Assessment of the effect of GFRP on the corrosion of steel reinforcement in confined RC by EIS

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Introduction

Reinforced concrete (RC) is the most popular construction material and it is used all over the world [1] as the essential element in most structures existing today. Its exposure to aggressive chemicals, like chlorides and sulfates, present in natural, urban and industrial environments, creates conditions for attack of the rebars and decrease of the structure performance [2-4], cracking, delamination and spalling [1, 5, 6, 7] that are common symptoms of reinforcement corrosion.

Due to these reasons, the construction field is looking for new materials, with new proprieties, often previously used in other technical applications. One type of such materials very attractive for application in concrete constructions is the fiber reinforced polymer (FRP). On such applications, a large number of studies have been made that show advantages of FRP application, such as increase of axial compressive load capacity in columns, improved flexural and shear load carrying capacities, increased ductility and improvement of seismic performance [8-13] all depending on adequate design. In beams, the increase of flexural strength, shear strength, torsional strength and fatigue resistance have been reported, e.g. in [8, 10, 14, 15, 16].

In addition, FRP is a product of easy installation, high chemical resistance, while having a minimal architectural impact [11]. Therefore, it has been used in the rehabilitation of several structures in USA, Japan and Europe [10].

Concerning the ability of the FRP to slow down the corrosion onset and corrosion activity in steel reinforcement, scarce work can be found in literature.

This article gives a contribution to the study of the corrosion of reinforcing steel when concrete is covered by glass fiber reinforced polymer (GFRP) in the presence of chloride ions. The electrochemical behavior was studied by electrochemical impedance spectroscopy in GFRP protected samples and in reference samples. Additionally, the effect of the water-cement ratio was evaluated.

Experimental

The concrete specimens have a cylindrical geometry with two ribbed steel bars that were used as electrodes. Two different water-cement ratio mixtures were used, namely W/C=0.50 and W/C=0.56. GFRP wrapped in half of the samples. The GFRP sheets were impregnated with resin and their application around the concrete cylinders was manual, by wet lay-up process. The basis of the specimens was coated with two epoxy resin layers. The specimens tested in this work are depicted in fig. 1. After cure, the specimens were partially immersed in 3% NaCl–solution, which intends to simulate sea water.

Two types of electrochemical methods were used, open circuit potential (OCP) monitoring and electrochemical impedance spectroscopy (EIS).

Fig. 1 – Samples: (a) without GFRP, (b) with GFRP.

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Results and Discussion

The OCP variation of the steel bars show for the reference specimens without GFRP, values around -450 mV with a slow decay to even more negative values as seen in Fig. 2. This suggests that in the early stages, the corrosion process is already active or the high concrete saturation induces cathodic polarization phenomena, which can shift the potential towards more cathodic values. In the case of specimens with GFRP until the end of the measurements, the OCP values are in the range 0 to -200 mV, indicating passive state of the steel rebars.

The results evidence the physical barrier effect provided by the GFRP coating that hinders the ingress of aggressive chloride ions from the media, while the hydration process in concrete take place. Therefore, the GFRP coating acts as an additional physical barrier, which strongly delays the access of chlorides and corrosion onset.

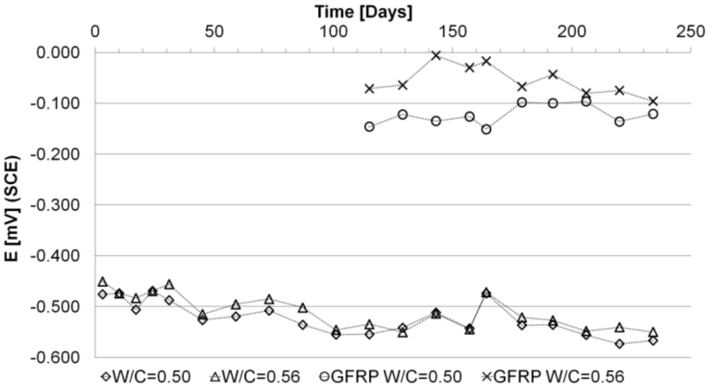

Fig. 2 – OCP evolution of the four types of samples.

The EIS results reveal significant differences between the concrete samples with and without GFRP. On the other hand, the EIS spectra present identical behavior for the samples with different w/c ratio.

The magnitude of the impedance modulus in the Bode plots evidence a progressive capacitive slope decay over the time in samples without GFRP, while for the GFRP samples the capacitive slopes are kept constant. The Bode plots also reveal an increase of the overall resistance for the samples coated with the GFRP.

Different equivalent circuits were used. In the samples without GFRP, a high frequency relaxation process could be detected and at later stages, when the corrosion process is in an advanced state, the simulation of the spectra requires a component to model the diffusion processes arising from charged species moving across the corrosion products layer.

The simulations made of the measurements along the time allowed to know the evolution of the concrete resistivity. For the samples without GFRP, the values are quite stable, being around 1500 Ω.cm in the 5 months of immersion. For the GFRP samples, the values obtained in the early days of immersion, are several times higher, being around 19000 Ω.cm, with a slightly trend to increase with the time due to the concrete hydration.

The presence of GFRP creates a barrier that delays electrolyte uptake, which is reflected in increased resistance.

The simulations also revealed the values of charge transfer resistance (table 1).

Table 1. – Evolution of charge transfer resistance with time of immersion.

Days	GFPR	W/C=0.50	W/C=0.56
		R_{ct} [Ω.cm^2]	
3	Without	$1.2\text{x}10^5$	$2.5\text{x}10^5$
	With	$6.7\text{x}10^5$	$2.3\text{x}10^5$
45	Without	$6.5\text{x}10^3$	$5.2\text{x}10^3$
	With	$5.5\text{x}10^5$	$2.3\text{x}10^5$
143	Without	$7.0\text{x}10^3$	$9.0\text{x}10^3$
	With	$8.5\text{x}10^5$	$3.2\text{x}10^5$
220	Without	$8.2\text{x}10^3$	$8.4\text{x}10^3$
	With	$8.6\text{x}10^5$	$1.3\text{x}10^5$

The samples with GFRP in the two different W/C ratios showed a stable charge transfer resistance along time, with an order of magnitude of 10^5 Ω.cm^2. This reveals the maintenance of the passive state all over the immersion period, in good agreement with the OCP results. In the samples without GFRP, after 45 days of immersion, all the samples show values below 10^4. After 5 months of immersion, these samples show stable charge transfer resistance values. Given the low values there is intense corrosion activity at the rebars.

The correlations between the charge transfer resistance values and the capacitive region slopes are in agreement with the correlations obtained in previous works [17]. For values between 10^6 Ω.cm^2 and 10^5 Ω.cm^2 the slopes are between -0.6 and -0.8 and for values <10^5 Ω.cm^2 the slope are < -0.6.

The corrosion current density can be calculated and with this value it is possible to estimate de corrosion rate in mm/yr. The values of the corrosion rate after 5 months of immersion show that the presence of GFRP, has reduced the corrosion rate more than 200 times. This trend clearly illustrates the barrier effects and the delay of the corrosion processes in concrete samples coated with GFRP.

Conclusions

Concrete rebars exposed to 3% NaCl solution, when not coated with GFRP show a fast corrosion onset and increase of the corrosion activity. For this type of samples, the open circuit potential variation is not conclusive, because it becomes affected by polarization effects of the cathodic process.

For the samples without GFRP no differences could be noticed for the different w/c ratios.

The GFRP samples revealed open circuit readings characteristic of the passive state, which was confirmed by the EIS measurements. The increased resistivity of these samples highlights the barrier effect of the GFRP layer that hinders the uptake of the NaCl solution.

Consequently, the concrete hydration processes can proceed, further increasing the concrete resistivity, decreasing the penetration of aggressive ions and promoting electrochemical stability of the reinforcing steel.

The presence of GFRP could reduce for more than 200 times the corrosion rate of the reinforcing steel when concrete samples with and without GFRP are compared.

The GFRP layers act as a physical barrier that contributes for the maintenance of the passive state of the rebars and for its reduced electrochemical activity.

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References

[1] S. Gadve, A. Mukherjee, S.N. Malhotra, Corrosion of steel reinforcements embedded in FRP wrapped concrete, Const. Building Mat. 23 (1) (2009) 153-161.

[2] J. Li, J. Gong, L. Wang, Seismic behavior of corrosion-damaged reinforced concrete columns strengthened using combined carbon fiber-reinforced polymer and steel jacket, Const. Build. Mat. 23 (7) (2009) 2653–2663.

[3] M.F. Montemor, Estudo da deterioração por corrosão de estruturas de Betão Armado (PhD thesis), IST, Lisboa, 1995.

[4] M.J. Shannag, H.A. Shaia, Sulfate resistance of high-performance concrete. Cem. Concre. Comp. 25 (3) (2003) 363–369.

[5] P. Huang, Y. Bao, Y. Yao, Influence of HCl corrosion on the mechanical properties of concrete. Cem. Concre. Res. 35 (3) (2005) 584 – 589.

[6] C. Lee, J.F. Bonacci, M.D.A. Thomas, M. Maalej, S. Khajehpour, N. Hearn, S. Pantazopoulou, S. Sheikh Accelerated corrosion and repair of reinforced concrete columns using carbon fibre reinforced polymer sheets. Can. J. Civ. Eng. 27 (6) (2000) 941–948.

[7] L.K. Spainhour, I.A. Wootton, N. Yazdani, Effect of Composite Fiber Wraps on Corrosion of Reinforced Concrete Columns in a Simulated Splash Zone. Third Int. Conf. Comp. Infras.," San Francisco, 2002.

[8] K.W. Neale, FRPs for structural rehabilitation: a survey of recent progress. Prog. Struct. Eng. Mater. 2 (2000) 133-138.

[9] H. Toutanji, L.S. Matthys, K. Audenaert, Behaviour of large-scale columns confined with FRP composites. Proceed. 2nd Inter. Conf. on FRP Comp. in Civil Eng. (2005) 321-326.

[10] H.V.S. GangaRao, N. Taly, P.V. Vijay, Reinforced Concrete Design with FRP Composites. CRC Press, 2007.

[11] Y.A. Al-Salloum, Experimental and Analytical Investigation of Compressive Strength of FRP-Confined Concrete. Final Rep. King Saud University. Kingdom of Saudi Arabia, 2007.

[12] A. Parvin, W. Wang, Concrete columns confined by fiber composite wraps under combined axial and cyclic lateral loads. Comp. Struct. 58 (4) (2002) 539–549.

[13] R. Benzaid, N.E. Chikh, H. Mesbah, Behaviour of Square Concrete Column Confined With GFRP Composite Warp. J. of Civil Eng. Manag. 14 (2) (2008) 115–120.

[14] A.K.Y. Hii, R. Al-Mahaidi, Torsional strengthening of reinforced concrete beams using CFRP composites. Proceed. 2nd Inter. Conf. on FRP Comp. in Civil Eng. (2005) 551-559.

[15] M. Ekenel, A. Rizzo, J.J. Myers, A. Nanni, Effect of Fatigue Loading on Flexural Permformance of Reinforced Concrete Beams Strengthened With FRP Fabric and Pre-Cured Laminate Systems. Comp. in Const., 3rd Inter. Conf., France, 2005.

[16] A. Mofidi, O. Chaallal, Shear Strengthening of RC Beams with EB FRP: Influencing Factors and Conceptual Debonding Model. J. of Comp. for Const. (2011) 62-74.

[17] M.F. Montemor, A.M.P. Simões, M.M. Salta, Effect of fly ash on concrete reinforcement corrosion studied by EIS. Cem. Concre. Comp. 22 (3) (2000) 175-185.