Materials Physics and Mechanics 43 (2020) 59-64 Received: November 28, 2019

CORROSION RESISTANCE AND MECHANICAL PERFORMANCE OF STEEL REINFORCEMENT, BEFORE AND AFTER SHOT-BLASTING PROCESS

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Abstract. As it is widely known, corrosion of steel reinforcement is one of the main causes of deterioration of the reinforced concrete structures. Corrosion phenomena combined with seismic loads aggravate the situation. For this reason, in the present paper, an effort is made to upgrade the performance of steel reinforcement against corrosion, using the shot blasting method. Precisely, two groups of specimens were prepared, one of which had previously been shot blasted. Afterwards, the specimens were undergone artificial corrosion, in order to compare the results of the developed corrosion damage. Some of them were inserted in a salt spray chamber and the rest of them were corroded via "impressed current density corrosion" technique. Finally, mechanical tests were executed, in order to make an assessment concerning the performance of the reference and the shot blasted material, before and after corrosion effect. Both selection of the double shot blasting process and experimental results that came out, were really encouraging.

Keywords: corrosion resistance, shot blasting, mechanical performance

1. Introduction

Corrosive agent constitutes a major problem for constructions located in coastal areas, since it keeps affecting their durability. According to established standards, safety of reinforced concrete structures is generally related to the expected service life of their individual construction materials, and mainly of steel reinforcement.

As it is widely known seismic areas, combined with harsh coastal environment, constitute a compounding conjunction, which is rich in chlorides, seismicity and vulnerability of the materials used, have detrimental results on the mechanical performance of various structures. Inevitably there are plenty of references in existing literature, concerning the consequences of corrosion damage on reinforced structures, and insufficient seismic response of structures that face durability issues [1-5].

In the present study an effort was made to increase corrosion resistance of high strength and ductility dual phase steel B500c category, with the use of shot blasting process, without any interference in the chemical composition or in the production mode. For the goals of the present study two different abrasives were used on the surface of the material. The first pass was performed with the use of angular and the second with the use of spherical pellets. The two-step treatment was used on the one hand for cleaning and on the other hand to develop

http://dx.doi.org/10.18720/MPM.4312020_7

compressive strain on the surface of steel bars, according to the pertinent protocols. Both reference and shot blasted specimens were primarily subjected to accelerated artificial corrosion and afterwards to mechanical tests, to evaluate their mechanical performance.

2. Thermomechanical Processing

The material examined in the present study is B500c- high ductility and strength- dual phase steel bar, which has been extensively used during the recent years (Table 1).

Technical class B500c steel has been produced so as to comply with the new, more demanding Hellenic Standards and Eurocodes.

Table 1. The minimum standards for high ductility steel B500c, set by the EC2

Class	Rp [MPa]	Ag [%]	Rp/Rm
B500c	500	≥7.5	≥1.15 <1.35

For the goals of the present study, ribbed bars of 1m length and nominal diameter 12mm were delivered and were prepared for their exposure to corrosive conditions.

In total 72 specimens were prepared, the 36 of which were subjected to shot blasting treatment. The specimens were shot-blasted twice. For the first pass were used angular olivine particles and for the second pass spherical glass beads. Angular geometry of the olivine pellets was critical to achieve a better abrasion on each surface, as well as to remove from the steel surface all the undesired impurities, even mill scale, the oxide layer which is produced by the material itself for self-protection.

Additionally, given that the standards which are mainly used in shot blasting process for the evaluation of the level of cleanliness of the material are visual (Table 2), in the present study Sa2.5 was adopted.

Table 2. Visual Standards

Description	International ISO-8501-1 [6]	American SSPC-SP [7]
White metal	Sa 3	SSPC SP5
Nearly white metal	Sa 2.5	SSPC SP10
Commercial blast	Sa 2	SSPC SP6
Brush-off blast	Sa 1	SSPC SP7

After the shot blasting treatment, a different exposed length was defined for each case, while the rest part of the samples was covered by wax. Table 3 presents in detail the total and the exposed –to corrosive conditions- length, as well as the type of mechanical testing that was used in each case. In total, 66 corrosion tests and 72 mechanical tests (6 non- corroded specimens included) were performed.

Table 3. Number of the specimens tested for the goals of the present study

Reference/Shot Blasted	Total Length [mm]	Exposed Length [mm]	Number of Specimens	Type of Mechanical Test
Reference	600	500	24	Tensile Tests
Shot Blasted	600	500	24	Tensile tests
Reference	250	10	12	LCF tests -Free Length 6D (±0.75%, ±1.25%)
Shot Blasted	250	10	12	LCF tests – Free Length 6D (±0.75%, ±1.25%)

When shot blasting preparation was completed, all specimens were exposed to artificial corrosive conditions. For the goals of the present ongoing study, two laboratory corrosion methods were used: salt spray chamber (according to ASTM B117-94 standard) and impressed current density technique (the parameters of which are not predicted by existing regulations). The long specimens were inserted to the chamber, while the short specimens were properly connected to an automatic system, imposing electrochemical corrosion of $1mA/cm^2$ current rate.

In both cases, solution 5% NaCl was selected because it simulates a severe corrosive environment, or a coastal environment [8-9] and comes in agreement with existing regulations concerning corrosion tests, such as B117 ASTM Standard. Additionally, NaCl content in the solution represents accurately the case of the Mediterranean countries, where hot climate results in higher salinity of the seawater, in contrast to northern countries, where river estuaries can be met. A typical example is the Arabian basin, where the salinity measured is even higher. Furthermore, at the Mediterranean countries, salinity of the sea increases during the summer periods, given the high temperatures recorded [10].

Furthermore, in the present study, in order to achieve a better approach to the environmental conditions for both methods, a severe exposure environment of wetting/drying (chloride ponding) was used. Such a testing regime simulates the chloride exposure of marine structures under splash and tidal zones [11], given that in reality, structures are subjected to wet and dry periods, rather than a constant relative humidity. Additionally, it is a common knowledge that during wetting, chloride solution penetrates a layer of the material; during the drying stage, the evaporation front moves inwards and takes some of the chloride with it [12]. It is deducted in theory that atmospheric corrosion rate of metals can be accelerated by increasing the frequency of wet-dry cycling [13]. Figure 1 presents the above-mentioned wetting and drying exposure for each method used.

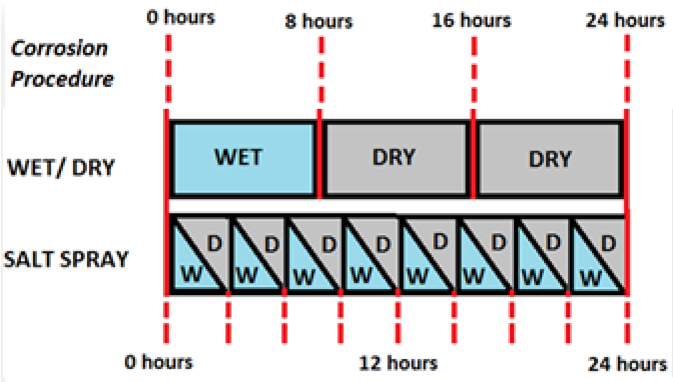

Fig. 1. The ponding cycles organised for each accelerated corrosion method used, for the goals of the present study

For salt spray chamber, seven exposure periods were selected and two for impressed current density technique. Three specimens were prepared for each exposure case, so as to achieve comparability and repeatability of the experiments.

After the exposure, the specimens were dried and cleaned according to ASTM G1-72 standard, in order to remove the corrosion products. The specimens were then weighted and the mass loss due to corrosion exposure was calculated with the use of Eq. 1:

$$x_p = \frac{m_0 - m_c}{m_0} * 100\% \,, \qquad (1)$$

where m_0 is mass of the non corroded specimens and mc reduced mass of the corroded specimens.

3. Results

The tensile tests were performed according to the ISO/FDIS 15630-1 specification, using a servo-hydraulic MTS 250KN machine with a constant elongation rate of 2 mm/min. The mechanical properties, yield strength Rp, ultimate strength Rm, and uniform elongation Ag, were determined. It should be noted that Ag was measured according to the manual method described in the relevant standard (on a gauge length of 100 mm, at a distance of 50 mm away from the fracture). The results of the mechanical tests performed are presented in Tables 4 and 5. In red color are reported the values that were measured below the threshold defined by EC2.

Table 4. Mechanical properties of the reference and the shot blasted specimens that were subjected to tensile tests, after being corroded in the salt spray chamber

Tensile Tests					
Corrosion Duration [Days]	**Mass Loss [%]**	**Rp [MPa]**	**Rm [MPa]**	**Ag [%]**	**Ud [MPa]**
Reference Samples					
0	0	561.43	654.13	9.36	58.63
30	6.7	506.61	595.62	7.14	38.65
40	7.8	500.00	587.00	6.80	37.00
45	8.1	498.40	584.00	6.60	36.45
50	8.6	497.00	580.00	6.60	35.80
60	9.47	490.53	572.78	6.58	34.17
75	11.42	467.80	548.11	5.54	29.48
90	12.48	453.29	530.99	4.85	25.17
Shot Blasted Specimens					
0	0	545.68	638.30	11.33	67.99
30	3.74	535.00	614.65	8.31	48.01
40	4.86	501.46	587.62	8.88	48.72
45	5.30	495.50	580.00	8.49	46.10
50	5.63	492.12	574.34	7.90	42.34
60	7.30	497.40	574.70	7.85	42.70
75	7.95	473.43	552.84	7.73	39.59
90	8.66	474.58	552.87	7.93	40.96

Table 5. Mechanical performance of the reference and the shot blasted specimens that were subjected to Low Cycle Fatigue tests, after being corroded with the use of impressed current density technique

Corrosion Duration [Hours]	**Mass Loss [%]**	**Exposed Length [mm]**	**Imposed Deformation [%]**	**Dissipated Energy Ud [MPa]**	**Number of Cycles**
Reference Specimens					
150	7.29	10	0.75%	4993.37	5464
300	10.98	10	0.75%	4036.57	3568
150	7.29	10	1.25%	2477.49	400
300	10.98	10	1.25%	2234.49	336
Shot Blasted Specimens					
150	7.92	10	0.75%	3806.25	2340
300	11.32	10	0.75%	3151.7	1926
150	7.92	10	1.25%	2583.92	382
300	11.32	10	1.25%	2176.39	306

4. Discussion

The goal of the present study is to investigate corrosion resistance and mechanical performance of steel reinforcement, with and without shot blasting process. The two laboratory corrosion methods used develop a different corrosion mechanism. Precisely, in salt spray chamber, only external surface is exposed to the aggressive conditions, whereas via the impressed current method, current traverses the material internally, corroding the whole volume of the material [14].

The varied corrosion mechanism seems to be responsible for the dissimilar mass loss percentages and the deflected mechanical behavior, between the reference and the shot blasted group of specimens. In accurate, external surface attack of corrosive environment, gave to the shot- blasted category a precedency, given the surface compressive strain that had been developed during the treatment of the material. After the primer shot with angular olivine pellets, that created notches while distracting the unwanted rust, the spherical glass beads delivered a more compact surface layer.

Compact layer was beneficial for the corrosion tests, conducted with the use of salt spray chamber, since the specific method attacks the material externally. On the contrary, impressed current density technique, which internally imposes the desired current, did not highlight any worth mentioning variation between the two categories, as far as mass loss is concerned. However, as far as low cycle fatigue testing is concerned, it was proved that surface ageing of steel reinforcement, in combination with the internally developing damage, are responsible for the drop recorded on the seismic performance of the shot blasted specimens.

This is because current, applied with impressed current density technique, affects the whole volume of the material and causes equal harm to both reference and shot blasted samples. Besides, the surface and subcutaneous layers of the shot blasted specimens, that were suppressed during the shot blasting process, are already more vulnerable-internally- than the pure material, given the existing ageing.

5. Conclusion

- •Purification of the steel surface with the use of combining shot blasting process, appears to significantly delay the degradation caused by corrosion in the case of salt spray chamber, as well as to keep the mechanical properties in a satisfying level, for quite a long exposure period.
- •In the case of impressed current density technique, reference and shot blasted materials demonstrated almost equal resistance against corrosion. This is owed to the fact that electrochemical technique affects the internal structure of the material tested.
- •Ageing factor that had already been developed after the shot blasting process was responsible for lower performance of the shot blasted specimens, in comparison to the performance of the reference samples, after the Low Cycle Fatigue Tests.

Acknowledgements. *No external funding was received for this study.*

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