CATHODIC PROTECTION OF CONCRETE STRUCTURES USING MAGNESIUM ALLOY ANODE

G T Parthiban, V Saraswathy and N S Rengaswamy

Central Electrochemical Research Institute, Karaikudi 630 006. INDIA

Cathodic protection of concrete structure is gaining more and more importance. Though the impressed current system is being widely used, sacrificial anode system is also gaining ground. It is well known that alloys of zinc, aluminium and magnesium are the candidate materials for use as sacrificial anodes. However, very little work has been done for evaluating their utility as compared with that done for utilizing impressed current system. In the present work cathodic protection of embedded steel reinforcement bars has been achieved by utilizing a suitable magnesium alloy anode, which is manufactured based on indigenous technology (CECRI know-how). The potential of the embedded steel and the current flowing between the anode and the embedded steel were monitored over a period of one year, in conventional M_2O (1:2:4 W/C 0.5) concrete. The results indicated that there is a considerable shift in potential in the presence of chloride. The steel was found to be well protected from corrosion, noticed after breaking open the tested concrete. The anode characteristics were evaluated at the end of the test period and the data obtained prove that the cathodic protection system utilizing magnesium alloy sacrificial anode is suitable under specific conditions.

INTRODUCTION

The premature failure of concrete structures due to corrosion of the embedded reinforcing steel poses a major problem in the service life of concrete structures. Among the several methods available for protecting the reinforcement steel from corrosion, cathodic protection is a major technique adopted. In UK alone, the investment in repairs to reinforced concrete, incorporating cathodic protection, has grown from $\approx$ 1,00,000 pounds/annum, during 1987, to more than 20,000,000 pounds/annum during 1993 [1]. This has been applied to several structures including the transit system tunnel [2,3]. Federal Highway Administration, USA, during April 1982, passed a memorandum providing FHWA's position on cathodic protection has stated that the most suitable scheme for protecting salt contaminated bridge decks, regardless of the concrete's chloride content, is cathodic protection [4].

Majority of the cathodic protection systems employed in concrete structures are utilizing the impressed current system [5-9]. Improper design and/or operation of the cathodic protection system have been observed to lead to premature failures in these systems [10,11]. Decrease in concrete resistivity due to seasonal fluctuation has been reported to have led to over-protection which in turn caused cracking or bond-degradation or increased alkali-silica reaction etc., [12,15]. Further the reinforcements being high strength steels, their susceptibility to embrittlement by the evolved hydrogen poses a major threat [16-18].

Even though different criteria for cathodic protection of the rebar embedded in concrete exist, the shift in potential of the rebar by -100 to -300 mV, on application of cathodic protection, is the most widely accepted one [19,20]. This has been observed to be independent of the size of agglomerate [21].

The schemes utilizing impressed current systems require continuous power supply, higher installation costs, stringent maintenance and monitoring, which render this method less adaptable in remote locations.

Hence, the use of sacrificial anodes for cathodic protection of the embedded steel in concrete structures is gaining more attention. Studies are mainly being concentrated upon the use of thermally sprayed zinc, use of galvanized rebars and aluminium anodes [22-25]. Due to the high alkalinity of the concrete medium and its inherent high resistivity, these systems suffer from lesser throwing power, higher self-dissolution, insufficient current distribution etc., so the utility of magnesium anode is favoured due to their inherently higher active potential.

Also, the use of plug-in type anodes offer major advantages in that they do not increase the over all weight of the structure, are easier to install and replace (when required), and involve lower installation and operating costs [26]. Based on the above, the present work concentrates on the use of plug-in type magnesium alloy anodes for the cathodic protection of embedded reinforcing steel in concrete structures.

EXPERIMENTAL

The concrete structures that were used to evaluate the cathodic protection were in the form of reinforced slabs of size 1 m x 1 m x 0.15 m and beams of size 1.6 m x 0.15 m x 0.2 m. The surface area of the reinforcing bars that has to be protected was calculated from the dimensions of the bars used. The steel reinforcement assembly was pickled, cleaned and photographed before being embedded. The slabs/beams were cast with a recess to accommodate the anode. Suitable provisions were made for establishing the electrical contact with the reinforcement rods. The magnesium alloy anode was designed for protecting the reinforcement rods for a period of two years. The shape of the anode was adjusted in the design so that it could be accommodated in the recess provided in the slab. The magnesium anodes of required size and shape were cast with an extension to core for establishing electrical contact and weighed. These were packed in a backfill containing bentonite clay, gypsum and sodium sulfate. This pack was placed in the recess after measuring the open-circuit potential of the reinforcement at different locations on the slab, with reference to saturated calomel electrode. Then, the magnesium anode was connected to the reinforcement

assembly within the slab so that the electrical contact was complete, through a micro-switch.

The potential of the reinforcement bar at different locations on the slab and the current flowing between the magnesium anode and the reinforcement were monitored periodically. Saturated calomel electrode (SCE) was used as the reference electrode. The above experiment was conducted with slabs and beams containing 3% chloride also. On completion of the experiment, the anode pack was removed from the concrete specimen and the anode was chemically cleaned. Then it was weighed. From the weight loss, the anode efficiency was calculated. The concrete specimens were broken open and the reinforcement assembly was photographed, after the experiment, for analysis.

RESULTS AND DISCUSSIONS

Fig. 1 illustrates the potential of the steel embedded in concrete which does not contain chloride and is not cathodically protected. Here, the potential of the steel is observed to polarize from -110 mV initially to less negative values as time progress and remain about -61 ± 22 mV during the period of investigation. Due to seasonal fluctuations, (such as rain), the potential is observed to be disturbed (shifted in the negative direction), as can be seen from the drop in potential. The potential was observed to reach the above mentioned range after about 20 days.

The effect of chloride addition on the potential of the embedded steel, which is not cathodically protected, is also shown in Fig. 1. Here, the potential is initially observed to be about - 425 mV. With time, this potential is observed to be polarized to about -257 ± 45 mV and remain in this range after about 20 days. It can be seen that the addition of 3% chloride by weight of cement to concrete shifts the potential
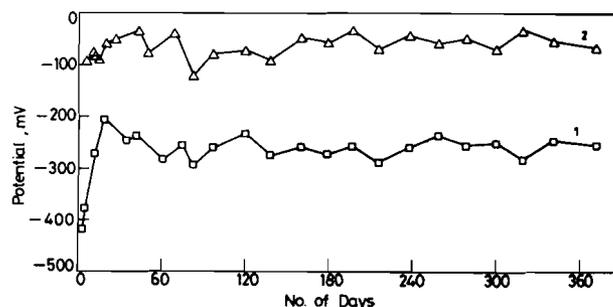
Fig. 1: Potential of steel as a function of time in concrete without cathodic protection
(1) With chloride   (2) Without chloride
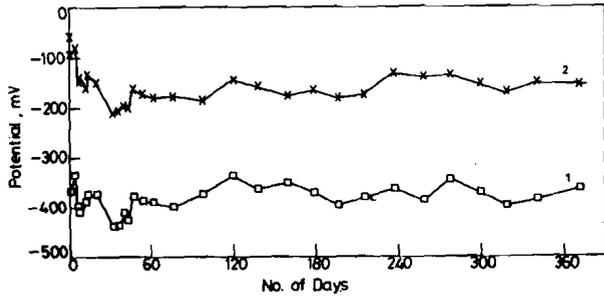
Fig. 2: Potential of steel as a function of time in
concrete with cathodic protection
(1) With chloride   (2) Without chloride

Fig. 4: Potential of steel as a function of distance from
anode in the presence of chloride in concrete
(1) 145 cm   (2) 110 cm   (3) 75 cm   (4) 40 cm   (5) 10 cm

of steel by nearly -200 mV when compared with that of steel embedded in a chloride free concrete.

In the chloride free concrete where cathodic protection was employed, the potential of the steel has been observed to be shifted from about -58 mV to -159 ± 34 mV, as illustrated in Fig. 2. In addition, it can be also observed from Fig. 2 that the potential of the rebar is shifted to this range in about 6 days. In the concrete containing chloride, where cathodic protection was employed, the potential of the embedded steel is observed to be shifted from about -259 mV to -382 ± 30 mV, as shown in Fig. 2. Here again the shift achieved is more negative than -100 mV.

On comparing the potentials of the steel embedded in concrete with and without chloride, it can be seen that the potential of the steel is shifted from -61 ± 22 mV (when chloride is absent) to -257 ± 45 mV on addition of 3% chloride in the absence of cathodic protection. In the presence of cathodic protection, it is observed that the potential of the steel is shifted from -159 ± 34 mV to -382 ± 30 mV on addition of 3% chloride. The potential of

the steel is shifted by nearly 200 mV when the chloride is added which can be attributed to the increased conductivity of the concrete. The variations in the potential of the embedded steel is due to the seasonal fluctuations such as heavy rains, in spite of periodic wetting of the concrete.

Fig. 3 illustrates the extent of polarization of the steel rebar as a function of distance from anode in the beam without chloride. It is observed that the extent of polarization becomes less and less as the distance from anode increases. The rebar nearest to the anode is polarized by -238 ± 62 mV while that farthest from the anode is polarized by -135 ± 31 mV.

Fig. 4 illustrates the extent of polarization of the steel rebar as a function of distance from anode in the beam with chloride. Here also, it is observed that the extent of polarization becomes less and less as the distance from anode increases. The rebar nearest to the anode is polarized to -391 ± 35 mV while that farthest from the anode is polarized by -396 ± 52 mV.
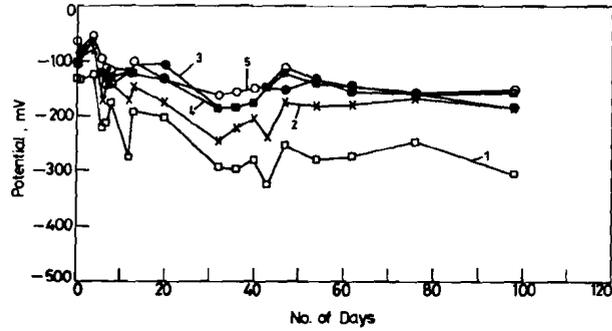
Fig. 3: Potential of steel as a function of distance from
anode in the absence of chloride in concrete
(1) 25 cm   (2) 60 cm   (3) 90 cm   (4) 125 cm (5) 140 cm
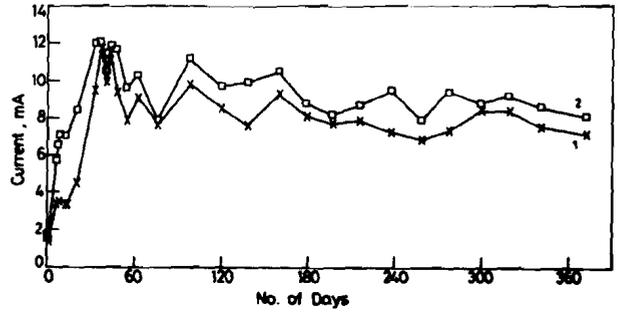
Fig. 5: Current flowing during cathodic protection in concrete
(1) Without chloride   (2) With chloride

255

TABLE I: Observations made on the surface of the concrete during the experiment

Specimen	Observation
With chloride and without cathodic protection	Reddish brown rust appeared on the surfae after 65 days and was observed to intensify with time
With chloride and with cathodic protection	No appearane of rust on the surface through out the test period

In both cases, as the distance from the anode increases, the shift in potential becomes relatively less and less. It is also seen that the extent of polarization in the beam containing chloride is nearly the same when compared with that in the beam which does not contain chloride.

The current flowing during cathodic protection in the concrete with and without chloride is plotted as a function of time in Fig. 5. The current increases rapidly with time initially and latter the rate of increase in current is observed to be reduced. Here also, considerable time is required for the reduction in the rate of increase in current. This can be attributed to the fact that the steel gets polarized fast due to the larger potential difference existing between the anode and steel initially. As polarization occurs there is a decrease in the potential difference and hence a decrease in the rate is observed. The current is relatively higher in the concrete which is not containing chloride. The current density was observed to be $2.681 \times 10^{-2} Am^{-2}$ in the concrete containing chloride and it was observed to be $2.844 \times 10^{-2} Am^{-2}$ in the concrete which did not contain chloride. This was observed to be sufficient for protection as compared to the values reported [10,17]. It can be observed that the current densities in both concrete (with & without Cl^-) are in the same order of magnitude. Also the extent of polarization achieved is also of the same order.

Table I gives the observations made on the various concrete surfaces periodically. The visual observations of the steel, after being removed from the concrete, indicated that it was well protected, even in the presence of chloride. For example, Fig. 6a illustrates the reinforcement assembly prior to embedment in the slab containing 3% chloride and Fig. 6b illustrates the protected reinforcement assembly which was embedded in the slab containing 3% chloride, after 365 days of testing. It is observed that the reinforcement is unaffected

due to the presence of chloride in concrete when the cathodic protection is employed. Hence, it can be inferred that the magnesium anode can be used to protect the reinforcement effectively.

The protection of the reinforcement steel embedded in concrete is confirmed by the shift in potential achieved and the effective current density [10,17], as illustrated in Figs. 6a and b. In the present investigation, the magnesium alloy anode was found to exhibit an anode efficiency of 50.34%.

The major advantage with the system studied is that the anodes can be easily replaced or inspected as and when required, to maintain the cathodic protection of the reinforcement.

These observation indicate that it is feasible to utilize magnesium anodes for the cathodic protection of the steel reinforcement in concrete. The major limitation with the above system is that these anodes can perform to a very limited extent in 'very dry' or 'highly resistive' concrete. But here, when the concrete is too dry or highly resistive,

Fig. 6a: Steel reinforcement assembly before being embedded in concrete containing 3% chloride
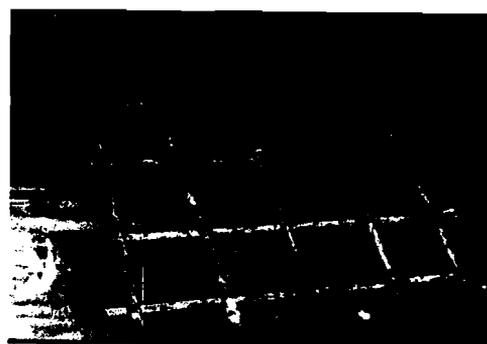
Fig. 6b: Steel reinforcement assembly after being embedded for one year with cathodic protection in concrete containing 3% chloride

the corrosion of the embedded steel would be very low or negligible.

The performance of this anode indicates that, it would be highly suitable for protecting steel embedded in concrete structures in marine atmospheres, since these structures would be exhibiting a relatively much lower resistivity than dry concrete or relatively a higher resistivity than a totally wet concrete.

CONCLUSIONS

* Magnesium alloy anode can be utilized to protect the embedded steel in concrete. This protective scheme is highly applicable for protecting the reinforcing steel embedded in concrete structures exposed to marine environment.

* The potential of the steel is shifted by nearly -100 mV or more, when magnesium anode is used.

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