CORROSION RESISTANCE PERFORMANCE OF FLY ASH BLENDED CEMENT CONCRETES

M. Kishore Kumar[1], P.S.Rao[2], B.L.P.Swamy[3], Ch.Chandra Mouli [4]

[1] *Associate Professor, Dept. of Civil Engg., GVP College of Engineering, Visakhapatanam, India,* **mkkgvp@gmail.com**
[2] *Director General, GVP-SIRC, GVP College of Engineering, Visakhapatanam, India,* **spulugurta@gvpce.ac.in**
[3] *Professor, Department of Civil Engineering, Vasavi College of Engineering, Hyderabad, India*
[4] *Assistant Professor, Department of Civil Engineering, SITAM, Vizianagaram, India,* **raghavassns@yahoo.com**

Abstract

Durability of reinforced concrete with respect to corrosion of reinforcement is one of the major aspects to be considered in the management of civil infrastructure systems. An accelerated laboratory test method developed at SERC where the concrete specimen containing rebar is subjected to polarization under a constant voltage in a sodium chloride solution. It is found that the current response with time follows that of a typical service life model indicating depassivation and corrosion propagation.

Index terms- Materials, cement, super plasticizer, workability, compressive strength etc.

---***---

INTRODUCTION

One of the major problems of durability of reinforced concrete is the rebar corrosion. Rebar corrosion occurs when the concrete fails to give adequate protection to the embedded steel. The problem gets compounded since the rebar corrosion damages the surrounding concrete during the process of corrosion reaction. It is a common opinion that rebar corrosion takes place mainly because of the failure of concrete to protect if from aggressive environment. The protection methods include, coating of steel, larger cover thickness, better quality concrete, corrosion inhibitors, and cathodic protection.

Portland cement concrete has been the construction material par excellence for decades for its mechanical strength and cost effectiveness, not to mention its properties in general that make it particularly well suited to building. Nonetheless, the destruction of natural quarries entailed in obtaining the prime materials involved, the energy intensity of Portland cement manufacture and the environmental impact of gas emissions (essentially Co_2 and No_x), etc., have prompted a search for alternative materials. Moreover, the use of conventional concrete is notoriously subject to durability issues, foremost among which are the problems generated by curing at high temperatures (construction during the summer months, thermal treatment during precasting, etc.,) or expansive reactions (aggregate – alkali reaction, formation of thaumasite, etc.). etc.

The service life of a reinforced concrete member with regard to corrosion can be modeled in a simple way as shown in fig.1. This model consists essentially two parts – one the "initiation period" and the other the "propagation period". Initiation period is influenced by the quality and thickness of cover concrete. The main parameter that qualifies the cover of concrete is the diffusion characteristic with regard to chloride ion. An accelerated laboratory test method developed at SERC where the concrete specimen containing rebar is subjected to polarization under a constant voltage in a sodium chloride solution. Using this method many specimens were evaluated for its corrosion resistance under two grades of concrete.

EXPERIMENTAL PROGRAMME

To increase the quality of concrete, cement is the main parameter in terms of strength and resistance. The experimental programme was divided into the following three phases.

- Identification of best cement
- Fly ash
- Tests on hardened concrete

Cement

In a first approach Grade 53 cements of different brands (namely C-1, C-11, C-111, C-IV and C-V) were tested as per IS: 4031-1968. The strength development was slightly lower as even required by IS:12269-1987. Beside compressive strength the hardening behavior and speed were investigated by measuring the heat development of a cement paste in a thermos container, which enabled semi-adiabatic conditions.

For the test a cement paste consisting of 200gms cement and 70ml water was mixed in a plastic beaker. Immediately after mixing, the beaker was placed in a thermos container and equipped with a thermo-wire. The temperature gain was recorded over about 22hrs. The heat generation of different cements relates to the strength gain for those cements are depicted in Chart 1.

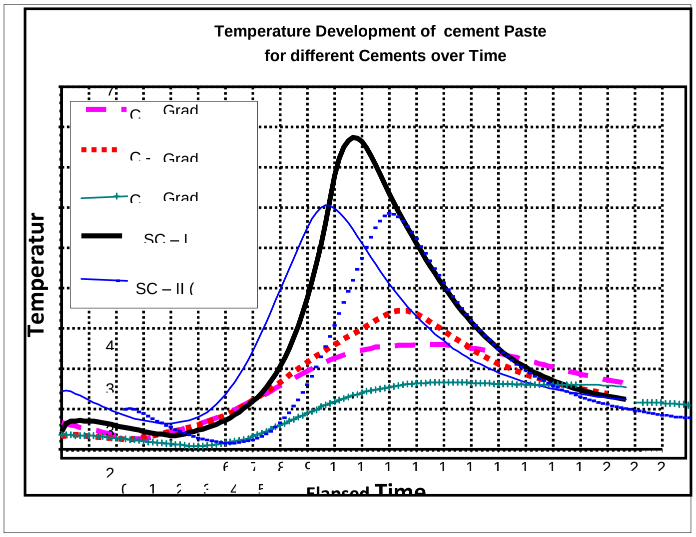

Fig - 1: Heat Generation of Cement

The only alternative to a grade 53 was special cement, which is used for the production of prestressed concrete elements (Railway sleepers) because of its high and consistent quality. The special cement of different brands were represented as SC-I and SC-II.

The one day compressive strength of special cement was 20-25Mpa which is considerably higher than tested for the common grade 53 cements and matched at 7days. The BIS requirements are greater than 27Mpa with 28-30 Mpa.

Physical Properties of Sleeper Cement

Tests are carried out as per IS: 4031-1968)
Normal Consistency – 29.5%

1. Specific Gravity – 3.15
2. Setting time (a) initial – 130 min
   (b) final – 220 min
4. Fineness - 3700 gm/mm² Blains

Note: Finally the best one even from the special cements is selected from the temperature curves for the investigated cements.

Advantages of Sleeper Cement

Its negligible chloride content protects against corrosion. High fineness enhances workability with proper water cement ratio, ensuring water cement ratio, density, compactness, smooth, waterproofed and durable concrete. Lower percentage of C3A resulting in low heat of hydration, reduces cracks and hence leading to greater durability.

Aggregates

Locally available river sand of specific gravity 2.53 with fineness modulus of 2.91 conforming to zone II The fines content in river sand affects the performance of SPs and crushed quarried granite stones of specific gravity 3.01 for 20mm aggregate and 2.96 of 10mm aggregate were used as fine and coarse aggregates respectively in all concrete mixes throughout the investigation.

Fly ash

Fly ash from the nearby thermal power plant was collected and was replaced with the cement at the time of making the concrete in different percentage of replacements. The Chemical composition and specific surface area of cement and fly ash are shown in Table 1.

Table - 1: Chemical Composition.

	Cement	Fly ash
L.O.I	1.48	1.80
IR	0.55	0.40
SiO_2	19.92	51.51
Al_2O_3	6.44	27.47
Fe_2o_3	1.16	7.23
CaO	63,28	4.39
MgO	0.63	1.86
SO_3	1.09	0.15
K_2O	-	3.46
Na_2O	-	0.70
Specific Surface (m^2/kg)	545	360

PERFORMANCE EVALUATION

The performance of different steel bars kept under different grades of blended concretes was assessed in the laboratory for its corrosion resistance property using the accelerated corrosion test method.

The experimental set up essentially consists of a non-metallic container, in which water mixed with 3.5% NaCl solution is to be poured to the required level. In this container, the cylindrical concrete specimen with rebar is to be placed centrally and around this a stainless steel plate is kept. The rebar of the concrete cylinder is connected through an electrical lead to a D.C. Power supply to the anode terminal (+ Ve) and the stainless steel plate to the cathode terminal (- Ve). This set up forms an electrochemical cell with rebar acting as anode and stainless steel plate as cathode. Fig.2 shows a schematic view of polarisation test setup. Number of such cells can be made and connected to a D.C. power pack of multichannel system. A constant voltage of about 3.0 V was applied from the D.C. Power pack.

Since chloride ions are negative ions, these will be attracted towards rebar which is serving as anode by migration through the concrete. For this applied voltage, there will be current response which can be measured using an ammeter and the current response will depend on the total resistance of the cell system. This applied voltage was kept constant and as the time increases, the chloride migration will increase and once sufficient chloride, equal to the critical chloride content for the type of steel rebar used reaches the steel surface, depassivation will occur and this will get reflected in a sudden increase in the current response. As the experiment continues, the current will increase indicating the activity of corrosion. This phenomenon will be distinctly predominant in the specimens with high % of fly ash replacement of concrete specimens.

On the other hand, the concrete specimens with replacement of fly ash will have high resistance and initially the current response will be considerably low.

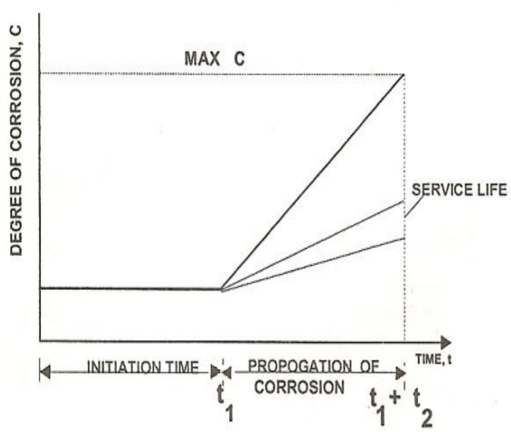

Fig.1 Service Life Model

As the time goes, the current may increase only slightly and will remain fairly constant at a low level depending on the dosage of fly ash content.

This is an indication that the dosage of fly ash increases the migration of chloride ions even under an externally applied electrical field. It is generally experienced that the polarisation test will normally require a period of 40 – 50 days by which time the rebar embedded in blended concrete specimens would undergo sufficient corrosion.

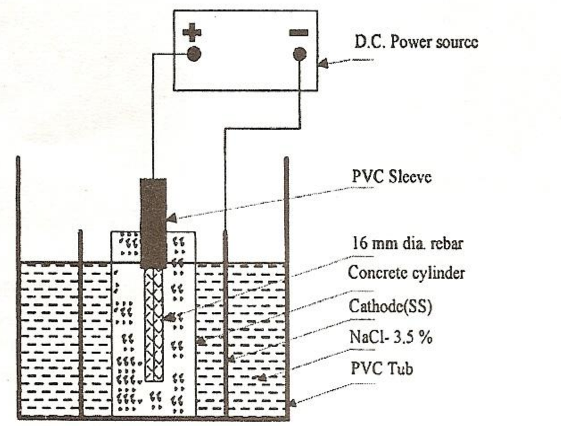

Fig.2 Test Set Up for Polarisation Experiment

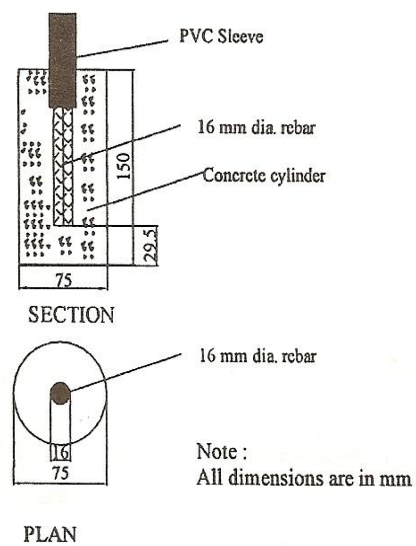

Fig.3 Details of Test Specimen

On completion of the polarisation test, the concrete cylinders were taken out and the weight loss of the rebar was determined. As this test simulates a real condition of a structure exposed to marine environment, the test results can be considered meaningful for a performance evaluation with regard to controlling corrosion.

Standardisation of the test method

The test method was standardised in the laboratory by considering different parameters such as variation in voltage, solution concentration, cover thickness and pre-conditioning and finally the values were standardised and are given below.

Applied constant voltage : 3.0V
Sodium chloride Concentration :3.5% NaCl
Preconditioning: Curing in Ca(OH)2 solution for 28 days
Specimen size: 75 mm dia x 150 mm height concrete cylinders

Specimen Details

The specimen consists of concrete cylinders of size 75 mm dia x 150 mm in height with a 16mm rebar embedded centrally. The positioning of the steel rebar gave an equal cover thickness of 29.5 mm all-round and also at bottom of cylinder. Fig.3. shows the schematic view of the test specimen for 75 mm x 150 m cylinder. Inside the cylinder, a length of 91.0mm of embedded rebar was exposed and the remaining length was well protected by a plastic tube and sealed with epoxy. In the protruded length, a small portion was used to connect the lead wire for electrical connection. The mix details are given in table 2. Companion cube specimens of size 150mm were also cast for the determination of its 28 days compressive strength. The specimens were taken out after 28 days curing in saturated calcium hydroxide solution and kept in the open atmosphere for 3 hours. These specimens were used for the accelerated corrosion test. Fig.4 shows the specimens ready for testing and Fig.5 shows the polarisation experiment in progress.

Graphs were drawn for current in mA Vs time in days for different specimens.

Fig - 4: Specimens ready for testing

Fig – 5: Polarization Experiment under progress

Table - 2: Mix Details.

Material	Content
Cement	384 kg/m³
Sand 0/2mm	572 kg/m³
Aggregates 5/10mm	441 kg/m³
Aggregates 10/20mm	841 kg/m³
Water	192 kg/m³
w/c-Ratio	0.50

Table - 3: Compressive strength of specimens of M25 grade of concrete cured in 5% NaCl solution.

Type of Concrete	7 Days Comp. Strength	28 Days Comp. Strength	90 Days Comp. Strength
A	15	27.2	29.3
B	9.11	23.52	29
C	10.28	29	30.13
D	7.66	24	31.11
E	7.33	25.3	26.55

The compressive strength of fly ash blended concrete specimens were compared with controlled concrete specimens cured in 5% sodium chloride solution at different ages. (after 28 days of normal curing in water). Compressive strength results are shown in table 3 and 4.

Table - 4: Compressive strength of specimens of M30 grade of concrete cured in 5% NaCl solution.

Type of Concrete	7 Days Comp. Strength	28 Days Comp. Strength	90 Days Comp. Strength
A	14.20	24.17	25.14
B	11.11	21.34	26.29
C	7.56	22.68	25.73
D	6.97	23.14	26.00
E	5.34	23.87	22.88

RESULTS AND DISCUSSION

Fig 6 and 7 shows the current Vs time plots for different of grades of concrete.

The change of slope at two locations of the specimens for different grades of concrete gives the initiation time and the time for cracking.

From fig. 6 it can be seen that the time for depassivation (i.e., the initiation time) for 30% replacement of cement with fly ash of M25 grade is 54 days compared with other % of replacements.

From fig. 7 it can be seen that the time for depassivation (i.e., the initiation time) for 30% replacement of cement with fly ash of M30 grade is 63 days compared with other % of replacements.

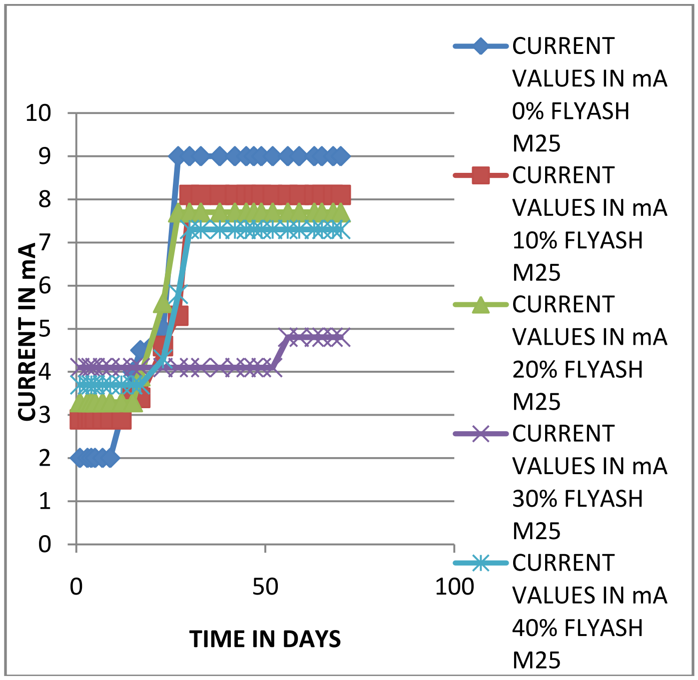

Fig – 6: Current Vs Time for Comparison of 0%, 10%, 20%, 30% and 40% Fly ash replacements in M25 Grade of concrete

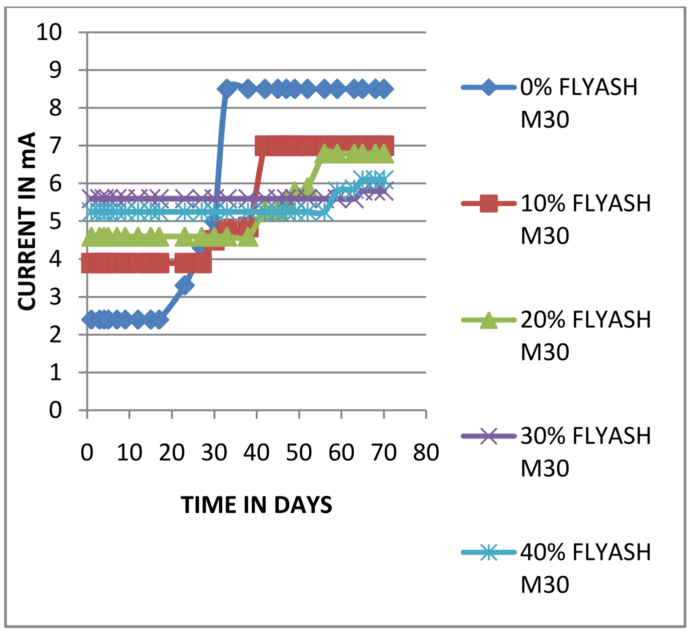

Fig – 7: Current Vs Time for Comparison of 0%, 10%, 20%, 30% and 40% Fly ash replacements in M30 Grade of concrete

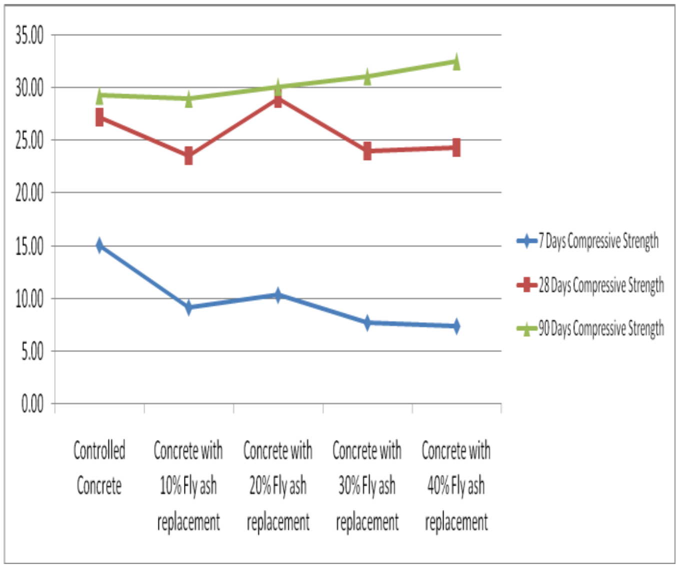

Fig – 8: Compressive strength of specimens cured in 5% Sodium Chloride solution of M25 grade mix with different percentage of Fly ash replacements.

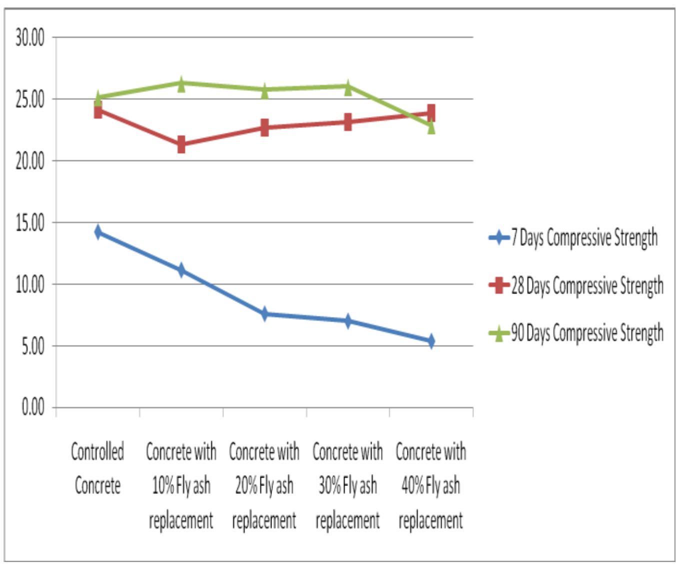

Fig – 9: Compressive strength of specimens cured in 5% Sodium Chloride solution of M30 grade mix with different percentage of Fly ash replacements.

CONCLUSIONS

From the graphs it was observed that with increase in the percentage of replacement of fly ash in a grade of concrete, the initiation time of corrosion increase. Also the initiation time increases with the increase in grade of concrete.

From the graphs the initiation time for controlled concrete is very less compared with fly ash blended concretes.

The initiation time is maximum for 30% replacement of cement with fly ash in both the grades of concrete.

The compressive strength of concrete specimens is high for 30% replacement of cement with fly ash in both the grades of concrete at 90 days of curing..

ACKNOWLEDGEMENTS

The Authors thank to the Management of GVP College of Engineering for providing facilities and funding to carryout this research work in Structural Engineering Laboratory.

REFERENCES

[1]. J.M.Miranda, A.Femandez Jimenez, J.A., Gonzalez, A.Palomo, " Corrosion Resistance in activated fly ash mortars" Cement and Concrete Research, Vol.35, PP 1210-1217, 2005.

[2]. A.Femandez Jimenez, A. Palomo, Activated fly ashes:enlarging the concept of cementitious material, in: R.K.Dhir, M.D.Newlands, L.J.Csetenyi (Eds), International symposia: " Role of cement science in sustainable development" Dundee, Scotland, pp. 325-334, 2003.

[3]. Al-Zahrani, M.M., Al-Dulaijn, S.U., Ibrahim M., " Effects of waterproofing coatings on steel reinforcement corrosion and physical properties of concrete". Cement and Concrete Composites, Vol.24(1), pp 127-137, 2002.

[4]. Rodrigues, M.P.M.C., Costa, M.R.N. Mendes, A.M.Marques, M.I.E., " Effectiveness of surface coatings to protect reinforced concret in marine environments", Materials and Structures, Vol.33 (234), pp 618-626, 2000.

[5]. A.Palomo, A.Femandez Jimenez, C. Lopez Hombrados, J.L.Lieyda, Precast elements made of alkali-activated fly ash concrete, Eighth CANMET/ACI International Conference on Fly ash, Silica fume, Slag and natural pozzolans in concrete, Supple. pp 530-545 Las Vegas (USA)

[6]. A.Palomo, M.W. Grutzeck, M.T.Blanco, Alkali activated fly ashes. A Cement for the future, Cement Concrete Research, Vol.29, pp 1323-1329, 1999.

[7]. S.D.Wing,K.L.Scrivener, Hydration products of alkali activated slag cement, Cement Concrete Research, Vol.25, pp 561-571, 1995.

[8]. P.Rodriguez, E.Rmirez, J.A., Gonzalez, Methods for studying corrosion in reinforced concrete, Mag.Concrete Research, Vol.46, pp 81-90, 1994.

[9]. C.Andrade, C.Alonso, F.J.Molina, Cover cracking as a finction of bar corrosion. Pert I. Experimental test, Materials and Structures Vol.26, pp 453-464, 1993.

[10]. C.L.Page, K.W.J. Treadaway, P.B.Bamforth, Corrosion of reinforcement in concrete, Society of Chemical Industry, Elsevier, Applied Science, London, 1990.

[11]. C.Andrade, J.A., Gonzalez, Quantitative measurements of corrosion rate of reinforcing steels embedded in concrete using polarization resistance measurements, Werk, Korros. Vol.29, pp 515-519, 1978.

BIOGRAPHIES:

M. Kishore Kumar obtained his master degree in Structural Engineering from PSG College of Technology, Coimbatore. He has been working as an Associate Professor at the department of Civil Engineering in GVP College of Engineering, Visakhapatnam. His areas of interest are durability of reinforced concrete structures, corrosion of reinforcement in concrete structures including prediction of residual and service life.

P. Srinivasa. Rao, eminent Structural Engineer and renowned professor of Structural Engineering, retired from Indian Institute of Technology, Chennai. He obtained B.Tech (Hons) in Civil Engg., & M.Tech. in Structural Engg., from IIT, Kharagpur and Doctorate from Technical University, Munich, Germany in 1965. He was currently the Director General, GVP-SIRC at GVP College of Engineering, Visakhapatnam. He has guided 18 candidates towards the Ph.D. degree in Civil Engineering. His areas of interest are Tall structures, Prestressed concrete structures, Design of Shell and folded plate structures, Durability of reinforced concrete structures.

B. L. P. Swamy obtained his Doctorate from Indian Institute of Technology, Delhi. He has been working as a Professor at the department of Civil Engineering in Vasavi College of Engineering, Hyderabad. His areas of interest are durability of reinforced concrete structures, corrosion of reinforcement in concrete structures and assessment of distress and repair of concrete structures.

Ch. Chandra Mouli obtained his master degree in Infrastructural Engineering and Management from GVP College of Engineering, Visakhapatnam. He has been working as an Assistant Professor at the department of Civil Engineering in SITAM, Vizianagaram. His area of interest are corrosion of reinforcement in concrete structures and durability of Reinforced concrete structures