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# Mechanical Characteristics of dual-phase steel B500c after shot peening process

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***Abstract***

During the last decades, many durability problems have been recorded on reinforced concrete (RC) structures, which are located in coastal areas. Chloride corrosion is among the various degradation mechanisms of steel reinforcement which lead to the premature deterioration of RC structures.
In this paper, an effort was carried out to increase the corrosion resistance of high ductility dual-phase steel (B500c), without any interference in the chemical composition or in the production mode, but through shot peening process. More specifically, shot peening treatment was used on the one hand in order to clean the surfaces of the steel bars and to remove the "impurities" that act as underlying destructive cores on them, and on the other hand, in order to create surface compressive stresses. The whole process was carried out according to the pertinent protocols, with the use of olivine pellets. Subsequently, the corrosion resistance behavior of the steel was experimentally examined, both with and without shot peening process. The specimens were inserted in a laboratory salt-spray exposure chamber, in accordance to the ASTM B117-94 specification (directly exposed to the corrosive medium), for different periods, under 8 cycles wet/dry per day. The two specimens groups (with and without shot peening) were subjected to tensile tests. The first results were very encouraging, as shot peened specimens recorded lower pit depths and lower mass loss percentages improving, in this way, their corrosion resistance. At the same time, these specimens showed higher mechanical performance in comparison to the common ones. The first positive results of the shot peening process triggered the continuation of the present paper through further investigation.

***Keywords—corrosion, mechanical performance, shot peening, pits***

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## I. *Introduction*

Corrosion of steel reinforcement is one of the most important durability issues in reinforced concrete design, since it can impair not only the appearance of the structure, but also its strength and safety, with the subsequent reduction in the cross sectional area of the reinforcement and with the decrease of bond with the surrounding concrete [1,2]. It can be initiated due to de-passivation of the protective thin oxide film of the steel reinforcement, through the action of highly concentrated chlorides. In coastal regions (or marine environments), where high chloride concentrations are encountered, chloride-induced corrosion is the major source of environmental deterioration of reinforced concrete structures. [1,3,4,5,6]
Because of this phenomenon, the adoption of a category of steel which exhibits higher corrosion resistance and better mechanical performance is particularly important. This was the reason for which over the last decades the global industry (automotive and aerospace) has adopted the use of dual-phase steels, as it combines high mechanical performance with low cost.
As it is known, dual-phase steels of reinforced concrete show an outer high strength core (martensitic phase) and a softer core (ferrite-perlite phase), Beyond these two obvious phases, there is a transition zone called bainite phase. The mechanical performance of B500c steel results from the combination of the mechanical properties in each of the individual phases, where the increased strength properties are credited to the presence of the outer martensitic zone whereas the increased ductility in the presence of the ferittoperlitic core. Besides, dual-phase steels present interesting mechanical properties results not only when they are sufficiently protected from corrosion, but also from the initial phase of their corrosion.
Nonetheless, the corrosive agent maintains a problem, since it keeps affecting the durability of the constructions. More specifically, chloride induced damage of reinforced steel results in concrete cracking and spalling, destruction of the protective steel barrier and formation of pits as well as notches and cavities on the steel surface. These phenomena constitute the initiation of serious problems, which become more severe in harsh and aggressive environments due to the severe ambient salinity, high temperature and humidity and also due to the ingress of chlorine through wind-borne salt spray [7,8,9,10,11,12].
The present study is a part of an ongoing research which focuses on the corrosion consequences and protection against corrosion in reinforced steel [13,14,15]. In the present study an effort was carried out to increase the corrosion resistance of high ductility dual-phase steel (B500c), without any interference in the chemical composition or in the production mode, but through shot peening process, in order to study the discrimination of the

corrosion behavior and the mechanical performance against the reference specimens. More specifically, shot peening treatment was used not only in order to clean the surfaces of the steel bars and to remove the "impurities" that act as underlying destructive cores on them, but also, in order to create compressive stresses on the surface of the material. The whole process was carried out according to special protocols which refer to the category of hot-rolled steel.

# II. *Experimental procedure and Results*

## A. *Shot peening process*

In shot peening process the most important selection criteria are: the type and the geometry of the particles, the rate and the angle of the incidence, as well as the duration of the process.

During shot peening process, the particles of the material incident on the metal surface, creating a field of compressive stresses and deformations. Through this procedure, is achieved the improvement of the mechanical strength properties under monotonic and fatigue loads. The level of the desirable surface compressive stress and the depth (in reference to the external surface) of the compressive deformation constitute the basic elements of the shot peening process. These factors are determined by the shot stream velocity which is controlled by the blast wheel speed or air pressure and the type of the particles of the incident material. The geometry of the particles of the incident material, which present abrasive action, affects significantly the performance of the process. The particles (grit) which have angular geometry, due to their high cutting action, are more appropriate for the removal of the soft and brittle surface impurities, such as the oxidation products on the corroded metal surfaces. For the evaluation of the purity of the under-treatment material, optical standards are usually used (Table 1).The most common of these standards are NACE Standards (National Association of Corrosion Engineer)[16], SSPC Standards (Steel Structures Painting Council)[17] and ISO 8501-1[18] .

The material used in the present study was olivine and for its selection all the essential factors were taken into consideration. Olivine pellets, have angular geometry, and present dynamic natural mineral abrasive. The desirable purity level is Sa3. The characteristics of olivine pellets (shape, color, hardness, specific density, grain sizes) are presented in Figure 1 and in Table 2.

TABLE 1: SUMMARY OF THE DIFFERENT QUALITIES IN SURFACE PREPARATIONS USED BY SOME STANDARDS

| Description | International ISO-8501-1 | American SSPC-SP |
|---|---|---|
| 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 |

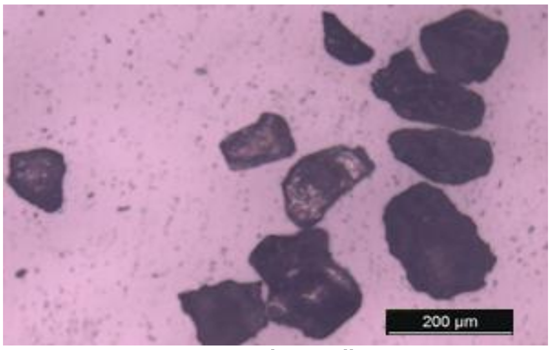


*Figure1. Olivine pellets*

TABLE 2. CHARACTERISTICS OF OLIVINE PELLETS

| | |
|---|---|
| **Properties** | Shape : sub-angular to angular<br>Color : pale green<br>Hardness : 6.5-7 Mohs<br>Specific density : 3.25 kg/dm3 |
| **Chemical Composition (Indication only)** | MgO 49.00-50.00%<br>SiO2 41.50-42.50% in bound form, <1% free silica<br>Fe2O3 6.80-7.30%<br>Al2O3 0.40-0.50%<br>CaO 0.05-0.10%<br>Cr2O3 0.20-0.30%<br>MnO 0.05-0.10%<br>NiO 0.30-0.35% |
| **Grain sizes** | GL40 0.063-0.25mm |

The treatment was applied at an angle of incidence of 45 degrees, the rate of the abrasive- blasting was 2 sec/area and the distance between the nozzle and the surface of the specimens was defined about 25-40cm according to the respective regulations. Upon the completion of the surface inspection of the specimens, three tensile tests were performed for each district group (the reference, SP-olivine1 and SP-olivine2). The abbreviation Ref refers to the reference specimens, without shot peening treatment, and SP-olivine 1 refers to the reference specimens which have sustained the shot-peening process once. Accordingly, SP-olivine 2 refers to the reference specimens which have sustained the shot-peening process twice. In Figures 2, 3, 4 and 5 are shown the surfaces of the three specimen groups (reference, SP-olivine1 and SP-olivine 2). Through these photos the gradual improvement of the surface roughness can be ascertained. After a series of mechanical tests on the non- corroded specimens, SP-olivine 1 category was chosen for further analysis, among the two shot-peened groups, because SP-olivine 2 specimens exhibited mechanical degradation phenomena in comparison to the reference ones. On the contrary, the SP-olivine1 specimens showed higher mechanical performance in comparison to the Reference and the SP-olivine2 specimens. Table 3 presents the average values of the mechanical properties of the specimens of the three categories.

TABLE 3. MECHANICAL PROPERTIES OF THE SPECIMENS: REFERENCE, SP-OLIVINE1, SP- OLIVINE2

| | Rp (MPa) | Rm (MPa) | Ag (%) | Ud (MPa) |
|---|---|---|---|---|
| **Reference** | 561.43 | 654.13 | 9.36 | 58.63 |
| **SP-Olivine 1** | 581.4 | 659.1 | 9.85 | 61.75 |
| **SP-Olivine 2** | 553.69 | 638.02 | 8.855 | 53.24 |

(a) Reference (b) SP-Olivine1

(c) SP-Olivine2

*Figure 2: Surface view of the specimens a) Reference, b) SP-Olivine 1, c) SP-Olivine2.*

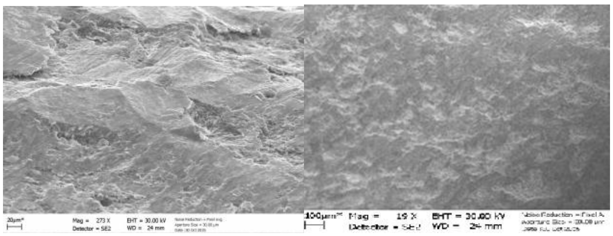


*Figure 3. View of the external surface of the reference specimens, before the Shot Peening treatment.*

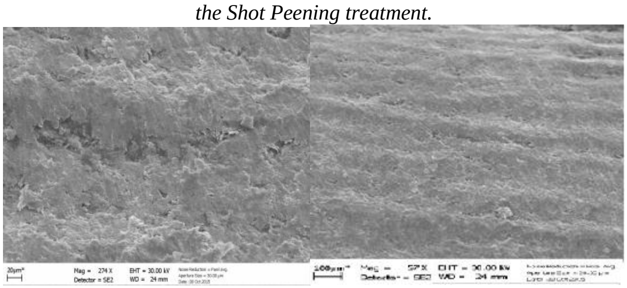


*Figure 4. View of the external surface of the SP-olivine1 specimens, after the shot-peening process.*

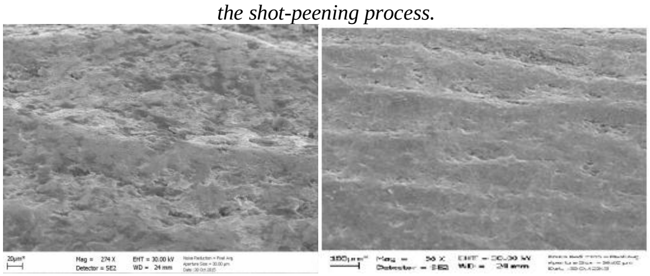


*Figure 5. View of the external surface of the SP-olivine2 specimens, after the shot-peening process.*

## B. Measurement of surface hardness

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to an adaptable load. The full load is normally applied for several seconds. The hardness is determined by the use of equation (1).

$$HV = 1.854\ \frac{P}{d^2} \qquad (1)$$

In the equation, $d_1$,$d_2$ are the two diagonals, $d = \frac{d_1+d_2}{2}$ is the arithmetic mean of the two diagonals of the print (mm), HV is the Vickers hardness and P is the imposed load in kg. Due to the high external roughness of steel bars, a load of 3kg was imposed for 30 seconds. Table 4 presents the qualitative results of the measurements, of the surface hardness, taken from the two reference specimen groups (non-corroded). The upgraded hardness of SP-olivine1 specimens, in contrast to the Reference ones, signifies the upgraded durability as well, despite the fact that it refers to a small areal density. The range of the print values of the SP-olivine1 specimens is significantly lower than the print values of the Reference specimens.

TABLE 4: MEAN VALUES OF THE SURFACE HARDNESS OF THE REFERENCE AND THE SP-OLIVINE1 SPECIMENS, BEFORE CORROSION PROCESS.

| Category | d1 | d2 | D | HV |
|---|---|---|---|---|
| **Reference** | 0.1365 | 0.156 | 0.14625 | 260 |
| | 0.1375 | 0.1575 | 0.1475 | 255.71 |
| | 0.1475 | 0.1545 | 0.151 | 243.99 |
| | 0.163 | 0.112 | 0.1375 | 294 |
| | 0.165 | 0.133 | 0.149 | 250.58 |
| | 0.14 | 0.1335 | 0.13675 | 295.49 |
| | 0.1455 | 0.157 | 0.15125 | 243.18 |
| | | Average | | 263 |
| **SP-Olivine1** | 0.137 | 0.137 | 0.137 | 296.4 |
| | 0.125 | 0.143 | 0.134 | 309.82 |
| | 0.1355 | 0.136 | 0.13575 | 301.89 |
| | 0.1315 | 0.137 | 0.13425 | 308.67 |
| | 0.145 | 0.141 | 0.143 | 272 |
| | 0.1475 | 0.125 | 0.13625 | 299.68 |
| | | Average | | 298 |

## C. Corrosion procedure

In the present study, bare specimens with nominal diameter 12mm of steel type B500c (tempcore) were examined. According to EC2 and EC8- part 3 [19-20], for high ductility and high strength steel bars, such as B500c, the requirements for the material are: Yield strength ≥ 500 (MPa), 1.15 ≤ Rm/Rp ≤ 1.35, and the elongation at maximum load ≥ 7.5%.

In the present study were used 33 steel bar specimens in total, which were prepared in accordance to the IS0 15630-1 standards [21]. The specimens were separated into two groups, apart from 3 which were submitted to a SP-olivine2 process and were used for the initial mechanical tensile tests (non corroded). Each group included 15 specimens (3 for each corrosion period). The first group was used as Reference case and the second as SP-Olivine1. The initial mass for each specimen was measured using a precision scale (± 0.01gr).Then, all the specimens, apart from 9 which were used as reference -SP olivine1 -SP olivine 2 (non corroded), were inserted in a salt spray corrosion chamber, which simulates harsh coastal conditions in accordance to the ASTM B117-94 specification (directly exposed to the corrosive medium) [22].The salt spray laboratory corrosion was conducted for different time periods such as 30, 45, 60 and 75 days.

During the corrosion test experiment the specimens were sprayed with a solution which was consisted of 5%w.t. salt in distilled water and pH ranging between 6.5 and 7.2, switching 8 wet / dry cycles per day, at 35°C temperature.

At each testing date specimens were removed from the salt spray chamber, washed with clean running water to remove any salt deposits from their surfaces and air-dried. The corrosion products were removed from the surface of the specimen by means of a brittle brush, according to ASTM G1 specification [23].Subsequently, corrosion resistance behavior of the steel was experimentally examined. The two specimens groups (with and without shot peening) were subjected to tensile tests. The first results were very encouraging, as shot peened specimens recorded lower pit depths and lower mass loss percentages improving, in this way, their corrosion resistance. The local pitting effects, which constitute the result of the non-uniform corrosion due to chloride attack, are possibly culpable of the change of the cross-section geometry and of the non-uniform stress distribution, due to stress localization in the top of the pits [24,25] and of the degradation of the mechanical properties of the material as well.

## D. *Mass loss*

The corrosion damage that occurred in both shot-peened and reference specimens, was measured as the mass loss of the rebars before and after the completion of the predetermined exposure time in the corrosive environment. In what follows the term mass loss refers to the mass of all specimens before and after different corrosion exposure time.

$$M_1 = \frac{M_i - M_f}{M_i} * 100 \quad (2)$$

Where $M_1$ is the mass percentage and $M_i$, $M_f$ are the masses before and after the corrosion of the specimens respectively. Table 5 presents the mass loss percentages of reference and SP-olivine 1 specimens after remaining in accelerated salt spray corrosion chamber for various time periods up to 75 days.

TABLE 5: MASS LOSS PERCENTAGES OF REFERENCE AND SP-OLIVINE 1 SPECIMENS AFTER REMAINING IN ACCELERATED SALT SPRAY CORROSION CHAMBER FOR VARIOUS TIME PERIODS, UP TO 75 DAYS.

| Corrosion time (days) | Mass loss of steel bars (%) | |
|---|---|---|
| | Reference steel bars | Shot peened (olivine1) |
| 30 days | 6.7 | 4.51 |
| 45 days | 8.15 | 5.95 |
| 60 days | 9.47 | 8.01 |
| 75 days | 10.42 | 10.01 |

## E. *Calibration of critical pit parameters*

The calibration of critical pit parameters consists in the definition of the pit depth and pit length in the critical cross-section, which constitute important factors for the mechanical performance of corroded steel bars.

Equation 3 gives a simplified expression describing the localization stresses factor over the notch tip : where p and L were the pit depth and pit length respectively, while n shows the notch tip as pictured in Figure 6 under plain strain distribution hypothesis.

$$\sigma_n = \sigma_o * \left(1 + \frac{4p}{L}\right) \quad (3)$$

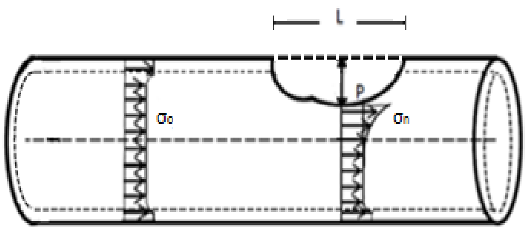
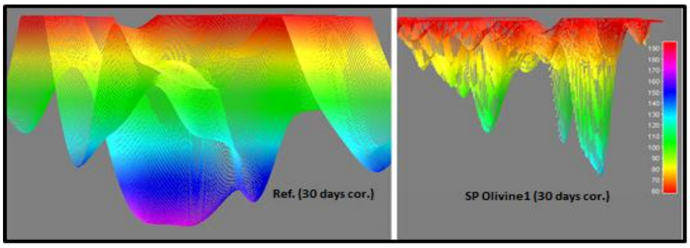


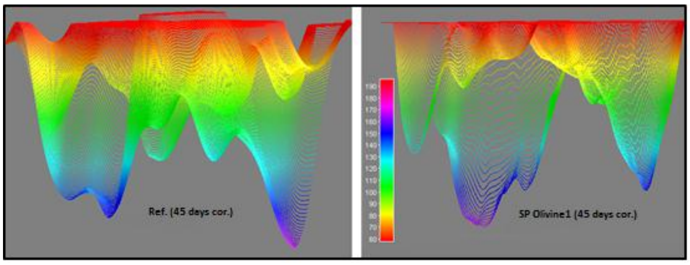

*Figure 6: Depiction of the σn stress to the notch pit and the corresponding distribution at the intersection of dual phase steel bar*

Pits were identified along the length of the bars (away from the grips, to avoid damage through wedging effects), on samples directly exposed to salt-spray for 30, 45, 60 and 75 days. Stereoscopical images taken at the locations of the pits (using a ×10 magnification lens) and several pit depth measurements were taken in order to calculate the average pit depth (in addition to the maximum pit depth).

ImageJ, a scriptable Java application was also used for further analysis of the pits.A multi-color-scale was normalized, using special filter algorithms, in order to bring the resolution and the lighting conditions (between the photos taken at different testing dates) to a common level. Based on the individual values according to the multi-color-scale intensity of the photos taken, three-dimensional (3D) surface plots of representative pits were also determined to obtain a visual representation of the size of pits measured. In addition, the area of each pit was calculated using imaging software analysis.Figure 7 depicts two representative types of pits found on the specimens of the two categories (Reference and SP olivine1) after 30 days of corrosion. Through Figure 7, can be perceived that the geometric characteristics (depth, area, length L) of the pits found on the Reference specimens are significantly deeper than those found on SP- olivine1 specimens.




*(a)*




*(b)*

*Figure 7: Depiction of characteristic pits after (a) 30 ( b) 45 days of on Reference and SP-olivine1 specimens .*

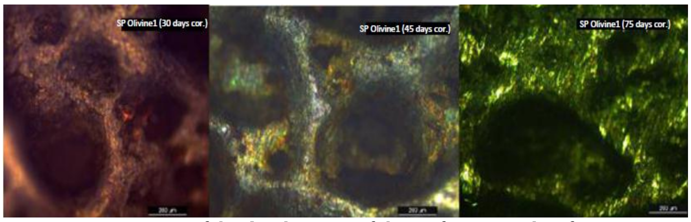



*Figure 8: Depiction of the development of the surface pits taken from SP-olivine1 specimens.*

Figure 8 presents the development of the surface damage, due to pitting growth, after 30, 45 and 75 days of corrosion. It can be observed that there is a tendency to coalescence just as in the reference specimens.

Pitting measurements took place along the whole length of one specimen of each category (ref and SP olivine1), for each corrosion period. The specimens selected for the measurements at each exposure period, showed mass loss values almost equal to the mean values. The measurement results, of both specimen groups, for 30 days of corrosion, showed that the average depth for the Reference group is significantly higher than 300μm, unlike the SP olivine1 group where the average is below 100μm. In Table 6, the measurements presented (mean and max) are taken from pits deeper than 100μm

TABLE 6: GEOMETRICAL PIT CHARACTERISTICS

| Corrosion Time | Reference | | | | | SP Olivine1 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean pit depth (μm) | Max pit depth (μm) | Mean pit area (mm^2) | Max pit area (mm^2) | L(mm) | Mean pit depth (μm) | Max pit depth (μm) | Mean pit area (mm^2) | Max pit area (mm^2) | L (mm) |
| 30 days | 385 | 502 | 1.155 | 2.239 | 1.21 | 133 | 157 | 0.196 | 0.414 | 0.492 |
| 45 days | 406 | 506 | 1.195 | 2.321 | 1.234 | 196 | 223 | 0.564 | 1.422 | 0.695 |
| 60 days | 430 | 510 | 1.278 | 2.465 | 1.276 | 242 | 269 | 0.634 | 1.519 | 0.935 |
| 75 days | 495 | 699 | 1.364 | 3.04 | 1.318 | 285 | 313 | 0.664 | 1.504 | 1.16 |

## *F.* ***Mechanical tensile tests***

The Reference and the SP-olivine1 specimens (corroded and non corroded), were cut to the tensile testing length of 460 mm, according to ISO 15630-1 standards [21] and were subjected to mechanical tensile tests. The tensile tests were performed 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). For the estimation of the mechanical stress, the nominal diameter of 12mm was taken under consideration, for both specimen groups. An analysis of the results of the mechanical tests revealed the mechanical properties that are summarized in Table 7. Table 7, shows the mass loss (%), the yield point Rp, the maximum strength Rm, the uniform deformation Ag, the energy density Ud for both groups of samples (Reference and SP-Olivine1).

TABLE 7: RESULTS OF MECHANICAL PROPERTIES AND MASS LOSS (AVERAGE VALUES) OF REFERENCE AND SP-OLIVINE1 SPECIMENS

| Corrosion Duration | Reference Specimens | | | | | SP-Olivine 1 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mass loss (%) | $R_p$ (MPa) | $R_m$ (MPa) | $A_g$ (%) | $U_d$ (MPa) | Mass loss (%) | $R_p$ (MPa) | $R_m$ (MPa) | $A_g$ (%) | $U_d$ (MPa) |
| 0 days | 0 | 561.43 | 654.13 | 9.36 | 58.63 | 0 | 581.4 | 659.1 | 9.85 | 61.75 |
| 30 days | 6.70 | 506.61 | 595.62 | 7.14 | 38.65 | 4.51 | 538.5 | 619.35 | 7.89 | 46.07 |
| 45 days | 8.10 | 498.4 | 584 | 6.6 | 36.45 | 5.95 | 510.25 | 589.15 | 8.33 | 46.1 |
| 60 days | 9.47 | 490.53 | 572.78 | 6.58 | 34.17 | 8.01 | 498 | 574 | 7,12 | 39.4 |
| 75 days | 10.42 | 467.80 | 548.11 | 5.54 | 29.48 | 10.01 | 480.5 | 561 | 6.18 | 32.3 |

# *III.* ***Discussion***

The findings, concerning the mechanical performance of the specimens which have been shot peened with olivine pellets, are quite interesting. In particular, from Table 3 can be proved that the strength properties in SP-olivine1 specimens exhibited raise. More specifically, yield point (Rp) upgraded up to 3.56%, uniform elongation (Ag) up to 5.23% and energy density (Ud) up to 5.32%, against reference specimens. On the contrary, in SP-olivine2 specimens, a mechanical degradation has been recorded. More specifically, yield point was reduced by 1.40%, uniform elongation (Ag) by 5.34% and energy density (Ud) by 9.19%. Noteworthy is the increase of energy density (Ud) of SP-olivine1 samples over the corresponding value of SP-olivine2 category by 13.8%. From Table 5 can be noted that SP-olivine1 specimens exhibited higher corrosion resistance, in comparison to the reference specimens given the fact that for 30,45,60 and 75 days of corrosion they recorded decrease of the mass loss percentages equal to 32.68% , 27% , 15.44% και 3.93% respectively.

From these results, it becomes clear enough that shot peening process needs further investigation and that it can be used as a possible anti-corrosion method for concrete reinforcement steel bars. The analysis leads to the conclusion that after an extended exposure to corrosion, both specimen groups (reference and SP-olovine1) show the same corrosion resistance. Table 6 shows that after 30 days of corrosion, the mean and the maximum pit depth recorded on SP olivine1 specimens, is lower than the depths recorded on the reference specimens by 65.50% and 69%.After 45 days of corrosion, the mean and the maximum pit depths of SP olivine1 specimens, are lower than the depths of reference specimens by 56.80% and 57.70% respectively. After 60 days of corrosion, the corresponding percentages became 43.7% and 47.25%. This fact indicates that after a relatively high exposure to corrosion, the percentage difference of the pitting depth seems to decline. From the same Table can be concluded that after 30, 45 and 75 days of corrosion, the mean pit area estimated in SP-olivine1 category, is lower than the mean pit area in reference category by 83%, 53% and 51% respectively. This fact suggests that over the corrosion time, a significant reduce is observed on the percentage differences which concern the pit areas. Given the fact that the geometric characteristics (depth, area and length L) of the pits of both specimen groups (reference and SP-olovine1) directly affect the stress development in the end of each pit, the following points can be observed: The pits found on SP-olivine1 specimens are more shallow, present smaller areas and shorter lengths. However, they are sharper than the pits observed on Reference specimens. Moreover, on SP-olivine1 specimens there is a plethora of short (adjacent) pits, which through extended corrosion exposure, are lead to coalescence and depth increment. Taking into account these results, a comparison was conducted concerning pitting characteristics of each specimen group. From the comparison (concerning the type, the shape and the geometry of the pits)among the two categories (Figures 7a and 7b), the upgraded mechanical performance of the corroded SP-olivine1 specimens can be confirmed , in comparison to the reference category (Table 7).The analysis of the results leads to the conclusion that the shape and the geometry of the pits can seriously affect the mechanical performance, the service life and the lifetime of the steel bars used in concrete reinforced structures.

After the completion of 75 days of corrosion, the specimens of both groups (reference and SP-olivine1) recorded equal mass loss values. This fully confirms the rapid mechanical degradation of SP-olivine1 specimens, compared with the reference ones (Table 7). At the same time, energy density values have been recorded almost equal to each other, which means 29.50 MPa for the Reference category and 32 MPa for the SP-olivin 1 case.

As it is widely known, the stress field distribution over the cross section of a non corroded dual phase steel bar B500c (tempcore), is totally related to the heterogeneous material properties throughout the steel cross-section. For the corroded material though, the determination of the stress field distribution is even more complicated. Good mechanical performance of SP-olivine1 specimens, against Reference specimens, maintained after various corrosion exposure times. More specifically, the two most important mechanical properties (according to EC2), yield point (Rp) and uniform elongation (Ag) , after 30 , 45, 60 and 75 days of corrosion showed the following results: Lower reduction of the yield point, by 58.2% , 18.80% , 44.5% and 13.6%. Similar was the drop of the elongation limit, under the maximum strength, with corresponding values equal to 33.80% , 62.70% , 19.53% and 16.76% . A similar response was recorded for the loss percentage of the strain energy of SP-olivine1 specimens, against the Reference specimens, after various corrosion exposure times From Table 7 can be shown that reference specimens recorded corrosion damage with mass loss values equal to 6.70%, after 30 days of corrosion. This value, is not unrealistic for corroded reinforcing steels of older buildings at coastal sites, since the corresponding deformation appears Ag=7.14%<7.50%, which is lower than the thresholds determined by EC2 for high ductility steel bars. The same specimens, after 45 days of corrosion, recorded corrosion damage equal to 8.10%, yield point Rp=498.5MPa<500MPa and uniform elongation Ag=6.60%<7.50%, which are lower than the thresholds (according to EC2)for high ductility steel bars as well. These values show that reference specimens failed to compile with the EC2 standards even before the first 30 days of corrosion. On the contrary, the mechanical performance of the shot peened specimens stopped obeying the EC2 standards, just before the first 60 days of corrosion. Furthermore, the Reference specimens recorded a drop of energy density (Ud), by 38% in contrast to the 21% which was recorded for the SP olivine1 specimens, after 45 days of corrosion. This means 45% lower drop. This finding is particularly important on determining the duration of useful life of steel. Although the standards do not require for the evaluation of the energy density Ud the reinforcing steel, however, the property of the energy density is a material property which characterizes the damage tolerance potential of a material and may be used to evaluate the material fracture under both, static and fatigue loading conditions [26]. Note that energy density may be directly related to the plain strain fracture toughness value, KIC, e.g. [27], which evaluates the fracture of a cracked member under plain strain loading conditions. The observed appreciable reduction on tensile ductility may represent a serious problem for the safety of constructions in seismically active areas. As during the seismic actions, the reinforcement is often subjected to stress events at the region of low cycle fatigue, the need for a sufficient storage capacity of the material is imperative. In Figure 9 are presented the changes in the mechanical performance of the two specimen groups (reference and SP-olivine1) as a function of time. The mechanical performance threshold and the useful service life are taken into account as well.

In conclusion, the completion of a certain corrosion time resulted in mechanical performance degradation mechanism, for the case of the SP-olivine1 specimens. Indeed, shot peening application on steel causes a plastic surface deformation, which leads to a surface compression of the material. This compression results in the sealing of the exposed, to the environment, corrosion paths. Through this process, SP-olivine1 material, shows not only an increased corrosion resistance, but also a mechanical upgrade, in comparison to the Reference case. Shot peening process application on structural steel acts positively during a reasonable period of time. However, due to the "nature" of this process, the desirable plastic deformation, which is pursued through the shot peening process, inevitably causes rapid surface aging to the material. As a result, after a predetermined corrosion period, the defense of the material gets abolished and the temporarily hidden corrosion paths get reactivated. Consequently, the material is exposed again to the aggressive factors.

The present study is a part of an ongoing research which is taking place at the Laboratory of Technology and Strength of Materials, of Mechanical and Aeronautical Engineering Department of University of Patras. The goal is to improve the corrosion resistance of dual-phase high ductility steel bars, B500c category.

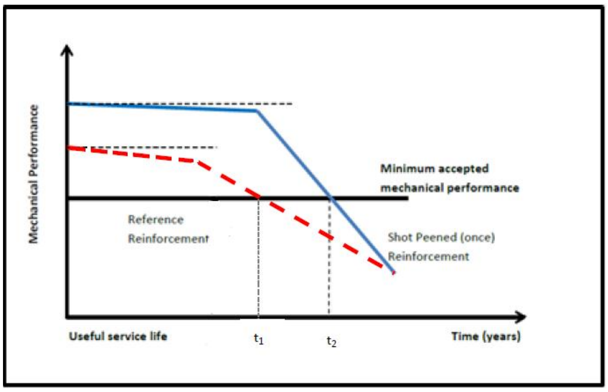



*Figure 9: Graph presenting the changes in the mechanical performance of the two specimen groups (reference and SP-olivine1) as a function of time.*

## IV. Conclusions

The main conclusions of the presented work are described in the next points:

1. In both specimen groups the experimental study showed a non-uniform distribution of the material properties throughout the steel cross-section which is owed to a pitting variety which proceeds in relation to the imposed corrosion time.
2. For a reasonable period of time, the mass loss values of the SP olivine1 specimens were diminished in comparison to the reference specimens. This conclusion can be combined with the significantly increased measurements of surface hardness taken from SP olivine1 specimens.
3. The upgraded mechanical performance of the SP olivine1 specimens, against the reference specimens, was confirmed by the corrosion damage mapping, which define different pit geometries with respect to the expected corrosion level. For a reasonable period of time, the geometric characteristics of pitting seem more aggressive in reference specimens than in the SP-olivine1 category.
4. Shot peening process application on structural steel acts positively during a reasonable period of time. However, due to the "nature" of this process, the desirable plastic deformation, which is pursued through the shot peening process, inevitably causes rapid surface aging in the material. As a result, after a predetermined corrosion period, the defense of the material gets abolished and the temporarily hidden corrosion paths get reactivated. Consequently, the material is exposed again to the aggressive factors.
5. The conclusions of this study proved to be quite interesting, since shot peening-olivine1 process, on dual phase steel bar specimens B500c, had a positive impact not only on the corrosion resistance, but also on the mechanical performance against Reference specimens during a reasonable period of time.

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