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Possibility of Testing the Compressive Strength of Concrete on the Halves of Prisms Specimens

Ana ROMIĆ
University of Split

Sandra JURADIN
University of Split

Nives OSTOJIĆ-ŠKOMRLJ
University of Split

Marko BERETIN
University of Split

Abstract: Compressive strength, as the main mechanical property of the building materials, depends on geometrical characteristics of the tested specimens: cube, cylinder or prism. Unlike concrete strength tests, where different specimens are used to determine compressive and flexural strength, those values are tested on the same prism specimens for the cement mortar. The purpose of this study is to investigate the possible correlation between values of compressive strength obtained on half concrete prism (10 cmx10 cmx40 cm) after flexural test with compressive strength on standardized 15 cm and 10 cm cubes. Three concrete mixtures have been tested and every mixture had a different maximum grain size of aggregate, namely 8 mm, 16 mm and 31,5 mm. Same type and quantity of the cement are used in all mixtures with the same water/cement ratio. The workability of the fresh concrete was examined by using the slump-flow method. Nine specimens are prepared for each concrete mixture; three for every dimension. According to the obtained results, it can be assumed that there is a significant level of connection of compressive strength values between half-prism and both 10 cm and 15 cm cube specimens. Results showed there is a possibility of using half-prism concrete specimens after the flexural test for the evaluation of compressive strength. This would reduce the number of test samples and the problem of sample disposal after the test.

Keywords: Concrete, Compressive strength, Flexural strength, Size of the test specimen

Introduction

The basic quality indicator for both cement and concrete is the compressive strength. The main difference between testing concrete and hardened cement mortar is in the number of required specimens: cement mortars flexural and compressive strength tests can be performed on the same specimens (HRN EN 196-1, 2016). After the flexural test, prisms are divided into two approximately equal parts and can be used to determine compressive strength. To perform a compressive test, concrete specimens were prepared following defined requirements (HRN EN 12390-1, 2012). Concrete parts of a prism tested in flexure sometimes can be used for determination of compressive strength. This experiment is called “equivalent cube test” and can be obtained by applying the load through square steel plates on the half prism. The compressive strength on half prism is approximately the same as the strength of a standard cube of the same size or due to test conditions, the strength of a modified cube can be, on average, 5 per cent higher than that of a cast cube of the same size (Neville, 1995).

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Compressive strength is the least susceptible to change when high and diameter ratio (h/d) is 2. After the ratio exceeds 4, the geometrical characteristic no longer affects strength. In lager samples possibility of the weakest link appearance is much higher (Matulić et al., 2016).

The wide-ranging research works (Matulić et al. 2016; Sabnis and Mirza, 1979; Zabihi and Eren, 2014; Kumari, 2015; Del Viso, et al., 2007; Day, 1994a and Day 1994b) carried out results for different concrete types, curing and storage processes. It has been determined that average compressive strength and standard deviation (Sabnis and Mirza, 1979) decrease with increasing of specimens dimensions. According to Matulić et al. (2016), measured dynamic modulus of elasticity can significantly correlate with compressive strength obtained by the destructive method in functional dependence of of the test specimen's dimensions. However, precautions must be taken when determining compressive strength based on values of dynamic modulus of elasticity, because a small error in measurement results drastically changes in compressive strength value. Encountering a defect, smaller specimens have shown higher sensitivity in reduction of dynamic modulus of elasticity, and this model can be used as a rough approximation.

To rationalize material consumption and reduce the problem of sample disposal after testing, the purpose of this study is to determine if there is a possibility of concrete compressive strength assessment based on half-prism compressive strength results and comparison with results obtained on standard 10 cm and 15 cm cubes. It should be noted that such results cannot be used for determination compressive strength class.

Experimental part

Materials and preparation of test specimens

For the testing purpose, three mixtures were made. The same type of cement (CEM II/B-W 42.5 N) was used for all mixtures and with equal quantities. The mass of cement was selected to be 350 kg and the w/c ratio was selected to be 0.55 for all concrete mixtures. The fractions of the crushed limestone aggregate used for preparation of concrete mixture were 0/4 mm, 4/8 mm, 8/16 mm, and 16/31,5 mm, with a grain size distribution curves as shown in Figure 1.

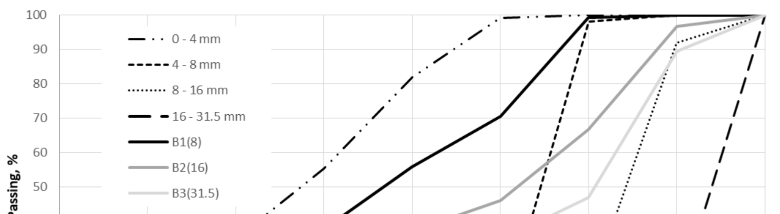

Figure 1. Grain-size distribution curves of aggregate fractions and concretes

Every mixture has a different maximum grain size of aggregate, namely 8 mm, 16 mm and 31, 5 mm. In this study, the ratios of different aggregate fractions were determined to make the granulometric curve of the combined aggregate batch to come closest to target Fuller curve (B curve), Figure 1.
Table 1 shows the concrete compositions. The mixture label contains the maximum grain size.

. Table 1. Concrete mix designs

Mix	Cement (kg)	Water (l)	w/c	Aggregate			
				0-4 mm	4-8 mm	8-16 mm	16-31.5 mm
B1 (8)	350	192.5	0.55	1326.72	490.70	0	0
B2 (16)	350	192.5	0.55	952.08	292.95	585.89	0
B3 (31.5)	350	192.5	0.55	627.10	166.00	959.10	92.22

All concrete components were weighed and placed into the moistened automatic concrete mixer. Dry components were mixed for 1 minute, and 5 more minutes with added water. The mixtures were cast into prism mold with dimensions of 10x10x40cm, and cubic molds with a length of 10 cm and 15 cm, while vibrated during casting. Nine specimens for each concrete mixture were tested, i.e. three per every dimension. After 24 h, the specimens were removed from the molds and cured in water at room temperature around 21 °C and 95% relative humidity until testing, according to EN 12390-2 (2019). Compressive strength, flexural strength, ultrasonic pulse velocity (UPV) and mass of the specimens were measured 28 days after sample preparation. The flatness of all surfaces of the tested specimens was insured according to HRN EN 12390-1 (2012).

Test results of fresh concrete

Fresh concrete was tested by using the slump- method (Figure 2) according to HRN EN 12350-2 (2019) and placed into the slump class, shown in Table 2. The obtained results are following Haktanir et al. (2012):

> Workability in the fresh phase and strength in the hardened form of structural concrete are, to a great extent, dependent on the gradation of the combined aggregate batch, and the proportioning of different size aggregate groups is a crucial step in concrete mix design.

Table 2. Results of the slump-flow test

Mixture	Slump-flow (mm)	Class
B1(8)	40	S1
B2(16)	170	S4
B3(31,5)	185	S4

As can be seen in Table 2 and Figure 2, by increasing the maximum grain size, the proportion of the fine fraction is smaller and workability of concrete is better.

Figure 2. Measuring slump on mixtures B1(8), B2(16) and B3(31.5) (Beretin, 2020)

Results and Discussion

The tests of hardened concrete

Flexural strength

According to HRN EN 12390-5 (2019), testing of concrete flexural strength is performed on 10x10x40 cm prisms by loading them with a constant rate of 0.05 MPa/s. Half of the prism should be leaning on the central parts of the upper plate of the hydraulic press, and the lower part of the plate is spaced 30 cm apart, leaving a space of 5 cm on each side of the prism (Figure 3.)

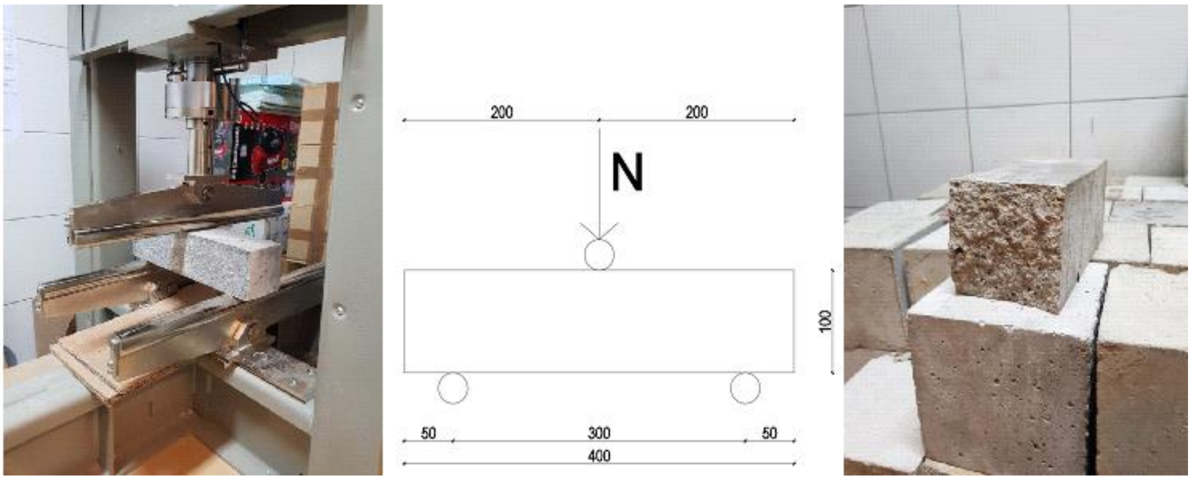

Figure 3. Testing flexural strength of concrete on prisms (Beretin, 2020)

Flexural concrete strength was calculated according to the (1) and showed in Figure 3, where N represents specimen breaking force, L is the length of the specimen, b is the specimen edge length and h is the specimen high:

$$f_t = \frac{3}{2} \cdot \frac{N \cdot L}{b \cdot h^2} \qquad (1)$$

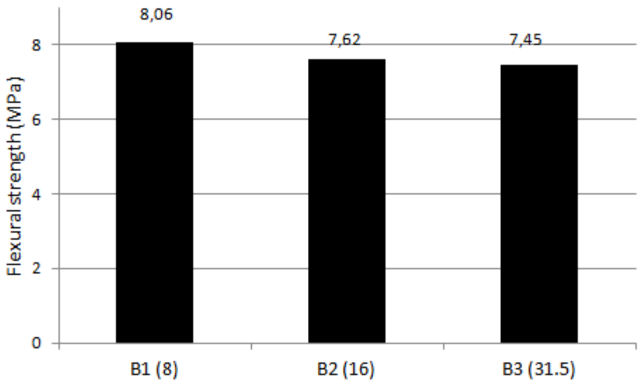

Figure 4. Flexural strength

Test results have shown a decreasing trend of flexural strength with an increased maximum grain size of aggregate. The relation is approximately linear in range of 0.5 MPa. The maximum standard deviation value (0.63 MPa) of the same mixture and dimension of specimens showed mixture with maximum grain aggregate of 16 mm.

Compressive strength

At the 28th day, the compressive strength of the hardened concrete specimens was tested on cube specimens of 10 and15 cm edge length with a loading rate of 0.6 ± 0.4 MPa/s according to EN 12390-3 (2019). After the flexural test on prism specimens has been preformed, both half fragment of the same prism were tested for compressive strength. Prism testing was conducted with 10x10 cm steel plates whose thickness was 4 mm. By placing the steel plates on both sides of the machine interaction plates before testing, it is ensured that the test on the concrete prism corresponds to the test conditions on the prisms of the standard cement mortar.

The mean values of compressive strength on tested specimens are shown in Figure 5. It was noticed that the compressive strength of every concrete mixture decrease with the decrement of specimens' dimensions, not conforming to different previous abovementioned studies (Matulić et al., 2016). The highest value (47.09 MPa) of compressive strength gave mixture B1 (8 mm max grain of aggregate) on 15 cm cube. The same trend of compressive strength behavior was noticed on 10 cm cubes, but this specific specimen's dimension is the most susceptible to maximum grain size. The relationship between sample size and maximum aggregate grain (l_{min}/D_{max}) should be taken into account when interpreting the results of the concrete properties (Śliwiński and Duźy, 2020). Results of compressive strength are in the same range for 10 cm and 15 cm cubes and B1 (8 mm) and B2 (16 mm) mixtures. The largest deviation from average compressive strength at the mixture level gave a geometric shape of the prism (around 1.5 MPa) for mixture B3. Comparing all three concrete mixtures based on cube dimension, the highest standard deviation had the mix B1 in 15 cm cube (0.67 MPa), and mixture B3 for 10 cm cube (1.4 MPa).

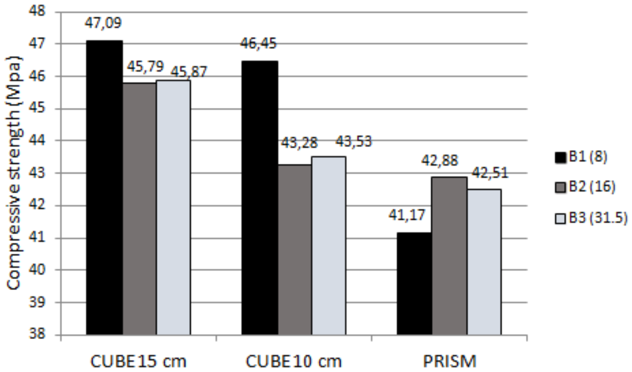

Figure 5. Compressive strength of concrete

The correlation analysis between compressive strength on 10 cm and 15 cm cubes versus prism was carried out to determine the possibility of estimation of compressive strength based on before-flexural-tested prisms. Correlation test is shown in Figure 6.

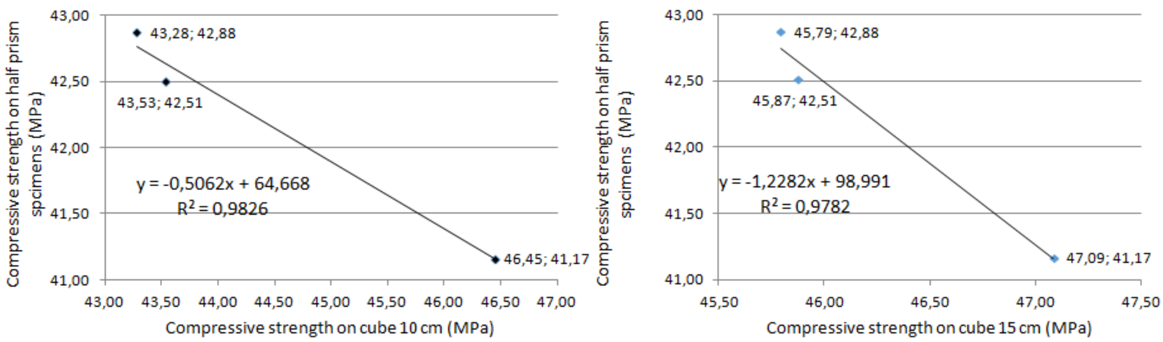

Figure 6. Correlation between compressive strength specimens

The connection between both conducted tests is significant, and in rage around 0.99. According to the obtained results, it can be assumed that there is a possibility of using prism specimens after the flexural test.

Dynamic modulus of elasticity

Before the flexural and compressive test was carried out, mass and the ultrasonic pulse velocity (UPV) of every specimen was measured in order to determine the dynamic modulus of elasticity, according to HRN EN 12504-4 (2004) and expression:

$$E_{din} = \frac{v^2 \rho (1+\mu)(1-2\mu)}{1-\mu} \tag{2}$$

where: v is mean ultrasonic wave velocity (m/s), ρ is concrete density (kg/m^3) and μ is the Poisson coefficient. Dynamic modulus of elasticity (Figure 7) showed inverse behavior in comparison with compressive strength results. The highest modulus of elasticity has mixture B3 on prism (53.62 GPa), and 15 cm cube followed the same trend of behavior with maximum values for the same mix. Mixture with 16 mm maximum grain of aggregate (B2) has the highest modulus of elasticity on 10 cm cubes. Generally, if the shape and dimensions of specimens are observed, the lowest value was obtained on 10 cm cubes. The mixture type B1, where the maximum grain of aggregate is 8mm, gave the lowest dynamic modulus of elasticity irrespective of the size of the tested specimens. Deviation in dynamic modulus of elasticity is more variable compared to compressive strength: mixture B2 gave the highest deviation for 10 cm cubes (1.3 GPa), while mixture B3 gave the maximum deviation of 0.95 GPa for 15 cm cubes. The mixture with 16 mm maximum grain of aggregate (B2) gave a maximum deviation of 1.2 GPa for the prism specimens. The similar trend in deviation of dynamic modulus of elasticity was shown in both mixtures B1 and B2.

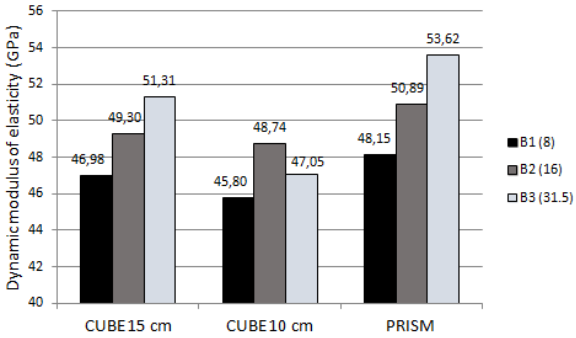

Figure 7. The dynamic modulus of elasticity

Coefficient of correlation for dynamical modulus of elasticity between 15 cm cube and prism is high (0.99). Meanwhile, the same test with 10 cm cube gave a significantly lower value of coefficient: 0.43. (Fig 8.) Possible cause of lower correlation can be found in the above-mentioned relationship between the minimum sample size l_{min} and the maximum aggregate grain D_{max}. The authors in (Śliwiński and Duźy, 2020) recommend that relationship l_{min}/D_{max} is in range < 5.0; 10.0 > and for the cube with 10 cm edge, these values for maximum grains 8 mm and 31.5 mm are outside the recommended interval. Also, EN 12390-1 (2012) specifies that a specimen shall have a minimum cross-section size of l_{min}/D_{max} > 3.5, which for D_{max} = 31.5 mm is not met. There is also "wall effect", according to which: *If the maximum size of aggregate is large in relation to the size of the mould, the compaction of concrete and the uniformity of distribution of the large particles of aggregate are affected*, (Neville, 1995). A clear conclusion cannot be given based on a small number of specimens.

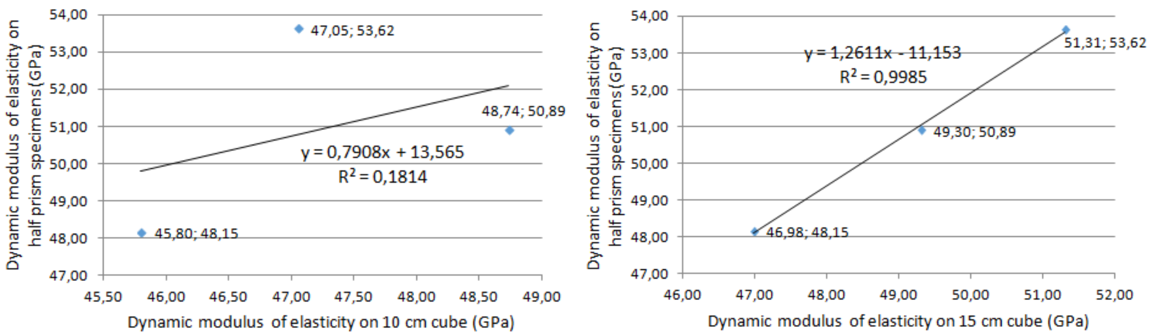

Figure 8. Correlation between dynamic modulus of elasticity of specimens

Conclusion

The sample size can significantly affect the assessment of properties that are sensitive to the composition of concrete. Although the basic cube dimension for the testing is 150 mm, the possibility of using the half prism specimens after flexural test to determine the compressive strength of the concrete was carried out in this paper. Three concrete mixtures with three different maximum grain size of aggregate (8 mm. 16 mm and 31.5 mm) were prepared and tested. Values of compressive strength were determined for each specimen's dimension: half concrete prism and 15 cm and 10 cm cubes, while the values of the dynamic modulus of elasticity were determined on concrete prism (10cmx10cmx40cm) and on both dimensions of the cube.

The relationship between the compressive strength of the 10 cm and 15 cm cubes and compressive strength of half of the prism specimens is significant, with R = 0.99. Coefficient of correlation for dynamical modulus of elasticity between 15 cm cube and prism indicates a strong relationship (R = 0.999), but the relationship between 10 cm cube and prism is weak. The reason for this result can be an unfavorable cross-section size of l_{min}/D_{max} for a mixture with D_{max} = 31.5 mm and/or wall effect and/or a small number of tested specimens.

According to obtained results and correlation on 15 cm cubes, same prism specimens (10x10x40cm) divided in half after flexural test and then tested under a pressure can be used to determine estimated compressive strength, although they are not the same size in cross-section. This test is not scheduled for determining or evaluating the class of concrete. For a much stronger correlation between the above mentioned compressive strengths, more extensive research should be performed with a larger number of specimens. Testing half of the prisms after the flexural strength test would reduce the number of test specimens as well as the problem of construction waste disposal.

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Author Information

Romić Ana
University of Split
Faculty of Civil Engineering, Architecture and Geodesy,
University of Split, Croatia
Matice hrvatske 15, 21000 Split
Contact e-mail: *ana.romic93@gmail.com*

Sandra Juradin
University of Split
Faculty of Civil Engineering, Architecture and Geodesy,
University of Split, Croatia
Matice hrvatske 15, 21000 Split

Nives Ostojić-Škomrlj
University of Split
Faculty of Civil Engineering, Architecture and Geodesy,
University of Split, Croatia
Matice hrvatske 15, 21000 Split

Marko Beretin
University of Split
Faculty of Civil Engineering, Architecture and Geodesy,
University of Split, Croatia
Matice hrvatske 15, 21000 Split