Corrosion of Reinforcing Steel - A Discussion on Evaluation Methods

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The last effort of technologists is to obtain the best quality of concrete both mechanical and durability (service-life) in severe environments as marine or industrial. Problem is how to evaluate the durability of concrete. A lot of methods have showed being able to apply for evaluation of reinforcing steel corrosion, but there are a number of limitations with each method.

Through some results obtained from works of authors and literature, a discussion was made in this paper with purpose to select the suitable methods for measurement and evaluation of reinforcing steel corrosion in concrete.

Keywords : *reinforcement, durability, inhibitors, electrochemical measurements.*

1. Introduction

Concrete structure has been widely applied for houses, buildings, towers, offshore wharves, flatforms, ships, bridges... The durability of concrete structures in different environments is interested by a number of investigations all over the world. What desires the durability of concrete? Answer of this question should be quite different. But conclusion is that the damage of concrete structures is mainly caused by the corrosion of reinforcing steel. By human experience, the constructions built by standard materials have service life (durability) not less than hundreds years. Unfortunately, many cases in practice, only after several years (five or ten), in the surface of concrete structures have been appeared points with black-brown color demonstrated the initiation of corrosion.

Patient efforts of researchers and technologists are to seek the concrete with high quality, high durability, i.e. the long service life. To serve this purpose, it needs to evaluate the durability of concrete. There are a number of methods electrochemical and/or non-electrochemical for evaluating the corrosion of concrete and reinforcing steel in concrete. The purpose of this paper is to interview some practical methods and discuss some idea based on testing results and literature about evaluating methods for corrosion of rebar in concrete.

2. Electrochemical methods

2.1 Evaluating the rebar corrosion in cement extract solution

Electrochemical measurements in cement extract solutions has been used to study the function of cement types, inhibitors, chemical admixtures, as well as the effecting of environment factors on corrosion of rebar. Two advantages of this application are: First, in solution dissolves almost all compositions of cement, it can be representative for concrete body; Second, measurement is simple, good reproductive. These manners do not deal with mechanical property of concrete, therefore this is used for orientation evaluation only.

In cement extract solution can be performed all electrochemical measurements, as: *polarization curve, polarization resistance, impedance meter, corrosion potential or current measurement.* By these techniques, almost all data needed for corrosion evaluation can be calculated, *as corrosion rate, passive regions, passive potentials and currents.*

Polarization curve

Fig. 1, is anodic polarization curves of mild steel in alkaline and different extract solutions present of sodium nitrite-as inhibitor for rebar in concrete. From measurement, some electrochemical data can be calculated and

Table 1. Electrochemical parameters and corrosion rate of mild steel in different solutions

Solution	Corrosion potential mV (SCE)	Corrosion current mA/cm^2	Corrosion rate (mm/y)
Cement extract	-395	0.98	0.011
+ 0,2% $NaNO_2$	-295	1.30	0.015
+ 1,0% $NaNO_2$	-293	1.77	0.020
+ 3,0% NaCl	-450	5.46	0.063
Calcium hydroxide	-370	0.8	0.009
+ 0,2% $NaNO_2$	-356	1.35	0.016
+ 1,0% $NaNO_2$	-332	1.66	0.019
+ 2,0% $NaNO_2$	-320	1.77	0.020
+ 0,2% NaOH	-390	1.61	0.018
+ 1,0% NaOH	-425	6.19	0.072
+ 3,0% NaCl	-530	12.79	0.148
Calcium hydroxide			
+ 3,0% NaCl + 0,2% $NaNO_2$	-505	10.82	0.125
+ 3,0% NaCl + 1,0% $NaNO_2$	-472	6.6	0.077

indicated on table 1, where the corrosion rate is calculated by polarization resistance measurement. It is apparent that in calcium hydroxide, sodium nitrite is better inhibitor than in cement and cement paint extract solutions, it maybe is by effecting of cement composition.

Sodium nitrite is not adequate inhibitor for mild steel in concrete absent of chloride ions. The sodium ions increases the corrosion rate of mild steel even nitrite ions are present. Unfortunately, in chloride ions containing media, sodium nitrite exhibits sufficient inhibition effect for rebar in concrete

Corrosion potential-time curve

For corrosion status evaluation of rebar in concrete can be used corrosion potential-time measurement method in laboratory (in extract solution or in concrete specimen) or in the field. This method was standardized in ASTM C 876-80 (or ASTM C876-91)

Fig. 2. show the different corrosion status of rebar in concrete specimens with different concentration of calcium nitrite (NC). In presence of 0.35% (by weight of cement) of NC, corrosion potential is quite negative (around the free corrosion potential of mild steel in solution), rebar is in the active corrosion status; with 2.5% of NC, corrosion potential searches more positive, rebar is in the passive status; It is apparent that the 2.5% is the optimum concentration of calcium nitrite for protection of steel in concrete.

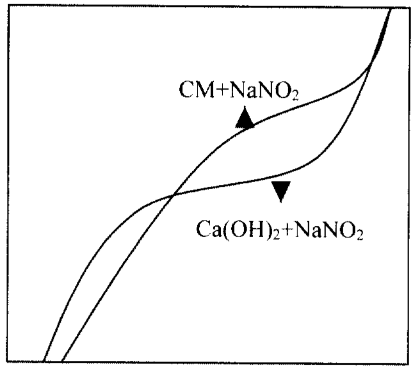

Fig. 1. Polarization curves of mild steel in cement extract and $Ca(OH)^2$ in the presence of 0.2% sodium nitrite

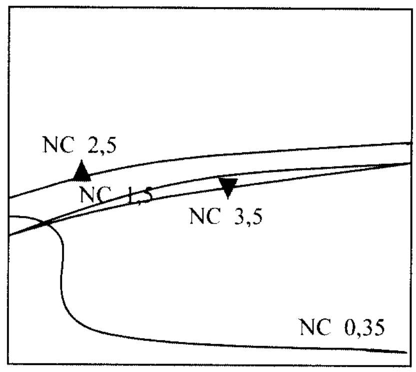

Fig. 2. Corrosion potential-time curves with different concentrations of calcium nitrite (NC) inhibitor

Advantage of potential-time curve measurement is able to apply in the field. In the Fig. 3 is illustrated the change of potential of rebar in concrete tested in the Cua Lo Beach in Central Vietnam. On this figure, we can see the different corrosion characteristics of rebar in marine-conditions with different components (admixtures) of concrete. From 4 years testing data can be shown that DCI as well as calcium nitrite is effective inhibitors for corrosion of rebar in sea-conditions.

Limits of this method are:
- Comparative evaluation.
- Evaluation of corrosion possibility (not able to calculate the corrosion rate).
- Poor reproductivity (disturbility).

Rodney P.[2)] has noted that the measurement of the corrosion potential of reinforcement in concrete is commonly specified to ASTM. The assessment of the results is however, very dependent on the unique circumstances of

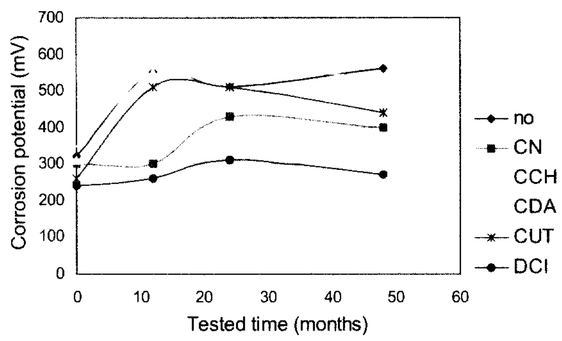

Fig. 3. The change of corrosion potential in CuaLo Tests

the particular structure. Results can be easily obtained but the assessment is an engineering skill.

Nowaday exist a lot of equipments based on this principle such as CANIN, GECOR and more advanced *Potential Wheel* which permits the continuous rapid collection of reinforcement potentials and provides simple linear or micro-computer for data-storage or more detailed analysis.[3)]

As showed by B. Elsener and H. Bohni,[4)] the potential range indicating active corrosion on different bridge decks with ASTM C 876-91 standard stretches from -0.2 to -0.57V, that for different conditions (that is concrete cover, humidity, chloride content) different potential values indicate corrosion.

Clearly that this method still is not so reliable and certain for corrosion evaluation of reinforcement in concrete.

Polarization Resistance Measurement

A more suitable method for evaluation of reinforcement corrosion in concrete is polarization resistance measurement. The corrosion of steel in cement extract solution, cement extract solution containing different admixtures and aggressive components as well as in concrete or mortar is sufficiently evaluated by this method. Comfortably, the measurement is very quick, Software program can translated automatically to corrosion rate. Not real corrosion rate measured, but it is able to evaluate and compare the different admixtures, aggressive or composition of concrete on rebar corrosion characteristic and can be a good orientation to select admixtures or concrete composition

2.2 Another methods

Impedance meter

Some authors were used AC impedance method to evaluate the corrosion behavior of steel in concrete as: J.A. Gonzalez[5)] D.G. John, *et al.*[6)] It was showed adequate benefit of application of this method for concrete corrosion study. From impedance meter can be saw the mechanism of process; calculated necessary parameters for corrosion evaluation such as: corrosion rate, double layer capacity. As shown by J.A. Gonzalez[5)]:

1 – The AC impedance technique is a useful tool to calculate some characteristic parameters of the corrosion process but the accuracy in R_p determinations is similar or even smaller than that of the other techniques.

2 – In the particular case of steel embedded in concrete, the linear polarization has been demonstrated to be a useful technique for easy and quick calculation of the instantaneous corrosion rate.

On the other hand, the equipment for AC impedance meter is rather expensive, measurement technique is not simple, particularly in results interpretation, it takes a long time performance (even some days for once measurement) and not so easily to apply in the field

Recently, some papers describe about galvanostatic pulse, resistivity measurement for assesment of rebar corrosion in concrete.

3. Indirect methods

3.1 ASTM G109

This method is based on measurement the current passed a resistor between two bars embedded in once concrete specimen causing a galvanic coupling.[6)] This test method describes a procedure for determining the effects of chemical admixtures on the corrosion of metals in concrete. It can be used to evaluate materials intended to inhibit chloride - reduced corrosion of steel in concrete as well as to evaluate the corrosivity of admixtures in a chloride environment. The concrete parameters are as follows: *cement content of 600 ± 5 lb/yd³ (356 ± 3 kg/m³), 0.5 ± 0.01 water to cement (W/C) ratio and 6 ± 1% air. So*, it is impossible to apply this method for different types of concrete.

On the other hand, in this method, measured current is derived by following formula:

$$I = V / (r + R)$$

Here : I : Current passed: mA
V: different voltages between two pieces of metal in same specimen of concrete (mV).
r : resistivity of resistor selected (10 or 100Ω)
R: Resistivity of concrete (Ω):

In many cases such as High Performance Concrete (HPC) or High Strength Concrete (HSC), R ⟶ ∞, I ⟶

0, the accuracy of measurement of passed current is not adequate.

3.2 ASTM1202 or Modified ASTM 1202

New tendency to estimate the corrosion behavior of steel in concrete is based on the determination of chloride penetration into concrete. This test method is created on the conception that if concentration of chloride in concrete is exceeded a threshold as 0.5% weight of cement, corrosion of rabar initiates.

H. Trinh Cao et al.,[7] based on theory and experiments has shown a tentative classification on concrete quality based on the relationship between the modified total charge passed to chloride diffusion coefficients and effective porosity (at 50% RH) as below:

It is so-called rapid assessment for concrete quality, therefore, only 6 hours for once test series needed for quality evaluation. Unfortunately, it does not exist the direct relationship between chloride concentration and total charge passed, so evaluation is still unreliable.

P.V. Tuong, *et all.*, were indicated some results tested on silicafume modified concrete and listed in table 3.

Total charge passed of specimen N3 is smalest. The dosage of 16% of silicafume by weight of cement (56g/294g) can be considered in this case as an optimum for quality of concrete with respect to chloride penetration. According to concrete quality classification, this concrete could be grouped to good quality class (third), or low chloride penetration.

Table 2. Concrete quality classification

Modified total charge passed (Coulombs)	Concrete quality
>3000	Poor
2000-3000	Reasonable
1000-2000	Good
500 -1000	Very good
< 500	excellent

Table 3. The composition of concrete and total charge passed

No	Cement (g)	Silicafume (g)	Water (ml)	Total charge passed (C)
N1	308	42	154	2594
N2	301	49	150	2580
N3	294	56	147	1977
N4	287	63	143	3125
N5	280	70	140	3345
N6	273	77	136	3529

4. Concluding remark

Quality of concrete is correspondent with the corrosion characteristics of rebar, but for evaluation of corrosion behavior of rebar is still opened problems. Many electrochemists have concentrated efforts to solve this problem. Electrochemical methods is very useful for this purpose but still exist a number of limitations for application, particularly in the field.

Some indirect methods seem to be easy to perform but can not directly predict the corrosion of rebar embedded in concrete, whilst the gravimetric traditional method is limited by a very low corrosion rate.

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