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Effect of coarse grain aggregate on strength parameters of two-stage concrete

Wpływ kruszywa gruboziarnistego na parametry wytrzymałościowe betonu dwuetapowego

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Abstract. Two-stage concrete (TSC) is a special type of concrete that the method of its construction and implementation is different from conventional one. In TSC, coarse aggregate particles are first placed in the formwork and voids between them are subsequently injected with a special cementations mixture. TSC has been successfully used in many applications, such as underwater construction, casting concrete sections congested with reinforcement and concrete repair. Coarse aggregate forms about 60% of the total volume of TSC, while coarse aggregate forms about 40% of the total volume of conventional concrete. In TSC stresses are transferred through contact areas between coarse aggregate particles. In this paper coarse aggregate size influence on strength parameters of TSC and comparing it with conventional concrete is done (by uniaxial compressive strength test and Brazilian tensile strength test). According to results of tests in this paper, the TSC with finest grain of coarse aggregate has higher compressive and tensile strength, higher modulus of elasticity and less Poisson's ratio from conventional concrete.

Keywords: two-stage concrete; conventional concrete; uniaxial compressive strength; tensile strength; modulus of elasticity.

Streszczenie. Beton wykonywany dwuetapowo (TSC) jest specjalnym rodzajem betonu, a jego metoda wbudowania i zastosowanie różnią się od tradycyjnego. W TSC w pierwszej kolejności w szalunku układane jest kruszywo grube, a następnie pod ciśnieniem podawana jest specjalna mieszanka cementowa wypełniająca wolne przestrzenie między kruszywem. Technologia TSC została wielokrotnie zastosowana z powodzeniem w betonowaniu pod wodą do wykonywania zbrojonych elementów konstrukcyjnych oraz jako beton naprawczy. W TSC kruszywo grube stanowi ok. 60%, natomiast w betonie zwykłym ok. 40% całkowitej objętości. W TSC naprężenia przenoszone są przez obszary styku między ziarnami kruszywa grubego. W badaniach wykazano wpływ kruszywa grubego na parametry wytrzymałościowe TSC i porównano je z wynikami badań betonu wykonywanego w sposób tradycyjny (w przypadku jednoosiowego badania wytrzymałości na ściskanie i wytrzymałości na rozciąganie metodą brazylijską). Na podstawie uzyskanych wyników badań stwierdzono, że TSC zawierający ziarna małej średnicy charakteryzuje się lepszą wytrzymałością na ściskanie i rozciąganie, większym modułem sprężystości i mniejszym współczynnikiem Poissona niż beton zwykły.

Słowa kluczowe: betonowanie dwuetapowe; beton zwykły; jednoosiowy stan naprężenia; wytrzymałość na rozciąganie; moduł sprężystości.

The Two-Stage concrete (TSC) is made by placing the gravel into the mold and then filling the empty spaces between them by the mortar of sand and cement. Usually, emptying spaces between gravel are performed in two ways: weighing and injecting. In the weighting method, the mortar is poured on top of the mold filled with grit and, with the help of a compacting or vibrating, mortar fills the empty spaces. This method can be used in concrete with a maximum height of 300 mm. In the injection method, by placing the injection tubes inside the mold, the mortar is injected into the mold by the pump and the injection tubes are gradually increased [1].

TSC differs from conventional concrete (CC) in several aspects. First, all ingredients of conventional concrete are mixed together and then placed in the formwork, while in TSC the grout ingredients are mixed separately and then injected into the pre-placed aggregate mass as mentioned earlier. Second, TSC has a higher coarse aggregate content than that of conventional concrete. TSC can be considered as a skeleton of coarse aggregate particles resting on each other, leaving only internal voids to be filled with grout. Conversely, in normal concrete the aggregates are rather dispersed. Therefore, TSC has a specific stress distribution mechanism at which the stresses are transferred through contact areas between coarse aggregate particles. Coarse aggregate forms about 60% of the total volume of TSC, while coarse aggregate forms about 40% of the total volume of conventional concrete [2, 8].

Abdelgader [3], through some experiments, presented an algorithm for designing TSC. Additionally, he determined the optimal water-cement and sand-cement ratios for manufacturing TSC, and concluded that a water-cement ratio of 0.47 and a cement-sand ratio of 1 produce the highest mortar quality [3]. Compared to conventional concrete, TSC is superior in economic and geomechanical aspects and is less probable to develop cracks [4 – 7].

Due to the fact that most of the TSC volume is precipitated from the gravel particles, coarse grain aggregate grading can have important effects on the me-

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chanical properties of the concrete. Also, comparing the mechanical properties of TSC and CC can show the advantages and disadvantages of this particular type of concrete in comparison to CC [9, 10]. For this reason, in this study, two types of TSC and a CC were constructed and tested for 28 days of single-axial compressive strength test and Brazilian tensile strength test.

Materials and methods

In this research, to study the effect of coarse-grained particle size on TSC resistance and comparison with CC, two TSC types and one typical type of concrete, which were named TSC1, TSC2 and CC respectively, were constructed. In total, 75 test specimens were made of 150 x 300 mm for the various tests required. To determine the elasticity modulus and the Poisson coefficient from the test specimens, the cores were made and test specimens of 50 – 100 mm were tested.

In this study, coarse-grained aggregates, fine-grained aggregates, cement, and water were used to prepare the samples of TSC and CC. Additionally, expansion additives were used in the TSC mortar. Aggregates of similar origin obtained from the same mine were used in preparation of specimens for both TSC and CC. Moreover, the specific gravity of the aggregates used in the manufacture of TSC was 1550 kg/m^3 and 1610 kg/m^3 for TSC1 and TSC2. However, considering the differences in the grading and manufacture of TSC and CC, the grading of the consumed sand in preparation of specimens was different. Figure 1 demonstrates the sand grading used in specimens. Moreover, the parameters of the gradation curve for the consumed aggregates in this study are given in Table 1. The aggrega-

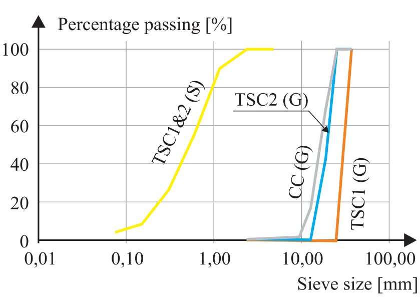

Fig. 1. The gradation curve for the aggregates
Rys. 1. Krzywa przesiewu zastosowanego kruszywa

Table 1. The parameters of the gradation curve for the consumed materials in this study
Tabela 1. Parametry kruszywa zastosowanego do badań

Parameter	G			S		
	TSC1	TSC2	CC	TSC1	TSC2	CC
D_{10} [mm]	27	15	12	0.17	0.17	0.22
D_{30} [mm]	29	17	15	0.33	0.33	0.63
D_{50} [mm]	30	20	17	0.53	0.53	1.4
D_{60} [mm]	32	21	18	0.66	0.66	1.9
C_u	1.19	1.4	1.5	3.88	3.88	8.64
C_c	1.03	1.09	0.96	1.03	1.03	1.05

G – gravel; S – sand; TSC – two-stage concrete; CC – conventional concrete; D_{10}; D_{30}; D_{50}; D_{60} – the effective size of grain; C_u – uniformity coefficient; C_c – curvature coefficient; G_{max} – the maximum grain size

te softness module for TSC and CC were 2.21 and 3.47, respectively.

Type II cement and drinking water were used for preparation of all specimens. The mixture ratios for different materials in 1 m^3 of TSC is given in Table 2. In order to prepare the mortar, the materials were mixed in a 30 l mixer and were mixed for 4 min. To prepare the TSC, 0.0053 m^3 of aggregates (equal to the volume of the mold) were placed in a cylindrical mold with the existing voids between which were filled by mortar with the help of vibrating table (ASTM C943-10.2000). The amount of consumed mortar in the TSC is equal to the void fraction. Consequently, 0.42 and 0.38 m^3 of mortar was used for TSC1 and TSC2 specimens. After their preparation, the TSC and CC specimens were placed and retained in the water in standard conditions. The amount of materials used per 1 m^3 of the TSC is calculated based on void faction and mortar mix plan. The mixture ratios for different materials per 1 m^3 of TSC and CC are given in Table 3.

Table 2. The mixture ratios in 1 m^3 of the mortar used for TSC1 and TSC2
Table 2. Skład zaprawy na m^3 zastosowanej do TSC1 i TSC2

W/C	S/C	C [kg]	S [kg]	W [kg]	EA/C
0.5	1	800	800	400	0.008

W – water; C – cement; S – sand; EA – expanding admixture

Table 3. The mix design for the prepared specimens in this study
Tabela 3. Projekt mieszanek do wykonania próbek do badań

Type of concrete	W/C	G [kg]	C [kg]	S [kg]	W [kg]
TSC1	0.5	1510	336	336	168
TSC2	0.5	1610	304	304	152
CC	0.57	1225	300	630	170

W – water; C – cement; G – gravel; S – sand; EA – expanding admixture

Results and discussion

In this study, to investigate the effect of coarse grain aggregate on TSC resistance and compare it with CC, uniaxial compressive strength tests and Brazilian tensile strength tests were performed on test specimens.

Compressive strength. Uniaxial compressive strength test was performed on 30 standard cylindrical test specimens (150 x 300 mm), including 10 test specimens of each type of concrete, and uniaxial compressive strength (σ_c) values for test specimens were calculated. Also, by centrifuging the cylindrical specimens, 10 test specimens of 50 x 100 mm from each test specimen were prepared. Using a strain gauge and performing a single-axial compressive strength test, the compressive strength (q_u), elastic modulus (E) and Poisson coefficient (υ) were also obtained for the test specimens. Figure 2 compares the mean values of the uniaxial compressive strength of concrete specimens, Figure 3 – the mean values of the modulus of elasticity of concrete specimens and Figure 4 – the mean values of Poisson's coefficient for concrete specimens constructed in this study.

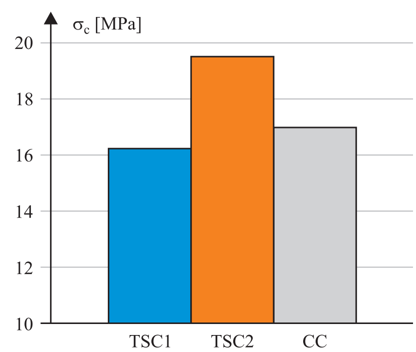

Fig. 2. Comparison of the compressive strength
Rys. 2. Porównanie wyników badań wytrzymałości na ściskanie

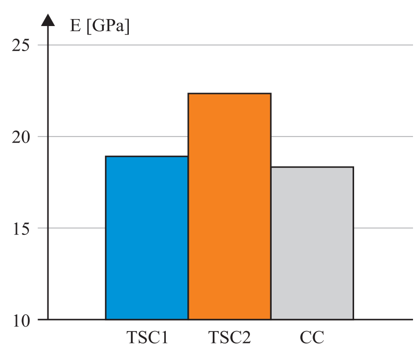

Fig. 3. Comparison of modulus of elasticity
Rys. 3. Porównanie wyników badań modułów sprężystości

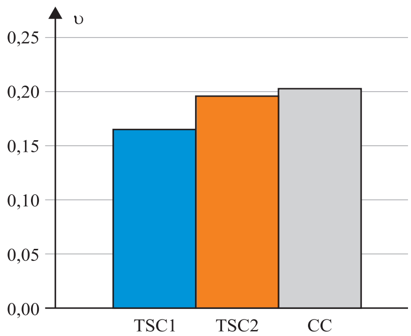

Fig. 4. Comparison of the values of Poisson's ratio

Rys. 4. Porównanie współczynników Poissona

Tensile strength. The Brazilian tensile strength test was performed on 10 standard cylindrical specimens (150 x 300 mm) of each type of concrete and the tensile strengths of the test specimens were calculated. Figure 5 also shows the comparison of tensile strength values for different test specimens.

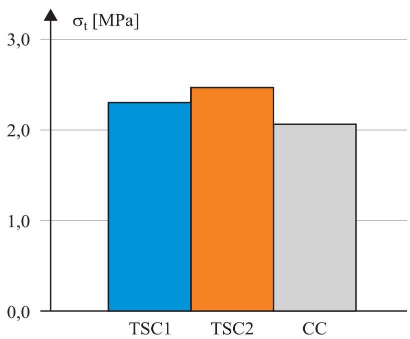

Fig. 5. Comparison of tensile strength values

Rys. 5. Porównanie wyników badań wytrzymałości na rozciąganie

The relationship between compressive strength and tensile strength. Based on the results obtained from the experiments and the drawing of the tensile strength curve based on the compressive strength, the equation (1) to (3) were obtained for TSC1, TSC2 and CC specimens, respectively. Figure 6 also shows the relationship between tensile strength and compressive strength in this study.

$$\sigma_t = 0.4945\sigma_c^{0.5529} \quad (1)$$

$$\sigma_t = 0.5463\sigma_c^{0.5112} \quad (2)$$

$$\sigma_t = 0.5251\sigma_c^{0.4847} \quad (3)$$

σ_t and σ_c – respectively tensile strength and compressive strength of the concrete.

By combining the results of TSC1 and TSC2 test specimens and drawing the tensile strength and compressive

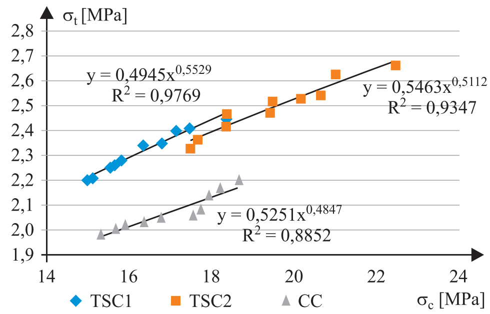

Fig. 6. The relationship between compressive strength and tensile strength

Rys. 6. Zależność między wytrzymałością na ściskanie a wytrzymałością na rozciąganie

strength curve, the relationship between compressive strength and tensile strength in TSC was obtained in accordance with equation (4). Figure 7 shows the relationship between the compressive strength and tensile strength in TSC.

$$\sigma_t = 0.6383\sigma_c^{0.4601} \quad (4)$$

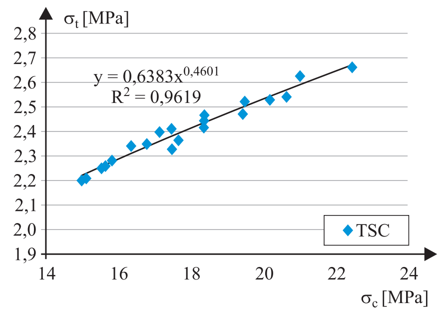

Fig. 7. The relationship between compressive strength and tensile strength for TSC

Rys. 7. Zależność między wytrzymałością na ściskanie a wytrzymałością na rozciąganie TSC

Conclusion

According to the experiments carried out in this study, it can be concluded that coarse grain aggregates play a very important role in the two-stage concrete resistance parameters. The fine grained gravel increases the compressive strength, increases the tensile strength, increases the elastic modulus, and reduces the TSC Poisson's coefficient. Using finer gravel, the TSC compressive strength was 1.15 times higher than that of conventional concrete. The modulus of elasticity of TSC2, 1.22 times the CC. The tensile strength of the TSC with finer aggregate was also 1.2 times higher than that of CC. The Poisson ratio of TSC of the second type was 0.96 times the CC. According to the results, TSC with suitable mix selection has higher resistance properties than CC and can withstand higher compressive and tensile strengths than CC. Due to the increasing use of concrete and the fact that TSC can be technically and economically better than conventional concrete, it is recommended to apply applied research in this subject.

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