prof. dr inż. Hakim S. Abdelgader [1)]
dr inż. Ali S. El-Baden [2)]

Mechanical properties of no-fines concrete

Właściwości mechaniczne betonu jamistego

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Abstract. The paper presents a laboratory study to determine the relationship between compressive strength of no-fines concrete (NFC) and its tensile strength measured both by double-punch test and modulus of rupture test methods. The compressive strength was carried on 100 x 100 x 100 mm cubes. The specimens for tensile strength tests were 150 x 150 mm cylinders, and 100 x 100 x 500 mm beams. Crushed limestone was used as coarse aggregate with max size of 19 mm. Sixteen concrete mixes were prepared with water-to-cement ratios: 0.40; 0.42; 0.44; and 0.46 cement-to-aggregate ratios (C/A) 1 : 5, 1 : 7, 1 : 9, and 1 : 11. The total of 48 cubes, 48 cylinders, and 48 beams were prepared. Compressive and tensile strength tests were carried on the concrete specimens according to relevant standards ASTM-C39/C39 M. 2016 and ASTM-C78/C78 M. 2015 and the average of three results was recorded each time. It was found that tensile strength measured by modulus of rupture test gave higher results than that measured by double-punch test. The tensile strength from the double-punch test was about 20% of the compressive strength and from the modulus of rupture was about 30% of the compressive strength according to test results obtained in this study.
Keywords: no-fines concrete, laboratory study, compressive and tensile strength.

Streszczenie. W artykule przedstawiono badania laboratoryjne mające na celu określenie zależności pomiędzy wytrzymałością betonu jamistego na ściskanie i rozciąganie, stosując próbę podwójnego przebicia i trzypunktowego zginania. Wytrzymałość na ściskanie badano na kostkach 100 x 100 x 100 mm. Wytrzymałość na rozciąganie określono na próbkach walcowych 150 x 150 mm oraz belkowych 100 x 100 x 500 mm. Jako kruszywo grube zastosowano kamień wapienny o maksymalnym uziarnieniu 19 mm. Przygotowano 16 mieszanek betonowych o wskaźniku w/c: 0,40; 0,42; 0,44 i 0,46 oraz proporcji cementu i kruszywa (C/A) 1 : 5, 1 : 7, 1 : 9 i 1 : 11. Łącznie wykonano 48 kostek, 48 próbek walcowych i 48 belkowych. Próby na rozciąganie i ściskanie wykonano zgodnie z normami ASTM-C39/C39 M. 2016 i ASTM-C78/C78 M. 2015, za każdym razem wyznaczając średnią z trzech pomiarów. Wytrzymałość betonu na rozciąganie otrzymana w wyniku próby zginania była większa niż w przypadku próby podwójnego przebicia. W stosunku do wytrzymałości na ściskanie wytrzymałość betonu na rozciąganie w próbie podwójnego przebicia stanowiła 20%, a wytrzymałość na zginanie w próbie trzypunktowego zginania – 30%.
Słowa kluczowe: beton jamisty, badania laboratoryjne, wytrzymałość na rozciąganie i ściskanie.

No-fine concrete (NFC) is composed of cement paste and coarse aggregate only, the fine aggregate being omitted in order to have large voids uniformly distributed through its mass in the hardened state. Aggregate particles are covered by a thin layer of cement grout (up to 1.3 mm thick) and are in point-to-point contact with each other [1]. NFC has little resistance to penetration of water, but there is also very little capillary action. A part from its use in housing and multistory flats, NFC has been used to a limited extent for car park areas, roads, tennis courts and as drainage medium [1]. It can also serve as an insulating layer and as a damp-proofing material. If water is aggressive to concrete, NFC will not be suitable for drainage purposes. NFC is a form of lightweight porous concrete. The advantages of this type of concrete are lower density (usually 1600 ÷ 2000 kg/m^3), lower cost due to lower cement content (180 ÷ 260 kg/m^3 depending on the mix ratio), lower thermal conductivity (λ = 0.7 W/mK for NFC in comparison to λ = 2.0 W/mK for dense concrete), no segregation and relatively low drying shrinkage [7]. The cost of NFC is 55 ÷ 75% of normal concrete depending on the mix ratio used. The aggregate may be gravel, crushed rock, blast furnace slag, and lightweight aggregate. The size of the aggregate is usually 10 ÷ 20 mm [6, 7]. Compressive strength of NFC is in the range of 1.37 ÷ 13.73 MPa [6]. Experience has shown that the water-to-cement ratio to be used is 0.38 ÷ 0.52, since using high water-to-cement ratio causes the cement grout to run off the aggregate particles and possibly block the voids at the bottom of the form, and if the cement grout is too dry it will not coat the aggregate particles properly [6, 8]. The main objective of this work was to investigate the relationship between modulus of rupture, tensile strength and compressive strength of NFC made of several mixes using local materials. All laboratory tests were carried out at the Civil Engineering Department, University of Tripoli.

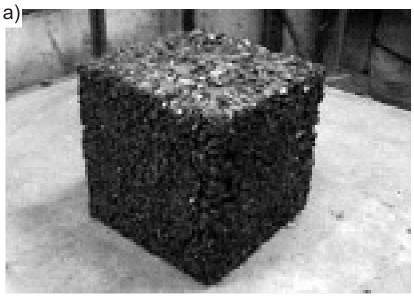
Test specimens

Ordinary Portland cement (Type I) was used throughout the testing program. Crushed limestone with maximum size of 19 mm was used as coarse aggregates. Sixteen concrete mixes were prepared with four water-to-cement ratios (0.40; 0.42; 0.44 and 0.46). For each water-to-cement ratio four different cement-to-aggregate ratios were used (1 : 5; 1 : 7; 1: 9 and 1 : 11). The test specimens used for compressive strength were 100 x 100 x 100 mm cube (Photo 1a). The specimens for tensile strength tests were 150 x 150 mm cylinders (Photo 1b), with using two steel punches of one fourth the concrete specimen size (37.5 x 37.5 mm) and 100 x 100 x 500 mm beams were used for modulus of rupture test. The total of 48 cubes, 48 cylinders,

1) Full Professor of Civil Engineering Department, University of Tripoli, Tripoli, Libya
2) Associate Professor of Civil Engineering Department, University of Tripoli, Tripoli, Libya
*) Adres do korespondencji:
hakimsa@poczta.onet.pl

and 48 beams were cast and after demoulding them the next day, they were water cured in the laboratory for 28 days. Photo 1 show sample of NSC specimens.

a)



b)

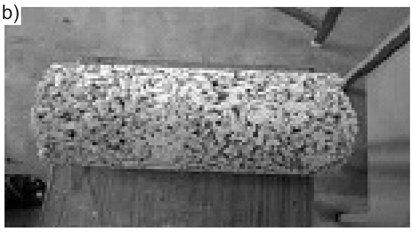


Photo 1. Sample of NSC specimens: a) cube; b) cylinder
Fot. 1. Próbki wykorzystane w badaniach: a) kostka; b) walec

Testing method

Compressive and flexural strength tests were performed according to the appropriate ASTM standard [2, 3]. Tensile strength test was carried out by using the double-punch test method. This test method for measuring tensile strength of concrete is an indirect tension test. It has been introduced by Chen [4]. In this test method, a compressive load is applied to a concrete cylinder along its axis through two steel punches placed on the top and bottom surfaces of the cylinder as shown in Photo 2. Chen and Yuan [5] recommended the following formula for computing the tensile strength in a double punch test for concrete:

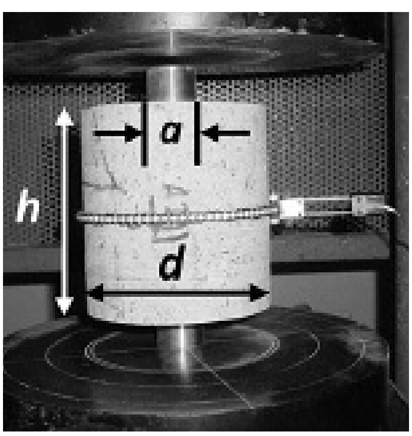


Photo 2. Specimen under testing
Fot. 2. Próbka walcowa podczas badania

$$f_t = P/\pi\ (1.2dh - a^2)\ [MPa] \quad (1)$$

Where: f_t – tensile strength; P – applied failure load; d – radius of the concrete cylinder; a – radius of steel punch; h – hight of the concrete cylinder.

The use of 152 x 152 mm cylinders with two 38 x 38 mm steel punches was recommended. Therefore, based on this recommendation a cylinder size of 150 x 150 mm was used with two steel punches (37.5 x 37.5 mm).

Experimental results

Compressive strength. The obtained results from the compressive strength tests carried on the cube (100 x 100 x 100 mm) specimens are given in Table 1. This table reveals that the effect of water-to-cement and cement-to-aggregate ratios on the average compressive strength is very appreciable. The lowest average compressive strength obtained was 2.33 MPa and the highest was 10.33 MPa.

Tensile strength. Tensile strength test results obtained from cylinder (150 x 150 mm) specimens is given in Table 2. The tensile strength test was performed on the specimens according to the method presented in reference [5]. Photo 3 presents the cracked specimen after double-punch failure. The cracks at the top and bottom faces of the specimens were all identical, with a circle of a punch diameter, which is almost the same as that of the loading area. This failure also consisted of several tensile radial cracks starting from the centre. Most of the cylinder specimens failed into three equal parts. This type of failure was almost identical to that given in Chen and Yuan [5]. The average ratio of tensile strength to compressive strength expressed as percentage was about 20 percent. The comparable value for this ratio for conventional concrete is 10 percent. The highest average tensile strength obtained was about 2.057 MPa, and the lowest was 0.524 MPa.

Table 1: Average compressive strength
Tabela 1. Średnia wytrzymałość betonu na ściskanie

Water-to-cement ratio (W/C)	Cement- to-average ratio (C/A)	Average compressive strength [MPa]
0.4	1/5	7.67
	1/7	4.83
	1/9	3.83
	1/11	2.33
0.42	1/5	9.33
	1/7	5.50
	1/9	4.67
	1/11	3.00
0.44	1/5	10.33
	1/7	6.00
	1/9	4.50
	1/11	3.83
0.46	1/5	7.00
	1/7	5.16
	1/9	3.16
	1/11	2.33

Table 2. Average tensile strength – cylinder specimens
Tabela 2. Średnia wytrzymałość betonu na rozciąganie – próbki walcowe

Water-to-cement ratio (W/C)	Cement- to-aggregate ratio (C/A)	Average tensile strength [MPa]
0.4	1/5	1.530
	1/7	1.000
	1/9	0.807
	1/11	0.544
0.42	1/5	1.996
	1/7	1.048
	1/9	0.887
	1/11	0.686
0.44	1/5	2.057
	1/7	1.120
	1/9	0.928
	1/11	0.786
0.46	1/5	1.412
	1/7	1.000
	1/9	0.686
	1/11	0.524

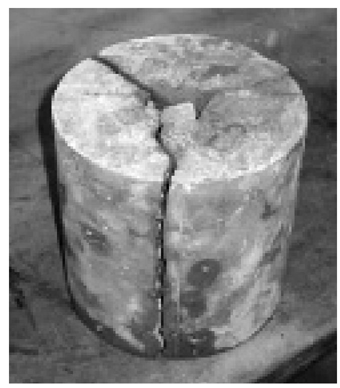


Photo 3. Failure modes of the double-punch specimen
Fot. 3. Zniszczona próbka walcowa

Modulus of rupture. The standard test method for flexural strength of concrete using simple beam with third-point loading according to ASTM C78 was used [3]. The specimens were loaded to failure and all of them were broken nearly to two equal parts (near centerline of span). The results of this test are given in Table 3. The average modulus of rupture is found to be about 30 per-

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Table 3. Average modulus of rupture strength – beam specimen
Tabela 3. Średnia wytrzymałość betonu na zginanie – próbki belkowe

Water-to-cement ratio (W/C)	Cement- to-aggregate ratio (C/A)	Average modulus of rupture [MPa]
0.4	1/5	2.250
	1/7	1.650
	1/9	1.425
	1/11	0.750
0.42	1/5	2.700
	1/7	1.770
	1/9	1.425
	1/11	1.050
0.44	1/5	2.850
	1/7	1.875
	1/9	1.500
	1/11	1.200
0.46	1/5	2.325
	1/7	1.830
	1/9	0.975
	1/11	0.705

cent of the compressive strength. The comparable value for this ratio for conventional concrete is 19 percent [6]. The highest average modulus of rupture obtained was 2.850 MPa, and the lowest was 0.705 MPa.

The strength properties of NFC (compressive, tensile and flexural) appear to be considerably lower than that of conventional normal weight concrete, according to the strength values obtained in this research work. These obtained strength values are sufficient enough for structural use of NFC. But, in general, because of the lower tensile and flexural strengths the use of NFC is limited to the applications where low bending loading is to be considered [6].

Relation between compressive and tensile strength

Figure 1 gives the relationship between compreesive and tensile strength of NFC measured by double-punch test method. Regression equation was obtained for this relationship which can predict the tensile strength of NFC from its comprssive strength value and it is as follows:

$$f_t = a \cdot f_c^b \quad \text{[MPa]} \quad (2)$$

Where: f_t – stands for tensile strength at 28 days; f_c – compressive strength at 28 days; a and b – empirical constants 0.218, and 0.955. The obtained correlation coefficient R^2 for equation (2) is equal to 0.9415.

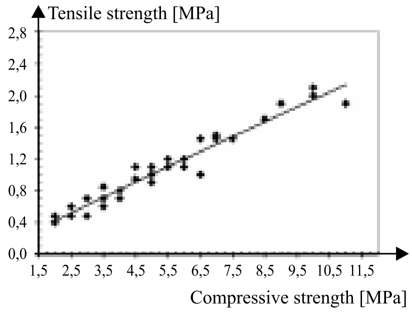

Fig. 1. Tensile strength versus compressive strength – cylinder specimens
Rys. 1. Zależność pomiędzy wytrzymałością na ściskanie i rozciąganie – próbki walcowe

Relation between compressive strength and modulus of rupture

The relationship between compressive strength and modulus of rupture is shown Figure 2. The following regression equation was obtained for this relationship.

$$f_r = d \cdot f_c^e \quad \text{[MPa]} \quad (3)$$

Where: f_r – stands for flexural strength at 28 days; f_c – compressive strength at 28 days; d and e – empirical constants 0.424, and 0.827. The obtained correlation coefficient R^2 for equation (3) is equal to 0.914.

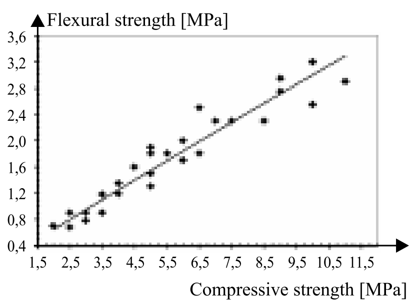

Fig. 2. Flexural strength versus compressive strength – beam specimens
Rys. 2. Zależność pomiędzy wytrzymałością na ściskanie i zginanie – próbki belkowe

Relation between tensile strength and modulus of rupture

The obtained modulus of rupture is always higher than the tensile strength obtained from the double-punch test. The average ratio of tensile strength to modulus of rupture is 65 %. The relationship between tensile strength and modulus of rupture strength is shown in Figure 3. The corresponding regression equation is:

$$f_t = m \cdot f_r^n \quad \text{[MPa]} \quad (4)$$

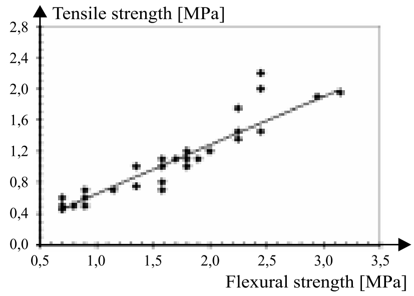

Fig. 3. Tensile strength versus flexural strength obtained on cylinder (vertical axis) and beam specimens (horizontal axis)
Rys. 3. Zależność pomiędzy wytrzymałością na rozciąganie uzyskaną z próbek walcowych (oś pionowa) i belkowych (oś pozioma)

Where: f_t – stands for tensile strength at 28 days; f_r – flexural strength at 28 days; m and n – empirical constants 0.609, and 1.085. The obtained correlation coefficient R^2 for equation (4) is equal to 0.885.

Conclusions

From the results obtained herein the following conclusions may be drawn:

- tensile strength obtained by double-punch test was about 20% of the compressive strength;
- modulus of rupture obtained in this work was about 30% of the compressive strength;
- tensile strength measured by the double-punch test was lower than the modulus of rupture;
- the effect of water-to-cement and cement-to-aggregate ratios was very appreciable on compressive, tensile and flexural strengths.

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