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Non Destructive Behavior of Corroded Reinforced Geopolymer Concrete Beams

Udhaya Kumar. T, Jayadurgalakshmi. M

Abstract*: Corrosion of steel reinforcement bar embedded in geo-polymer material has been an object of study to confirm its technical viability. The available alkalinity of geo-polymer material initially was suspected to be harmful for alkali-silica reaction, but then it was found to be beneficial to maintain passivity of the steel bar in concrete. Many researchers carried out studies on the influence of corrosion on bond, generally developed on the basis of experimental tests in specimens subjected to artificial corrosion. The current density applied to accelerate the corrosion influences the bond strength. Since, natural corrosion develops in a very long time, an artificial corrosion has been provided.

Keywords* : Artificial corrosion, Geo polymer, Corrosion, Current density.

I. INTRODUCTION

Among the greenhouse gases, CO_2 contributes about 65% of global warming. The amount of the carbon dioxide released during the manufacture of Ordinary Portland cement due to the calcinations of limestone and combustion of fossil fuel is approximately in the order of one tonne for every tonne of Ordinary Portland cement produced [1&2].
Cement production generated CO_2, which pollutes the atmosphere. The thermal manufacturing produces a waste called fly ash which is basically dumped on the earth, occupies larges areas. By producing geo-polymer concrete all the above mentioned issues shall be addressed by rearranging them. Since geo-polymer concrete does not use any cement, the production of cement shall be reduced and hence the pollution of atmosphere by the emission of CO_2 shall also be minimized. Corrosion of the reinforcement is a familiar form of degradation of reinforced concrete structures. As a matter of information the chemical attack varies the mechanical properties of together the steel rebars and concrete, and the bond characteristics. The problem of the durability of the reinforced concrete structure is arisen, dramatically, in the last decades. The analysis of the actual damages in Reinforced Concrete constructions has shown that one of the most dangerous degradation phenomena is connected to the corrosion of the rebars.

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* Correspondence Author
Udhaya Kumar.T, Department of Civil Engineering, Vel Tech University, Chennai, India. Email: tudhayakumar@veltechuniv.edu.in
Jayadurgalakshmi.M, Department of Civil Engineering, Vel Tech University, Chennai, India. Email: jayadurgalakshmi@veltech.edu.in

II. SUMMARY OF THE LITERATURE

Materials used for the study are Cement, coarse Aggregate,
Low-calcium fly ash based geo-polymer concrete had excellent compressive strength, suffer very little drying shrinkage and it is suitable for structural applications. Alkaline liquid that contain soluble silicates are proved to increase the rate of hydration reaction compared to alkaline solutions that contained only hydroxide. Compressive strength of geo-polymer concrete was proved to be increased with increase in percentage of replacement of fly ash with GGBS. Fly ash can be replaced by GGBS up to 30%, beyond that fast setting was observed. Maximum compressive strength of about 52MPa was attained in ambient cured Research works on reinforced GPC revealed that structural behaviour of GPC's and conventional concretes are essential and similar in nature, except that some time at the same strength level, GPCs may tend to have lower modulus of elasticity. About the mechanical strengths, only qualitative information is available which can be used to decide about any particular combination of GP mixes to achieve the desired level of strength. Low calcium fly ash based geo-polymer concrete had good corrosion performance and yielded longer time to failure than the OPC concrete when subjected to impressed voltage test. The electrical resistivity and permeability of the fly ash-based GPC were not significantly affected by the severe marine environment. Limited amount of research works has been conducted on the corrosion behaviour of reinforced geopolymer concrete. Ultrasonic Pulse Velocity studies on reinforced cement concrete and geopolymer concrete subjected to accelerated corrosion was very scare and limited.

III. MATERIALS & EXPERIMENTAL PROCEDURE

The materials such as Cement, Fly ash, Ground Granulated Blast Furnace Slag, Fine aggregate, Coarse aggregate and Alkaline solution were used in the present work. The methods of study of characteristics are presented.

A. Ultrasonic pulse velocity test (UPV)

It was found that the velocity depended upon the elastic property and geometry of the material. The measuring equipment consists of an electrical pulse generator, a pair of transducers, an amplifier, and an electronic timing device for measuring the time interval elapsing between the onset of a pulse generated at the transmitting transducer and the onset of its arrival at the receiving transducer. Transducers of 50 to 60 kHz are found to be useful for most of the applications in concrete testing. A typical measuring instrument is as shown in figure 3.2.

Figure 3.2: Testing of corroded specimens using UPV measuring Apparatus

B. Flexural Testing

Fig 3.3 shows the arrangement for flexural testing. At the age of 28 days after casting, the specimens were tested under two-point bending to determine their load- deflection curves and the ultimate flexural strength as shown in Fig 3.4. The test specimen was mounted in a UTM of 200kN capacity. The supports of the beam rested on a interval of length 500mm.The effective span of the beam was 400mm. The load was applied on two points each 70mm away from centre of the beam towards the support.

Dial gauge of 0.01mm least count were used for measuring the deflections under the load points and at the mid span for measuring the deflection. The dial gauge readings were conducted at different loads. The load was applied at intervals of 1.52 kN until the first crack was observed. Subsequently the load was applied at intervals of 3.04 kN The behaviour of the beam was observed carefully and the first crack was observed. The load and mid span deflection data for each specimen were recorded at predetermined load intervals until failure.

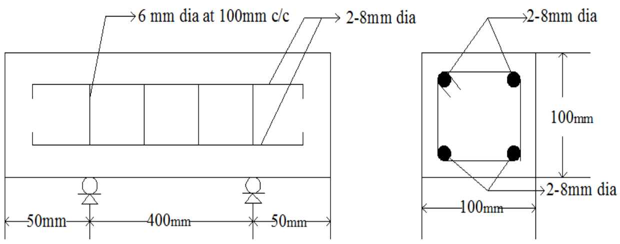

Figure 3.3: Details of the beam specimens

Fig.3.4: Arrangement for two-point bending test

IV. RESULTS AND DISCUSSIONS

In this chapter, the experimental results obtained are discussed and presented in the form of tables and graphs. The test results of flexural behavior of corrosion induced RCC beams and GPC beams are discussed in detail.

a) Compressive strength

Compressive strength of geopolymer concrete and cement concrete cubes was tested at 28 days of age after casting on standard compression testing machine of 3000kN Capacity, as per IS: 516-1959. Each of the compressive strength test data corresponds to the mean value of the compressive strength of three test concrete cubes. The average compressive strengths for the GPC and OPC specimens were 38MPa and 27MPa at 28 days respectively.

b) Ultrasonic pulse velocity test (UPV)

Table 4.1 & 4.2 shows the ultrasonic pulse velocity test results of GPC and RCC specimens and Fig. 4.1 (a) & (b) represents the graphs for ultrasonic pulse velocity test results of GPC and RCC specimens. In general, ultrasonic pulse velocity varies from 3.95 km/s to 3.03 km/s for GPC specimens and 4.58 km/s to 3.63 km/s for RCC specimens. It is evident from the graphs that UPV decreases when percentage of corrosion increases irrespective of type of concrete, density of corrosion current passed. And also, UPV was decreased when the density of corrosion current was increased. Percentage reduction in UPV for various percentages of corrosion was more for RCC when compared to GPC. Maximum percentage reduction in UPV was about 17% and 20% for GPC and RCC specimens. The quality of concrete was also compared as per IS 13311, 1983. The quality of GPC was found be good up to 3mA/cm2 corrosion current density and up to 7.5% of corrosion. When GPC beams are subjected to 10% of corrosion, the concrete was of medium quality. The quality of RCC was found be good for all percentages of corrosion and density of corrosion current. It was reported that due to corrosion of steel, crack is formed between steel concrete interfaces which in turn results in reduced UPV of corrosion induced specimens.

Table 4.1 Ultrasonic pulse velocity test results for GPC

Icorr (km/sec)	1mA	2mA	3mA	4mA
Control	3.95	3.95	3.95	3.95
5% corrosion	3.8	3.69	3.59	3.24
7.5% corrosion	3.74	3.67	3.49	3.13
10% corrosion	3.71	3.61	3.43	3.03

Table 4.2 Ultrasonic pulse velocity test results for RCC

Icorr (km/sec)	1mA	2mA	3mA	4mA
Control	4.58	4.58	4.58	4.58
5% corrosion	4.37	4.23	4.11	3.94
7.5% corrosion	4.21	4.12	3.99	3.8
10% corrosion	4.12	3.94	3.85	3.63

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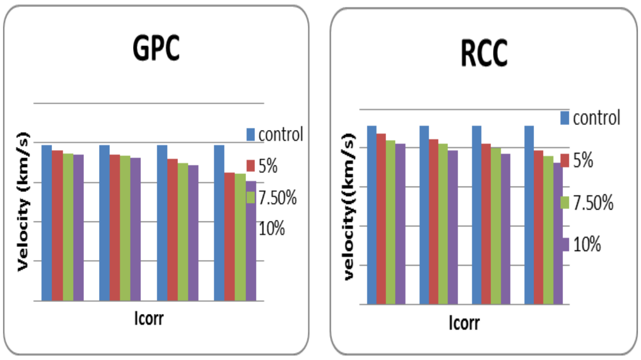
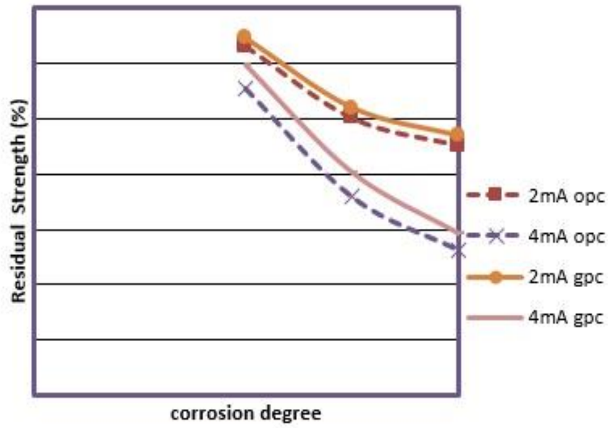


Fig: 4.1(a) UPV results for GPC Fig: 4.1(b) UPV results for RCC



c) Failure mode of corroded beam

The failure of corroded beams was initiated by bond failure at the tension reinforcement interface. Horizontal splitting of concrete was observed at about 60 to 70% of failure load and vertical cracks were noticed in pure bending zone at about 90% of failure load.

d) Residual moment capacity of corroded beams

Residual moment capacity (R) of corroded beams were calculated as the ratio of ultimate moment capacity of corroded beams and control beams in percentage and presented in Table. 4.3. Fig 4.2 shows that the residual moment capacity of beams decreases with increasing Icorr as expected. With increasing Icorr, the metal loss will be higher, and this in turn will reduce the residual moment capacity of corroded beams. Fig 4.17 illustrates the effect of corrosion rate on the residual moment capacity of beams subjected to different degrees of corrosion induced in the reinforcement at four different corrosion rates. A comparison of two plots (Fig 4.3) for 5%, 7.5% and 10% corrosion shows that the residual moment capacity of corroded beams would be higher for GPC when compared with RCC. It was also noticed that residual moment capacity of corroded beams was significantly decreased with increasing corrosion rate and degrees of corrosion

Table 4.3: Experimental moment capacity of corroded beams

Degree of corrosion (%)	Corrosion current density (mA)	Experimental Ultimate moment capacity of corroded beam (Mex,c)		Experimental Ultimate moment capacity of un corroded beam (Mex,uc)		Residual Moment Capacity =Mex,c/ Mex,uc x 100	
		RCC	GPC	RCC	GPC	RCC	GPC
5%	1	7.70	8.51	8.11	8.92	94	95
	2	7.30	8.11	8.11	8.92	90	90
	3	6.89	7.70	8.11	8.92	85	86
	4	6.08	7.30	8.11	8.92	75	81
7.5%	1	6.89	7.7	8.11	8.92	85	86
	2	6.49	7.30	8.11	8.92	80	81
	3	5.67	6.49	8.11	8.92	70	72
	4	4.86	5.67	8.11	8.92	60	63
10%	1	6.49	7.30	8.11	8.92	80	81
	2	5.67	6.08	8.11	8.92	69	68
	3	4.46	5.27	8.11	8.92	55	59
	4	3.65	4.05	8.11	8.92	45	45

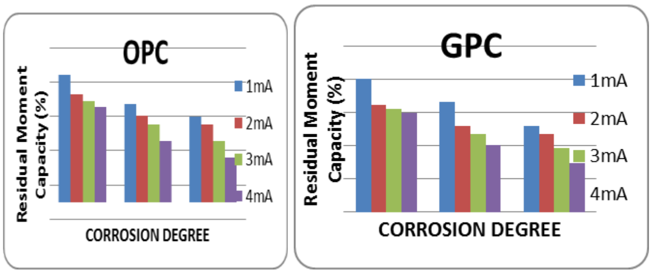


Fig 4.3: Effect of corrosion rate on flexural strength of beams

V. CONCLUSION

Based on the experimental results, the following conclusions were obtained.

- In general, ultrasonic pulse velocity of corroded beams was less when compared to control beams.
- Percentage reduction in ultrasonic pulse velocity was more in RCC when compared to Reinforced GPC and it was about 20.74 % and 17.21 % in RCC and GPC when compared to control beam respectively.
- Residual moment capacity of GPC beams was higher when compared to RCC beams.
- Reinforced geopolymer concrete shows good resistance to corrosion and can be used for structural applications.
- Maximum reduction rate in ultimate load carrying capacity of corroded RCC and GPC beams was almost comparable.

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AUTHORS PROFILE

Udhaya Kumar.T, Working as an Assistant Professor at Vel Tech, Avadi from June 2016 to till now. Published a paper on International Conference on Sustainable Practice in Civil Engineering "Studies on corrosion of reinforcement geopolymer concrete beams", 2017, ISBN : 978-93-86176-74-5. Life Member in "The Indian Society for Technical Education", New Delhi, India, ISTE.
Life member in "International Association of Engineers" Hong Kong, IAENG, Membership No:179103
Life Member in "International Association of Hydrological Science" South Africa, IAHS.
Life Member in "American Society of Civil Engineers" South Africa, ASCE.

Jayadurgalakshmi. M, Working as an Assistant Professor at Vel Tech, Avadi from February 2017 to till now. Published a paper on "Investigation of Concrete Reformed by Partial Replacement of Rice Husk Ash". Life Member in "The Indian Society for Technical Education", New Delhi, India, ISTE. Life Member in "International Association of Hydrological Science" South Africa, IAHS. Life Member in "American Society of Civil Engineers" South Africa, ASCE.

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