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A COMPARATIVE STUDY ON REINFORCEMENT CORROSION
IN FERROCEMENT AND REINFORCED CONCRETE BY
ACCELERATED TESTING

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ABSTRACT

In this paper are presented the results of a comparative study on reinforcement corrosion in ferrocement and traditional reinforced concrete. These results were based on an experimental procedure that consisted of the submission of material samples to a cycle of immersion and emersion in a saline bath and the reinforcement corrosion was evaluated by measurement of the reinforcement electrochemical potential by a copper sulphate half-cell. A correlation of electrochemical potential with the reinforcement cover and the water/cement ratio is established by an empirical expression.

INTRODUCTION

One of the most important aspects of the ferrocement technology is that which refers to the protection against reinforcement corrosion due to the reduced reinforcement cover which is used in ferrocement when compared with traditional reinforced concrete. This subject earned the attention of various works presented by researchers in the 2nd and 3rd International Symposium on Ferrocement.

Two aspects have been considered to have the strongest relationship with the reinforcement corrosion of reinforced concrete and, by extension, on that of ferrocement: a) the reinforcement cover and the quality of the concrete and b) the crack width. There is no consensus of opinion as to which of these aspects is most important [1]. In this work the aspects related to item a) only are analysed.

The aim of this work is to present the results of a comparative study of the protection degree of ferrocement reinforcement in relation to those of traditional reinforced concrete, in which it was considered the influence of the reinforcement cover and the mortar quality. It was employed an experimental procedure in which the corrosion was accelerated and the protection degree of reinforcement was evaluated based on the electrochemical potential.

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MATERIALS

The mortar dosage has been commonly used in ferrocement structures in Brazil is one part of cement, two parts of small aggregate and water/cement ratio (w/c) of 0.4 (1:2 w/c=0.4), in mass.

In the mortar used in this work, the above dosage was denominated material A, and two other dosages with lower cement contents of 1:2.5 w/c= 0.48 and 1:3.0 w/c= 0.56, were denominated B and C respectively. The water/cement ratios of materials B and C were determined so as to have the same consistency as material A. The mixture of the concrete employed in this study was one part of cement, 3.01 parts of small aggregate, 3.68 parts of large aggregate with a water/cement ratio of 0.72 (1 : 3.01 : 3.68 w/c= 0.72). This concrete was denominated material D.

The materials used in the ferrocement and in the concrete were: ordinary portland cement; small aggregate - quartz sand with a characteristic maximum diameter of 2.4mm and a fineness modulus of 2.61 and large aggregate - crushed basalt with a maximum diameter of 12.5mm.

Table 1 shows the main characteristics of the materials studied as well as the average compressive strength after 28 days (f_{c28}), measured on cylindrical specimen.

Tab.1- Main characteristics of the materials studied

MATERIAL	MORTARS			CONCRETE
	A	B	C	D
Cement/aggregate	1:2	1:2.5	1:3	1:3.01:3.68
w/c	0.40	0.48	0.56	0.72
Cement contents (kg/m ³)	679	574	497	281
Water contents (kg/m ³)	272	276	278	202
f_{c28} (MPa)	35	31	20	14

The reinforcement used in all samples was a single layer of welded mesh (with a 50 x 50 mm² opening and 2.77 mm diameter steel wire with yield strength of 600 MPa). Before of moulding, the reinforcement was scraped with chloric acid and scoured with water. The reinforcement cover used in this study are present in Table 2.

The samples were prismatic with an exposed surface of 150 x 150 mm² in the accelerated test and with a thickness as stipulated for the reinforcement cover on both faces. In order to maintain the reinforcement in position, poly-estirene reinforcement spacers in the laminate form were used. Figure 1-a illustrates the dimensions of the samples and the positioning of the spacers. In order to guarantee dimensional precision and identical conditions of the exposed surfaces, a metallic mould was used (Fig 1-b).

Tab.2- Reinforcement cover employed in the study

Material	Reinforcement cover (mm)			
A	3	6	9	12
B	3	6	9	12
C	6	9	12	15
D	15	20	25	30

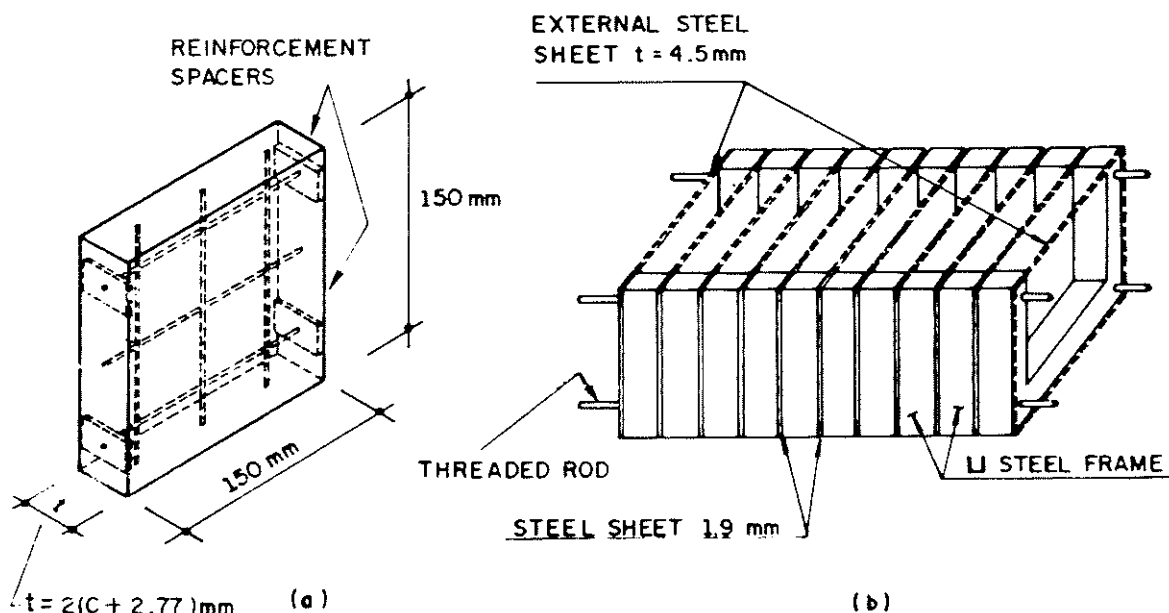


Fig.1- Dimensions of the sample, positioning of spacer and mould scheme

The samples were taken out of the mould from 24 to 48 hours after the moulding and immersed in a water tank for 28 days. Shortly afterwards, they were dried in ambient air, painted with epoxy paint on the faces that correspond to the thickness and identified. Four replicas of samples were moulded for each material and each reinforcement cover, resulting a total of 64 specimens.

EXPERIMENTAL PROCEDURE

The experimental procedure consisted in submission of the samples to a cycle of immersion in a saline bath and emersion into an atmosphere with accelerated drying by infra-red lamps [2]. The cycle time of immersion and emersion was approximately 58 minutes, the sample was in contact with the bath during a third of this period.

The equipment for corrosion acceleration consisted basically of a horizontal axle and the samples were fixed in a radial position by a gadget (Photos 1-2).

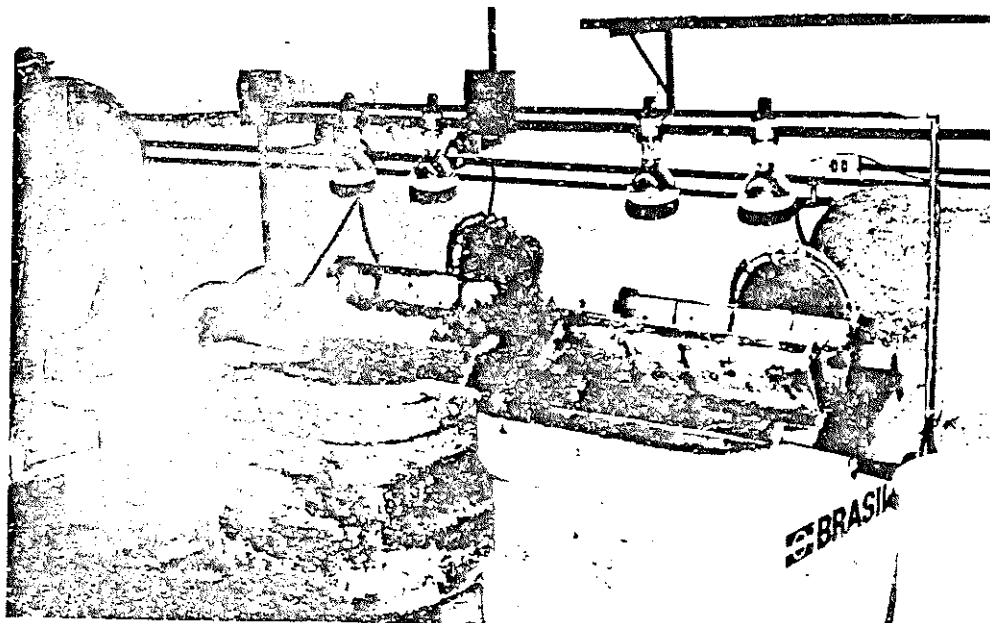


Photo 1- General view of equipment for corrosion acceleration



Photo 2- Detail of equipment in operation

The bath used was a artificial sea water containing the main salts found on the brazilian coast, that is: 0.55M sodium chloride, 0.053M magnesium sulphate and a Ph level of approximately 8 [3].

The reinforcement corrosion measurements were performed according to ASTM C876-87 [4] with a copper sulphate half-cell (CSE). In order to measure the electrochemical potential one end of the reinforcement was exposed by retirement of a spacer and connected to the positive pole of a multimeter of high impedance.

The half-cell consisted of a glass tube with a porous filter of mean granulometry at the bottom and a teflon screw-on in the top. The half-cell was filled with a solution obtained from the dissolution of copper sulphate crystals of analytic purity until saturation in de-ionized water. The metallic element of contact was a copper rod of commercial purity, the extremity of which was immersed in the solution and the other extremity was maintained external for connection to the negative pole of the multimeter (Photo 3).

In order to guarantee the electrical connection between the half-cell and the concrete surface was used a poliurethane foam of polyester open cell type with an apparent density of 21,5 kg/m³ cut in the cap shape and which was perfectly adjusted to the invert of the glass tube. This foam was maintained humid with a contact solution composed of 1 litre of distilled water and 5 ml of a commercial wetting agent.

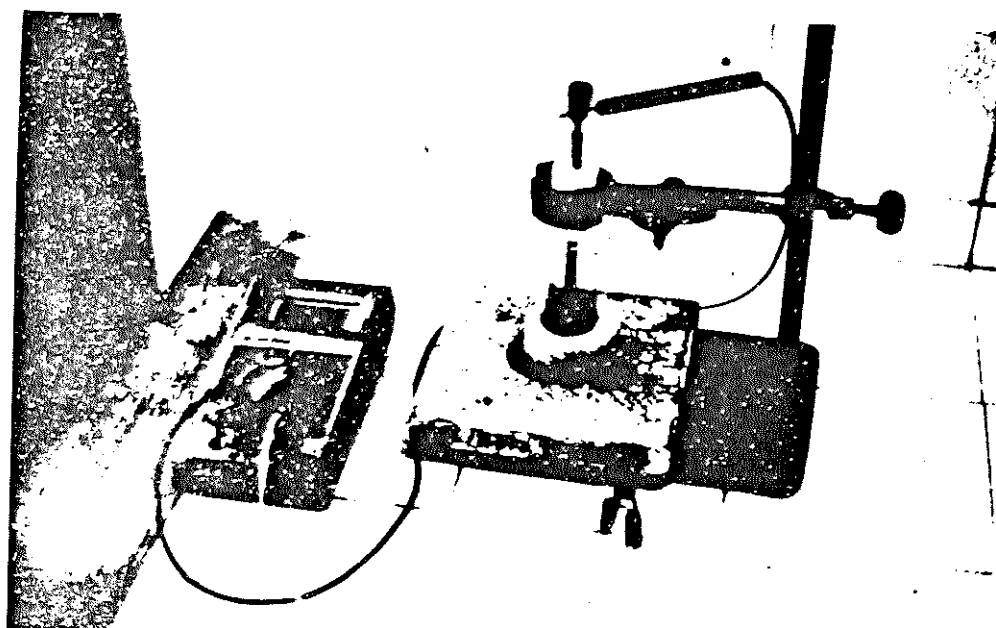


Photo 3- Measuring of the electrochemical potential

RESULTS AND DISCUSSIONS

The measured potentials after 180 days of accelerated attack are presented in Table 3.

Tab. 3- Electrochemical potential measured

sample(*)	electrochemical potential (-mV CSE)				
	1	2	3	4	average
A3	537	593	595	622	587
A6	504	431	463	522	480
A9	399	519	452	371	435
A12	451	486	392	476	443
B3	597	608	626	599	583
B6	504	505	618	596	556
B9	-	-	-	-	-
B12	-	-	-	-	-
C6	574	538	580	552	561
C9	523	569	512	538	536
C12	421	522	477	457	469
C15	453	500	487	401	460
D15	514	581	474	560	532
D20	501	524	461	411	474
D25	381	500	426	547	464
D30	471	379	466	437	438

The first character is related to the material
the others are related to the reinforcement cover

The Series B9 and B12 were discarded due to problems related to the moulding process and the positioning of the reinforcement in the surfaces that were not intended to be exposed. At the time of their fabrication it was believed that this would not provoke any untoward consequences, however the results obtained were shown to be in error and for this reason were abandoned.

It must be pointed out that the reinforcement spacers created a preferential way for the attack on the reinforcement. The epoxy paint did not produce the desired effect on the faces on which the spacers were placed, which was to guarantee that the attack occurred only on the unpainted faces of the samples. As a consequence it was shown that practically all the samples, both the most protected and the least protected, showed corrosion of the reinforcement at the faces on which the spacers were located. Although the preferential direction of the corrosion attack provoked by the spacers was not as desired this occurrence did not compromise the study because the measurement of the electrochemical potential was performed in the center of the samples at some distance from the region of the greatest influence of this type of attack.

In the analysis of the results, the following empirical relations were adopted:

$$E = \alpha (w/c)^{\beta} c^{\gamma} \quad (1)$$

where:

- E = measurement of the electrochemical potential (mV CSE)
- w/c = water/cement ratio
- c = reinforcement cover (mm)
- α, β, γ - adjustment coefficients

By a multiple linear regression between the logarithm of the potential as a function of the water/cement ratio and of the reinforcement cover, equation (2) was obtained, where the correlation coefficient was 0.76.

$$E = -1064 (w/c)^{0.41} c^{-0.22} \quad (2)$$

Figure 2 shows the curves obtained using equation (2) considering all the material, along with the average values of the potential of each series shown in Table 3. Figure 3 shows in a three-dimensional diagram the values obtained using this same equation.

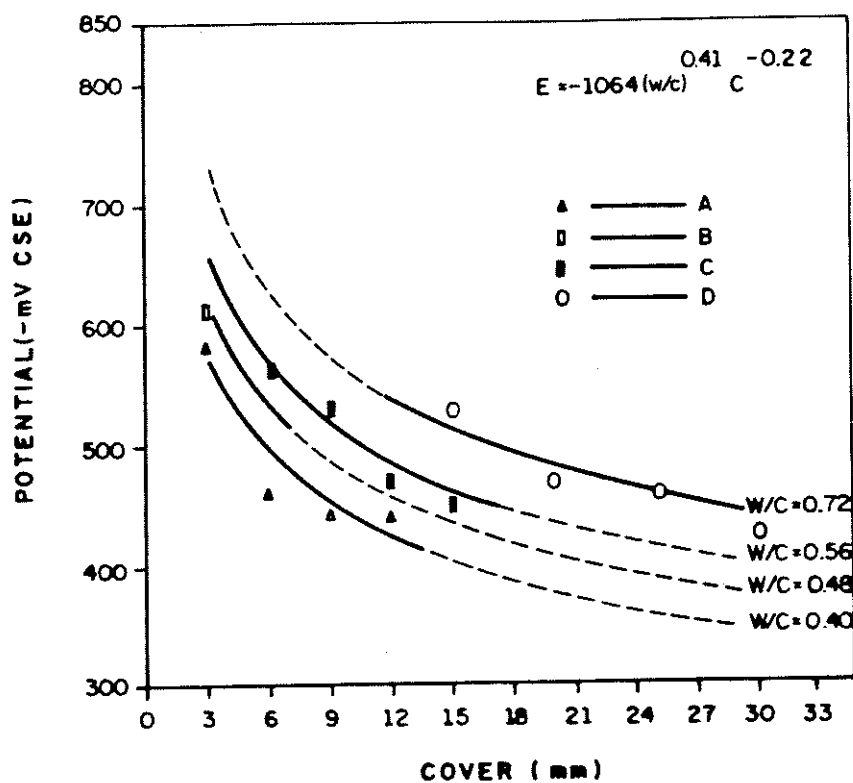


Fig. 2- Electrochemical potential curves and average experimental values

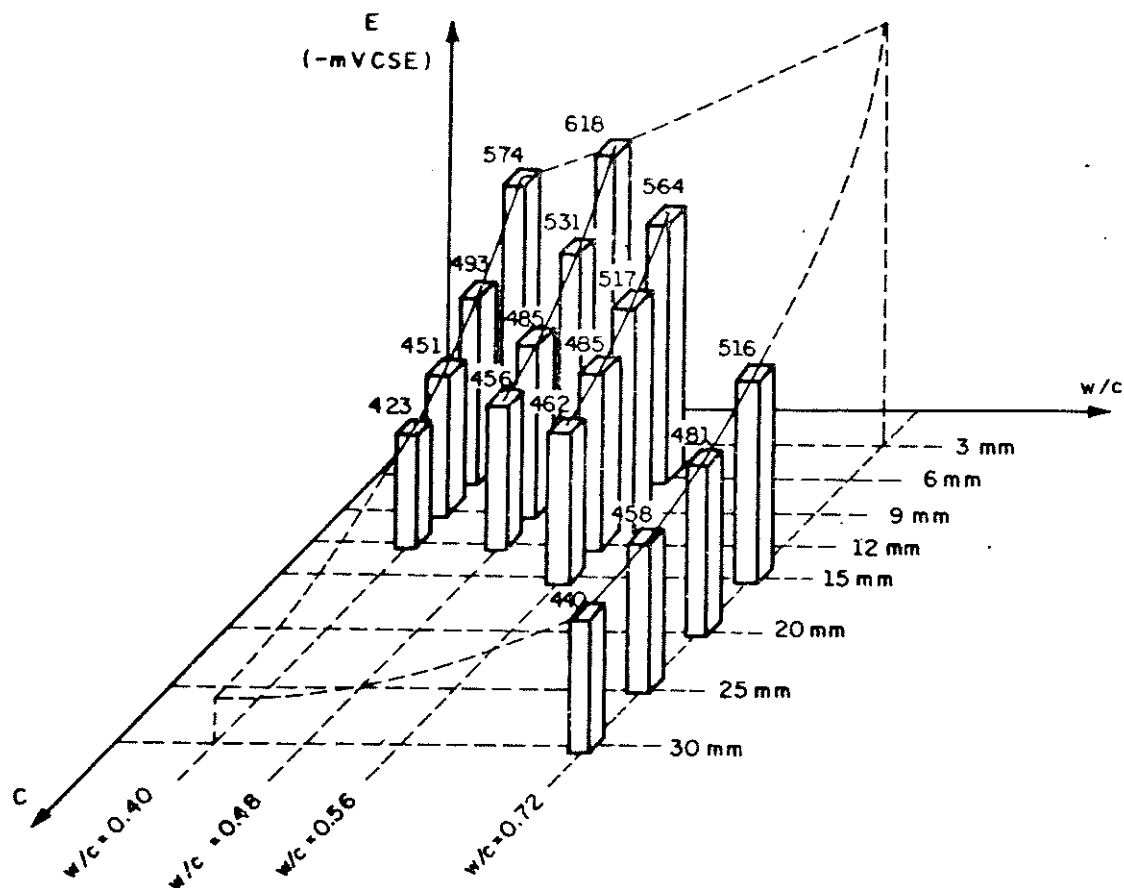


Fig. 3- Electrochemical potential calculated by equation (2)

From the equation (2) determined by regression some simulations can be made such as an evaluation of the reinforcement cover of ferrocement with a certain water/cement ratio that confers the same degree of protection of a concrete with established values of reinforcement cover and water/cement ratio; or an evaluation of the water/cement ratio of ferrocement for a known reinforcement cover that provides the same degree of protection for a concrete with known reinforcement cover and water/cement ratio.

Based on these considerations, it was determined that a ferrocement with a water/cement ratio of 0.4 should have a reinforcement cover of 6.7 mm in order to have the same reinforcement protection of a concrete with a water/cement ratio of 0.72 and a reinforcement cover of 20 mm.

After the potential measurement the samples were carefully broken-up in order to remove the reinforcement and proceed a visual inspection in which good qualitative agreement with the measured values was observed. Photo 4 shows the mesh final aspect of some samples.

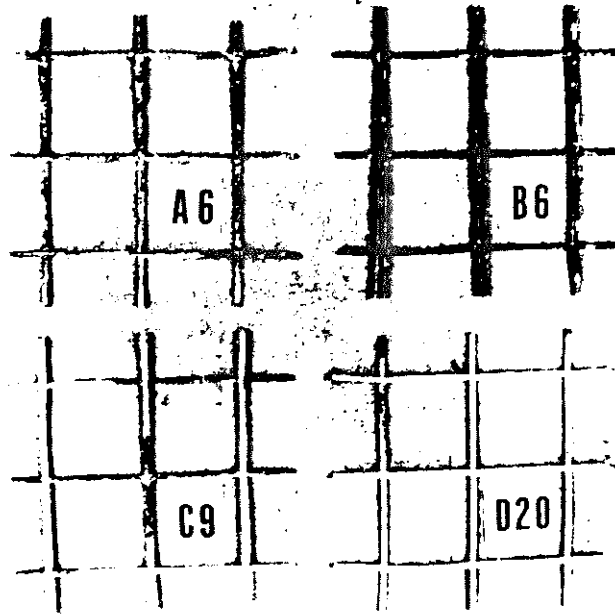


Photo 4- Corrosion of some reinforcement samples
after the test

FINAL REMARKS AND CONCLUSIONS

The results show the great importance of using low water/cement ratios for ferrocement. For example, for a piece with reinforcement cover of 5mm, when the water/cement ratio is increased from 0.4 to 0.48 (+20%), the reinforcement cover should be increased, according to equation (2), to 7 mm (+40%) in order to result in the same degree of protection for identical conditions of compaction, curing, etc.

From equation (2), evaluations of the reinforcement cover may be made for ferrocement in order to obtain the same protection degree of reinforced concrete (the reinforcement cover of which are generally established by codes). For practical applications further studies are necessary to investigate other factors not considered in this paper, such as the formation and width of cracks, quality control, fabrications tolerance, etc.

The results obtained with this study indicate the possibility of using the same procedure for comparative studies of reinforcement corrosion in concretes in general when considering other variables beyond those studied here such as, for example: the type of cement, the curing conditions, the compaction conditions, the use of types of protective paint, the composition of the bathing solutions, the type of steel, the use of corrosion inhibitors, etc, all in a relatively simple form.

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