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MONITORING OF REINFORCEMENT CORROSION BY IMPEDANCE TECHNIQUE

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ABSTRACT

Monitoring of reinforcement corrosion by d.c. polarisation technique is found to be unreliable due to high resistance of concrete. In this aspect, a.c. impedance method is found to be useful since the resistance of concrete is eliminated in the measurements. The impedance of the steel embedded in concrete with and without chloride has been measured for the frequency range of 1 mHz to 10 kHz at the corrosion potential using the frequency response analyser. It has been found that the impedance behaviour of steel in concrete without chloride is of pure capacitive nature due to passivation of steel by the concrete. But in the case of steel in concrete containing 4% chloride the impedance diagram is found to be a distorted semicircle owing to the corrosion of steel. From the impedance values, it is possible to monitor the corrosion of reinforcement by periodic measurements.

Key words: Impedance technique, reinforcement corrosion, corrosion monitoring

INTRODUCTION

The problem of corrosion of reinforcement embedded in concrete is fairly well known now and has been engaging the attention of scientists throughout the world. Accelerated corrosion of reinforcements in bridges is a common problem in many countries. From the various case studies reported, it can be realised that within a period of 10-20 years, the durability of concrete structures can be seriously affected by reinforcement corrosion [1]. Monitoring of reinforcement corrosion thus becomes important from the point of view of predicting the durability of reinforcement concrete structures.

Several techniques have been tried in the past by various workers to monitor corrosion of steel in concrete in a non-destructive way. Potential-time measurements have been evaluated by several workers [2-6]. The potential of steel in concrete is influenced by the moisture content of the concrete, state of hydration of concrete, and temperature. It is well known that these electrode potential measurements can only predict the thermodynamic feasibility of the corrosion reaction, but give no reliable information on the corrosion rate. D.C. polarisation technique has been tried to study the instantaneous corrosion of steel in concrete [7-9], but the high electrical resistivity of concrete interferes with the measurement unless otherwise compensated. Moreover, the technique is a tedious one and the system is considerably perturbed during the study.

Recently, corrosion rate has been estimated [10] from polarisation resistance measurements with the electronic compensation for the ohmic drop. It is to be pointed out that if the concrete resistance is very high, then compensation is difficult to achieve. A.C. impedance technique appears quite promising since it is possible to eliminate the concrete resistance; besides it is a transient technique and can provide information on the corrosion mechanism as well. Surface film characteristics have also been studied [11].

In this paper, the usefulness of A.C. impedance technique in monitoring reinforcement corrosion in chloride-free as well as chloride-contaminated concrete is examined.

EXPERIMENTAL

The experimental set-up used in the present investigation is shown in figure 1. 12 mm dia and 50 mm long polished and degreased mild steel rod embedded in a cylindrical concrete specimen (50 mm dia and 100 mm long) was used as the working electrode. A perforated mild steel cylindrical specimen (75 mm dia and 100 mm long) surrounding the concrete specimen was used as auxiliary electrode. Saturated calomel electrode was used as reference electrode.

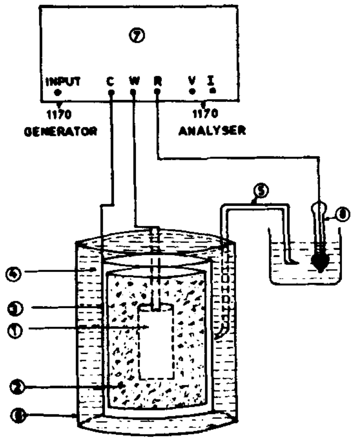

Fig. 1 : Setup for impedance measurements
1. Mild steel test specimen with stem
2. Concrete specimen
3. Mild steel auxiliary electrode
4. Electrolyte
5. KCl agar agar bridge
6. Glass container
7. Electrochemical interface
8. Saturated calomel electrode

Impedance measurements were made using a SOLARTRON 1170 FREQUENCY RESPONSE ANALYSER with ELECTROCHEMICAL INTERFACE (Model 1186). Frequency range of 1 mHz to 10 kHz was used and studies were made at open circuit potential.

Particulars of the concrete mix design used in the study are as follows:

Mix ratio	.. 1:1.79:2.01 by weight
Water-cement ratio	.. 0.50
28 days cube strength :	20 N/mm^2
Cover over steel	.. 20 mm
Curing time	.. 28 days
NaCl added in the mix	.. 0% and 4% by weight of concrete

After curing for 28 days, the specimens were normally kept exposed to the open atmosphere and whenever periodic measurements are to be made, they were kept immersed in 0.04 N NaOH solution at that time only and measurements taken. Concrete specimens were broken open at the end of the test period and the mild steel rods were visually examined for rust spots.

For comparison, studies were also carried out on mild steel specimens directly immersed in 0.04 N NaOH solution containing no chloride or 4% NaCl (0.04 N NaOH represents the aqueous concrete environment).

RESULTS AND DISCUSSION

The impedance behaviour of steel in concrete containing 0% NaCl is shown in figure 2 for various durations. It is observed that the impedance is of

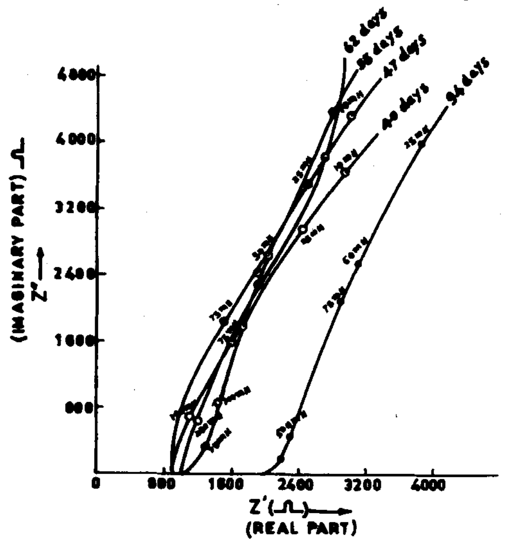

Fig. 2: Impedance diagram for RCC specimen with no chloride

resistive type in the frequency range 10 kHz to 10 Hz and of capacitive type in the frequency range 10 Hz to 1 mHz. The passive nature of the steel is indicated by the curve being near vertical in the frequency range 10 Hz to 1 mHz. This variation of impedance with frequency is due to a geometric capacity arising from a film in which there is a little mobile charge. Such behaviour has been observed on metals like nickel and chromium under passive conditions [12-13]. Over a period of 43 to 72 days, there is not much variation in the impedance behaviour. The passive condition of rebar was also revealed by the value of the steady state potential which was around −100 mV vs SCE. Visual observation of the steel rod at the end of the test period indicated negligible rusting (<0.5% of area exposed).

The impedance behaviour of similar mild steel specimen immersed directly in 0.04 N NaOH solution is shown in figure 3. The behaviour is almost similar to that embedded in concrete as shown in figure 2.

Subsequent studies were made with chloride-contaminated active environment. The impedance behaviour of steel embedded in concrete containing 4% NaCl by weight of concrete is shown in figure 4. The impedance behaviour changes from Warburg type to a distorted, semicircle with time, indicative of charge-transfer reaction. Initial Warburg behaviour arises due to diffusion of chloride ion towards the steel specimen. With time, corrosion occurs due to chloride ingress and a semicircular behaviour is observed. It can also be seen that the diameter of the semicircle decreases with time indicating increase in corrosion rate with time. Visual observation of the rod at the end of the test period indicated rusting to an extent of 15% of the area exposed. A steady state value of −450 mV vs SCE indicative of active condition was observed for this ystem (Fig. 5).

Figure 6 shows the impedance behaviour of mild steel specimen directly immersed in 0.04 N NaOH containing 4% NaCl. Semicircular behaviour due to charge transfer reaction, similar to that obtained in figure 4 is observed here also.

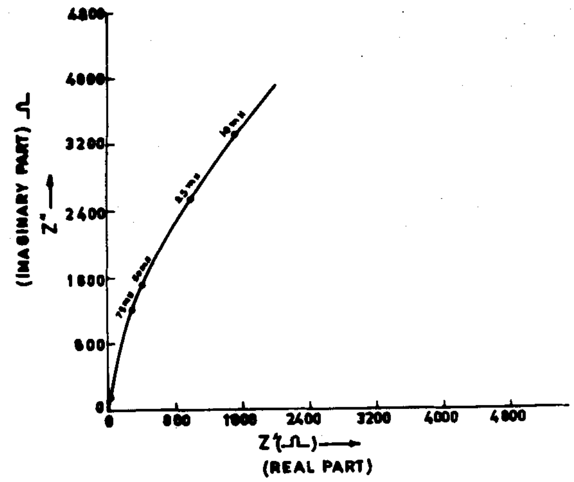

Fig. 3: Impedance diagram for mild steel in 0.04 N NaOH

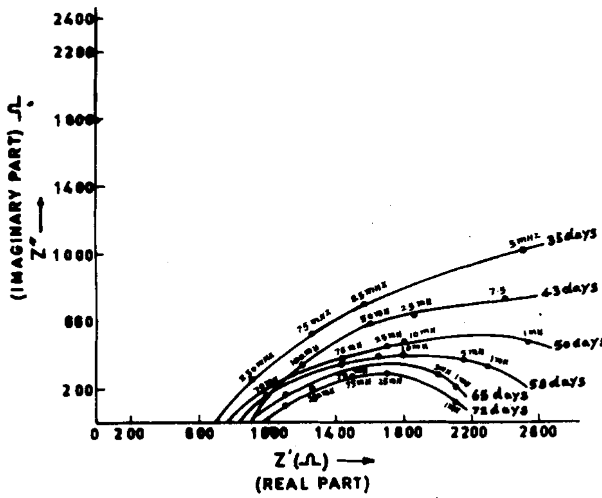

Fig. 4: Impedance diagram for RCC specimen with 4% NaCl admixture

Corrosion rates may be estimated from the impedance data using the equation [14].

$$i_{corr} = \frac{K}{R_t}$$ where

i_{corr} is the corrosion current,

K is constant, and

R_t is the charge transfer resistance value.

From potentiostatic polarisation studies, the value of K for the system under study is found to be 25 mV.

R_t, the difference between high and low frequency values of impedance, is obtained from the impedance plot.

The variation of i_{corr} with time for mild steel rod embedded in concrete containing 4% NaCl by weight of concrete is given in Table - I. It can be seen that the corrosion rate increases with time and reaches a steady value after 65 days.

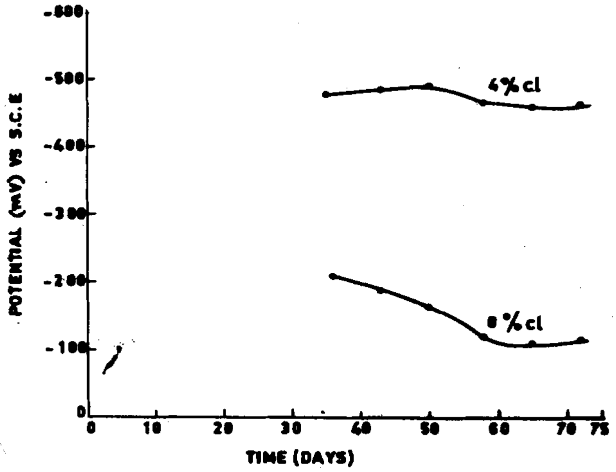

Fig. 5: Potential-time behaviour of steel embedded in concrete

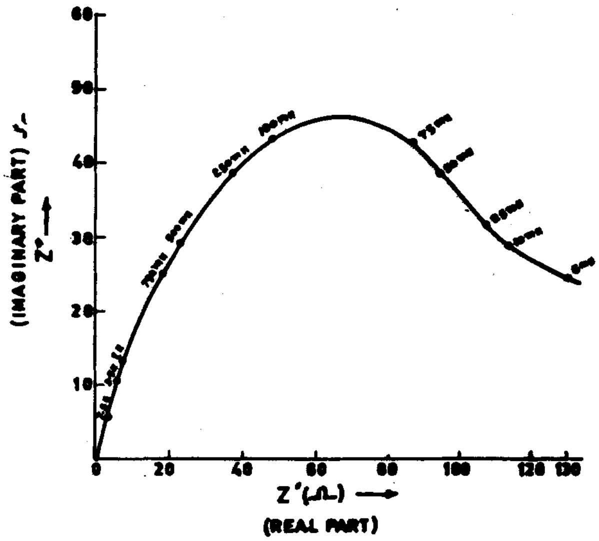

Fig. 6: Impedance diagram for mild steel in 0.04 N NaOH + 4 % NaCl

Table I: Variation of I_{corr} with time for R.C.C. specimen with 4% NaCl

Days	R_t Ω	I_{corr} (μA)
43	4040	6.1
50	2720	9.0
58	2020	12.2
65	1320	18.6
72	1300	18.9

CONCLUSION

It is shown that the A.C. impedance technique can be used for monitoring the corrosion of steel reinforcements embedded in concrete in a non-destructive way. However, further studies are required to establish the feasibility of using this technique for in-situ measurements.

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