Strength, bond and durability related properties of concretes with mineral admixtures

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Abstract

This paper reports the strength, bond and durability related properties of concretes with fly ash and silica fume as cement replacement materials (CRM). It includes out pullout tests carried out following IS 2770 (Part-I) and RILEM. While the durability properties obtained were on the expected lines, the bond performance in specimens with 30 percent fly ash and 10% silica fume showed lower strengths, with 6 to 16% variations, compared to the concretes of OPC alone. Nevertheless, the bond stresses were higher than those recommended.

Keywords: Admixture, fly ash, silica fume, pull-out test, bond strength.

Introduction

Durability of concrete plays an important role in the service life of RCC structures. It can be enhanced by improving impermeability, resistance to chloride ion diffusion and abrasion resistance. One of the ways to achieving this is by adding superplasticisers and mineral admixtures.1 Also, high performance concrete (HPC) can be produced by minimising the water cement ratio with the help of superplasticisers and carefully selecting mineral admixtures such as fly ash, ground granulated blast furnace slag (GGBS), metakaolin and silica fume.2,3 Many researchers have demonstrated the beneficial effects of using GGBS and fly ash as CRMs and obtained a reduction in the rate of penetration of chloride ions into concrete reducing the potential of chloride induced corrosion.

The other aspect of this investigation – bond strength, is an interfacial property between the steel and surrounding concrete. It is essential for the efficient load transfer from concrete to steel and vice versa. Gjorv et al conducted pull-out tests to study the effect of condensed silica fume (CSF) on the mechanical behaviour of the steel concrete bond and reported that adding up to 16 percent CSF by weight of cement showed an improving effect on pull-out strength up to 76 MPa compressive strength.6 They explained the increase based on the reduced accumulation of free water at the interface during casting and densification of the transition zone due to pozzolanic reaction between calcium hydroxide and CSF. De larrard et al observed that bond strength in HPC was higher than that in OPC concrete. They attributed the increase to tensile strength and bar confinement improvements in HPC.7 On the other hand, Hwang et al reported that replacing cement with silica fume in their HPC experiment decreased the bond strength.8 They concluded that the presence of silica fume in concrete was responsible for the loss of adhesion between concrete and steel at the ribs. Galeota et al studied the mechanical properties of high volume fly ash concretes including the bond strength between steel and concrete.

Table 1. Physical and engineering properties of raw materials

Physical Properties	Cement	Sand	Aggregate
Specific gravity	3.15	2.67	2.68
Bulk density, kg/m^3	-	1680	1600
Fineness modulus	-	2.78	6.81
Initial setting time, minutes	110	-	-
Final setting time, minutes	220	-	-
Compressive strength of mortar cubes @ 28 days, N/mm^2	52.40	-	-

They demonstrated in 28 day cured specimens that the average bond stress values decreased by about 25 percent compared to the reference concrete (without fly ash). Their test results also suggested that the adhesion between steel and concrete in fly ash specimen was less than that of the OPC specimen.

Research significance

Research reports on the effect of mineral admixtures on the fresh and long term properties of high performance concrete are many, however, literature on the bond behaviour of rebars embedded in concrete containing pozzolans such as fly ash and silica fume is scarce. From the environmental and sustainability point of view, there is a growing need to use supplementary cementitious materials such as fly ash and silica fume in RCC construction in India and world wide. The structural behaviour of reinforced concrete is affected by several variables such as quality of raw materials, geometry of rebar, method of casting and compaction. The lack of sufficient information on the bond behaviour of concretes with supplementary cementitious materials necessitated the present study. This paper attempts to evaluate the effect of locally available fly ash and silica fume on the bond characteristics of deformed bars. Experimental studies were conducted on different concretes made of OPC alone (OPC), OPC with 30 percent fly ash (OPF) and OPC with 10 percent silica fume as cement replacement material (CRM).

Experimental details Materials used

The materials used in the study were cement (53 grade), fine aggregate (river sand passing through 4.75 mm), coarse aggregate (crushed granite stone 60% passing through 20 mm and 40% passing through 12 mm), class-F fly ash, silica fume, superplasticiser and water. Table 1 gives the properties of cement, sand and coarse aggregate.

Table 2. Chemical composition of Fly ash

Compound	Percentage content
SiO_2	52.52
Al_2O_3	32.63
Fe_2O_3	6.16
CaO	N.D
MgO	N.D
Na_2O	0.02
SO_3	4.95
MnO	0.03
K_2O	0.11
Loss on ignition (LoI)	1.39

The water used was ordinary potable ground water. Fly ash was obtained from Ennore thermal power plant, Chennai and belonged to class-F. Table 2 presents the chemical analysis of fly ash. A well known brand of silica fume was used. Its chemical and physical properties are presented in Table 3.12 Thepolycarboxylate ether based superplasticiser (SP) was used to get a slump of 80-150 mm. The superplasticiser complied with IS 9103 requirements with specific gravity of 1.09 and solid content of not less than 30%.

In this investigation, concrete specimens with three types of binders were studied; (i) OPC alone, (ii) OPF (OPC with 30% fly ash as cement replacement material, CRM), and (iii) OPS (OPC with 10% silica fume as CRM). For each specimen type, three water to binder (w/b) ratios were used viz. 0.55, 0.45 and 0.35. Thus, a total of 9 concrete specimens were prepared. ACI 211 guidelines were followed while proportioning the mixes.13 Table 4 gives the quantities of materials per cubic metre.

Table 3. Chemical and physical properties of silica fume

Compound	Percentage content
SiO_2	96.5
CaO	1.40
Fe_2O_3	0.15
MgO	0.20
Al_2O_3	0.15
K_2O	0.04
Na_2O	0.20
Physical properties	
Specific gravity = 2.3	
Bulk density = 225 kg/m^3	
Specific surface = 20,000 m^2/kg	
Average particle size = 0.14 mm	

Tests conducted

The main objective of the investigation was to understand the bond behaviour of deformed rebar in these concrete mixes. Tests were also performed to evaluate the mechanical and durability properties using standard test specimens (150 x 150 x 150 mm cubes for compressive strength, 100 x 100 x 500 mm prisms for flexural strength, 150 diameter and 300 mm height cylinders for split tensile strength, 75 mm diameter 150 mm height cylinders for water absorption and 100 diameter and 200 mm height cylinders for rapid chloride permeability). In addition. The ultrasonic pulse velocity test was carried out on the cubes specimens before testing them for compressive strength.

For understanding the bond behaviour, two types of specimens are common in the literature; pull-out test specimens and beam test specimens. Popular standard pull-out test methods include the concentric pull-out test methods specified in the American society for testing materials (ASTM), Union of testing and research laboratories for materials and structures (RILEM), British standards (BS), Bureau of Indian standards (BIS or IS) and Chinese Standard, The beam test methods are specified by ASTM and RILEM.14 In this study, the bond behaviour was studied using both BIS or IS 2770 and RILEM pull-out test specimens. 15,16 Although pullout tests are controversial because concrete surrounding the embedded steel bar is compressed during pullout, unlike the actual loading situations encountered in service, especially in flexural members, several researchers have used this tests for evaluating steelconcrete bond characteristics.17, 18-21 Notwithstanding the controversy surrounding the pull out tests, experimental studies were carried out due to the simplicity of these tests and for comparison of various specimens.

During casting, specimens were compacted using a vibration table. After 24 hours, the specimens were removed from the mould and water cured for 28 days. The IS pull-out test specimen was a 150x150x150mm cube with a rebar cast vertically, conforming to IS 2770 and IS 1786. The RILEM test specimen was a 160x160x160mm cube with a rebar cast horizontally. The embedding length of the 16 mm diameters rebar was maintained at 80 mm in both IS and RILEM specimens. This facilitated the loading the specimen in a Universal Testing Machine (UTM) for measuring the free end slip. In the BIS specimen, a 6 mm diameter mild steel rod was used as the transverse reinforcement with a pitch of 25mm such that the outer diameter of helix (spirals) was almost equal to the size of the cube (Figure 1).15 Each end of the helix was welded to the next turn. Since, RILEM pull-out moulds were readily not available in the market; they were prepared by following the RILEM specification (Figure 2).15,

A sleeve of PVC conduits with a diameter slightly higher than that of the rebar ensured the correct bar embedment length, 80 mm, was in contact with the concrete

Figure 1. BIS Specimen

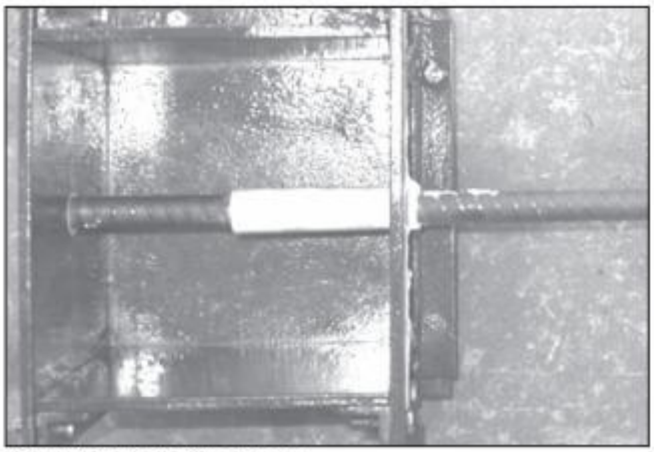

Figure 2. RILEM Specimen

A 12 mm thick wooden plank with a 20 mm diameter hole was used at the bottom of the IS pull-out mould such that the rebar projected 10 mm from the mould bottom. Before starting to pour the concrete, the rebar was placed in the hole vertically and held firmly. After pouring a small quantity of concrete, the spiral reinforcement was placed at the centre of the mould and then the pouring was completed

RILEM pull-out specimens were cast in the larger moulds without providing any transverse reinforcement. A vibrating table ensured that the concrete was well compacted. A wooden sheet 150x150mm with a 20mm diameter hole at centre was placed on the top of the mould to ensure verticality of the rebar. Specimens were kept in the moulds for 24 hours before demoulding and keeping them in water for 28 days for curing

Conclusions

The ultrasonic investigation data showed that the quality of concrete used in downstream concrete I-girder, span no. 1 from Jabalpur end was very poor to doubtful in quality. A number of honeycomb patches were found in the web caused by the presence of jumbled up reinforcement bars at bottom as well as shear zone. The concrete had not reached such areas especially the bottom flange portion.

References

Mohammed Firdous M.Z., Chellapan A., Prabhakar J. and Srinivasan P., Assessing quality of in-situ concrete in turbo generator foundation using UPV measurement, The Indian Concrete Journal, February 2005, Vol.70, No.2, pp 41-46.

Prabhakar J., Ramanjaneyulu K., Chellapan A., Srinivasan P., Mohammed Firdous M.Z. and Annamali S., Investigation of a prilling tower, The Indian Concrete Journal, October 2003, pp 1354-1360.

Komlos K., Popvics S., Nurnbergerova T., Babal B. and Popvics J. S., Ultrasonic pulse velocity test of concrete properties in various standards, Cement & Concrete Composites, 18 (1996) 357 – 364,

Elsevier Science Limited. __ Non-destructive Testing of concrete method of test – Ultrasonic Pulse Velocity, IS 13311: Part 1: 1992, Bureau of Indian Standards, New Delhi.

Recommendation for measurement of velocity of ultrasonic pulse in concrete, BS 1881: Part 203: 1986, British Standard Institution, London, 1986.

Guideline to the use of non-destructive methods of test for hardened concrete, BS 1881: Part 201: 1986, British Standard Institution, London, pp 14-15. Shishir Kumar Sahu, Assessment of concrete quality from Pulse Velocity test, CE and CR, August 98, pp 43-45.

Shiv Kumar, Non destructive testing of bridges, Indian Railways Institute of Civil Engineering, Pune 2005, pp 11-22. Shiv Kumar, Bridge inspection and maintenance, Indian Railways Institute of Civil Engineering, December 2005, pp 71-73.

Ayaz Mahmood, Structural health monitoring using non destructive testing of concrete, Thesis submitted to National Institute of Technology, Rourkela for B.E., 2008.