ACROSS
www.across-journal.com
Proceedings of the International Conference “Interdisciplinarity and Cooperation in Cross-border Research”
Chisinau, Republic of Moldova, June 2022
Vol. 6. No. 2 – Engineering

CORROSION - AN UNDESIRABLE PHENOMENON FOR REINFORCEMENT OF ADVANCED MORTARS AND CONCRETE

Loredana JUDELE[1], Dorina ISOPESCU[1], Ion RUSU[2], Daniel LEPADATU[1]

[1]*Technical University Gheorghe Asachi of Iasi, Iasi (Romania)*

[2]*Technical University of Moldova, Chisinau (Republic of Moldova)*

Abstract

Constructions made out of mortar and cement concrete are unveiled to advanced chemical corrosion processes, especially when placed in aggressive environments. The study follows the behaviour of concrete with a slag content of 10 % exposed to chlorine corrosion, as well as carrying out analyses aimed at monitoring the evolution of mechanical resistance of concrete samples, containing slag when immersed in various aggressive solutions. The corrosive agents acting on the above-mentioned elements are in particular chlorine ions. These compounds may also be found in considerable quantities in industrial emissions and their effect is intensified by an increase in humidity, temperature or steam, or other corrosive gases, possibly accompanied by inadequate ventilation. The analysis of complex chemical processes highlights the influence of different corrosive agents on the resistance of this concrete.

Keywords: corrosion, mortars, concrete, granulate slag

1 Introduction

Cement concrete, without additives, is not resistant to such aggressive agents as salt water. The presence of basic granulated blast furnace slag in concretes and mortars subjected to this type of corrosion agent improves their behaviour in such media. Industrial wastes such as furnace slag or fly ash are a major source of pollution and its storage requires additional protection surfaces and measures, it is much more useful to recycle, recovery and reintroduce it into the industrial circuit.

Cement concretes are subjected to the pronounced corrosion processes if they are exposed to the aggressive environments (including marine corrosion). In general, reinforced concrete is a corrosion-resistant material, capable of withstanding a wide range of harsh environments, including marine and / or industrial conditions. Due to either the carbonation of the concrete or the penetration of chlorides into the concrete, the reinforcement of the reinforcing steel takes place, which leads to the rapid corrosion of the steel with a significant loss of cross-section.

Samples made from concrete containing cement with 10% slag were subjected to saline water corrosion. To highlight the different behaviour of the binder without slag there were made, in parallel, samples with Portland cement only. The samples were placed in the corrosive medium of saline solution with a concentration of 2% and in the sea water. The compressive strength was determined on cubic and cylinder samples and the graphs showing the time evolution of strength were drawn. The statistical analysis shows the time evolution of mechanical strength.

Intensive studies have been carried out worldwide on the effect of different kinds of media on cement components. To illustrate the studies in the field, one can mention the contribution of Wu *et al.*, who studied the transport of chloride ions in concrete [1,2]. The penetration of ions into concrete is a complex phenomenon, due to the fact that concrete is a kind of non-homogeneous material, and micro defects or damage are produced during the service period.

2 Materials and methods

The experimental program was designed in such a way as to reveal the physical-mechanical characteristics of the samples of concrete, with or without slag admixtures. According to the European Normative NE 012-99 [3], the cubic samples, 150×150 mm in size, were manufactured from concretes through vibration, and they were introduced into corrosive environments, after a previous curing for 28 days maturation in tap water, taking into account the slower reactions of the slag compared to those of the cement.

2.1 Concrete recipe

A concrete recipe was designed for the construction of a lighthouse (located on the beach) [4]. The calculation was made for one cubic meter of concrete. The exposure class is determined: XS_1. The concrete will be poured with the pump. The maximum size of the unit is 16 mm. From the durability conditions, the concrete class is established: C25/30. Also, from the conditions of durability they are established: the ratio: A/C = 0.4; impermeability degree: P12; gelivity degree: G150; freeze-thaw resistant aggregates. Choose the type of cement: SRII / A-S 32.5. S3 workability is adopted - the settling must be within 120 ± 20 mm. The water dosage is established: A = 230 l, which can be reduced by 10-20% if plasticizer additives are used and increased by 10% for the 0-16 mm aggregate.

$$A' = 230 - 23 \ \ 207\ l/m^3 \tag{1}$$

The final amount of cement:

$$A'/C' = 0.4 \Longrightarrow C' = A'/0.4 = 207/0.4 = 517.5\ kg/m^3 \tag{2}$$

The amount of aggregates (total and sorts):

$$A_g = \rho_{ag} \tag{3}$$

$$A_g = \rho_{ag} \tag{4}$$

For concrete samples with the addition of slag, 10% of the amount of cement was replaced [5]. Samples made from concrete containing cement and cement with slag were subjected to the salt water corrosion. To highlight the different behaviour of the binder without slag there were made, in parallel, samples with Portland cement only. The samples were placed in the corrosive medium. The compressive strength was determined on cubic samples and graphs showing the time evolution of strength were drawn. The statistical analysis shows the time evolution of mechanical strength.

Figure 1. Expulsion of concrete due to infiltration of salt water.

The corrosion process of steel is generally accompanied by an increase in its volume (the volume of oxide from corrosion is about eight times higher than that of the metal from which it comes), which leads to pressure on the concrete adjacent to the reinforcement and respectively, to the appearance of some stretching efforts in its mass (Figure 1). When they exceed the value of the tensile strength of the concrete, the cracking processes of the concrete in the coating layer are triggered, a phenomenon which favours the acceleration of the corrosion process. In most cases, the concrete coating can be removed, leaving the reinforcement unprotected (Figure 2).

Figure 2. Due the corrosion process, the concrete coating can be removed, leaving the reinforcement unprotected.

Blast furnace slag (Figure 3) is a by-product of the manufacturing process of steel (it is composed of oxides and sulphur compounds of metals, the main components being: SiO_2,

Al_2O_3, CaO, MgO). It develops the property of latent hydraulicity when, in a glassy and fine form, it is rapidly cooled with water. This is the process by which most slags are made, these being cementitious materials up to a certain point, while other types of slags become cementitious materials in the presence of activators such as Portland cement and calcium sulphate [6,7].

The performance of a blast furnace slag inside a concrete is relatively independent of its properties, cementitious or not. In ordinary concrete, when a cement economy is desired, an amount of about 10 to 50% of the total volume of cement can be added, but if the durability (resistance to sulphate action) of the concrete is to be improved, the percentage of slag will be at least 50% of the total amount of cement [8-11].

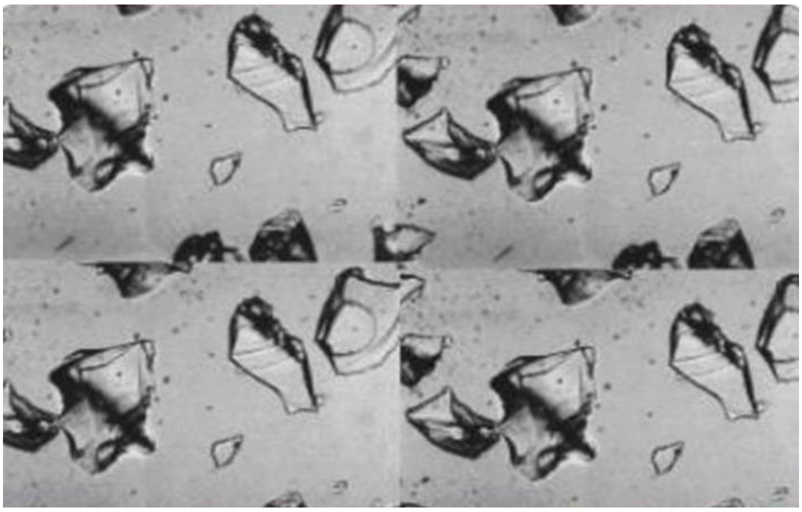

Figure 3. Microscopic photography of granulated blast furnace slag granules.

The field of view is 400 µm wide.

3 Results and discussion

Cubic samples were made and placed in 2% saline solution, sea solution and water. Compressive strengths were tested at different time intervals (Tables 1 and 2) and graphs of resistance variation over time were drawn up (Figures 4 and 5) [12-14].

Table 1. Compressive strength for standard sample.

	Water	**Saline solution 2%**	**Sea solution**
1 month	30.7	27.8	27.7
3 months	31.2	27	25.5
6 months	32	25.9	21.9
12 months	32.4	23.3	20.2

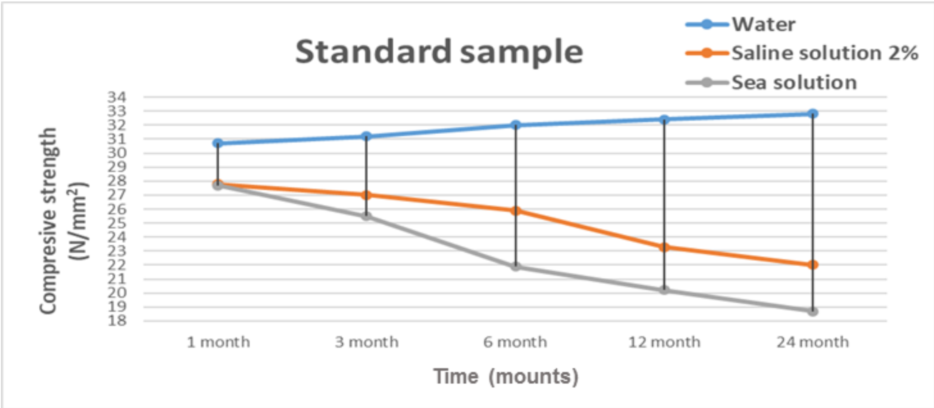

Figure 4. Compressive strength evolution in different corrosive agents for the standard simple.

Analysing the obtained results, it can be observed that the compressive strengths decrease by 7% in the case of samples subjected to corrosion in seawater solution, compared to those in saline solution of 4.6% in the first month to reach a loss of strength of 13.2% respectively, at 21.7%.

Table 2. Compressive strength for the simple with slag.

	Water	**Saline solution 2%**	**Sea solution**
1 month	30.2	28.5	28.1
3 months	30.7	28.2	27.6
6 months	31	27.3	25.8
12 months	31.4	25	22.3

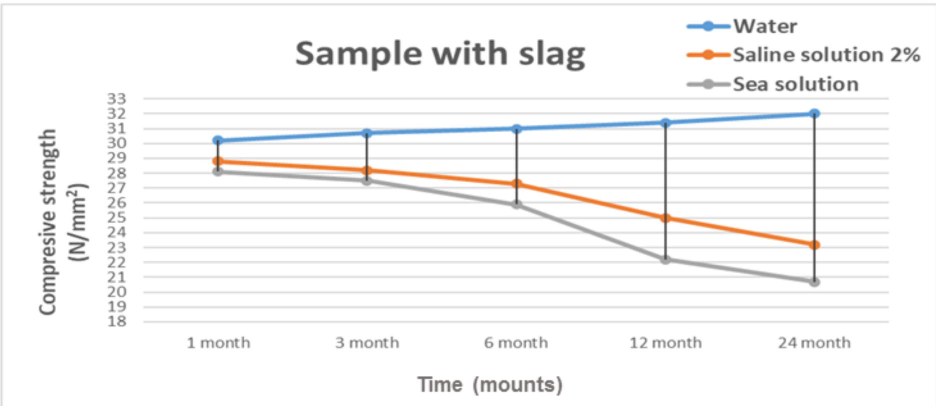

Figure 5. Compressive strength evolution in different corrosive agents for the simple with slag.

In the case of slag samples, the compressive strength decreases with the addition of slag by 1.6% per month to 3% at 12 months for the initial sample; instead for those in saline, the strength increases by 2.5% per month to 6.8% at 12 months respectively, by 1.4% at one month to 9.4% at 12 months for those in seawater.

4 Conclusions

Laboratory tests and the conclusions drawn from the interpretation of the obtained results make it possible to anticipate the possible degradations and to early intervene to limit the additional costs that may arise in the event of major consolidation interventions.

As both the graphs and the results show, the addition of slag improves the resistance to corrosion caused by salt water (the samples being subjected to both saline and seawater corrosion).

Concretes and cement mortars, without additives, are not resistant to aggressive agents as salty water. The presence of basic granulated blast furnace slag in concretes and mortars subjected to this type of corrosion agent improves their behaviour in such medium.

The use of recyclable materials as additives in concrete provides that the behaviour of the concrete is improved and, at the same time, its price decreases. For example, the slag improves the internal structure of the concrete matrix.

Concrete is considered to be an ideal protective medium for steel, but the use of salts and the increase in the concentration of carbon dioxide in the modern living environment due to pollution implicitly lead to the corrosion of reinforcements inside the concrete. Lack of protection and degradation will eventually lead to the failure of reinforced concrete elements. Corrosion is a natural phenomenon that cannot be suppressed but only slowed down.

ACKNOWLEDGMENTS

This paper was realized with the support of project EFECON – ECO-INNOVATIVE PRODUCTS AND TECHNOLOGIES FOR ENERGY EFFICIENCY IN CONSTRUCTION, POC/71/1/4 - Knowledge Transfer Partnership, Cod MySMIS: 105524, ID: P_40_295, Project co-financed by the European Regional Development Fund.

References

[1] Wu, J., Li, H., Wang, Z., Liu, J. (2016) Transport model of chloride ions in concrete under loads and drying-wetting cycles. *Construction and Building Materials*, 112, 733–738. https://doi.org/10.1016/j.conbuildmat.2016.02.167

[2] Zhu, X., Zi, G., Cao, Z., X. Cheng, X. (2016) Combined effect of carbonation and chloride ingress in concrete. *Construction and Building Materials*, 110, 369–380. https://doi.org/10.1016/j.conbuildmat.2016.02.034

[3] NE 012-99 Practical code for the execution of concrete and reinforced concrete works.

[4] ASRO (2002) Concrete. Specification, performance, production and conformity. SR EN 206-1/2002, National Standardisation Body: Bucharest, Romania.

[5] ASTM C 618 (2019) Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for use in Concrete.

[6] Lepadatu, D., Barbuta, M., Rujanu, M., Judele, L., Mitroi, R. (2018) Fly ash concrete with fibers: comparison of tensile strength using neural network and design of experiments methods.

Environmental Engineering and Management Journal, 17(6), 1321–1328. DOI:10.30638/EEMJ.2018.131

[7] Babor, D., Judele, L., Lepadatu, D. (2017) Nitric corrosion resistance of special mortars with high slag content. *Romanian Journal of Materials*, 47(3), 353–360.

[8] Guo, X., Shi, H., Hub, W., Wub, K. (2014) Durability and microstructure of CSA cement-based materials from MSWI fly ash. *Cement and Concrete Composites Journal*, 46, 26–31. https://doi.org/10.1016/j.cemconcomp.2013.10.015

[9] Zhu, Y., Wan, X., Han, X., Ren, J., Luo, J., Yu, Q. (2022) Solidification of chloride ions in alkali-activated slag. *Construction and Building Materials*, 320, article no. 126219. https://doi.org/10.1016/j.conbuildmat.2021.126219

[10] Eddariy, Y., Lamdouar, N., Cherradi, T., Rotaru, A., Barbuta, M., Mihai, P., Judele, L. (2020) 'Experimental Investigation of the Effects of NaOH and KOH Solution on the Behavior of Concrete Square Columns Reinforced By JFRP Composites'. In: *The 5th World Congress on Civil, Structural, and Environmental Engineering (CSEE'20),* Virtual Conference – October, 2020 Paper No. ICSECT 167. DOI:10.11159/icsect20.167

[11] Pacheco, J., de Brito, J., Chastre, C., Evangelista, L. (2019) Experimental investigation on the variability of the main mechanical properties of concrete produced with coarse recycled concrete aggregates. *Construction and Building Materials,* 201(2), 110–120. https://doi.org/10.1016/j.conbuildmat.2018.12.200

[12] ASRO (2013) Testing Hardened Concrete. Part 13: Determination of Secant Modulus of Elasticity in Compression. SR EN 12390-13/2013, National Standardisation Body: Bucharest, Romania.

[13] ASRO (2009) Testing Hardened Concrete. Part 3: Compressive Strength of Test Specimens. SR EN 12390-3/2009, National Standardisation Body: Bucharest, Romania.

[14] ASRO (2010) Testing Hardened Concrete. Part 6: Tensile Splitting Strength of Test Specimens. SR EN 12390-6/2010, National Standardisation Body: Bucharest, Romania.