Significance of Fibres in Enhancing Strength and Corrosion Resistance of Fly Ash Blended Quarry Dust Concrete

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Abstract— Quarry dust which is generally considered as a waste material can be used as an economical alternative to the river sand since it has become a meager construction material and also highly pricey. Fly ash, which is the residue from coal-fired power plants, when used as partial replacement of cement in concrete, results in reduction of cement consumption and CO_2 production besides enhancing strength and durability properties. Deterioration of concrete structures due to rebar corrosion is a matter of significant concern since the cost of repairing and rehabilitation of these structures is very expensive. Fibres can be utilized to obtain a durable concrete with low shrinkage and improved strength properties. The objective of this work is to study the influence of polypropylene fibre in enhancing the strength and durability properties of fly ash blended concrete containing quarry dust as fine aggregate. The mechanical properties studied were compressive strength, split tensile strength, and flexural strength in addition to water absorption. The resistance to corrosion was evaluated by means of impressed voltage technique in saline medium, rapid chloride penetration test (RCPT) and weight loss method. From the results it has been arrived that fly ash blended quarry dust concrete along with polypropylene fibre can be effectively and economically utilized in the construction industry.

Keywords— Concrete, Corrosion resistance, Durability, Fly ash, Quarry Dust, Strength, Workability

I. Introduction

THE demand for natural sand is quite high in developing countries since the available sand cannot meet the intensifying demand of construction sector. Because of its limited supply the cost of natural sand has incredibly increased and its consistent supply cannot be guaranteed. Under these circumstances, quarry dust, a byproduct from the crushing process of stones which is available abundantly from rock quarries at low cost in many areas, can be used as an economical alternative to the river sand. Ilangovan[1] studied the usage of quarry dust as hundred percent substitute for natural sand in concrete and conducted experiments to judge the properties of fresh concrete and strength properties. Studies reported here have shown that the strength of quarry dust concrete is comparatively 10-12 percent more than that of similar mix of conventional concrete and durability of quarry rock dust concrete under sulphate and acid action is higher to that of conventional concrete[2],[3]. Sahu[4] and Naidu[5] have reported that concrete containing quarry dust as fine aggregate is promising greater strength, lower permeability and greater density which enable it to provide better resistance to freeze/thaw cycles and durability in adverse environment. As reported by Hameed[6], Nagaraj and Zahida Banu[7] the use of quarry dust as fine aggregate will also reduce environmental impact, if consumed by the construction industry in large quantity. However, the use of quarry dust in concrete is generally limited due to the high cement paste volume needed to obtain an adequate workability of concrete. The increase of water demand of quarry dust concrete mixtures can be mitigated using high-range water reducing admixture or super plasticizer [8]. But these remedies increase the cost of construction. In such situations, use of mineral admixtures such as fly ash in concrete increases the workability, consistency and reduces the water demand [9],[10]. The spherical shape of fly ash particles causes an improvement in the workability and the particles alter the flocculation of cement resulting in lowering the quantity of water required [11],[12]. However, fly ash causes a slight reduction in early strength. Therefore, the concurrent use of quarry dust and fly ash in concrete will lead to the benefits such as, the decrease in early strength by the addition of fly ash is reduced by the addition of quarry dust and the decrease in workability by the addition of quarry dust is reduced by the addition of fly ash [13],[14]. The use of fly ash as concrete admixture not only extends technical advantages to the properties of concrete but also contributes to the environmental pollution control [15].

Corrosion is an irreversible interfacial reaction of steel with its environment which results in consumption of the material leading to structural deterioration and failure in concrete structures[16]. Corrosion of steel rebar generates stress, causing cracking and spalling of the concrete cover. Spalling of the concrete cover is considered to be the most dangerous effect of corrosion which further accelerates and leads to structural weakening with high cost of repair[17]. High permeability of concrete allows the ingress of salt and moisture into the concrete[18]. Recent investigations have revealed that the amount of spalling and the extent of cracking can considerably be reduced by use of suitable fibres[19]. Fibre Reinforced Concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibres[20]. Fibre-reinforced concrete (FRC) has been

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http://dx.doi.org/10.15242/IICBE.C0314086

successfully used in construction for its excellent flexural-tensile strength, resistance to splitting, impact resistance and excellent impermeability, and frost resistance[21]. It is also an effective way to increase toughness, shock resistance, and resistance to plastic shrinkage cracking of the mortar[22],[23] Numerous studies were carried out to investigate the use of various fibres in enhancing the strength and durability properties of conventional concrete[24],[25]. The corrosion resistance performance of concrete having quarry dust as fine aggregate with fibres has not been discussed much. In this study the influence of polypropylene fibres has been studied in different proportioning to improve the strength and corrosion resistance characteristics of the fly ash blended concrete having quarry dust as fine aggregate instead of river sand. Strength and corrosion tests were performed on standard specimens to establish the role of the fibres in reducing permeability and improving durability of the concrete elements.

II Experimental Procedure

A. Materials used

Portland Pozzolana Cement was used throughout the experimental investigation. Locally available well-graded quarry dust, conforming to Zone-II having specific gravity 2.68 and fineness modulus 2.70 was used as fine aggregate. Natural granite aggregate having density of 2700kg/m3, specific gravity 2.7and fineness modulus 4.33 was used as coarse aggregate. Class C fly ash was used to replace cement at 30%. High yield strength deformed bars of diameter 16mm was used for corrosion test. Recron-3s polypropylene fibre was used at three volume fractions namely low volume fraction (less than 1%), moderate volume fraction (1% to 2%) and high volume fraction(greater than 2%) by weight of cement. The aspect ratio was 54.54. To increase the workability of fibre reinforced quarry dust concrete commercially available super plasticizer ROFF 320 at the dosage of 0.4 % by weight of cement has been used. To attain strength of 20 N/mm^2, a mix proportion was designed based on IS 10262-1982 and SP23:1982(21). The mixture was 1:1.517:3.38 with water cement ratio 0.45.

B. Methodology

Concrete cubes of size 150 x 150 x150mm, beams of size 500 x 100 x 100 mm, cylinders of size 150mm diameter and 300 mm long were cast for compressive, flexural and split tensile strength tests. Triplicate specimens were cast for each test. After 24 hours the specimens were demoulded and subjected to water curing. After 3, 7, 28, 56,90and 180days curing the specimens were tested as per IS: 516 – 1964. Cylinders of size150mm diameter and 300 mm long with rods of 70cm length kept at the centre were used for determination of bond strength. Water absorption of hardened concrete specimens was calculated based on ASTM C642-81. Concrete cylinders of size 75 mm diameter and 150 mm length with centrally embedded a high yield strength deformed(HYSD) steel bar of 16mm diameter were used to assess the corrosion protection efficiency under accelerated test conditions and weight loss measurement. After 28 days curing the specimens were subjected to acceleration corrosion process in order to accelerate reinforcement corrosion in the saline media (3% Sodium chloride) under a constant voltage of 6 volts from the D.C power pack. For weight loss measurement the cylinders were immersed in 3% NaCl solution under alternate wetting (3days) and drying (3days) conditions over a period of 90 days. At the end of 90days the cylinders were broke open and the final weight of the specimens was taken and the loss in weight was calculated. From the weight loss obtained corrosion rate is calculated. The RCPT is performed by monitoring the amount of electrical current that passes through concrete discs of 50mm thickness and 100mm diameter for a period of six hours. A voltage of 60 V DC is maintained across the ends of the specimen throughout the test. One lead is immersed in a sodium chloride(NaCl) solution(0.5N) and the other in a sodium hydroxide(NaOH) solution (0.3). The total charge passed through the cell in coulombs has been found in order to determine the resistance of the specimen to chloride ion penetration.

III Results And Discussion

A. Strength tests

Compressive, split tensile and flexural strength tests were conducted to investigate the mechanical properties of fibre reinforced fly ash blended quarry dust concrete and the results are shown in fig 1 to 3. Fig 1 shows the compressive strength test results. Comparing the performance of the fly ash blended quarry dust concrete with variable fibre additions it is observed that the incorporation of fibres did not show any adverse effects on the compressive strength and there was a marginal increase frm 3% to 10% which is statically insignificant. It is also observed that the effect of fibres is more efficient on further loading after collapse.

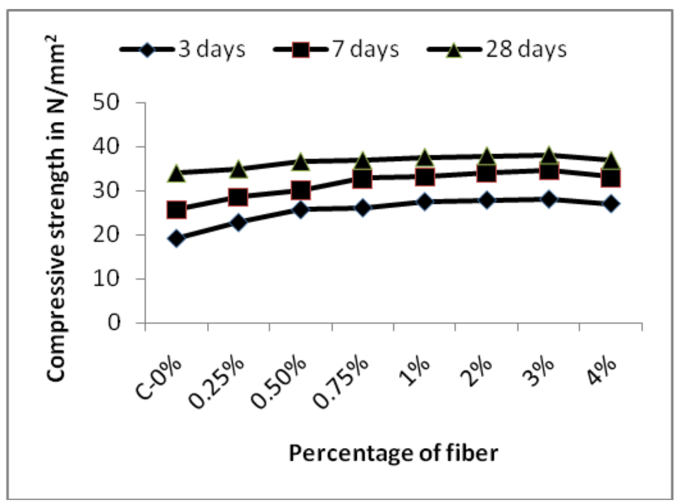

Fig 1 compressive strength development

Following the results of flexural strength (fig 2), the results of fibre reinforced fly ash blended quarry dust concrete showed an appreciable increase in flexural strength. Also, increase in the fibre volume fraction clearly shows the better performance. From the fig it is evident that 0.25% addition of fibre shows 18% increase in the flexural strength, while the addition of 0.5% gives hike of 26% and 0.75% yields the increase in the strength value of about 31%. Further, addition of fibre from 1% to 3% gives 35%, 38%, and 42% respectively.

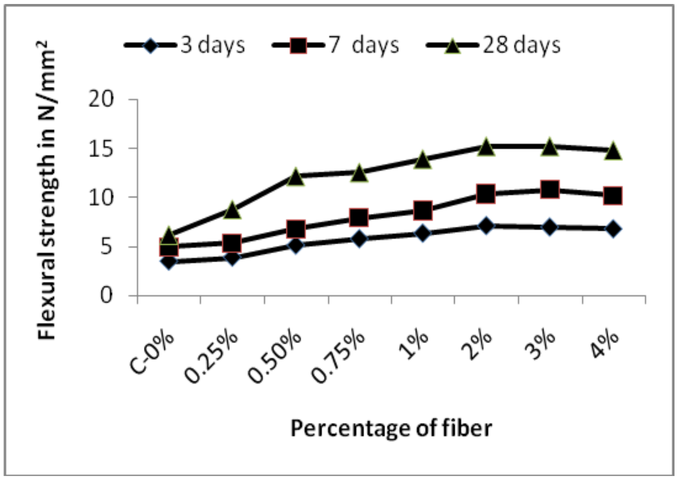

Fig 2 Flexural strength development

This is due to the contribution of more fibres during tensile load before fracture of the samples. This is because uniform distribution of fibres tends to stop cracks from propagating by holding the concrete together. The fibres thus form a sort of multi-dimensional reinforcement that distributes tensile stresses more evenly throughout the concrete. However 4% yields a comparatively lower value than 3%. Because at higher percentages the toughness is increased this would offer very good impact resistance.

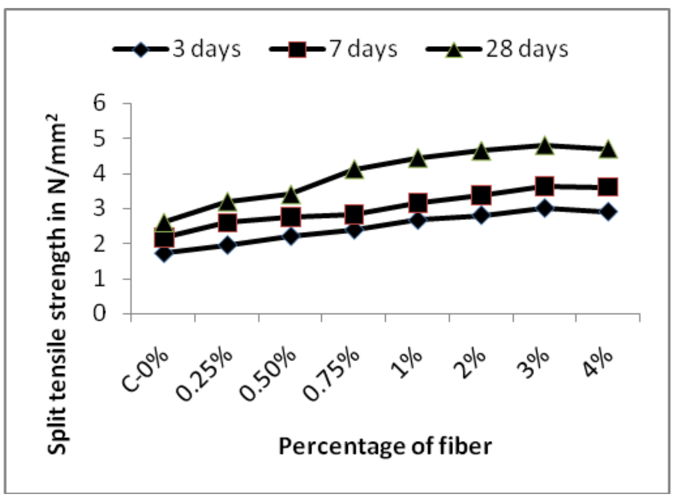

Fig 3 Split tensile strength development

In accordance with fig 3, it is understood that, split tensile strengths of fibre added fly ash blended specimens (fig 3) were higher than the reference concrete. The splitting tensile strengths of the 0.25, 0.5% and 0.75% were 15%, 23% and 28% higher, respectively, than that of the control concrete (C-0%) which show the good improvement. It can also be observed that specimens containing the fibre with high volume fraction 1% to 3% show the better split tensile strength among all concretes about 32%, 35% and 39% respectively. The uniform distribution of fibres throughout the concrete results in prevention of propagating cracks at the aggregate paste interface itself. Improvement in split tensile strength is predictable when the fibre proportion is increased since the plane of failure is distinct (diametric). The higher the number of fibres bridging on the diametrical 'splitting' crack, the higher would be the split tensile strength. Nevertheless, by increasing the fibre content to 4 % there was a marginal reduction in the strength values.

B. Water absorption

The results of water absorption tests indicate that addition of fibres has a small but generally positive effect in reducing water absorption. By adding the fibre to concrete, durability parameters of concrete were improved as is shown in fig 4. It is clearly shown that introducing fibres to the concrete decreased water absorption of concrete.

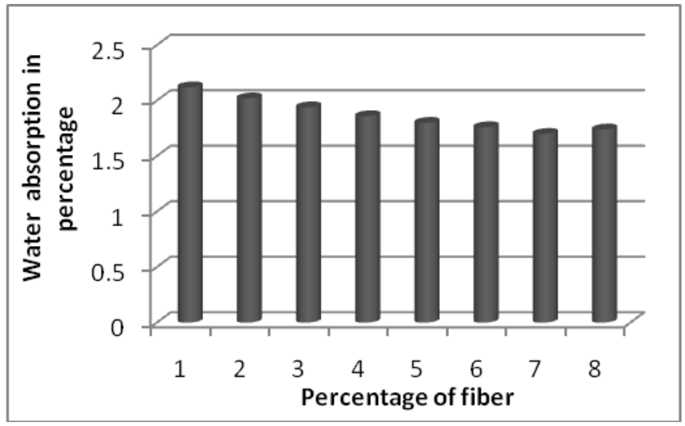

Fig 4 Water absorption capacity after 28 days

C. Corrosion tests

Rapid Chloride Penetration Test (RCPT)

Low permeability is the key to good durability. Permeability, cracking and corrosion were found to be interrelated and the effects of these factors affect the durability of concrete.

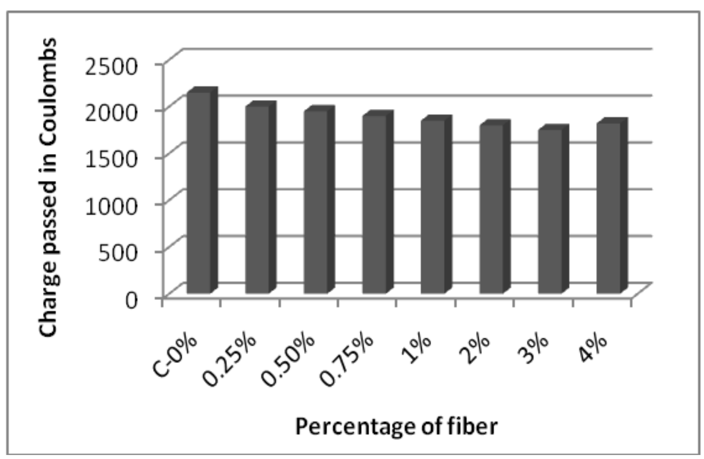

Fig 5 rapid chloride penetration

Fig 5 shows the chloride diffusion results of the different volume fractions of fibres. The chloride ion penetration in the form of charge passed in coulombs is shown in the fig 5. The performance of the flyash blended quarry dust concrete with 0.25%, 0.50%,0.75%, 1%, 2%, 3% and 4% of fibres are observed to be 6.9%, 9.3%, 11.6%, 13.5%, 16.3%,18.6% and 15.3% greater than the control specimen. In addition, a feature of polypropylene reinforced concrete, is that once the concrete has sustained cracking, the fibres help maintain the integrity of the structure by forming ties in the cement matrix across the crack.

Impressed voltage test

The corrosion resistance performances resulted from impressed voltage measurement at various percentages of fibres with respect to time are shown in fig 6. The current intensity with respect to time for various percentages of inhibitors is shown in figure. The corrosion initiation time for control concrete is found to be 204 hours. In accordance with fig 6, it is to be noted that even the minimum value of the corrosion initiation time with respect to the addition of fibres is slightly higher than that of the control specimens. 0.25% , 0.5% and 0.75% addition of fibre showed 7%, 12% and 18% improvement respectively and 1%, 2% and 3% addition of fibres exhibited 20%, 23% and 25% improvement in corrosion resistance. The impressed voltage test results show that due to the addition of fibres permeability of the concrete was considerably reduced and the time taken for initiation of corrosion in concrete with respect to accelerated chloride penetration has been increased significantly.

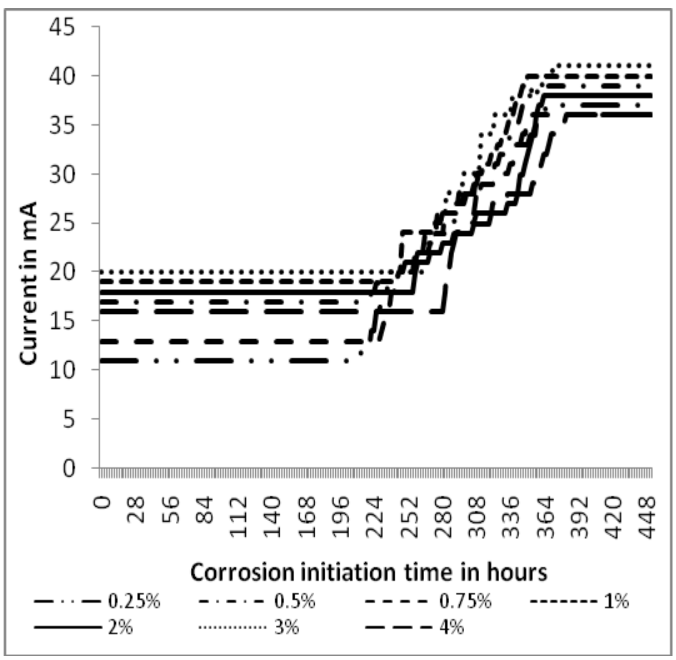

Fig 6 Corrosion initiation time Vs Current

D.Weight loss measurement

Fig 7 demonstrates the average corrosion rate calculated in mmpy for various percentages of the fibres from weight loss measurements. The results obtained from the weight loss method indicated that, 0.25%, 0.50%,0.75%, 1%, 2%, 3% and 4% addition of fibres have reduced the corrosion rate by 5%, 8%, 11%, 14%, 16%,19% and 21% respectively.

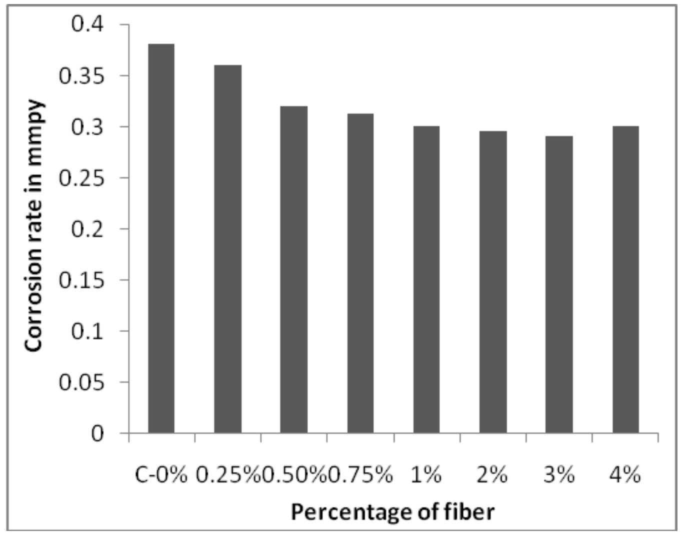

Fig 7 Corrosion rate in mmpy

The same trend was observed in impressed voltage test and RCPT test also. Because of the reduction in permeability, fibre reinforced quarry dust concrete may require less depth of reinforcement cover than conventional concrete.

IV CONCLUSION

I. The utilization of quarry dust and fly ash as construction materials not only reduces the construction cost but also contribute to a very satisfactory outlet of these industrial by-products which were earlier considered as waste materials and dumped on huge quantities on barren lands causing pollution problems.

II. Incorporation of polypropylene fibres in flyash blended quarry dust concrete enhances the the continuity and integrity of concrete thereby increasing long-term tensile strength, which is beneficial to the safety and durability of concrete structures.

III. The addition of a low volume fraction of polypropolyne fibres inhibits micro- cracking, bleeding and increase cement hydration in fresh concrete, thereby reducing surface permeability and reduction in formation and growth of micro cracks in concrete. Hence, it offers low permeability which in turn contributes to better durability and corrosion resistance.

IV. Moderate volume fraction distributes localised stresses, thereby reducing damage from impact, flexural fatigue, cracking, spalling and delaminating in hardened concrete. These composites can be used in construction methods such as shotcrete and in structures that require energy absorption capability.

V. High volume fraction lead to strain hardening of the composites. Because of this improved behaviour, these composites are suggested for high-performance fiber reinforced composites (HPFRC).

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