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Evaluation of partial Replacement of Fine Aggregate by Quarry Dust in Fiber Reinforced Concrete

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Abstract - The present study investigates the possible utilization of Quarry dust in the Fiber Reinforced Concrete (FRC) as a fine aggregate using mechanical properties of hardened concrete. Further, the mechanical properties and life cycle assessment is compared with the conventional concrete. The fine aggregates are replaced with quarry dust by 10%, 20% and 30% and evaluated in terms of compressive strength, split tensile strength and flexural strength for M30 grade of concrete at 7 and 28 days of curing period. From the results, the there is a significant improvement in the strength of the FRC when fine aggregate is replaced with QD in terms of compressive strength, split tensile strength and flexural strength. The workability of the concrete is also improved with the addition of the QD in the FRC due to presence of smooth surfaces with the addition of the QD. The addition of QD in the FRP saves the environment and it is a eco-friendly process. However, the cost of the manufacturing of FRP is almost same as that of the nominal concrete.

Key Words: Concrete, Fiber, Quarry dust, cost analysis

1. INTRODUCTION

Concrete is one of the widely used material around the world for construction purpose. Its manufacturing involves consumption of large quantity of cement, fine aggregate, and coarse aggregate. Generally, the fine aggregate used in the concrete is a river sand which is naturally available in nature. The utilization of river sand involves the degradation of the quality of the water, possible erosion of the river bank and river bed etc (Ahmad et al. (2022), Manasseh, (2010)). As a alternate to the -river sand, Quarry Dust (QD) can be used which is a waste by-product from the rock processing industry. QD is generally used for landfills that causes several environmental issues like contamination of water, more particulate matter in air, decrease in the porosity of soil, contamination of ground water etc (Sudheer et al. (2016)). Utilization of this QD in the manufacturing of concrete reduces the environmental issues. At the same time, there will be a reduction in the consumption of natural sand. Further, the utilization of QD in place of river sand can save up to 20% of the total cost (Manasseh, (2010)). Previous studies observed improvement in the tensile strength, flexural strength, elastic modulus, workability, abrasion resistance with the replacement of river sand with QD (Chitlange & Pajgade (2010), Mir (2015), Ephraim et al. (2012)). Similarly, the utilization of fibers in the concrete helps in the increase in the tensile strength upto 20% more than that of the nominal concrete and develops resistance against bending stresses (Das et al. (2018)). Due to advantages of fibre reinforced concrete, it is used in many applications like rigid pavements, slope stability purpose, for lining of tunnels, hydraulic and blast resistant structures (Wafa (1990)). Several studies have incorporated QD in different types of concrete. Elseknidy et al. (2020) studied the mechanical properties of concrete by incorporating aluminum dross, fly ash and QD. The maximum compressive and flexural strength is observed at 20% QD. Subbulakshmi and Vidivelli (2018) observed that maximum compressive and flexural strength at 50% of quarry wastes in the high-performance concrete mix. Febin et al. (2019) evaluated the concrete blocks made of QD in different proportions of fine aggregate replacement and found that the maximum compressive and tensile strength at 60% of QD. Hussain et al. (2020) compared the concrete made of different types of fibers like glass, Steel, PPF and observed that the PPF is economical and yields the same benefits that of remaining fibers. Among the studies, the optimum dosage of the QD varies in between 20% to 60% for different types of concretes. Limited studies explored the incorporation of QD in the Fiber reinforced concrete. In the current study, 0.5% of Polypropylene fibres were used and evaluated the mechanical properties of Fiber Reinforced Concrete where the Quarry dust is replaced with the fine aggregates by 10%, 20% and 30%. The mechanical properties include compressive strength, split tensile strength and flexural strength for M30 grade of concrete at 7 and 28 days of curing period. Further, the Life Cycle Assessment (LCA) is carried to compare the FRC made of QD with the conventional concrete.

2. Materials and Methods

A 53 grade Ordinary Portland Cement is selected and tested its properties according to IS 4031: 1988 and shown in the Table 1. Locally available river sand is used as fine aggregate and crushed stone aggregate of 20 mm maximum size is used as coarse aggregate and their properties were tested according to the IS 383: 1970 and IS 2386: 1963 as shown in the Table 2 and Table 3. It is observed that all the materials properties are fall within the specification limitations. Quarry dust which is a by-product of stone crushing industry collected from local quarry is used partially as a fine aggregate in the FRC and its properties were shown in the Table 2. After the determination of the physical properties of different aggregates and cement, mix design is carried for the M30 grade of concrete for conventional concrete as well as for FRC having 0.5% of polypropylene fibre where the fine aggregate is replaced with QD at different percentages (10, 20, 30) and both the mixes properties were compared as shown in the Table.4. The poly propylene fibres of length 12 mm, diameter 0.03 mm having a strength of 500 MPa were incorporated in the concrete. The prepared concrete samples of nominal concrete and FRC were evaluated in terms of compressive strength, tensile strength, flexural strength and workability. This follows the cost analysis of the conventional concrete and FRC made of QD.

Table -1: Physical Properties of Cement

Test	Result	Specification limitation	Test Code
Fineness of Cement (%)	2	10	IS 4031: 1988
Specific gravity	3.10	3.10-3.15	IS 4031: 1988
Normal Consistency (%)	32	26-33%	IS 4031: 1988
Initial Setting time (min)	28	>30	IS 4031: 1988
Final Setting time (min)	590	<600	IS 4031: 1988

Table-2: Physical properties of Coarse aggregate

Test	Result	Specification limitation	Test Code
Specific gravity	2.78	2.5-3.0	IS: 2386-1963
Water Absorption	0.1%	1-2%	IS:2386 – 1963 Part-III
Flakiness Index	11.8%	25%	IS: 2386-1963
Elongation Index	5.4%	45%	IS: 2386-1963

Table-3: Physical Properties of fine aggregates

Test	Result	Specification limitation	Test Code
Specific gravity	2.67	2.4-2.9	IS: 2386-1963 (Bureau of Indian Standards, 1963)
Fineness modulus	2.47	Zone-II	IS 383-2016 (Bureau of Indian Standards, 2016)
Water absorption (%)	0.8	<2	

Table-4: Details of the Concrete Mixes

Mix Id	Cement (Kg/m^3)	Water (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Fine Aggregate (Kg/m^3)	Polypropylene fibre (Kg/m^3)	Quarry dust (Kg/m^3)
NC	413	186	1172	693	9	-
FRC - 10% QD	413	186	1172	600	9	69.3
FRC - 20% QD	413	186	1172	554.4	9	138.6
FRC - 30% QD	413	186	1172	485.4	9	207.6

3. Results and Discussions

Slump cone test on Concrete mixes

The slump cone test is simple one that measures the workability of concrete using a slump cone whose height is 30 cm and the diameter of the lower end of the cone is 20 cm and the top end of the cone is 10 cm. The slump cone test is conducted generally on the fresh concrete immediately after mixing to measure the ease of work with the concrete. From the obtained results as shown in the Fig.1, it is observed that there is an increase in the slump value in the FRC compared with NC. Further, the slump value is increases with the replacement of natural sand with QD. This clearly indicates that the replacement of sand with QD increases the workability of the mix due to the smooth surface of the QD. However, some studies observed a decline in the workability of the concrete with the increase in the QD in the total mix [16]. The slump value is greatly influenced by the water absorption capacity and fineness of the QD that is used.

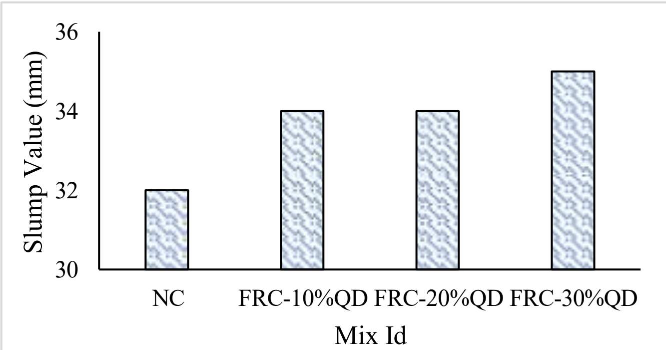

Fig- 1: Comparison of Slump value for different mixes

Compressive Strength of Concrete

The compressive strength is the basic property of the concrete that is used to distinguish the concrete and it is conducted on hardened concrete after reaching sufficient curing period. As the concrete strong in compression, this test measures the strength of concrete in compression. To conduct this test a Standard cube of dimensions 150mm×150mm×150mm is prepared and cured for 7 days and 28 days. After, the specimens are cleaned and subjected to compression at a rate of 140 kg/cm² per minute until failure. The maximum load that is taken by the specimen is recorded. Three specimens were considered for each type of mix in order to avoid discrepancies. The compressive strength is calculated using the equation (1). The test results were shown in the Fig. 2. From the results it is observed that the compressive strength of the FRC is more than compared with the NC. Further, there is an increase in the strength of concrete with the increase in the QD. There is a 20% increase in the compressive strength of concrete when concrete is added with 0.5% Polypropylene fibre and 30% of QD. Another study observed more than 20% of gain in strength when the sand is replaced with QD (COLLEPARDI (2007)). The addition of the QD helps to reduce the porous nature of the concrete there by increases the density of the concrete along with the strength.

$$\sigma = \frac{P}{A} \qquad \dots (1)$$

Here, σ is the compressive strength, P is the maximum or peak load, and A is the surface area of the specimen.

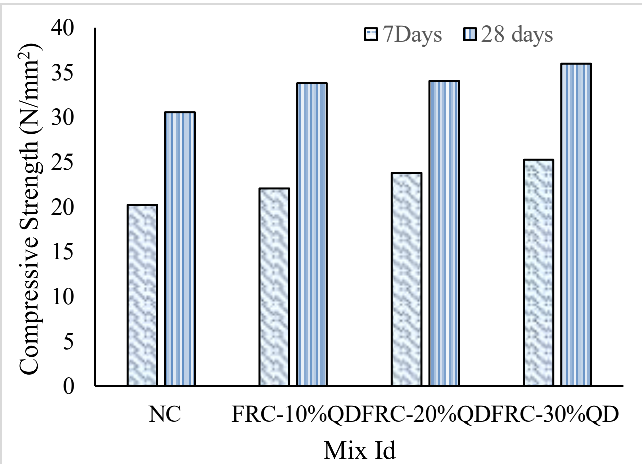

Fig- 2: Comparison of compressive Strength of Concrete mixes

Split tensile strength of Concrete

Concrete is generally weak in tensile. It is difficult to measure the tensile strength of the concrete directly. However, the tensile strength can be measured indirectly by applying a direct load on diametric plane of the cylindrical specimens that will create the tensile stress along the length of the sample. This test is important to understand the cracking of concrete in tension. The cylindrical specimens of size 300 mm length and 150 mm diameters were casted and cured for 7 days and 28 days before testing. The cured specimens were tested in a compression testing machine until it splits, and the failure load is recorded. The split tensile strength is measured using the equation (2). It is obvious that the FRC is having higher tensile strength compared with the NC because of the presence of the fibers. There is a significant increase in the tensile strength of the concrete by 10% with the addition of 30% QD (FRC-30%QD).

$$ITS = \frac{2P}{\pi DL} \qquad \dots (2)$$

Here, ITS is Indirect Tensile Strength, P is the peak load, D is the diameter of the specimen and L is the length of the specimen.

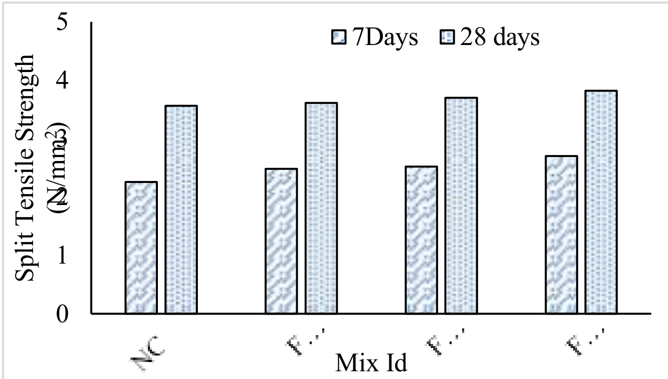

Fig- 3: Comparison of Split Tensile Strength of Concrete mixes

Flexural Strength of Concrete

Flexural strength measures concrete's ability to resist bending where both tension and compression occurs in the beam under loading. Flexure strength is used for design of beams and pavements which undergoes bending under loading. To measure the flexure strength, a beam of size 100mm× 100mm× 500mm is prepared. Total 6 specimens were prepared for each mix combination and 3 are tested after 7 days of curing period and remaining are tested after 28 days of curing period. The beam is tested on a flexural strength testing machine and loaded at two points until failure. The flexural strength is calculated by using the equation (3). The flexural strength of different mixes was shown in Fig. 4 where there is an improvement in the flexural strength of FRC with 30%QD compared with NC. However, the improvement is less significant compared with other tensile and compressive strengths.

$$f_{cr} = \frac{Pl}{bd^2} \qquad \dots (3)$$

Here, f_{cr} is the Tensile Strength, P is peak load, l is Length of the specimen, b is the width of the specimen, d is the depth of the specimen

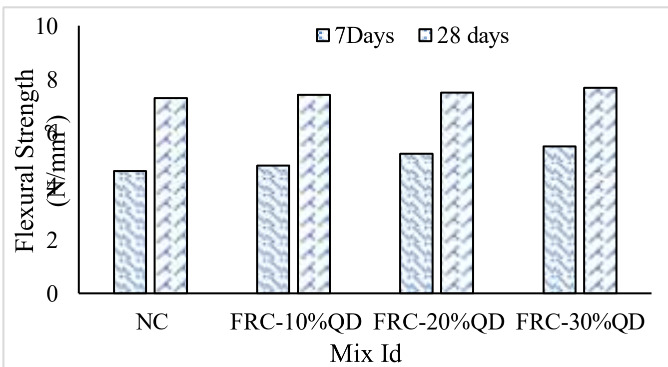

Fig- 4: Comparison of Flexural Strength of Concrete mixes

Cost comparison of concrete made of QD

Economic analysis is very important in selecting the materials. Although, the FRC made of QD has superior mechanical properties over NC, the cost benefit analysis to be done to consider the FRC made of QD in real time applications. The standard schedule rates were used to calculate the costs of different concrete. The QD considered here as a waste and did not consider additional cost for QD. The cost is calculated for the preparation of 1 m^3 of concrete as shown in the Fig.4. From the results, there is no significant changes in the cost of the FRC with QD and the NC are observed. The addition of the PPF into the concrete increased the cost of the FRC. But, the inclusion of the QD decreased the utilization of the natural sand and also it is an environmentally friendly alternative and solved the land filling and dumping problems of QD.

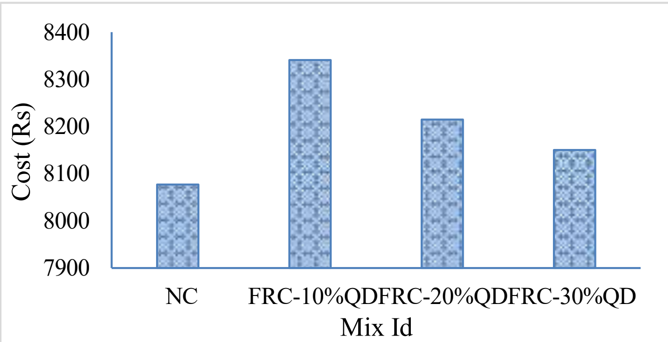

Fig- 4: Comparison of cost of Concrete mixes

4. CONCLUSIONS

All the experimental data shows that the quarry dust concrete with optimum replacement of sand by quarry dust shows far better physical and mechanical properties than the normal concrete. The following conclusions are drawn from the results:

1. Up to 30% replacement of sand by quarry dust in the FRC shows better results than that of the Nominal Concrete. Further replacement of sand by QD can be studied in the future research.
2. The compressive strength is increased by 20% when fine aggregate is replaced with 30% QD in the FRC.
3. The value of split tensile strength increased from 3.56Mpa to 3.82Mpa for 28 days up on replacement with 30% quarry dust in FRC.
4. The value of flexural strength increased from 7.3Mpa to 7.68Mpa for 28 days upon replacement with 30% quarry dust in FRC.
5. Utilization of QD in the concrete mixes is environmentally friendly, helps to reduce the waste. When compared in terms of costs, there is no significant changes in the cost when QD is replaced with fine aggregate in the FRC because of polypropylene fibers are costlier.

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