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Effect of ferrocement jacketing on the flexural behaviour of beams with corroded reinforcements

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HIGHLIGHTS

- Influence of cover thickness and strength of concrete on accelerated corrosion was investigated.
- Effect of corrosion on the flexural behaviour of RC beams was studied.
- Flexural behaviour of corroded RC beams after retrofitting with ferrocement jacketing was evaluated.

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ABSTRACT

Corrosion of reinforcement is one of the main causes of deterioration of Reinforced Cement Concrete (RCC) structures which affects the load carrying capacity and its durability. Though it is very difficult to completely eliminate the chances of corrosion, suitable retrofitting strategies can be introduced as a measure for the retrofitting of corrosion damaged structures to gain its original strength. The present work deals with the study of degradation of the ultimate load carrying capacity of the flexural members due to corrosion. Twenty-one RCC beams were cast, out of which, three beams were kept as control specimens, and the remaining were subjected to varying levels of corrosion (5, 10 and 15%) so that six specimens are obtained for each level of corrosion. Accelerated corrosion was induced by means of impressed current method. From each level of corrosion, three beams were subjected to loading corresponding to 70% of the ultimate load given by the remaining three specimens corresponding to that level of corrosion. Subsequently these beams were retrofitted by means of a U-wrap ferrocement jacketing. All the beams were tested under two point loading and the strength and behaviour of retrofitted beams were compared with control specimens.

1. Introduction

Corrosion of steel reinforcements is considered to be the reason behind the reduced service-life and failure of RCC structures. Use of pre-rusted steel, exposure to corrosive environment, loading conditions etc are some of the factors which impart corrosion in RCC structures. The effect of corrosion on RCC structures include cracking of the concrete cover, reduction and eventually loss of bond between concrete and corroded reinforcement and reduction of cross-sectional area of reinforcing steel [1]. Basically, the corrosion process has the ability to start in any environmental conditions and the rate of corrosion is determined by the harshness of the environment. Reinforcing steel is normally passive in concrete due to high alkalinity of the concrete pore solution. However, the penetration of harmful gases like CO into the concrete destroys this inhibitive property of the concrete and leads to corrosion [2]. The effect of corrosion on the load-bearing capacity and mechanical performance of corroded beams, exposed to wetting and drying cycles in a chloride environment under sustained loading without impressed current was also investigated by Yu et al. [3]. The seismic performance of reinforced concrete beams with corrosion induced in the transverse steel reinforcement by means of cyclic loading was studied by Ou and Chen and the results indicated that pitting corrosion increased with an increase in the corrosion level and the beams could sustain a corrosion weight loss of 6% in the hoops and maintain ductile flexural behaviour [4]. Experimental investigation of the behaviour of highly corroded reinforced concrete beams and also a study on the performance of a 27 year old corroded beam, revealed, brittle failure mode for the corroded RC

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beams [5,6]. The influence of simultaneous loading and corrosion of reinforcement on the structural performance of concrete beams was investigated and the results indicated that corrosion or an occasional over-loading or both are likely to cause concrete structures under service loads to collapse suddenly without significant deflection [7]. An experimental investigation on the flexural failure behaviour of RC beams having different weight loss of 0, 5, 10 and 30% due to corrosion was carried out by Okude et.al and it was reported that the rebars were broken at the final stage of loading [8]. With increasing duration of exposure to a corrosive environment, the steel mass loss increases appreciably, which lead to a significant reduction of the tensile ductility of the material [9]. Studies in the past indicated that the bond strength slightly improves at lower levels of corrosion. This is mainly due to the development of Ferrous oxide surrounding the reinforcements which offer a higher frictional force. However as the degree of corrosion increases the bond strength decreases rapidly due to the drastic reduction of diameter of bars and the ineffective portion of corrosion products on the reinforcements.

Suitable retrofitting strategies like jacketing using RCC, steel, Fibre-reinforced polymer and ferrocement can be introduced to reinstatement of corrosion damaged structures. The ultimate compressive strength increases with the change in orientation of square mesh from 90° to 45° if ferrocement is used as an external confinement to concrete specimen [10]. Also it was reported that strengthening through cast in situ ferro-mesh layer is the most efficient method [11]. CFRP sheets increased the fatigue capacity of the beams with corroded steel reinforcement beyond that of the control beams with un-corroded steel reinforcement [12,13]. The use of ferrocement as an external confinement to concrete specimens enhances the ultimate concrete compressive strength and failure strains [14]. The impressed current technique has been frequently used to study the effect of reinforcement corrosion on the cracking of concrete cover, bond behaviour, and load-bearing capacity of reinforced concrete structural members [15]. The advantage of this method over other accelerated techniques is the ability to control the rate of corrosion, which usually varies due to changes in the resistivity, oxygen concentration, and temperature. The predicted and actual mass loss values using impressed current method are very close and hence this technique can be used for studies involving accelerated corrosion [16,17]. The present paper deals with

1. The flexural behaviour of RC beams containing varying degrees of corroded reinforcement (5%, 10%, and 15% mass loss of reinforcement), and to compare the results with the control beam (beam with non-corroded reinforcement).
2. The effect of ferrocement jacketing in beams with different levels of corroded reinforcement and to compare the results with the non-retrofitted corroded beam, as well as with the control beam.

1.1. Accelerated corrosion setup

Accelerated corrosion was induced by means of impressed current technique. Fig. 1 shows the schematic diagram of accelerated corrosion setup. In order to induce corrosion in the steel rebars, an electrolytic cell with the rebar acting as anode and stainless steel rod as cathode, dipped in 4% NaCl solution acting as electrolyte was used. A constant DC voltage was applied to the electrolytic cell. The time required for achieving different levels of corrosion by mass loss was calculated using Faraday's Law [15] as per the following Eq. (1).

$$m = \frac{M\,It}{z\,F} \tag{1}$$

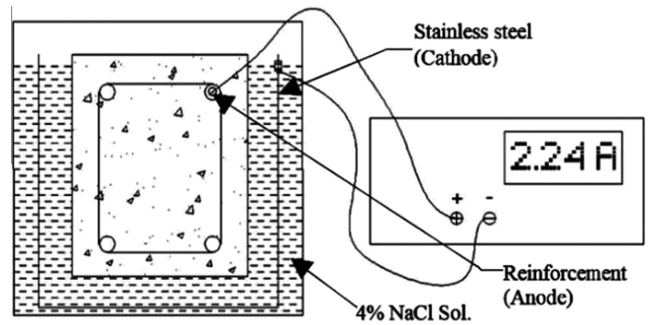

Fig. 1. Accelerated corrosion setup (Schematic diagram).

where, m is the mass of steel consumed (g), M is the atomic weight of metal (55.8 g for Fe), I is the current (amperes), t is the time (seconds), z is the ionic charge (2), and F is the Faraday's constant (96,485 A/sec).

2. Material properties and mix proportion

Materials and mix obtained in this investigation are suitable for M20 grade concrete which is generally used in all the RCC structures in the past and these structures are subjected to different degrees of corrosion depending on the environmental condition. As this investigation is deals with the effect of rehabilitation by ferrocement, the flexural members considered in this study were made of M 20 grade concrete. Portland Pozzolana Cement, crushed stones of 20 mm coarse aggregate, manufactured sand passing through sieve of size 4.75 mm and confirming to zone II of IS 383-1970 (reaffirmed 2002) as fine aggregates were used [18,19]. The mix design was done as per IS 10262-2009, to obtain a M20 grade concrete [20]. The mix proportion thus obtained was 1:1.8:2.9.

3. Experimental programme

3.1. Preliminary studies

Preliminary studies were conducted in order to determine whether the desired percentage of mass loss is obtained during the time calculated using Faradays' equation for the corrosion of steel reinforcements.

3.1.1. Determination of actual corrosion and corresponding strength of single bar

Bars of length 800 mm and varying diameters 6 mm, 8 mm, and 10 mm (3 samples each), were subjected to different levels of corrosion (5, 10 and 15% of mass loss), using accelerated corrosion technique. For this study the current was fixed as, 8A. The time

Table 1
Time and mass loss for single bare bars.

Diameter (mm)	Theoretical mass loss (%)	Time (seconds)	Actual mass loss (%)
10	5	9585.00	6.61
	10	19170.00	9.75
	15	28755.00	15.03
8	5	6590.54	6.02
	10	13181.31	9.83
	15	19771.64	14.98
6	5	3801.90	5.13
	10	7603.81	10.03
	15	11405.72	15.10