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COMPARATION OF LABORATORY AND IN-SITU TEST RESULTS OF MECHANICAL AND DURABILITY CONCRETE PROPERTIES FOR STADIUM STRUCTURE

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Abstract

One of the key issues for concrete structures exposed to weathering, besides all other loads, is durability of concrete. The most exposed concrete structures are stadiums. Destruction mechanisms for concrete structures defined by EN 1504 are: mechanical actions, chemical action, physical action, corrosion of reinforcement and fire. In this paper, the tests conducted on the case study stadium "Rodjeni" in the city of Mostar, are presented. The stadium consists of three grandstands, built in different periods, but with concrete of the same quality and class. North grandstand is 17 years old, west grandstand is 14 years old, and east grandstand was built in 2022. A series of in-situ tests to evaluate mechanical and durability properties were implemented, primarily on north and west grandstand. In addition to in-situ tests, laboratory tests were conducted on the same concrete, to evaluate mechanical and durability properties in laboratory conditions. These results are compared and presented in this paper.

Key words: *durability properties, mechanical properties, concrete, stadium*

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1. INTRODUCTION

Constructions durability is a pressing problem in construction practice today. Efforts of engineers are aimed at designing and building a structure whose durability is optimal, considering the ratio between investment and gained. It depends on the loads for which it is calculated, on the concept of encompassing the ultimate limit state and serviceability limit state, and on the reserves that the applied concept has at the beginning or during the lifespan. The durability of structures is ensured by considering the purpose of the structure, the material used, the projected service life, the maintenance program and the effects on the structure [1].

In this paper stadium "Rodjeni" in the city of Mostar, Bosnia and Herzegovina, is chosen as case study for analysis of mechanical and durability properties. Stadiums are one of the most exposed concrete structures to weathering. Stadium "Rodjeni" has been designed and redesigned several times, with multiple construction works performed. In figure 1 aerial view of the stadium is presented.

The stadium is located north of the city of Mostar and has been open since 1995. In the first years, the stadium had simple wooden and steel grandstand. Now, the stadium consists of three grandstands, built in different periods, with a total capacity of 7.000. North grandstand is 17 years old, west grandstand is 14 years old, and east grandstand was built in 2022. All grandstands have concrete of the same quality and class. The west grandstand consists of a ground floor, an upper floor and an auditorium. It is 14 m wide and 70 m long and is a combination of concrete and metal structure. The concrete pillars are followed by metal pillars, where the canopy is hung on them using tensioners. The slope of the canopy is 10%. The north grandstand consists of the ground floor and the auditorium and is not covered. The construction consists of three parts that are separated by a 5-7 cm dilation. The length of one segment is 35 m and the width is 12.50 m. The total length of the northern grandstand is 106.20 m. The construction is a combination of concrete and masonry structure. The east grandstand is similar in dimensions to the western. Their heights are the same, so the supports for the future (possible) roof are also the same.

The stadium had been analyzed several times by students and staff of the Dzemal Bijedic University of Mostar. The bearing structure is concrete, combination of beams, walls and columns, with concrete class C25/30. Walls, inner beams and columns were cast in place, and outer beams were prefabricated. The visual inspection was done, and general conclusion is that the stadium needs to be continually monitored and tested in order to apply right methods of reconstruction on time [3]. During 2022, a series of in-situ tests to evaluate mechanical and durability properties were implemented, primarily on north and west grandstand. Also, laboratory tests were conducted on the same concrete, to evaluate mechanical and durability properties in laboratory conditions. These results are compared and presented in this paper.

Figure 1. Aerial view of the stadium "Rodjeni" in Mostar [2]

2. IN-SITU TESTS

The in-situ nondestructive tests performed were: compressive strength by Schmitt hammer, concrete quality and dynamic modulus of elasticity by ultrasonic pulse velocity method, crack width by microscope. Tests were performed on the north and west grandstands, both from the outside and from the inside, on the auditorium, as well as in the interior rooms intended for offices, catering facilities etc. Beams, walls, and columns were tested. Both vertical and horizontal elements of the concrete structure were included. Specific locations were selected for testing, in order to obtain the most precise and clear results.

Used Schmitt hammer is digital in accordance with EN 12504-2 and ASTM C805. For pulse velocity method, Pulsonic analyzer is used. Ultrasound can help to detect changes in the concrete structure (cracks, nests), which results in a lower ultrasound speed. All changes in concrete are manifested through the speed of impulses. Crack width was measured using a microscope with an accuracy of 0.01 mm.

2.1. Test results

Compressive strength was tested on 24 locations on north grandstand from outside, 17 locations inside of the north grandstand, 21 locations on west grandstand from outside and 14 locations inside the west grandstand. Results are presented in table 1.

Results indicate that compressive strength for inner elements is significantly higher than for outer elements. In a way this is expected, since inner elements are protected from weathering. But, results for outer part of north grandstand are worrying low, lower than expected for concrete class. It can be observed visually that concrete elements from north grandstand have much more cracks than elements from west grandstand. This is confirmed by other tests.

Table 1. Compressive strength test results by Schmitt hammer

Measuring location	Average compressive strength (MPa)	Minimum (MPa)	Maximum (MPa)	Standard deviation
North grandstand, outer part	29,44	10,40	51,80	7,61
North grandstand, inner part	42,16	21,10	66,70	8,93
West grandstand, outer part	35,30	18,00	52,20	6,49
West grandstand, inner part	42,40	30,60	60,00	6,14

Concrete quality was tested by pulse velocity method. Changes in concrete structures are manifested through the speed of ultrasound. The equipment records time that pulse travels from transmitter to receiver, from which speed is calculated by:

$$v = {}^{L}/_{T} \ (\mathrm{km/s}) \quad (1)$$

where:
L – distance between transmitter and receiver
T – time of pulse travel

Based on the speed, concrete quality can be determined by BS1881: Part 203. In addition to concrete quality, dynamic modulus of elasticity can be calculated as:

$$E_d = v^2 \gamma \frac{(1+n)(1-2n)}{1-n} \ (\mathrm{MPa}) \quad (2)$$

where:
v – speed in km/s
γ – concrete density in kg/m^3
n – Poisson's coefficient

Locations of ultrasonic pulse velocity test are as for compressive strength. The test results are presented in table 2.

Average pulse velocity for north grandstand is 1,915 km/s, and average dynamic modulus of elasticity is 9.509,10 MPa. For west grandstand average pulse velocity is 2,485 km/s and E_d is 15.651,35 MPa. The Pulse velocity method confirmed the results of tested compressive strength. Low pulse velocity indicates the presence of cracks, nests etc. in concrete structure, which may appear due to insufficient vibration of the concrete. Standard BS1881: Part 203 [4] grades concrete quality, and for north grandstand quality of concrete is very low (v≤2), and for west grandstand quality of concrete is low (v=2,0 – 3,0).

Table 2. Ultrasonic pulse velocity test results

Measuring location	Average pulse velocity (km/s)	Average E_d (MPa)
North grandstand, outer part	1,60	6.886,60
North grandstand, inner part	2,23	12.131,60
West grandstand, outer part	1,76	7.735,90
West grandstand, inner part	3,21	23.566,80

Crack width was measured for visible large cracks. In general, crack appearance was irregular, different length and width. Cracks labeled P1-P10 are from north grandstand, and cracks labeled P11-P13 are from west grandstand. Results are presented in table 3.

Table 3. Crack width test results

Measuring location	Average crack width (mm)	Measuring location	Average crack width (mm)
P1	2,00	P8	2,82
P2	2,98	P9	2,03
P3	2,50	P10	3,50
P4	1,97	P11	5,67
P5	2,03	P12	0,90
P6	2,33	P13	2,03
P7	2,00		

The cracks are most common under and behind the auditorium seats. They are about 3 mm wide, and they extend the entire length of the northern grandstand. From the bottom of the grandstand to the top, there are cracks on every beam. There are less cracks in the western grandstand, and only 3 that were visible were examined. Much narrower and much shorter cracks, compared to the northern grandstand.

3. LABORATORY TESTS

To determine concrete mechanical and durability properties, concrete of the same quality (eg. C25/30) and the same composition was tested in laboratory conditions. Compressive strength was tested for 7, 14, 28, 56, 90 and 365 days of age. Flexural tensile strength, absorption, draying shrinkage and carbonation were also tested. Also, samples were tested by ultrasonic pulse velocity method, to assess concrete quality with nondestructive method. Prior to hardened concrete tests, fresh concrete was tested.

Concrete was made with CEM II/B–W 42,5 N cement and local three-fraction crushed limestone as aggregate. The quantity of cement was 360 kg/m^3, aggregate was 1878 kg/m^3, with w/c ratio 0,50. In total 24 samples from three mixtures were prepared. For flexural strength and shrinkage test prisms 10x10x50 cm were used, for carbonation cylinders Ø15/30 cm, and for all other tests cubes 15 cm were used.

3.1. Fresh concrete properties test results

Fresh concrete properties were tested, and results are presented in table 4. In total three mixtures were tested, thus average results are presented.

Table 4. Fresh concrete properties

	Slump (cm)	Air content (%)	Bulk density (kg/m^3)	Temperature (°C)
Average	14,70	1,70	1.912,70	14,90

3.2. Hardened concrete properties test results

Test results of flexural strength, absorption and bulk density are presented in table 5.

Table 5. Results of flexural strength, absorption and bulk density

	Flexural strength (MPa)	Absorption (%)	Bulk density (kg/m^3)
Average	9,95	2,76	2.319,00
St. dev.	0,187	0,059	3,60

Compressive strength was tested for 7, 14, 28, 56, 90 and 365 days of age. Results are presented as average in figure 2. Drying shrinkage test results are presented in figure 3.

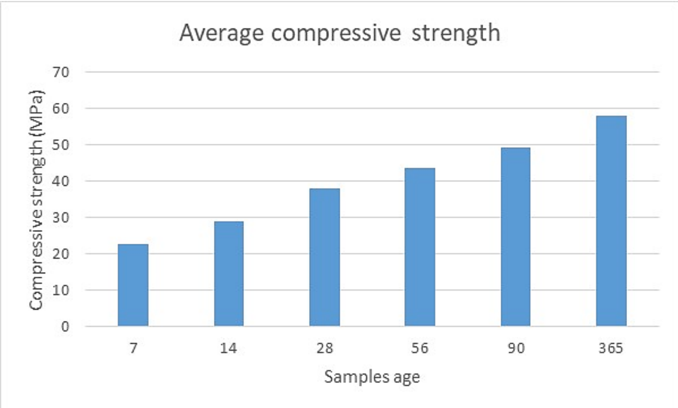

Figure 2. Average compressive strength test results

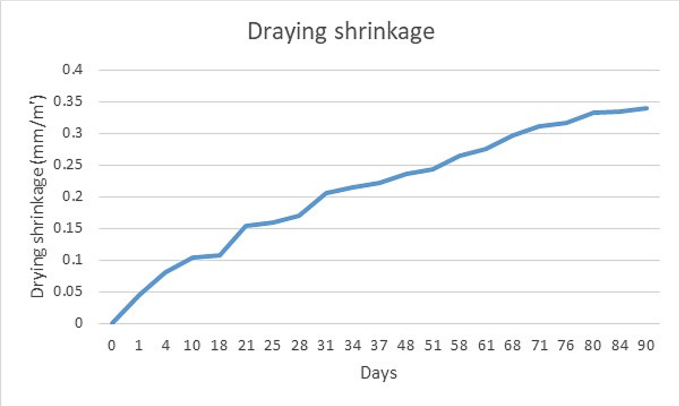

Figure 3. Drying shrinkage test results

28-days compressive strength reached expected values of about 38 MPa, and end values (90 and 365 days of age) reached about 50 MPa and 60 MPa. The final value of drying shrinkage is 0,34 mm/m', and is reached after 90 days of measures. After that, the results stagnate.

Carbonation was tested on samples 365 days of age. They were preserved outdoors in natural environmental conditions. A solution of phenolphthalein was used, sprayed on the concrete surface to detect the loss of concrete alkalinity, which is directly related to carbonation, in accordance with EN 13295 [5]. Samples were cut in half and then tested. The results are presented in table 6, and the test method in figure 4. In table 6 also are presented average pulse velocity obtained by the same method explained in 2.1 and dynamic modulus of elasticity.

Table 5. Average results of carbonation, pulse velocity and dynamic modulus of elasticity

	Carbonation (mm)	Average pulse velocity (km/s)	Average E_d (MPa)
Average	5,50	3,895	31.738,11
St. dev.	1,303	0,186	2.962,88

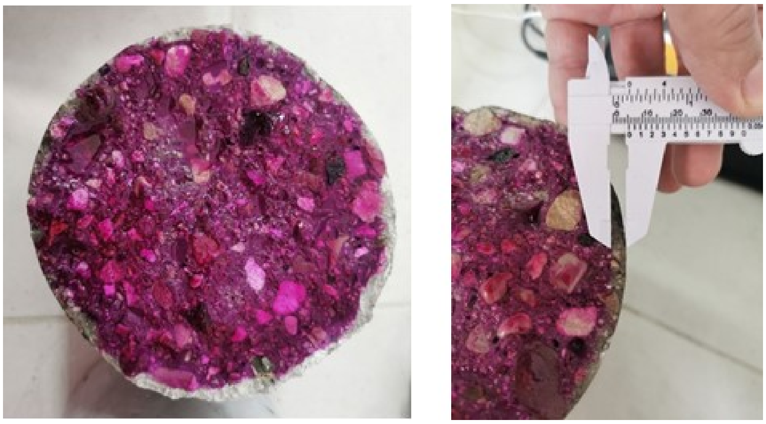

Figure 4. Measuring carbonation of concrete

4. DISCUSSION AND CONCLUSION

From the results of laboratory tests, it can be seen that prepared concrete reached strength of C25/30 concrete class. 90-day and 365-day compressive strength test results are as expected, about 50 MPa and 60 MPa, respectively. Concrete quality tested by ultrasonic pulse velocity is 3,895 km/s and is classified as "good" (v=3,5 – 4,5), according to BS1881: Part 203. Average dynamic modulus of elasticity in laboratory conditions was about 32 GPa, which is also expected for this concrete class. After 365 days of preserving the samples, average carbonation reached only 5,50 mm.

In-situ test results showed a slightly different situation. External elements of north and west grandstand showed lower compressive strength than inner elements. Inner elements have similar compressive strength for both grandstands. Test results for pulse velocity e.g. concrete quality follow the same pattern. The concrete quality of external elements for north grandstand is the lowest. Concrete quality of inner elements is higher for west grandstand compared to north grandstand. Although the north grandstand is older than west grandstand, the age difference is small to be a factor for difference in concrete quality. Poor concrete quality of elements from north grandstand can be the result of insufficient concrete curing and vibration.

On the other hand, this does not mean that whole elements are of the same quality. Sampling is needed to confirm these results by destructive tests. The visible deteriorations need to be repaired, but they do not affect construction load capacity and stability. Attention should be given to elements with small or no concrete cover for reinforcement.

The paper tends to emphasize the importance of quality control (laboratory and in-situ) during the construction process, from all parties involved. Construction durability can be significantly affected if the construction processes are not respected. This is especially visible for constructions exposed to weathering, which accelerates all degradation processes.

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