THE EFFECT OF USING RECYCLED CONCRETE ON THE MECHANICAL AND TECHNOLOGICAL PROPERTIES OF CONCRETE IN THE PRODUCTION OF PRECAST

PETR JUNGA[1], JAROSLAVA HEJDOVA[1], JURAJ RUZBARSKY[2]

[1]Mendel University in Brno, Faculty of AgriSciences, Department of Agriculture, Food and Environmental Engineering, Brno, Czech Republic

[2]Technical University of Kosice with a seat in Presov, Faculty of Manufacturing Technologies, Presov, Slovak Republic

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e-mail: petr.junga@mendelu.cz

The paper deals with the verification of the possibility of replacing natural aggregate with recycled aggregate concrete (RAC) in the production of precast concrete. In the practical experimental part, concrete mixtures with different proportions of recycled concrete are tested. The results shows that the use of recycled concrete as a substitute for aggregates is possible. However, the ratio of replaced aggregate is important because of the higher proportion of concrete recycled material would result in deterioration of the final properties of the concrete.

KEYWORDS

Aggregate, concrete, recycled aggregate concrete, precast concrete, compressive strength, modulus of elasticity

1 INTRODUCTION

The use of recycled concrete contributes to reducing the environmental impact of the concrete use in construction. The replacement of natural aggregates with recycled concrete leads in particular to savings in renewable natural resources and the rational use of construction and demolition waste. Concrete, as the most widely used construction and building material, has been dominating the construction material market since 1900s [Wallberg 2016]. Using of concrete accounts for around 8% of the global carbon dioxide emission [Warburton 2020]. The part of sustainable built environment is use of recycled aggregate (RA) from CDW to replace natural aggregate (NA) in new concrete application as recycled aggregate concrete (RAC) can provide benefits for the environment and economy (using of RA as a replacement of NA for concrete construction could save 10 to 20% of the material cost [Zheng 2017]. With recycling coarse aggregates (RCA) it is possible to recycle the major part of the concrete waste so the major part of debris filled is reduced in unauthorised lands. In the next twenty to thirty years the recycling of concrete will have a huge role as the natural resources of aggregates are decreasing over the time [Gangaram 2018]. It can be concluded, the compression strength, Split Tensile Strength and Flexural Strength of the RCA concrete is sufficient and further it is possible to reduce W=C ratio to rise the compression strength for concrete utilised recycled coarse aggregate. The workability may decrease if the W/C ratio is reduced. For that the super plasticizers are used to obtain the workability of desired level [Arun 2021].

2 MATERIAL AND METHODS

Experimental test specimens (concrete strength class C40 / 50) with different proportions of natural aggregate and recycled aggregate are made. Tests for Static modulus of elasticity are performed on the test beams (dimensions width 100 mm, length 400 mm and height 100 mm). Test specimens (dimensions 150 mm, 150 mm and 150 mm) are used for compressive strength and watertightness tests.

2.1 Experimental methods

All procedures and methods used in the experiment are based on technical standards:

ČSN EN 12390-3 Testing hardened concrete – Part 3: Compressive strength of test specimens

ČSN EN 12350-5 Testing fresh concrete – Part 5: Flow table test

ČSN EN 12350-7 Testing fresh concrete – Part 7: Air content – Pressure methods

ČSN ISO 1920-10 Testing of concrete – Part 10: Determination of static modulus of elasticity in compression

ČSN EN 12390–8 Testing hardened concrete – Part 8: Depth of penetration of water under pressure

2.2 Experimental instruments and equipment

Used laboratory instruments and equipment:

Two-column test press brand VEB WPM Leipzig.

Drying equipment POL-EKO-APARATURA.

Vibrating table.

Water pressure stool.

Freezing box KD-20-T3.1

Air Entrainment Meter 8 Liter (Form Test).

Laboratory concrete mixer.

Large - volume concrete mixer.

2.3 Preparation of experimental specimens and test procedure specification

The recipe for concrete strength class C40/50 is used as the starting recipe for the test concrete mixtures production. C40/50 is typical for the production of structural elements of skeletal structures. The original recipe is compiled with respect to the parameters of a real large-volume concrete mixer, and therefore for the most experimental mixtures it is important to convert these values to ideal ratios for a laboratory mixer. The proportion of all raw materials is recalculated to a defined volume. This fact is considered in the tables for each experimental mixture.

Figure 1. Compressive strength test of the experimental cube

3 RESULTS AND DISCUSSION

3.1 Composition of concrete mixtures and test results

Experimental concrete mix No. 1 presents concrete with the least amount (9,0 kg) of recycled aggregate. Specification of experimental mixture No. 1 is presented in Table 1. The volume of fresh concrete is 44 liters. The temperature of the fresh concrete is 21,5 °C. Results of concrete spilling test, compressive strength (after 1, 7 and 28 days) and modulus of elasticity are presented in Table 6. The compressive strength results after 28 days and the static modulus of elasticity meet the requirements of the standard for C40 / 50. Result of watertightness test is 12 mm.

No. of experimental mixture and concrete specification	Material specification	Theoretical mixture [kg]	Real mixture [kg]
No.1; C40/50, volume of the mixture 44 l	Cement 42,5 R	19,3	19,3
	NA fraction 0-4 mm	32,8	30,57
	NA fraction 4-8 mm	8,5	8,5
	NA fraction 8-16	28,1	28,1
	Water	7,63	7,32
	Plasticizer 2180.1	0,175	0,175
	RAC	9	9

Table 1. Composition of the experimental concrete mixture C40/50 No. 1

Experimental concrete mix No. 2 presents concrete with the 10,3 kg of recycled aggregate. Specification of experimental mixture No. 2 is presented in Table 2. The volume of fresh concrete is 66 liters. The temperature of the fresh concrete is 17,5 °C. Results of concrete spilling test, compressive strength (after 1, 7 and 28 days) and modulus of elasticity are presented in Table 7. The compressive strength results after 28 days and the static modulus of elasticity meet requirements of the standard for C40 / 50 like the first experiment. Result of watertightness test is 9 mm.

No. of experimental mixture and concrete specification	Material specification	Theoretical mixture [kg]	Real mixture [kg]
No.2; C40/50, volume of the mixture 60 l	Cement 42,5 R	26,3	26,3
	NA fraction 0-4 mm	47,8	45,8
	NA fraction 4-8 mm	14,7	14,7
	NA fraction 8-16	32,1	32,1
	Water	10,4	12,8
	Plasticizer 2180.1	0,239	0,239
	RAC	12,2	10,3

Table 2. T Composition of the experimental concrete mixture C40/50 No. 2

Experimental concrete mix No. 3 presents concrete with the 10,4 kg of recycled aggregate. Microporan aerating additives are also used. Specification of experimental mixture No. 3 is presented in Table 3. The volume of fresh concrete is 60 liters. The temperature of the fresh concrete is 17,3 °C. Results of concrete spilling test, compressive strength (after 1, 7 and 28 days) and modulus of elasticity are presented in Table 8. The compressive strength results after 28 days and the static modulus of elasticity do not meet requirements of the standard for C40 / 50 and achieve the worst parameters. Result of watertightness test is 11 mm.

No. of experimental mixture and concrete specification	Material specification	Theoretical mixture [kg]	Real mixture [kg]
No.3; C40/50, volume of the mixture 60 l	Cement 42,5 R	26,3	26,3
	NA fraction 0-4 mm	47,8	45,2
	NA fraction 4-8 mm	14,7	8,5
	NA fraction 8-16	32,1	28,1
	Water	8,84	13,24
	Plasticizer (2180.1)	0,239	0,239
	Aeration additive (Microporan)	0,043	0,043
	RAC	12,2	10,4

Table 3. Composition of the experimental concrete mixture C40/50 No. 3

Experimental concrete mix No. 4 presents concrete with the 162,5 kg of recycled aggregate. Cement N 52,5 is used, which is typical for winter production. Specification of experimental mixture No. 4 is presented in Table 4. The volume of fresh concrete is 1000 liters. The temperature of the fresh concrete is 17,4 °C. Results of concrete spilling test, compressive strength (after 1, 7 and 28 days) and modulus of elasticity are presented in Table 9. The compressive strength results after 28 days and the static modulus of elasticity meet the requirements of the standard for C40 / 50 and achieve the best parameters. Result of watertightness test is 9 mm.

No. of experimental mixture and concrete specification	Material specification	Theoretical mixture [kg]	Real mixture [kg]
No.4; C40/50, volume of the mixture 1000 l	Cement 52,5 N	430	430
	NA fraction 0-4 mm	800	756
	NA fraction 4-8 mm	250	250
	NA fraction 8-16	595	595
	Water	165	245,5
	Plasticizer 2180.1	4,2	4,2
	RAC	200	162,5

Table 4. Composition of the experimental concrete mixture C40/50 No. 4

Experimental concrete mix No. 5 presents concrete with the 15,3 kg of recycled aggregate. Cement 42,5 R is used. Specification of experimental mixture No. 5 is presented in Table 5. The volume of fresh concrete is 60 liters. The temperature of the fresh concrete is 16,9 °C. Results of concrete spilling test, compressive strength (after 1, 7 and 28 days) and modulus of elasticity are presented in Table 10. The compressive strength results after 28 days and the static modulus of elasticity meet the requirements of the standard for C40 / 50. Result of watertightness test is 13 mm.

No. of experimental mixture and concrete specification	Material specification	Theoretical mixture [kg]	Real mixture [kg]
No.5; C40/50, volume of the mixture 60 l	Cement 42,5 R	26,3	26,3
	NA fraction 0-4 mm	44,7	42,2
	NA fraction 4-8 mm	14,7	14,7
	NA fraction 8-16	29,1	29,1
	Water	10,4	15,2
	Plasticizer 2180.1	0,239	0,239
	RAC	18,4	15,3

Table 5. Composition of the experimental concrete mixture C40/50 No. 5

No. of experimental mixture	Parameter	Measured value
No.1	Mixture temperature	21,5 °C
	Spill test of concrete	430 mm
	Weight of specimen 1	7,82 kg
	Weight of specimen 2	7,93 kg
	Compressive strength test of specimen 1 (day 1)	16,9 Mpa
	Compressive strength test of specimen 2 (day 1)	11,3 Mpa
	Compressive strength test of specimen 1 (day 7)	31,1 Mpa
	Compressive strength test of specimen 2 (day 7)	25,4 Mpa
	Compressive strength test of specimen 1 (day 28)	56,5 Mpa
	Compressive strength test of specimen 2 (day 28)	54,3 Mpa
	Watertightness test	12 mm
	E-modulus of specimen 1	29,8 Gpa
	E-modulus of specimen 2	29,2 GPa
	E-modulus of specimen 3	29,7 GPa

Table 6. Results of experimental tests – concrete mixture No. 1

No. of experimental mixture	Parameter	Measured value
No.2	Mixture temperature	17,6 °C
	Spill test of concrete	400 mm
	Weight of specimen 1	7,80 kg
	Weight of specimen 2	7,77 kg
	Compressive strength test of specimen 1 (day 1)	34,0 Mpa
	Compressive strength test of specimen 2 (day 1)	34,2 Mpa
	Compressive strength test of specimen 1 (day 7)	46,4 Mpa
	Compressive strength test of specimen 2 (day 7)	46,7 Mpa
	Compressive strength test of specimen 1 (day 28)	50,4 Mpa
	Compressive strength test of specimen 2 (day 28)	51,8 Mpa
	Watertightness test	9 mm
	E-modulus of specimen 1	30,7 Gpa
	E-modulus of specimen 2	29,3 GPa
	E-modulus of specimen 3	29,5 Gpa

Table 7. Results of experimental tests – concrete mixture No. 2

No. of experimental mixture	Parameter	Measured value
No.3	Mixture temperature	17,3 °C
	Spill test of concrete	430 mm
	Weight of specimen 1	7,41 kg
	Weight of specimen 2	7,38 kg
	Compressive strength test of specimen 1 (day 1)	14,3 Mpa
	Compressive strength test of specimen 2 (day 1)	14,1 Mpa
	Compressive strength test of specimen 1 (day 7)	31,6 Mpa
	Compressive strength test of specimen 2 (day 7)	33,6 Mpa
	Compressive strength test of specimen 1 (day 28)	42,0 Mpa
	Compressive strength test of specimen 2 (day 28)	38,9 Mpa
	Watertightness test	6,2 mm
	E-modulus of specimen 1	24,9 Gpa
	E-modulus of specimen 2	23,3 GPa
	E-modulus of specimen 3	24,5 Gpa

Table 8. Results of experimental tests – concrete mixture No. 3

No. of experimental mixture	Parameter	Measured value
No.4	Mixture temperature	17,4 °C
	Spill test of concrete	505 mm
	Weight of specimen 1	7,55 kg
	Weight of specimen 2	7,52 kg
	Compressive strength test of specimen 1 (day 1)	31,1 Mpa
	Compressive strength test of specimen 2 (day 1)	29,7 Mpa
	Compressive strength test of specimen 1 (day 7)	45,3 Mpa
	Compressive strength test of specimen 2 (day 7)	43,9 Mpa
	Compressive strength test of specimen 1 (day 28)	54,0 Mpa
	Compressive strength test	54,5 Mpa

	of specimen 2 (day 28)	
	Watertightness test	9,0 mm
	E-modulus of specimen 1	26,6 Gpa
	E-modulus of specimen 2	25,7 GPa
	E-modulus of specimen 3	25,7 Gpa

Table 9. Results of experimental tests – concrete mixture No. 4

No. of experimental mixture	Parameter	Measured value
No.5	Mixture temperature	16,9 °C
	Spill test of concrete	490 mm
	Weight of specimen 1	7,42 kg
	Weight of specimen 2	7,46 kg
	Compressive strength test of specimen 1 (day 1)	13,7 Mpa
	Compressive strength test of specimen 2 (day 1)	13,2 Mpa
	Compressive strength test of specimen 1 (day 7)	30,4 Mpa
	Compressive strength test of specimen 2 (day 7)	29,3 Mpa
	Compressive strength test of specimen 1 (day 28)	44,6 Mpa
	Compressive strength test of specimen 2 (day 28)	42,4 Mpa
	Watertightness test	13,0 mm
	E-modulus of specimen 1	24,7 Gpa
	E-modulus of specimen 2	23,6 GPa
	E-modulus of specimen 3	23,7 Gpa

Table 10. Results of experimental tests – concrete mixture No. 5

3.2 Evaluation of concrete spill tests

Figure 2 presents Spill test which is used to assess the consistency of a fresh concrete mix. Very dense concrete causes poor workability and compactness of fresh concrete mix and the formation of unwanted air caverns. Thin concrete mixtures cause lower strength and sedimentation, when the aggregate is not evenly distributed in the concrete mass. Tests of all samples meet the requirements of the standard for concrete class C 40/50. Mixture No. 2 was denser (400 mm), but the difference is not significant. Mixture No. 4 has the highest value of the result. Mixture No. 4 has the highest result of this test (505 mm). This fact can be caused by the reason that this mixture is processed in real large-volume concrete mixer.

Figure 2. Spill test of the experimental concrete mixture No. 2

3.3 Evaluation of compressive strength tests

It is a basic strength test for the evaluation of concrete elements. Compressive strength results after 28 days are averaged. Mixtures No. 1 (55,4 MPa), No. 2 (51,1 MPa), No. 4 (54,2 MPa), meet the requirements of the standard. Mixture No. 3 with aerating additives has substandard parameters. Mixture No. 5 contains a larger amount of recycled aggregate, which had a negative effect on strength, similarly to Mixture No. 3. It can be stated that it is not appropriate to use recycled aggregate in larger quantities, because the strength is reduced. The use of aerating additives in mixture No. 3 need to be verified by further experiments, as it may not always be negative.

3.4 Evaluation of modulus of elasticity tests

The modulus of elasticity test defines the deformation characteristics of the material in compression. Modulus of elasticity results are averaged. The best results were obtained on test specimens of mixture No. 1 (29,4 GPa) and No. 2 (29,8 GPa) and meet the requirements of the standard. The parameters are worsened again in the case of mixtures No. 3 and No. 5.

3.5 Evaluation of watertightness tests

All results for the determination of water leakage on test specimens correspond to the standard. The best resistance to leakage was in the test specimens from the mixture No. 2 and No. 4 (9 mm). It can be stated that the use of recycled aggregate is possible in terms of watertightness.

3.6 Discussion

Experimental mixtures No. 1 and mixtures No. 2 have very good compressive strength and modulus of elasticity results. The results of the spill test were less acceptable. The watertightness test was satisfactory. The test results show that the mixture No. 3 (with aerating additive Microporan) is the least suitable variant. The test specimens show insufficient compressive strengths and values for the modulus of elasticity also do not represent good deformation characteristics. Mixture No. 4 is the only one made in a real concrete mixer. A cement of higher strength class (52.5 N) is used in this case. The result is the very good compressive strength. The spill test is the best of all experimental mixtures. The result of the modulus of elasticity is slightly better than in the case No. 3. The last mixture No. 5 is tested with a larger amount of concrete recycled aggregate. The results show that a higher amount of recycled aggregate in mixture has a negative effect on the properties of the finished concrete. Results of compressive strength test after 28 days are unsatisfactory (42,9 MPa). Result of waterproof test is worst (13 mm). Modulus of elasticity is smallest of all experimental specimens.

For comparison [Park 2013] stated that the compressive strength of recycled aggregate concrete had a decrease up to 7% if 0.05% aluminium impurities (size 2.5-5 mm) were in the aggregate. Study of [Brito 2005] stated that concrete strength of the RAC or the referential NAC (natural aggregate concrete) ranged mainly from 20 MPa to 80 MPa (i.e. 13 MPa to 23 MPa for non-structural concrete application). [Ruaa 2021] test results indicated that the percentage of compressive strength declines at different percentage of the recycled fine and coarse aggregates more than the tensile and flexural strength. Also, it was found that applying the recycled coarse and fine aggregates in concrete mixes with percentage of replacement 100% resulted in a less decreases in the strength. [Ruaa 2021] stated that the percentage of compressive strength declines at different percentage of the recycled fine and coarse aggregates more than the tensile and flexural strength. Also, it was found that applying the recycled coarse and fine aggregates in concrete mixes with percentage of replacement 100% resulted in a less decreases in the strength. [Donza 2002] stated that increase in compressive strength was attributed to the filler effect of RCA, part of which was finer than the natural sand, making concrete more compact and denser, reducing the internal stresses and early propagation of cracks. [Sowmya 2000] stated that compressive strength of concrete fabricated from the recycled aggregates was about 76% of the strength of concrete fabricated from natural aggregates for normal strength concrete (C16/20). [Kwan 2012] stated that higher proportion of RA was adverse on the mechanical strength and elastic modulus because of a higher porosity and a weaker interfacial transition zone (ITZ).

4 CONCLUSIONS

It can be stated that the use of recycled concrete as a substitute for aggregates is possible. However, the proportion of replaced aggregate is important, because a higher proportion of recycled concrete results in a deterioration of the final mechanical and technological properties of the concrete. The CSN EN 206 +A1 standard states the possibility of replacing aggregates with recycled material up to 30% if it is recycled material from a known source and it is used in concrete with the same degree of environmental criterion. If the correct technological procedure is followed, the precast production with recycled concrete is possible.

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CONTACTS:

Assoc. prof. Ing. Petr Junga, Ph.D.
Faculty of AgriSciences / Mendel University in Brno, Department of Agriculture, Food and Environmental Engineering
Zemedelska 1, Brno, 613 00, Czech Republic
+420 545 132 368, petr.junga@mendelu.cz

Ing. Jaroslava Hejdova
Faculty of AgriSciences / Mendel University in Brno, Department of Agriculture, Food and Environmental Engineering
Zemedelska 1, Brno, 613 00, Czech Republic
jaroslava.hejdova@mendelu.cz

Assoc. prof. Ing. Juraj Ruzbarsky, Ph.D.
Faculty of Manufacturing Technologies / Technical University of Kosice with a seat in Presov, Department of Manufacturing Processes Operation
Bayerova 1, Presov, 080 01, Slovak Republic
juraj.ruzbarsky@tuke.sk