the robo sand are much lesser in size than the natural sand. Hence there is a sort of pore refinement which increases the compressive strength of concrete. Same is the case of carbon black. Hence blending the two materials will give appropriate results with accordance with compressive strength. The optimum percentage replacement of robo sand is 50% and as of carbon black is 5% as shown in table III and table IV. Beyond this replacement the trend gets reversed.

TABLE III

Compressive Strength at 7 Days

Percentage Replacements	7 Days Compressive Strength (N/mm^2)	% Increase in Compressive Strength
Control Mix (0% CB + 0% RS)	17.1	-
5% CB + 10% RS	11.47	-32.92%
5% CB + 20% RS	12.98	-24.09%
5% CB + 30% RS	13.89	-18.77%
5% CB + 40% RS	16.84	-1.52%
5% CB + 45% RS	17.21	+0.64%
5% CB + 50% RS	17.52	+2.45%
5% CB + 55% RS	16.86	-1.40%
5% CB + 60% RS	15.2	-11.11%

TABLE IV

Compressive Strength at 28 Days

Percentage Replacements	28 Days Compressive Strength (N/mm^2)	% Increase in Compressive Strength
Control Mix	26.2	-
5% CB + 10% RS	24.95	-4.77%
5% CB + 20% RS	25.16	-3.96%
5% CB + 30% RS	26.12	-0.30%
5% CB + 40% RS	26.76	+2.13%
5% CB + 45% RS	28.21	+7.67%
5% CB + 50% RS	31.78	+21.29%
5% CB + 55% RS	29.42	+12.29%
5% CB + 60% RS	27.72	+5.80%

3. *Split Tension Test Results*

From the results of split tension test, we can conclude that with the increase in percentage of robo sand, the split tensile strength increases at 7 days and 28 days. At 7 days, it has been found that there is 32.96% increase in split tensile strength at 5% replacement of carbon black and 50% replacement of robo sand. At 28 days, there is 31.84% increase in split tensile strength at 5% replacement of carbon black and 50% replacement of robo sand. Hence blending the two materials will give appropriate results with accordance with split tensile strength. The optimum percentage replacement of robo sand is again 50% and as of carbon black is 5% as shown in Table V and VI. Beyond this replacement the trend gets reversed.

TABLE V

Split Tensile Strength at 7 Days

Percentage Replacements	7 Days Split Tensile Strength (N/mm^2)	% Increase in Split Tensile Strength
Control Mix	1.82	-
5% CB + 10% RS	1.78	-2.19%
5% CB + 20% RS	1.81	-0.54%
5% CB + 30% RS	1.92	+5.49%
5% CB + 40% RS	2.25	+23.6%
5% CB + 45% RS	2.36	+29.67%
5% CB + 50% RS	2.42	+32.96%
5% CB + 55% RS	2.38	+30.76%
5% CB + 60% RS	2.17	+19.23%

TABLE VI

Split Tensile Strength at 28 Days

Percentage Replacements	28 Days Split Tensile Strength (N/mm^2)	% Increase in Split Tensile Strength
Control Mix	2.92	-
5% CB + 10% RS	2.72	-6.84%
5% CB + 20% RS	2.86	-2.05%
5% CB + 30% RS	2.90	-0.68%
5% CB + 40% RS	3.28	+12.32%
5% CB + 45% RS	3.52	+20.54%
5% CB + 50% RS	3.85	+31.84%
5% CB + 55% RS	3.62	+23.97%
5% CB + 60% RS	3.211	+9.96%

4. Flexural Strength Test Results

From the results of flexural strength test, we can conclude that with the increase in percentage of robo sand, flexural strength increases both at 7 days and 28 days. At 7 days, it has been found that there is 37.96% increase in flexural strength at 5% replacement of carbon black and 50% replacement of robo sand. But at 28 days, there is 64.27% increase in flexural strength at 5% replacement of carbon black and 50% replacement of robo sand. This is again due to the filling ability of carbon black as well as robo sand. Hence blending the two materials will give more flexural strength than conventional concrete. The optimum percentage replacement of robo sand is again 50% and as of carbon black is 5% as shown in table VII and VIII. Beyond this replacement the trend gets reversed. The results are tabulated as

TABLE VII

Flexural Strength at 7 Days

Percentage Replacements	28 Days Flexural Strength (N/mm^2)	% Increase in Flexural Strength
Control Mix	4.61	-
5% CB + 10% RS	4.28	-7.15%
5% CB + 20% RS	4.62	+0.21%
5% CB + 30% RS	4.91	+6.50%
5% CB + 40% RS	6.125	+32.86%
5% CB + 45% RS	6.28	+36.22%
5% CB + 50% RS	6.36	+37.96%
5% CB + 55% RS	6.291	+36.46%
5% CB + 60% RS	6.0	+30.15%

TABLE VIII

Flexural Strength at 28 Days

Percentage Replacements	28 Days Flexural Strength (N/mm^2)	% Increase in Flexural Strength
Control Mix	4.87	-
5% CB + 10% RS	5.12	+5.13%
5% CB + 20% RS	5.2	+6.77%
5% CB + 30% RS	5.26	+8.00%
5% CB + 40% RS	6.628	+36.09%
5% CB + 45% RS	6.712	+37.82%
5% CB + 50% RS	8.00	+64.27%
5% CB + 55% RS	7.41	+52.15%
5% CB + 60% RS	7.283	+49.54%

5. Cost Analysis

The table IX shows the cost of conventional concrete without any replacement. The cost comes out to be Rs 5782.12 per cubic metre of concrete.After replacing the cement with carbon black by 5% and natural sand with robo sand by 50%, the total cost of concrete comes out to be Rs 5583.62 per cubic metre as shown in table X. The cost of concrete is reduced to Rs 198.5 per cubic metre which makes about 3.43% of total cost of concrete per cubic metre. This will help us to make concrete economical as compared to compared to conventional concrete.

TABLE IX

Cost Analysis without Replacement

S. No.	Material	Weight (kg/m^3)	Cost per kg (Rs)	Total cost of concrete per m^3
1.	Cement	372	7	2604
2.	Natural Sand	643.6	1	643.6
3.	Natural Coarse Aggregate	1267.26	2	2534.52
	Total			**Rs 5782.12**

TABLE X

Cost Analysis with Replacement

S. No.	Material	Weight (kg/m^3)	Cost per kg (Rs)	Total cost of concrete per m^3
1.	Cement	353.4	7	2473.8
2.	Natural Sand	321.8	1	321.8
3.	Natural Coarse Aggregate	1267.26	2	2534.52
4.	Carbon Black	18.6	5	93
5.	Robo Sand	321.8	0.5	160.5
	Total			**Rs 5583.62**

VI. CONCLUSIONS

- Based on the experimental work, it can be concluded that using robo sand and carbon black in concrete plays a significant role in increasing the strength and decreasing/ minimizing the corrosion of steel reinforcement which in turn increase the age of the concrete. It can be concluded that the strength of concrete increases and penetration of water in the concrete (permeability) decreases as the robo sand/quarry dust and carbon black content percentage rises. This is because when the carbon black at 5% replacement is added and natural river sand is replaced by quarry sand by 50%, the pores in the concrete gets blocked thereby increases the compressive strength, split tensile strength and flexural strength and in turn decreases the permeability. Thus in turn increases the durability and sustainability properties of the concrete.
- Moreover, replacing carbon black and robo sand in concrete will not only provide strength to concrete but also it will help in the waste management, thereby decreasing the environmental pollutions and ground water contaminations. Hence both the wastes will be managed effectively/properly.
- The cost of concrete is reduced to Rs 198.5 per cubic metre which makes about 3.43% of total cost of concrete per cubic metre. This will help us to make concrete economical as compared to compared to conventional concrete.

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