VERIZONA PUBLISHER
Publishing Your Ideas

www.verizonaonlinepublishing.com
Special Issue

Material Science and Engineering with Advanced Research

The Mechanical Characteristics of B500c Dual Phase Steel Category, After Two Different Shot Blasting Processes

Arg Drakakaki* and Ch Apostolopoulos

Department of Mechanical Engineering and Aeronautics, University of Patras, Greece

***Corresponding author:** Arg Drakakaki, Department of Mechanical Engineering and Aeronautics University of Patras, Greece; Tel: +302610969416; E mail: drakakaki@mech.upatras.gr

Article Type: Research, **Submission Date**: 03 February 2017, **Accepted Date:** 20 March 2017, **Published Date:** 13 June 2017.

Citation: Arg Drakakaki and Ch Apostolopoulos (2017) The Mechanical Characteristics of B500c Dual Phase Steel Category, After Two Different Shot Blasting Processes. Mater. Sci. Eng. Adv. Res Special Issue: 46-52.

Abstract

In this paper, an effort was made to enhance the chloride induced corrosion resistance of dual phase steel B500c with the use of shot blasting process. Specifically, after the surface cleaning of steel, which was achieved with the use of the blasting process, positive effects were recorded as far as the corrosion resistance is concerned. In the present study is presented the effect of the corrosion factor on common steel specimens (reference) and on specimens which have been shot blasted with the use of olivine and sinter ball pellets. All the specimens were immersed in the salt spray chamber, and were subsistent to 8 cycles wet/dry per day [1] (according to ASTM B117-94 standard), for various exposure periods. After the corrosion exposure, the results showed an increased corrosion resistance, lower pitting depths and lower mass loss percentages. The three specimens groups (reference specimens, specimens which had been shot blasted with the use of olivine pellets and specimens shot blasted with the use of sinter ball pellets) were subjected to tensile tests. The results showed an improved mechanical behavior for the two latter categories. Precisely, among the two shot blasted categories, olivine specimens demonstrated a better corrosion resistance and mechanical performance than the sinter ball specimens.

Keywords: Shot blasting, Dual phase steel, Mechanical properties, Corrosion resistance.

Introduction

As it is known, corrosive agent constitutes a major problem for constructions located in coastal areas, since it keeps affecting their durability. 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 lead to premature deterioration of structures, in synergy with moisture and high temperatures. Chloride induced corrosion of steel reinforcement constitute a failure mechanism, which lead to premature deterioration and performance degradation of the reinforced concrete structures. Due to the geographical position of our country (coastal and seismic), issues of diminished durability raise speculations and require management of the problem, as it is directly related to reliability and structural integrity issues of the structures. Issues of equal concerns recently led the European Unions to seek ideas and solutions to increase the corrosion resistance of high ductility dual phase steel bars (Rusteel and Newrebar). Something equally important is that according to ASCE (American Society Civil Engineering, 2010) infrastructures rehabilitation costs, due to corrosion of steel, were estimated 18 times higher than the corresponding costs demanded because of earthquake phenomena.

In the present study an effort was made to improve the anti-corrosion behavior and the mechanical performance of dual phase steel B500c, high ductility class, with the use of shot blasting process. Precisely, through this process both the removal of surface "oxides", which may act as "smoldering" areas to wear, and a soft compressive surface deformation were achieved, resulting in the persistence of the acceptable behavior of the material.

Shot Blasting Process

Certain factors which are important for the selection of the shot blasting process is the type and the geometry of the particles used, the flow rate, the impact angle as well as the duration of blasting. 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 abrasive material (grits). The geometry of the particles of the material which is primarily used as an abrasive, significantly affects the performance of the shot blasting process.

During shot blasting process, the particles which incident on the metal surface not only act abrasively, but they induce compressive deformations as well. The grade of the desired surface compressive stress and the depth (from the external surface) of the compressive deformation are the key elements of the protocol which is related to the shot blasting process. The standards which are mainly used in shot blasting process for the evaluation of the level of cleanliness of the material are visual. The standard grades of cleanliness for abrasive shot blasting, in accordance with NACE (National Association of Corrosion Engineer), SSPC (Steel Structures Painting Council) and ISO 8501-1 [2] are presented in Table 1.

Table 1: Grades of Cleanliness for Abrasive Shot Blasting

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

For the goals of the present study the materials which were used were: an angular material called “olivine” and sinter ball pellets. As detailed below, the characteristics of the materials used for this purpose are presented in Table 2 and Figure 1. For the method followed, the impact angle was equal to 45 degrees, the flow rate was 1,5-2 sec/unit area and the blasting distance was about 40cm.

For the selection of the desired cleanliness level of shot blasting treatment with the use of olivine particles two more groups of specimens were prepared. Each group was consisted of three specimens. The first group had been shot blasted with one pass of olivine, and the second one with two passes.

Upon the completion of the surface treatment (Figure1, Figure 2, Figure 3), three mechanical tensile tests were executed for each discrete specimen group (reference specimens, simple shot blasting treatment with the use of olivine pellets- olivine1 and double shot blasting process with the use of olivine pellets- olivine2. Among the two shot blasted categories (olivine1 και olivine2), olivine 1 was selected for further analysis, given the fact that olivine 2 demonstrated a mechanical property degradation against reference situation. Table 3 presents the average values of the basic mechanical properties of the samples**.**

Table 2: Characteristics of Olivine (a) and Sinter Ball Pellets (b)

(a)

Properties	Shape: sub-angular to angular Color: pale green Hardness: 6.5-7 Mohs Specific density: 3.25 kg/dm^3
Chemical Composition (Indication only)	MgO 49.00-50.00% SiO 241.50-42.50% in bound form, <1% free silica Fe_2O 36.80-7.30% Al_2O 30.40-0.50% CaO 0.05-0.10% Cr_2O 30.20-0.30% MnO 0.05-0.10% NiO 0.30-0.35%
Grain sizes	GL40 0.063-0.25mm

(b)

Properties	Shape: around Color: gray/black Hardness: 9 Mohs Specific density: 3.77 kg/dm^3 Loose bulk density: 2.1kg/dm^3
Chemical Composition (Indication only)	Al_2O_3 78.20% Fe_2O_3 13.00% TiO_2 1.82% CaO + MgO 0.22% SiO_2 4.21% in bound form, < 1% free silica K_2O 0.83%
Grain sizes	0.2-0.4mm 0.4-0.8mm 0.8-1.2mm 1.2-2.2mm

Citation: Arg Drakakaki and Ch Apostolopoulos (2017) The Mechanical Characteristics of B500c Dual Phase Steel Category, After Two Different Shot Blasting Processes. Mater. Sci. Eng. Adv. Res Special Issue: 46-52.

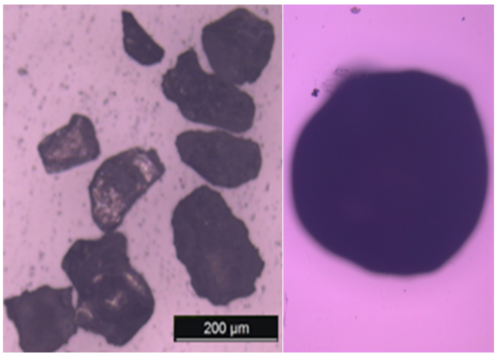

Figure 1: View of the olivine and sinter ball pellets

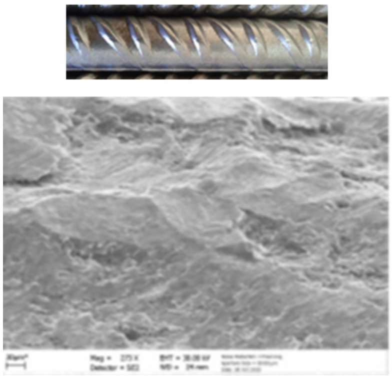

Figure 2: View of the external surface of a **Reference** specimen, before the shot blasting process

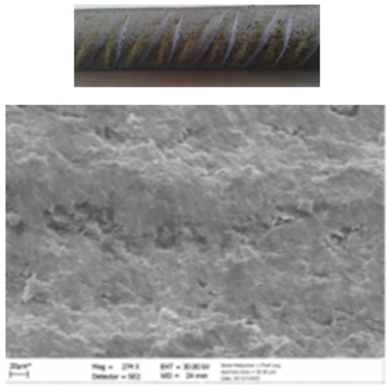

Figure 3: View of the external surface of an **Olivine 1** specimen, after the shot blasting process

Table 3: Mechanical Properties of the Specimens Before and After Shot Blasting Process with the use of Olivine Pellets

	R_p (MPa)	R_m(MPa)	A_g (%)	U_d(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

Corrosion process

In the present study, shot blasting process was used for B500c (tempcore) high ductility steel bar category, with 12mm nominal diameter. For the goals of the present study 75 steel bar specimens were used for all three categories, according to IS0 15630-1 standard [3]. The first category includes reference specimens, which have not been shot blasted. The second category includes specimens that have been shot blasted with one pass of olivine (Olivine 1), while the third one includes specimens which have been shot blasted with the use of sinter ball (aluminum oxide SB). The chosen cleanliness grade for olivine situation was Sa3 and for Sinter Ball Sa 2.5.

The desired cleanliness grade was the finest that can be achieved with the use of the specific materials, given the fact that Sa3 grade (pure metal) is not always feasible.

After the shot blasting process, the initial mass of each specimen group was measured.

Next, all the specimens, apart from 12 (3 reference -3 olivine1- 3 olivine2 and 3 SB) which were used as reference-non corroded samples, were inserted in a strong corrosive salt spray environment. The salt spray laboratory corrosion was conducted in a special salt spray chamber, in accordance with ASTM-B117-94 standard, at specific time periods such as 30, 40, 45, 50, 60, 75, and 90 days.

The corrosion damage that occurred in both shot-blasted and reference specimens, was measured as the mass loss of the rebars (ASTM Standard G1) [4] before and after the completion of the predetermined exposure time in the corrosive environment. Mass loss estimation can be given with the use of equation (1). In what follows the term mass loss refers to the mass of all specimens before and after different corrosion exposure time.

$$\Delta m = \frac{M_i - M_f}{M_i} * 100 \qquad (1)$$

Where M is the mass percentage, M_i, is the initial mass and M_f are the masses after corrosion of the specimens respectively. Table 4 presents the mass loss percentages of reference, olivine 1 and sinter ball specimens after remaining in accelerated salt spray corrosion chamber for various time periods up to 90 days.

Moreover, besides mass loss estimation, conventional mean diameter reduction of each category was calculated as well, after the completion of each corrosion period, taking into account the mass loss rates, according to DIN 50905-3 standard. The results that came out from equation (2) concerning the mean radius reduction are presented in Table 4.

For the evaluation of surface damage due to corrosion factor, a detailed examination – measurements took place on the three specimens groups, recording pits with depth higher than 100mm. Olivine 1 category was an exception, since pitting depth did not exceed the limit threshold of 100mm up to the 40 days of corrosion.

$$\Delta s = \frac{\Delta m}{A * \rho} \qquad (2)$$

where,

Δm, mass loss of the specimen (gr),

A the surface of the corroded area (cm^2) and

ρ density of steel (gr/cm^3)

Mechanical properties of steel

All specimens, corroded and non-corroded, were cut to the tensile testing length between 460 and 500 mm, according to ISO 15630-1 standards 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. For the estimation of the mechanical characteristics, the nominal diameter of 12mm was taken under consideration, for all specimen groups.

Table 4: Pitting Characteristics

Exposure time (days)	Mass Loss (%)	Local mean pit depth (μm)	Mean pit depth (μm)	Local max pit depth (μm)	Max pit depth (μm)	Mean pit area (mm²)	Max pit area (mm²)	Reduced radius Δs (μm)	L (mm)
Reference Specimens									
0	0	0	0	0	0	0	0	0	0
30	6,70	283	385	400	500	1,16	2,24	102	1,21
40	7,80	285	410	380	505	1,22	2,30	125	1,23
45	8,10	280	413	374	507	1,24	2,35	133	1,23
50	8,60	280	418	370	508	1,25	2,37	138	1,25
60	9,47	285	430	365	510	1,28	2,47	145	1,28
75	11,42	321	495	525	699	1,36	3,04	174	1,32
90	12,48	350	541	548	739	1,28	2,21	191	1,35
Olivine 1 Specimens									
0	0	0	0	0	0	0	0	0	0
30	4,51	67	133	91	157	0,20	0,41	66	0,49
40	5,45	98	175	128	205	0,43	1,05	77	0,62
45	5,95	109	196	136	223	0,56	1,42	87	0,70
50	6,60	107	212	135	240	0,61	1,50	105	0,77
60	8,01	96	242	123	270	0,63	1,52	146	0,94
75	10,0	96	285	124	313	0,66	1,50	189	1,16
90	12,9	125	314	156	345	0,70	1,52	189	0,98
Sinter Ball Specimens									
0	0	0	0	0	0	0	0	0	0
30	6,37	114	207	142	235	0,12	0,26	93	0,58
40	7,80	120	186	161	279	0,22	0,28	118	0,66
45	8,46	121	198	164	289	0,24	0,28	125	0,67
50	9,01	123	212	165	295	0,25	0,31	130	0,69
60	9,40	130	240	166	305	0,26	0,36	139	0,72
75	10,3	137	290	165	318	0,27	0,43	153	0,76
90	12,8	140	329	168	357	0,28	0,50	189	0,80

Results

Table 5 presents the mass loss (%), the yield point Rp, the maximum strength Rm, the uniform deformation Agt and the energy density Ud recorded for the three groups of specimens (Reference, Olivine1 and sinter ball) after the execution of the corresponding tests.

Despite the positive results of Olivine 1 against Sinter Ball, as far as the mechanical properties are concerned, just after the treatment ,a “local” negative point was recorded in meeting the acceptable range of Rm / Rp ratio (The acceptable limits for the ratio are : $1.15 \leq Rm / Rp \leq 1.35$. The issue was managed by adjusting the shot blasting parameters).

Discussion

Evaluating the mass loss percentages of the corroded specimens of the three steel bar categories, a common behavior is recorded among the reference and the sinter ball specimens, for all exposure periods. A common behavior was noticed on the mechanical properties of yield strength and uniform deformation as well.

Consequently, although sinter ball category seems to comply with the requirements of the regulations for uniform deformation higher than 7.50% and yield strength higher than 500MPa, up to the completion of the 30 first days, however, mechanical properties recorded a dramatic decrease during the period between 30 and 45 days of exposure. During the following exposure periods sinter ball specimens showed similar mechanical performance to the reference ones. On the contrary, olivine 1 specimens demonstrated a mechanical performance which was in agreement with the regulations, up to 60 days of exposure in the harsh environment of the salt spray chamber ($XS_1/_3$-EN 206-1), postponing the undesirable effects of corrosion and offering both an optimistic forecast and a significant prolongation to the acceptable mechanical properties of B500c steel. However, until the completion of 90 days of exposure, the material shows a significant deterioration on the depleting energy reserves, a part

Table 5: Mechanical Properties of the Specimens Beforeand After Corrosion

Exposure time (days)	Reference	Olivine1	Sinter Ball
Yield StrengthRp (MPa)			
0	561.4	581.4	553.7
30	506.6	538.5	510.6
40	500.0	520.0	490.1
45	498.4	510.3	486.6
50	497.0	505.0	480.0
60	490.5	498.0	470.0
75	467.8	480.5	456.0
90	453.3	434.8	451.0
Ultimate StrengthRm (MPa)			
0	654.1	659.1	642.1
30	595.6	619.4	589.0
40	587.0	600.0	575.0
45	584.0	589.2	571.1
50	580.0	585.0	566.0
60	572.8	574.0	558.0
75	548.1	561.0	545.7
90	531.0	514.0	537.7
Uniform DeformationAgt (%)			
0	9.36	9.85	10.3
30	7.14	7.89	7.67
40	6.80	8.10	6.15
45	6.60	8.33	5.50
50	6.60	8.00	5.10
60	6.58	7.12	5.20
75	5.54	6.18	5.25
90	4.85	4.76	5.53
Energy DensityUd (MPa)			
0	58.63	61.75	62.95
30	38.65	46.07	42.53
40	37.00	46.00	33.00
45	36.45	46.10	29.48
50	35.80	44.50	28.00
60	34.17	39.40	27.50
75	29.48	32.30	26.85
90	25.17	22.96	27.91
Rm/Rp			
0	1.17	1.13	1.16
30	1.18	1.15	1.15
40	1.17	1.15	1.17
45	1.17	1.15	1.17
50	1.17	1.16	1.18
60	1.17	1.15	1.19
75	1.17	1.17	1.20
90	1.17	1.18	1.19

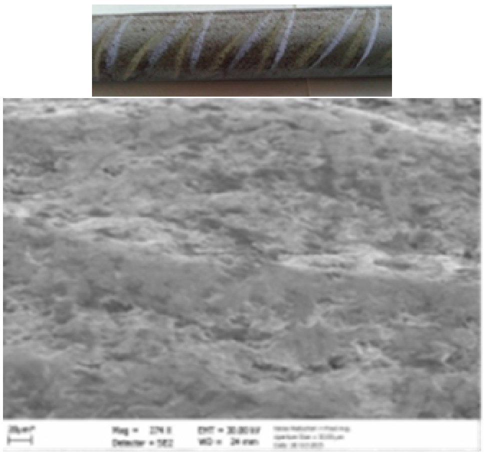

Figure 4: View of the external surface of an **Olivine 2** specimen, after the shot blasting process

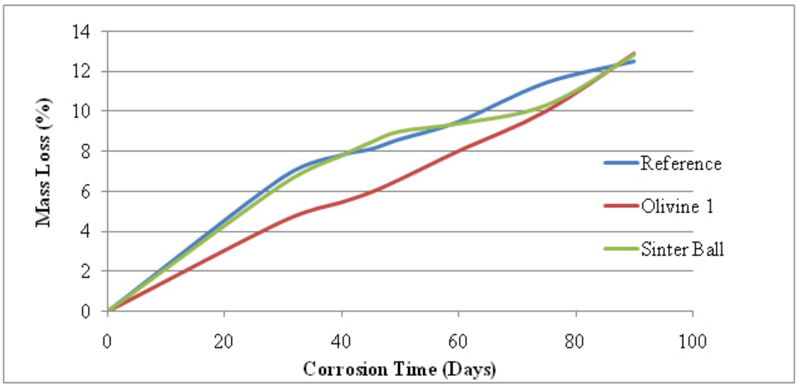

Figure 5: The mass loss rate of the reference and the shot blastedspecimens

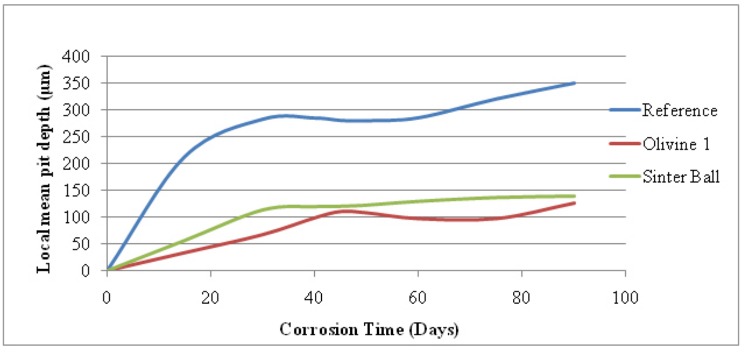

Figure 6: Local mean pit depths for reference and shot blasted specimens after exposure in salt spray environment

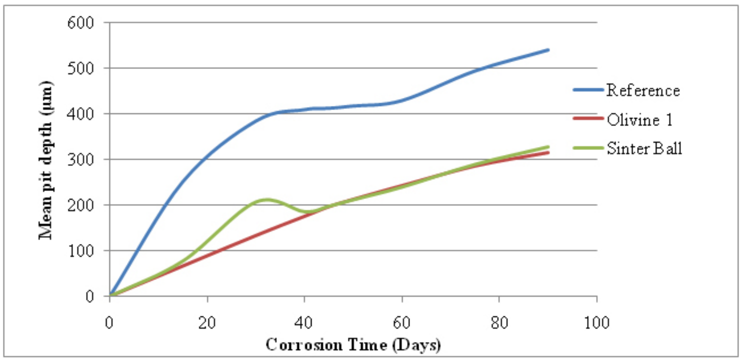

Figure 7: Mean pit depths for reference and shot blasted specimens after exposure in salt spray environment

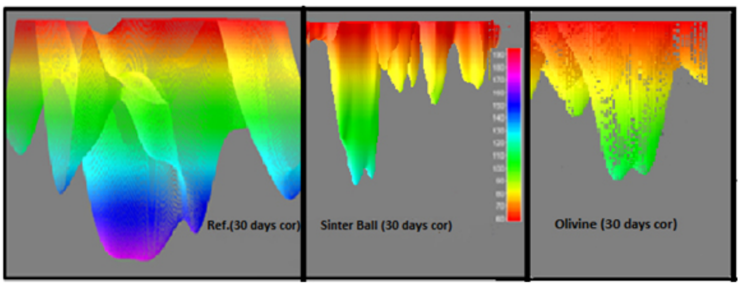

Figure 8: Depiction of characteristic pits (Image J) on Reference, Olivine1 and Sinter Ball steel bar specimens, after the same exposure time (days)

of which was spent due to the unavoidable surface aging which proceeds from the shot blasting process.

Furthermore, as far as the surface wear is concerned, shot blasted specimens olivine 1 demonstrated maximum pit depths equal to 157μm, 223μm, 270μm and 313μm after 30, 45,6 and 75 days of corrosion respectively, over 500μm, 507μm, 510μm and 700μm of the reference samples. The maximum pitting surfaces that were recorded on the olivine 1 specimens were accordingly depleted in comparison to the reference category. To be more precise, shot blasted specimens showed areas equal to 0.414 (mm^2), 1.42 (mm^2), 1.52 (mm^2), 1.50 (mm^2) and 1.52 (mm^2) against 2.24 (mm^2), 2.35 (mm^2), 2.47 (mm^2), 3.04 (mm^2) and 2.21 (mm^2) respectively, after 30, 45, 60, 75 and 90 days of corrosion.

Additionally, taking into account the results of the paper [5], concerning B500c dual phase steel, relative stress concentration at the end of each maximum pit can be evaluated, with the use of equation (3).

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

With the use of equation (3) it can be concluded that: after the completion of 30 days under corrosion, relative stress concentration for the case of reference specimens is σ_o*2,3 against σ_o*1,74 of olivine1 specimens. The corresponding value after 45 days is σ_o*2,22 against σ_o*1,79 . This fact demonstrates a quantitative tendency of the shot blasted samples towards higher concentration of mechanical stresses.

Conclusions

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

Shot blasting process with the use of olivine pellets may have a positive impact on dual phase steel B500c on both anti-corrosion behavior and the mechanical characteristics before and after corrosion.

Shot blasting treatment which was achieved with the use of small angular particles of olivine affected the material in a positive way. The process managed a better abrasion (compared to the bigger spherical Sinter Ball particles), offering a more efficient surface cleaning in areas which were predisposed to corrosion. Additionally, Mg nuggets which were detected on the metal surface (after the treatment), constituted sacrificial elements of the material. This fact, in combination with the plastic compressive deformations of the steel surface excluded several corrosion diodes of the material.

References

1. ASTM Standard B117. Standard Practice for Operating Salt Spray (Fog) Apparatus. ASTM International, West Conshohocken, PA; 2003. doi: 10.1520/B0117-97; 1997.
2. ISO 8501-1: Preparation of steel substrates before application of paints and related products -- Visual assessment of surface cleanliness, Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings.
3. ISO 15630-1: International Standard. Steel for the reinforcement and prestressing of concrete – test methods. Part 1: reinforcing bars, wire rod and wire; 2002. SSPC: Steel Structures Painting Council).
4. ASTM Standard G1. Standard practice for preparing, cleaning, and evaluating corrosion test specimens, ASTM International, West Conshohocken, PA; 2011.
5. Drakakaki Ar, Apostolopoulos Ch, Koulouris K. Mechanical Characteristics of dual-phase steel B500c after shot peening process. Proc. of the Third Intl. Conf. on Advances in Civil, Structural and Construction Engineering – CSCE; 2015. doi: 10.15224/ 978-1-63248-079-8-102.