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Use of Recycled Aggregate in the production of Structural Concrete

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***Abstract*:** *The application of building rubble made from damaged or demolished structures is an important problem in every large city. After each construction disaster concrete rubble is exported to landfills but it may be a good construction material. This paper presents the possibilities of recycled aggregate application in concrete mix-recycled aggregate concrete (RAC) for the needs of construction of reinforced concrete structures. Recycling the concrete materials is one of the measures to reduce the burden on public fill capacities. Motivations for adopting recycled concrete as an aggregate source include the preservation of natural resources, effective utilization of a growing waste stream and energy savings.*

Keywords: *recycling, recycled aggregate concrete, environmental protection, reinforced concrete beams, reuse of building materials;*

1. Introduction

The problem of reusing concrete debris was noticed since many years. In developed countries such as Japan, Germany or the USA secondary aggregates called Recycled Coarse Aggregate are a commercial product which is used on a large scale. The main reason is that recycled aggregate contains significant amount of porosity in clinging mortar or paste. Some studies concerning concrete and reinforced concrete (RC) made of recycled aggregate have been made [1],[2],[3]. One of these problems is the high porosity of such aggregate which is the result of the presence of old cement mortar in its composition. This old cement mortar, which surrounds natural aggregate, can cause its increased absorption and shrinkage of concrete. The amount of mortar surrounding the aggregate may vary and fluctuate up to 50% of the volume of such aggregate. The schematic structure of recycled coarse aggregate (RCA) is shown in Figure 1.

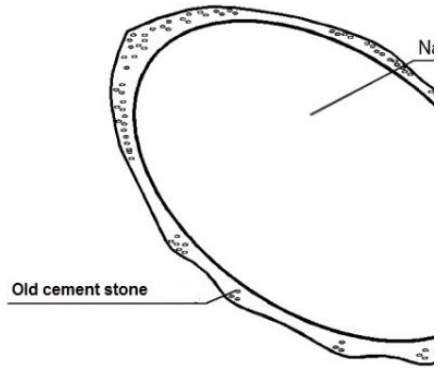

Fig. 1: Schematic structure of RCA grain

2. Own research of recycled aggregate concrete

The exploratory studies showed reduced strength of concrete with recycled concrete as compared to the natural aggregate [4],[5],[6]. Research shows that compressive strength of RAC is about 10%-15% smaller than concrete made of natural aggregate but there were such a series where the difference increased up to 40% see Figure 2. The presence of old concrete stone negatively affects the new formed concrete, reduces its strength, coefficient of elasticity and increases shrinkage and creeping of concrete. Engineers and constructors have concerns about the possibility of the use of recycled aggregate concrete (RAC) in concrete construction.

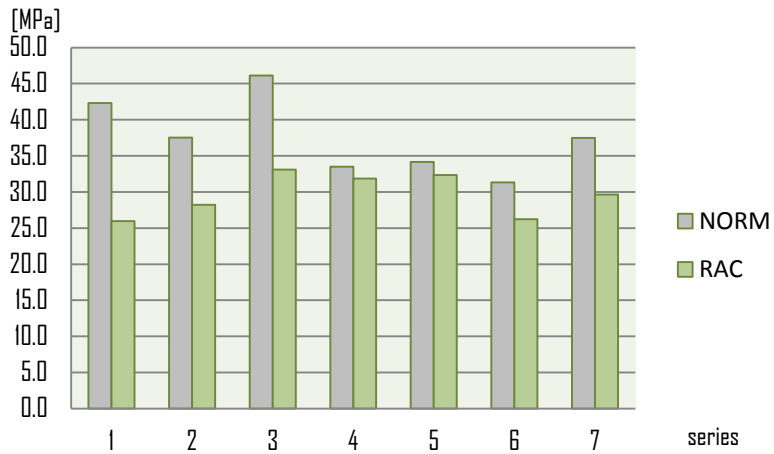

Fig. 2: The average compressive strength of NORM and RAC

Also the comparison of the mean strength of concrete evaluated from the tests conducted on model beams is shown in Figure 1. Reduction of tensile strength was at a level of- 10 ÷ 20%. Shrinkage of RAC was about 30 ÷ 55% greater as compared to the concrete made of natural aggregate.

3. Assumptions for experimental research of concrete samples

As part of the initial testing of concrete samples studies were carried out. All samples were without reinforcement. Measurements were made in two stages. In the first stage tests samples were conducted force until failure. These measurements were used as a reference point for successively conducted research on models of reinforced concrete beams. In the exploratory studies on samples without reinforcement it was also carried out studies long-time behaviour, aimed at analysis of the deformation of the micro-level as a function of time at constant loading force. Loading force was taken as approx. 30% of destructive force, observed in short-time studies. observation took thirty days. The tests were examined 2 series, the first was made completely on the natural aggregate (NAT), the second was made with recycled aggregate concrete (RAC).

Because of the small cross section of the concrete samples is restricted to use only a fraction of 2-4 mm as a coarse aggregate. Table 1 shows the mix of concrete formulations used in experimental research. In both mixes the fine fraction (0 - 2 mm) was made from the natural river sand.

TABLE I: Data composition of recycled aggregate concrete and natural aggregate concrete used in tested beams

w/c	Cement, [*kg*]	Water [*l*]	Sand, [*kg*]	Coarse aggregate, [*kg*]
				2-4 mm
0,7	270	190	575	689

The loading scheme in a three-point test is shown in Figure 3, the test stand during long-term tests are shown in Figure 4. The stand was equipped with a dial gauge to measure the deflection in the middle of the span.

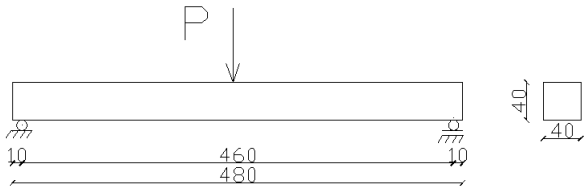

Fig. 3: The scheme of tested samples [mm]

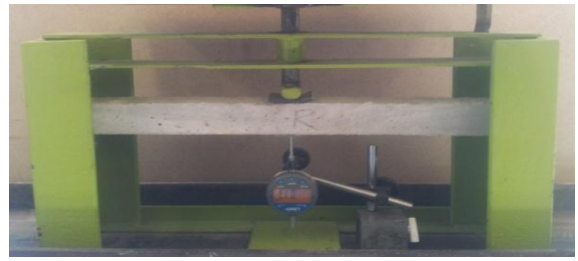

Fig. 4: The view of the test stand showing the method of samples loading in long-term tests

4. Discussion of research findings

4.1. Short time loading of concrete samples

The exploratory studies on concrete samples are shown in Fig.5. During the load deflection was in the middle of the span measured. The graph shows the relationship between force [N] and deflection, until the failure. The tests clearly showed that samples made of the secondary aggregate have a higher deflection and have less load capacity than the control elements made of ordinary aggregate. Flexural strength and compressive strength of concrete samples are shown in Table 2. Flexural strength was about 10% lower in RAC series and only 3% lower compressive strength were examined for samples (4x4x4cm).

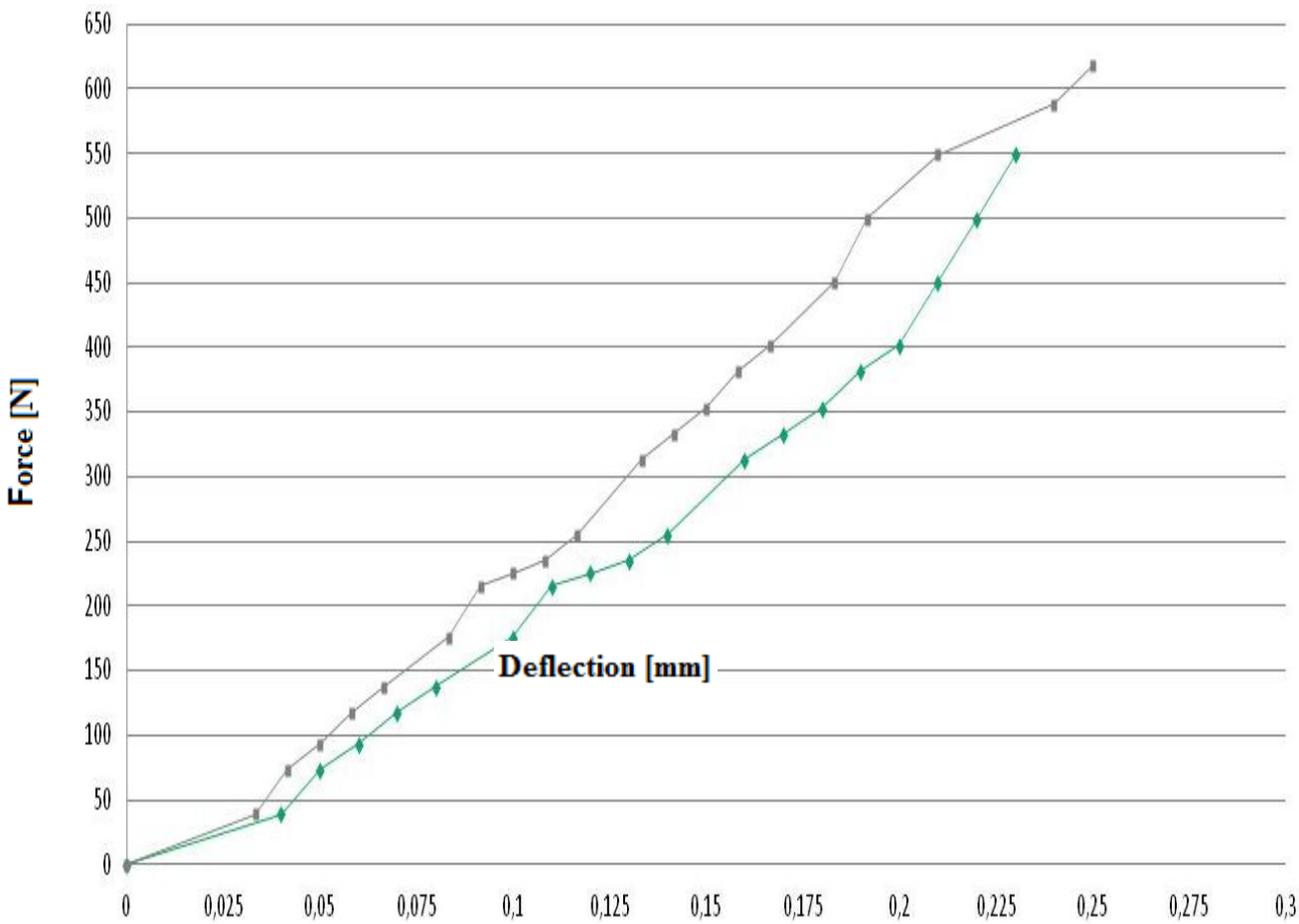

Fig. 5: Diagram of deflections [mm] of NAT and RAC samples under short time loading [N]

TABLE II: Flexural and compressive strength of concrete in tested samples

Series specification	Type of aggregate	Cross section [cm]	flexural strength f_{ct} [MPa]	compressive strength f_{cm} [MPa]	
1	NAT	4x4	7,3	37,2	39,1
1	NAT	4x4	8,2	39,7	37,8
2	NAT	4x4	8,0	38,3	39,0
2	NAT	4x4	8,4	39,2	38,7
3	NAT	4x4	7,2	37,9	36,4
3	NAT	4x4	7,8	38,6	39,6
	average		7,8	average	38,4
4	RAC	4x4	7,6	39,5	38,4
4	RAC	4x4	6,9	35,9	38,2
5	RAC	4x4	6,5	34,6	36,4
5	RAC	4x4	6,2	39,4	36,4
6	RAC	4x4	7,1	39,5	38,1
6	RAC	4x4	7,8	36,2	35,4
	average		7,0	average	37,3

4.2. Long time loading of concrete samples

Long-term tests were made similarly to short-time tests. The value of the force was accepted at the level of 30% of destructive force. The time dependent diagrams of deflections for two tested samples are presented in the Figure 6. It is clearly seen that the deflections of RAC samples are visible larger during all the time of loading in comparison with the NAT samples. The differences between deflections of the two samples after 35 days of testing were about 24%. The table 3 shows the average deflection measured at weekly intervals.

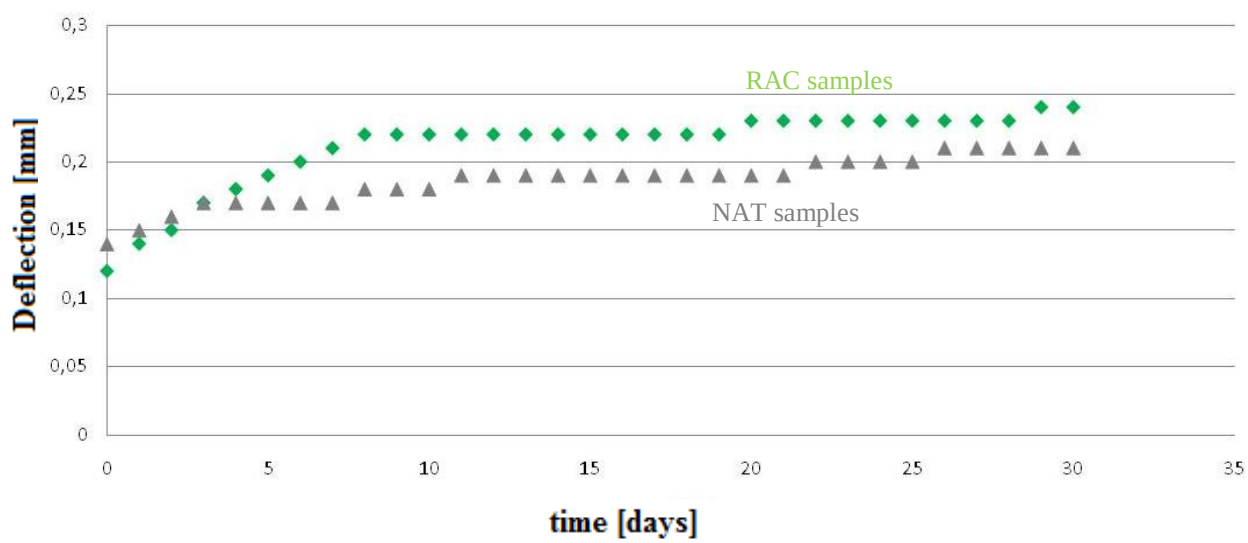

TABLE III: Deflection of concrete samples under long-term load

time/ concrete type	1-7 days	8-14 days	15-21 days	22-28 days
NAT	0,17	0,19	0,19	0,21
RAC	0,21	0,22	0,23	0,24
Δf [%]	1,24	1,16	1,21	1,14

5. Assumptions for experimental research of reinforced concrete beams

As part of the research some series of reinforced concrete beam models were tested (with the scheme shown in Figure 7). The beams were simply supported with the span of 999 mm. Cross-sections were 80x120 mm. The load was a system of two concentrated forces (the arrangement of reinforcement and the loading of model beams were shown in Figure 7). Five series of model beams were created any consisted of three specimens. The characteristics of reinforcement and concrete used were shown in Table 4. Concrete used for all series had similar composition. Concrete class C20/25 with plastic consistency was designed. Beams of R-series were created from the concrete made of crushed coarse recycling aggregate of C16/20 class. The load was subjected by two concentrated forces applied in the one-third of beam span's length.

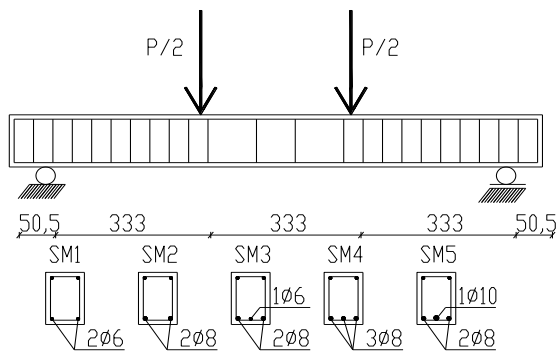

Fig. 7: The scheme of tested beams and the loading

Reinforced concrete model beams were subjected to short time bending tests on the test stands. The specimens were gradually loaded every 2kN till to failure. During the process of loading the cracks were examined and deflection in the mid span of beam was measured. Values of the cracking moment, the layout and width of crack openings were recorded. Beam deflections were measured using inductive sensors produced by Megatron Muenchen with the measuring range of 25 and 50 mm and the accuracy of 0.001 mm. Additionally, by using the DEMEC sensor the concrete strains were measured in several vertical cross sections and at several levels of the depth of the beam cross-sections.

TABLE IV: The specifications and main characteristics of tested model-scale beams

Series number	Series specification	Flexural reinforcement	Reinforcement ratio [%]
1	SM1-N, SM1-R	3Ø6	1,00
2	SM2-N, SM2-R	2Ø8	1,20
3	SM3-N, SM3-R	2Ø8+1Ø6	1,50
4	SM4-N, SM4-R	3Ø8	1,75
5	SM5-N, SM5-R	2Ø10+1Ø8	2,50

The measured deflections of reinforced concrete model beams with the reinforcement percentage of 1,00% was shown in Fig.8 and the beams with the reinforcement percentage of 1.20% - in Fig. 9. The results of reinforced concrete model beams tests showed in each series visible differences in behavior of beams made of recycled concrete in comparison to the beams made of natural aggregates. Beams made of recycled aggregates concrete (RAC) were cracked at a lower values of bending moment and showed greater deflections under comparable short time loads.

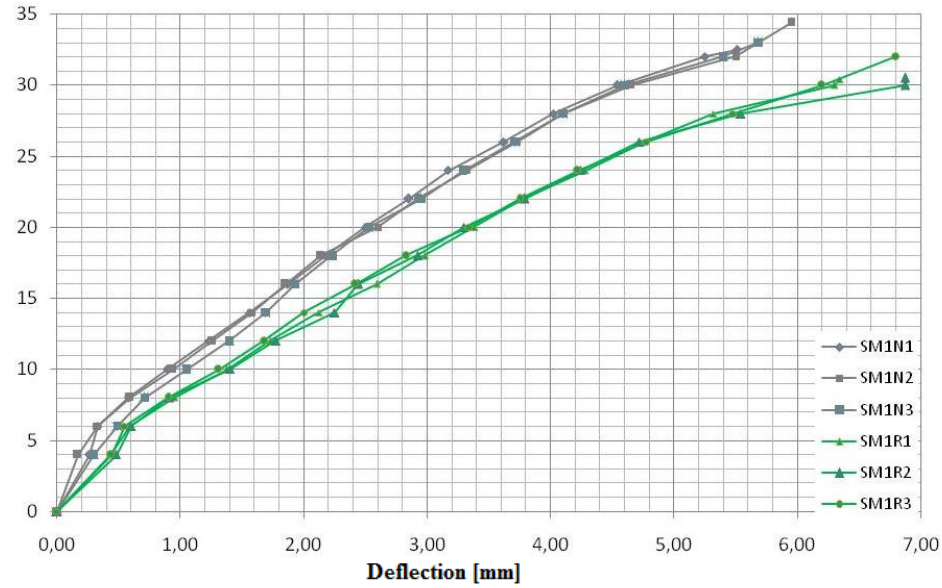

Fig.8. Diagrams of mean deflection values versus applied load for model-scale beams of SM1 series

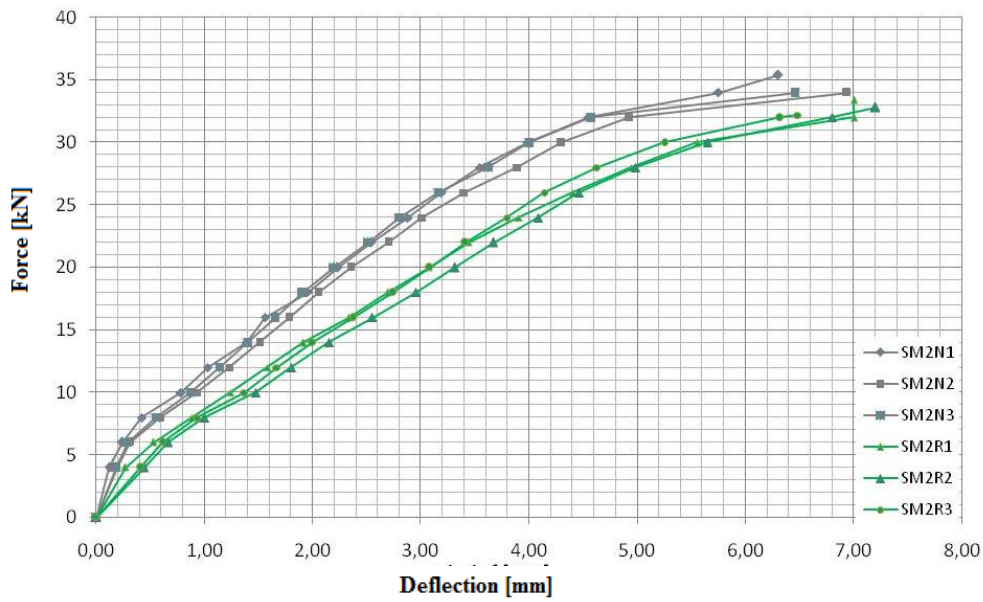

Fig.9. Diagrams of mean deflection values versus applied load for model-scale beams of SM2 series

To analyze the deflection of reinforced concrete model beams was evaluated the quantitative RAC beams to NAT beams. The comparison was made on the basis of calculation of the k_f indicator according to formula (1), and the results are shown in Table V.

$$k_f = \alpha_N / \alpha_R \tag{1}$$

where:

$\alpha_N [mm]$ - deflection of beams made of natural aggregates measured at selected level of loading

$\alpha_R [mm]$ - deflection of beams made of recycled aggregates measured at selected level of loading

TABLE V: The specifications and main characteristics of tested model-scale beams

Beam type	Series specification	Reinforcement ratio [%]	Force							
			P = 10 kN		P = 20 kN		P = 30 kN		P = 40 kN	
beam N / beam R	SM1	1,00	0,96 / 1,36	0,71	2,54 / 3,34	0,76	4,6 / 6,46	0,71	-- / --	--
beam N / beam R	SM2	1,20	0,86 / 1,36	0,63	2,26 / 3,15	0,72	4,1 / 5,48	0,75	-- / --	--
beam N / beam R	SM3	1,52	1,18 / 1,43	0,83	2,58 / 3,12	0,83	4,4 / 5,31	0,83	-- / --	--
beam N / beam R	SM4	1,78	1,11 / 1,38	0,80	2,75 / 3,26	0,84	4,72 / 5,35	0,88	-- / --	--
beam N / beam R	SM5	2,50	0,84 / 0,89	0,94	2,11 / 2,26	0,93	3,29 / 3,66	0,90	4,87 / 5,39	0,90

6. Summary and conclusions

Research has shown that it is possible to reuse concrete waste as recycling aggregate in concrete structures, but it should be taken into account the reduced strength properties of this concrete, and the increased time dependent deformability.

The research did not show a significant decrease in the flexural capacity compared to the carrying capacity of beams made of natural aggregates.

The lack of national guidelines and standards concerning the design of load-bearing elements made from recycling aggregate concrete makes it more difficult to widespread such uses of this concrete in constructions.

7. References

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