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Experimental Study on the Use of Granite as Fine Aggregate in Very-High-Strength Concrete

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Experimental Study on the Use of Granite as Fine Aggregate in Very-High-Strength Concrete

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Abstract. The aim of the study is to assess the usefulness of using granite aggregate to make very-high-strength concrete. The paper presents a comparative analysis of the results that are obtained for three types of concrete mixtures. The main components of the analysed concretes are sand or granite aggregates and cement CEM I 52,5 with the addition of microsilica and fly ash. The first, basic concrete mixture is made using sand as aggregate. The main assumption for the basic concrete mixture is to obtain a compressive strength of not lower than 100 MPa in normal conditions of curing in water. Furthermore, using the aggregate fractions up to 2 mm and the semi-liquid consistency (i.e. ≥S3) of the concrete mixture are assumed. The second concrete mixture contains granite aggregate added in the same proportion as sand in the basic mixture. While in the third concrete mixture, the granite aggregate is used taking into account density factor. Laboratory tests are carried out in range of compressive and flexural strength of concrete. Furthermore, the investigations of the consistency of concrete mixtures and the water absorption by the hardened concrete are presented in the paper. Comparative analysis of the obtained results indicates that the exchange of sand to granite aggregate improves the compressive and flexural strength of concrete. Compressive strength of concrete based on granite aggregate is 10% higher than that of concrete based on sand. The test results indicate that both concrete made of sand and concrete made of granite aggregate can be qualified as very-high-strength.

1. Introduction

The analysis of high strength concrete made with using different types of additives is the subject of various studies. These studies differ in scale, scope, and detail degree of analysis. Experimental analysis for the strength properties of High Performance Concrete (HPC) is presented in [1], while the results for HPC made using recycled aggregates are presented in [2]. The influence of elevated temperatures on the strength proprieties of High Performance Concrete is presented in [3], [4] and [5]. The influence of various additives on properties of High Strength Concrete is presented in [6]. In most cases, in order to achieve very – high strength of concrete above 100 MPa, it is necessary to use an increased amount of cement (over 700 kg /m^3), various types of additives, such as fibres or applied special curing conditions.

The aim of this work is to investigate the granite aggregate usefulness to make very-high strength concrete without special curing conditions. Granite is a magma deep rock with a crystalline structure, made of quartz, potassium feldspar, plagioclase and biotite. Granite is a common rock with a content of over 65% SiO_2, which has a compressive strength of 100-250 MPa and a tensile strength of 5 -15 MPa. Experimental investigations on the use of granite aggregate in high strength concrete mixtures

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are presented in [7] and [8]. The obtained results indicate that granite aggregate influences the concrete strength improvement. Comparative analysis of influence of aggregate type including granite on mechanical properties of high-performance concrete subjected to high temperature was presented in [9]. In all analysed cases, the use of granite aggregate in HPC can be positively evaluated.

The purpose of the work is to check the impact of using granite aggregate on the properties of very high strength concrete. In the paper, the results of a comparative analysis of a very high-strength concrete made on the basis of sand and granite aggregate are presented. The main aim during the development of the composition of concrete mixtures was to ensure the practical use of the very high strength concrete mixture in structural elements with a complex, spatial structure of reinforcement. The consistency class of the concrete mixture not lover than S3 was assumed. The aim is to obtain the maximum strength with using the typical components of the concrete mixture and with maintaining the traditional care conditions. Moreover, the use of the aggregate fraction up to 2 mm and the use of cement CEM I 52.5 in the amount of up to 600 kg / m^3 was assumed.

2. Subject of study

The tests were carried out for three recipes of concrete mixtures made using cement CEM I 52.5. The basic concrete mixture designated as MS was designed on the basis of sand whose fraction was from 0.125 mm to 2 mm. The value of the coefficient *w/c* = 0.33 and the value of the coefficient *w/b* = 0.26 was assumed. The *w/c* ratio expresses the weight relation of the amount of water to the amount of cement used to make the concrete mixture. While the *w/b* ratio expresses the relation of the amount of water to the amount of cement including the addition of ash and microsilica. The ratio *w/b* was determined in accordance with standard [10] assuming a coefficient *k* value of 2 and 0.4 for microsilica and fly ash, respectively. Then, the base concrete composition was modified by exchanging sand into granite aggregate with the same fraction and with assumption the ratios value of *w/c* = 0.33 and *w/b* = 0.26. On the basis of the modified recipe of the base concrete, the MG1 series concrete was designed containing granite aggregate added in the same proportion as sand in the concrete mixture MS. The composition of MG2 mixture was determined using the aggregate density factor. The amount of granite aggregate was proportionally increased, with simultaneous reduction in the amount of cement, fly ash, microsilica and water. The assumed values of *w/c* and *w/b* coefficients remained unchanged. The composition of basic concrete MS and concretes MG1 and MG2 that based on granite aggregate are presented in Table 1.

Table 1. Compositions of basic concrete MS and concretes based on granite aggregates MG1 and MG2

Component	Quantity per unit volume of concrete mixture		
	MS Series	MG1 Series	MG2 Series
Aggregate type	Sand	Granite	
Cement CEM I 52.5 [kg]	600	600	567
Fly ash [kg]	100	100	94.5
Microsilica [kg]	80	80	75.6
Agreggate – fraction 0.125-1 mm [kg]	768.5	786.5	822
Agreggate – fraction 1-2 mm [kg]	650	650	695
Water [dm^3]	190	190	180
Additives [dm^3]	7.8	9.0	9.0

Fly ash used as an additive to concretes meets the requirements of the standard [11]. Due to the calcination loss not exceeding 5%, fly ash has been classified as category A and category N due to its fineness, with a density of 2100 kg / m^3 (± 200 kg / m^3).

The consistency of a concrete mixture is tested using the slump test in accordance with the standard [12]. The results of the consistency tests that are carried out for base concrete mixture MS and concrete mixtures on granite aggregates MG1 and MG2 are presented in Table 2.

Table 2. Results of testing the consistency and temperature of concrete mixtures.

Parameter	Concrete mixture [MPa]		
	MS Series	MG1 Series	MG2 Series
Slump [mm]	140	120	110
Consistency class	S3	S3	S3
Temperature of concrete mixture [°C]	18	18	18

The test results indicate differences in the consistency of concrete mixtures. With the increase of the amount of granite aggregate in the concrete mixture, a reduction of the consistency class was observed.

3. Experimental investigations of compressive strength

The tests were carried out on cubes of 100 mm. The specimens were prepared and conditioned in accordance with the standard [13]. After 28 days of curing, the concrete compressive strength tests were carried out in accordance with the standard [14]. The results of compressive strength tests for concretes are presented in table 3.

Table 3. Compressive strength of cubic concrete specimens with dimensions of 100 mm after 28 days of curing

Specimen number	Compressive strength $f_{c,i}$ [MPa]		
	MS Series	MG1 Series	MG2 Series
i=1	115.3	131.3	115,8
i=2	119.5	122.2	121.8
i=3	114.8	127.9	120.3
$f_{c,av}$	116.5	127.1	119.3
Standard deviation	2.08	3.75	2.55

Comparative analysis of the results shows that the highest compressive strength was obtained for MG1 concrete. MG1 concrete is made of granite aggregate that was added in the same proportion as sand in basic concrete MS. MG1 concrete strength is 9% higher than MS concrete strength and 6.6% than MG2 concrete. MG2 concrete is composed of granite aggregate taking into account the coefficient reducing the amount of cement and water due to differences in density of granite aggregate and sand. MG2 concrete strength is only 2.4% higher than MS concrete strength.

Comparing the strength results obtained on individual concrete specimens, we can also notice a greater convergence of the compressive strength tests results obtained for concrete MS made on sand, Figure 1. The standard deviation of results for MS is only 2.08, while for concrete series MG1 and MG2 composed of granite aggregate it is 3.75 and 2.55, respectively.

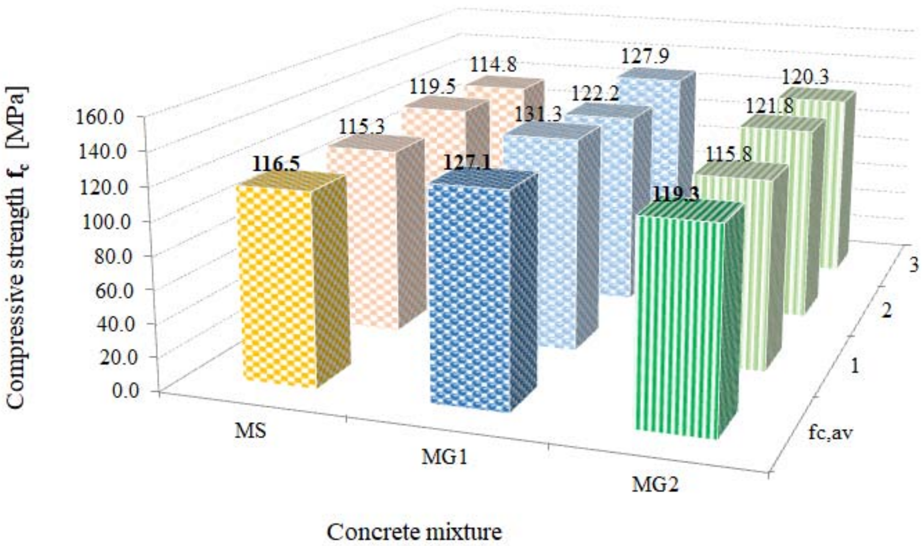

Figure 1. Compressive strength obtained for MS, MG1 and MG2 concrete series

4. Experimental investigations of flexural strength

The test of flexural strength of concrete with the centre - point loading was carried out for three series of concrete MS, MG1 and MG2 in accordance with standard [15]. Flexural strength of concrete is an indirect measure of the tensile strength. In each series, three rectangular specimens with dimensions of 40 x 40 x 160 mm were subjected to testing. The flexural strength is given by the equation:

$$f_{cf} = \frac{3Fl}{2d_1 d_2^2} \tag{1}$$

where:

f_{cf} is flexural strength of concrete, in MPa,

F is maximum load, in N,

l = 120 is the distance between the supporting rollers, in mm,

d_1 = 40 and d_2 = 40 are the lateral dimensions of the specimen, in mm.

In the experimental test for each specimen, the maximum force F is determined. The force F is the basis for determining the flexural strength of concrete according to the equation (1). In Table 4, the test results of flexural strength of concrete are presented.

Table 4. Flexural strength of concrete

Specimen number	MS Series		MG1 Series		MG2 Series	
	F_i [kN]	f_{cf} $[MPa]$	F_i [kN]	f_{cf} $[MPa]$	F_i [kN]	f_{cf} $[MPa]$
i=1	5.66	15.93	6.10	17.16	6.04	16.99
i=2	5.71	16.05	6.07	17.07	6.11	17.18
i=3	5.65	15.90	5.91	16.62	6.24	17.55
$f_{cf,av}[MPa]$		15.96	16.95		17.24	
Standard deviation		0.063	0.235		0.233	

The tests showed that the highest value of flexural strength was obtained for concrete of the MG2 series that contains the least amount of cement and increased amount of granite aggregate. The average flexural strength of concrete MG2 is 8% higher than the strength of the MS base concrete and 1.7% higher than the strength of MG1 concrete that contains granite aggregate and the maximum amount of cement. However, the test results obtained for concretes MG1 and MG2 on the basis of granite aggregates are characterized by the highest standard deviation, which is almost four times larger than the standard deviation of the results obtained for concrete of the MS series.

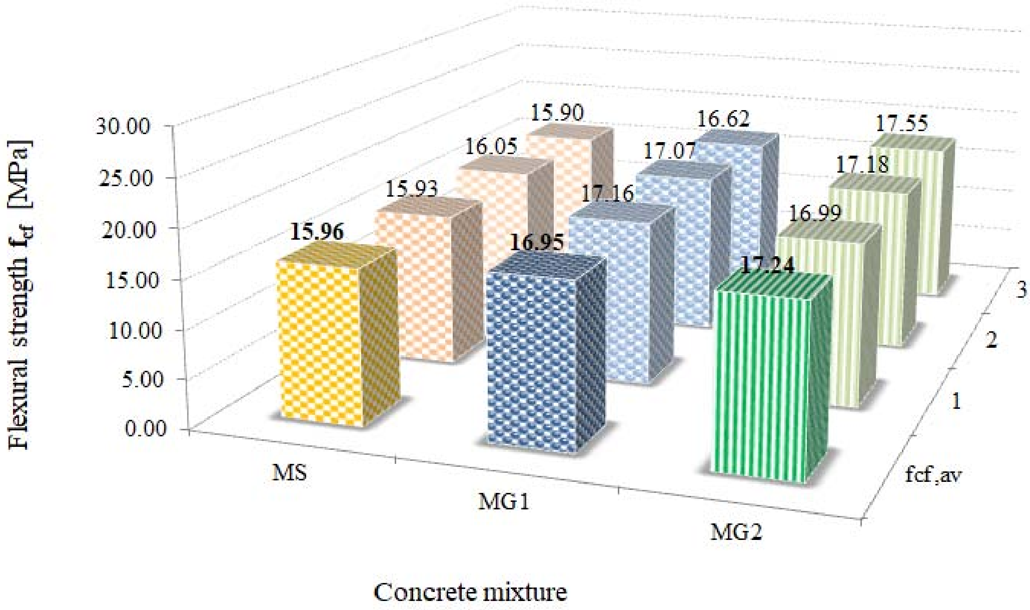

Figure 2. Concrete flexural strength of MS, MG1 and MG2 concrete series

When comparing the results obtained in flexural and compression tests, it can be noticed that flexural strength of MG2 concrete is 14.5% of compressive strength achieved after 28 days, for MG1 concrete the relation is 13.3%, whereas for MS-based concrete the relation is 13.7%. The relationship between average flexural and compressive strength is shown in Figure 3.

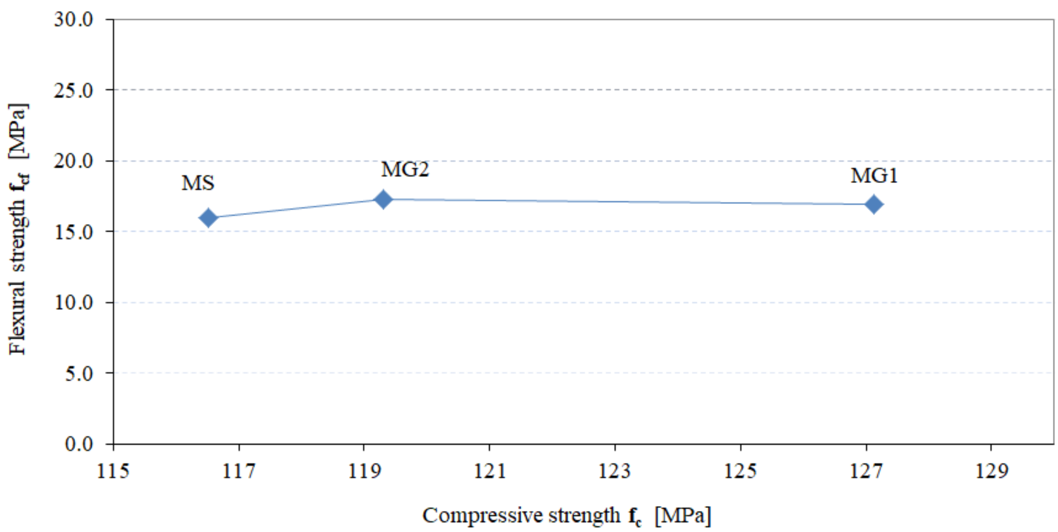

Figure 3. Flexural strength vs. compressive strength of concrete series MS, MG1 and MG2

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5. Simplified test of the water absorption by hardened concrete

Simplified test of the water absorption in hardened concrete of the MS, MG1 and MG2 series was carried out by comparing the weight of cubic specimens before insertion into water and immediately after being removed from the water after 28 days of curing. The first measurement of the specimen's weight was carried out after 20 hours from their implementation, immediately after the demoulding of specimens. The concrete specimens were conditioned in water at a temperature of 20-22 °C to the 28th day of curing. In order to provide proper circulation of water, the space between the specimens and between the specimens and the side of the curing tank was not less than 20 mm. The second measurement of the weight of specimens was made after 28 days of curing when they were taken out of the water. The measurements were made using an electronic balance with an accuracy of 0.01 g. The tests were carried out on cubic specimens with 100 mm side for each series of concrete. The water absorption parameter for each concrete specimen is determined on the basis of the formula:

$$w_i = \frac{m_i^1 - m_i^{28}}{m_i^1} \cdot 100 \qquad (2)$$

where:

w_i is the parameter of water absorption in hardened concrete, in %,

m_i^1 is the weight of the i-th specimen after demoulding in the first day of curing, in g,

m_i^{28} is the weight of the i-th specimen after 28 days of ripening in water, in g.

The results of measurements are summarized in Table 5.

Table 5. The water absorption by hardened concrete

Specimen number	MS Series			MG1 Series			MG2 Series		
	m_i^1 g	m_i^{28} g	w_i %	m_i^1 g	m_i^{28} g	w_i %	m_i^1 g	m_i^{28} g	w_i %
i=1	2365.58	2374.68	0.38	2403.72	2420.10	0.68	2342.59	2356.30	0.59
i=2	2366.63	2378.15	0.49	2353.19	2369.40	0.69	2299.23	2312.80	0.59
i=3	2366.99	2377.55	0.45	2351.89	2369.50	0.75	2330.29	2344.70	0.62
w_{av}	0.44			0.71			0.60		
Standard deviation	0.042			0.030			0.010		

Comparative analysis of the results presented in Table 4 indicates that the lowest absorption parameter is obtained for specimens of MS concrete made using sand. Concretes MG1 and MG2 composed of granite aggregate were characterized by a higher water absorption compared to MS concrete. The average value of the absorbability parameter for MG1 concrete is 61.3% higher, and for MG2 concrete it is 36.4 % higher than the average value of the absorption parameter for concrete MS. The average value of the absorbability parameter for MG1 concrete is 18.3% higher than for MG2 concrete, which contains the largest amount of granite aggregate.

6. Conclusions

The results of the conducted investigations indicate the improvement of the strength properties of concrete after using granite aggregate instead of sand. Compressive strength of concrete based on MG1 granite aggregate is 9% higher than that of MS base concrete. The MG1 concrete is also characterized by the 6% higher flexural strength compared to MS concrete. However, the highest value of flexural strength is obtained by MG2 concrete that contains an increased amount of granite aggregates. This strength is 8% higher than the strength of MS concrete. It should be noted that reducing the amount of cement with additives and water, while increasing the amount of granite aggregate in the MG2 concrete, caused a considerable decrease in the compressive strength of the concrete with a simultaneous increase of the flexural strength of concrete. The results of testing the consistency of concrete mixtures indicate a significant change of the consistency after application of granite aggregate. Granite aggregate is characterized by a greater water demand. As the amount of granite aggregate increases in the concrete mixture, a smaller slump is observed. Ensuring the assumed consistency of a concrete mix containing granite aggregate requires increasing the amount of plasticizing additives. An important feature of the designed concrete mixtures is a very-high compressive strength and consistency that allows it to be used in construction in practice. Due to the use of aggregates with a fraction of up to 2 mm, these concrete mixtures can be used for structural elements with a complex, spatial structure of reinforcement. Modification of the base mixture by using granite aggregate while maintaining the assumed aggregate and consistency fraction allowed to obtain concrete with a significantly increased compressive strength. Both the base concrete composed of the sand and the concrete series containing granite aggregate can be qualified for very-high-strength concrete.

In view of the obtained test results, the suitability of using granite aggregates for very-high-strength concrete can be concluded. It is advisable to carry out further investigations in order to optimize the composition of the concrete depending on the necessary strength properties.

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