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Characteristics of Recycled Concrete Aggregates from Precast Slab Block Buildings

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Abstract. Precast slab block buildings (PSBB) typically and frequently occur in Central and Eastern Europe, as well as elsewhere in the world. Some of these buildings are currently used beyond their service life capacity. The utilization of recycled materials from these buildings with regard to applying the principles of sustainable construction and using recycled materials will probably be significant in the following years. Documentation from the manufacturing processes of prefabricated blocks for precast slab block buildings is not available, and also it is difficult to declare technological discipline during the construction of these buildings. Therefore, properties of recycled concrete aggregates (RCA) produced from construction and demolition waste (C&DW) of precast slab block buildings build between 1950s to 1990s are not sufficiently known. The demolition of these buildings is very rare today, but it can be assumed an increase in demolitions of these buildings in the future. The use of RCA in new concrete requires verification/testing of the geometrical and physical properties of RCA according to the EN 12 620+A1 standard. The aim of the contribution is to present a case study of the demolition of slab block building with emphasis on RCA usage. The paper presents the results of the tests according to European standards for determining selected geometrical and physical properties of the RCA. The paper describes and evaluates tests such as determination of particle size distribution - Sieve Analysis, content of fine particles, determination of density and water absorption. The results of the properties testing of RCA are compared with the properties of natural aggregate. The general boundary conditions of RCA particular tests are presented.

1. Introduction

Reducing the volume of construction and demolition waste is one of the world's and European's priorities [1] [2]. The global volume of C&DW is currently estimated about 3 billion tons per year [3]. Since most of the buildings contain a significant amount of concrete, it is logical that concrete rubble becomes a large proportion of the C&DW volume. Moreover, up to 70% of the concrete volume is constituted by aggregates [4]. It is unavoidable to handle recycled concrete efficiently and exploit its full potential for the creation of the sustainable construction industry principles. The current usage of concrete with recycled concrete aggregates depends on the available information about its physical and geometrical properties. Especially, if we talk about the utilization of RCA in a higher strength class concrete, particularly the utilization of RCA in the mix design for structural concrete. This issue is in Central and Eastern Europe augmented by widespread proportion of prefabricated buildings, constructed between 1950s and 1990s. All this is the reason for determining the appropriate manner

for reusing of RCA in the following years. Except for the extensive reconstructions and revitalizations that are currently underway, these buildings are already occasionally demolished now. The demolitions of PSBB are performed in the central Europe very rarely. It can be supposed that the number of demolitions of PSBB will grow over time due to their inconvenient comfort parameters, and thus a reduced demand for this type of housing. Other reasons are structural deficiencies, inadequate thermal insulating, fire safety requirements, etc. Many PSBB do not satisfy current legislative standards. There are also locations where are blocks of flats unoccupied and ruined in the Czech Republic and it is therefore a brownfields. The authors presented a paper about the re-use of these brownfields for recreational purposes in previous years [5], but the current situation and especially the large amount of these types of buildings also calling for the establishment of a sustainable solution of re-using materials from existing buildings which are near to end of their service life capacity and going to be demolished. The further application as a filling material can be considered as a waste of material with profitable properties. The paper presents a new findings about recycled aggregates, which comes from a PSBB near the city of Brno in the Czech Republic. Results from testing of properties of RCA originating from these types of buildings have not been presented yet.

1.1. Precast slab block buildings

To understand the scale of the problem of PSBB in Central and Eastern Europe, it is appropriate to present some statistical information. There are 214,760 residential buildings in the Czech Republic and 65,641 of them are precast slab block buildings, which is 35.56%. In these buildings lives 26.79% of the Czech population, which is 2,760,142 people. In these buildings are the total of 1,218,788 flats, which is 29.69% of all flats in the country. The flats determined as reduced quality housing is 66,831 flats, which affects approximately 5.5% of all flats [6]. The PSBBs are from 25 to 60 years old, depending on the year of execution. It means that in many cases PSBBs panels have achieved almost 70-75% of the estimated service life, i.e. they have reached approximately 25-70% of the expected "accounting life" (75-85 years). More than half of these buildings will reach 50-60% durability until year 2025 [7]. This is therefore a large and complex problem. In the Figure 1 the typical example of precast slab block building is presented.

Figure 1. A typical precast slab block building in its original condition in Brno

1.2. Recycled concrete aggregates

Obtaining appropriate quality of RCA from PSBB is the basic precondition for further effective use. Hitherto, the PSBB are demolished only in the traditional way, i.e. without material type separation. Components (concrete, glass, insulating material, etc.) are thus mixed and some of them even in an irreversible manner. Mixed C&DW does not have any meaningful use and thus gives rise to inapplicable C&DW. The recycled aggregates with undefined properties could be used to places with zero or low properties requirements. The new approach consists in determining of the necessary tests for evaluation of the properties of RCA, but also in the identification of appropriate recycling procedures of C&D waste for a subsequent use. Figure 2 shows a mobile jaw crusher for construction rubble in the process. The crusher is located on a typical courtyard owned by a construction company engaged in recycling of construction rubble in the city of Brno. In proposed case study was necessary to separate tested RCA immediately after the crushing directly into loader spoon and then into the bags.

Figure 2. Mobile jaw crusher during operating process at the plant

2. Methodology for RCA testing process

It is necessary to take preliminary test specimens from the demolished building before the RCA test performing. Specimen collection can be performed before the total demolition through partial sampling or removing parts of the constructions using core drills; or samples can be collected after the total demolition. In the case of core drilling, the cores have usually insufficient volume for an objective assessment of the entire building. In our case, the test specimens (concrete pieces) were collected after the total demolition of the PSBB Hotel Dukla in the town of Blansko. The individual elements for the construction of this PSBB were made in the precast factory in Blansko and construction was finished in 1981. Due to system planning of the Communist Party, mix design and types of used components for prefabricated elements can be read from the historical document "Enterprise Material Consumption Standards" for the "Building Structures Brno Enterprise" from January 1975. This document prescribes the mix design of concrete mixtures of the precast parent concrete with the designation B170, B250 and B330. A cement with the designation SPC250 which corresponds to today's Mixed Portland Cement CEM II 42.5 or PC400 was used which corresponds to today's Portland cement CEM I 42.5. Sand 0-4mm and gravel 4-8mm and 8-16mm has been transported from the quarries Ostrožská Nová Ves, Bratčice and Božice. Plasticizer was probably used in the mixture in dosage 0.735l/l q of cement because this admixture was recommended for the precast production.

It is necessary to be able to clearly identify which structure (walls, ceilings and stairs) each sample comes from. For the experiment two types of concrete were selected, namely R4 from peripheral concrete wall and R5 from concrete interior walls. The samples of concrete were crushed by mobile

jaw crusher to a fraction of 0-32mm and then sorted by coarse sieves into the basic fractions 0-4 mm, 4-8 mm, 8-16 mm and 16-32 mm.

For testing it is required to establish the minimum volumes of test samples for analysis, which are defined by the standards. The minimum amount of aggregate for individual tests is given for each test in the text below. For the appropriate use of recycled aggregate it is necessary to establish individual test methods by which we can indicate the properties of RCA. Valid methods for testing of aggregates according to EU standard EN 12 620+A1 [8] for concrete aggregates were selected. These individual tests were carried out according to the chronology of implementation.

2.1. Determination of particle size distribution - Sieve Analysis

A necessary characteristic for establishing new formulations of new concrete from RCA is to identify particle size distribution curve by Sieve Analysis. The test was performed according to EU standard EN 933-1:2012 [9]. It was selected sieving of the washed and dried aggregate. Drying of aggregates was carried out for 24 hours at ambient $110 \pm 5\ ^\circ$ C. Then aggregate was naturally cooled down and was weighed the mass M_1. For the test it was used the standard set of sieves according to EN933-2 [10] with square holes network: 0.063; 0.125; 0.25; 0.5; 1; 2; 3.15; 4; 5.6; 8; 11.2 and 16 mm. Test sample weight was according to EU standard for each fraction, i.e. 0-4 mm, 4-8 mm, 8-16 mm and 16-32 mm. The weight of aggregates trapped on each sieves were recorded and the percentage of aggregates trapped on each sieve calculated according to the formula (1) from the standard [9]:

$$\frac{R_i}{M_1} * 100\ [\%] \qquad (1)$$

where M_1 is the total mass of the test sample weight and R_i is the weight of material trapped on each sieve i. The results are presented graphically in the particle size distribution curves in Results.

2.2. Aggregate fines particles analysis

To determine the content of fine particles in the aggregate it was used the EU standard EN933-1: 2012. After the fall of aggregates through all sieves including sieve 0.063 mm, this residue was dried for 24 hours at $110 \pm 5\ ^\circ$C. The sample was then naturally cooled and the mass of M_2 was weighed. The percentage of fine particles was calculated according to the formula (2) from the standard [9]:

$$f = \frac{(M_1 - M_2) + P}{M_1} \times 100 \qquad (2)$$

where M_1 is the dry mass of aggregates samples in kilograms, M_2 is the dry mass of the residue trapped on the sieve 0.063 mm in kilograms and P is the mass of separated material passing the sieve 0,063 mm in kilograms. According to Table 1 the content of fine particles was evaluated and categorized. The results of the proportion of fine particles M_2 are described in Results.

Table 1. Table for the evaluation of fine particles contents for 0-4mm fraction [9]

Aggregates	Undersize of sieve 0.063 mm	
0-4 mm fraction	**≤ 3%**	f3
	≤ 10%	f10
	≤ 16%	f16
	≤ 22%	f22
	> 22%	f declare

2.3. Determination of particle density and water absorption

Determination of particle density and water absorption of RCA was performed in accordance with the EN 1097-6: 2013. Particle density was determined on the aggregate dried in a drying oven at 110 ± 5 °C and then by using a pycnometer method [11]. Firstly the aggregate was submerged in water in the pycnometer and weighed. Then the aggregate was taken out, pycnometer filled up with water and weighed. The principle of this test consists in the difference of weights of the pycnometer with and without the aggregate as well as the level of grains saturation. Apparent specific gravity ρ_a, oven-dried particles density ρ_{rd} and saturated surface dried particles (SSD) ρ_{ssd} were calculated according to the formula (3) (4) (5) from the standard [11]:

$$\rho_a = \rho_w \frac{M_4}{M_4 - (M_2 - M_3)} \ [\text{Mg/m}^3] \tag{3}$$

$$\rho_{rd} = \rho_w \frac{M_4}{M_1 - (M_2 - M_3)} \ [\text{Mg/m}^3] \tag{4}$$

$$\rho_{ssd} = \rho_w \frac{M_1}{M_1 - (M_2 - M_3)} \ [\text{Mg/m}^3] \tag{5}$$

Water absorption after 24 hours immersion WA_{24} was calculated according to the formula (6) from the standard [11]:

$$WA_{24} = \frac{100 \times (M_1 - M_4)}{M_4} \ [\%] \tag{6}$$

where ρ_w is the density of water in Mg/m³, M_1 the mass of saturated surface dry aggregates in grams, M_2 is the mass of the pycnometer containing saturated aggregates immersed in water in grams, M_3 is the mass of the pycnometer filled with water and M_4 is the mass of aggregates after drying in grams.

## 3. Results and discussion

Selected properties of two different kinds of RCA processed from C&DW originated from demolition of precast slab block buildings were tested and compared with the properties of natural aggregates. For the tests was used marking R4 for RCA from peripheral concrete wall from light weight concrete with lightweight granule slug aggregates and R5 for RCA from interior concrete wall. After first visual check it can be stated that the quality of R4 is higher, concrete has more grey colour and grains of aggregates are firmly fixed into cement paste. Grains of RCA R4 have sharp edges and it is visible that strength of aggregates is comparable with cement past because cracks are formed not only in cement paste but also through aggregate grains itself. Further properties of RCA R4 are expected to be influenced by to porosity of crushed lightweight granule slug aggregates. Grains of RCA R5 are more yellow shade and seems to be more rounded, without sharp edges from crushing process. It is visible that the quality of concrete from inner walls is lower than concrete for RCA R4.

Particle size distribution of whole amount of supplied RCA was taken. Both RCA were supplied in two different fractures; fine about 0-8 mm and course 8-32 mm. These two fractures were in laboratory conditions sieved into fractions 0-4 mm, 4-8 mm, 8-16 mm and 16-32 mm, which are commonly used for a concrete production in Czech Republic. All properties of RCA R4 and R5 were measured on these fractions produced in laboratory.
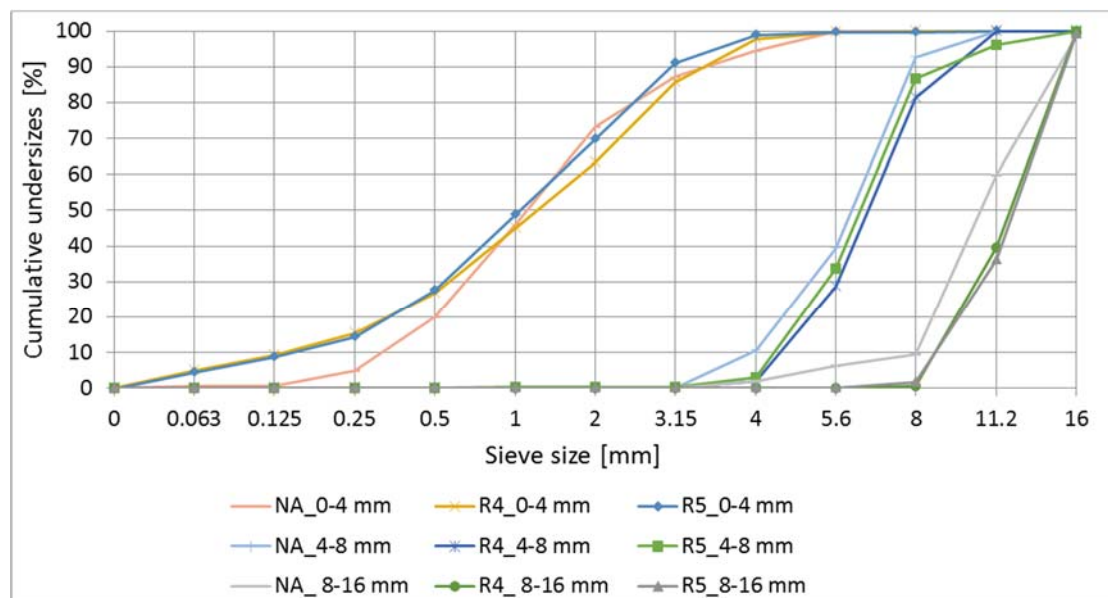
Particle size distribution of single fractions were carried out according to EU standard and the results are presented in Figure 4. Both RCA fractures 0-4 mm contain higher amount of fine particles under 0.125 mm consist mostly of crushed cement paste and sand. These fines have higher water absorption

but also can contain residual unhydrated cement grains and that could contribute to strength rise of new concrete. Fraction 4-8 mm and 8-16 mm are very similar for all tested aggregates.

	0-4 mm	4-8 mm	8-16 mm	16-32mm	32mm-more
RCA R4	23.86	40.65	58.34	80.21	100
RCA R5	23.59	38.87	62.81	81.83	100
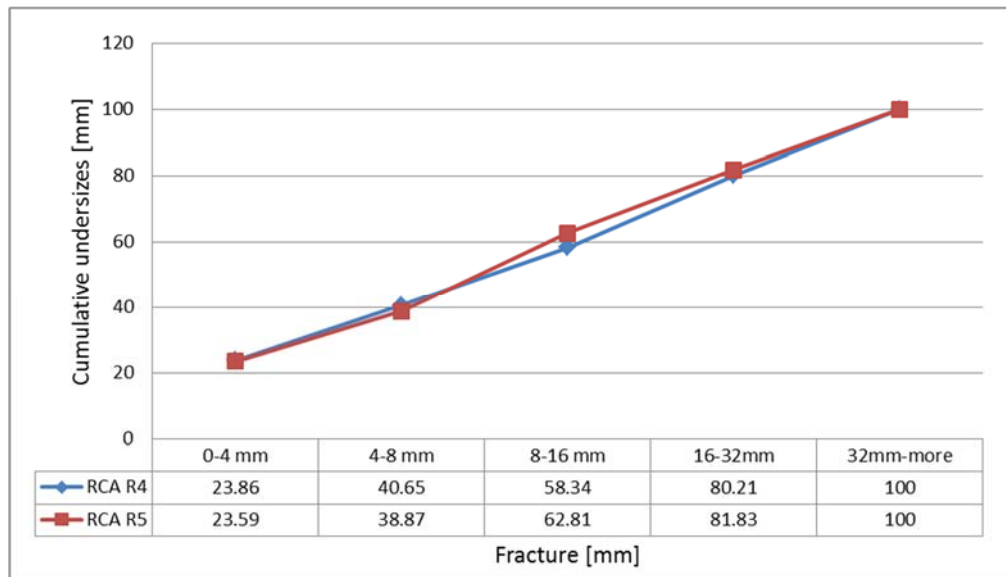
Figure 3. Particle size distribution curves of the RCA R4 and R5

Figure 4. Particle size distribution curves of the NA, RCA R4 and R5

The content of fine particles for RCA R4 is 16.8%. This is probably due to the fact that the R4 comes from peripheral concrete wall which includes lightweight granule slug aggregates. The sample of RCA R4 also crumbled more during crushing than the sample RCA R5. For the sample RCA R5 which comes from internal concrete wall, the content of fine particles reaches 9.97%. In this case it could be caused by lower content or lower strength class of cement in maternal concrete (concrete used for production of RCA). These are still high values in comparison with the 3% for NA. High content of fine particles is directly linked with water absorption of RCA mostly the fraction 0-4 mm. Evaluation of fine particles content is presented in Table 2 and in graphical form in Figure 5.

Table 2. Evaluation of fine particles content in fraction f 0/4 mm

| Aggregates	Undersize of sieve 0.063 mm	
NA	f3	3 %
R4	f22	16.08 %
R5	f10	9.97 %
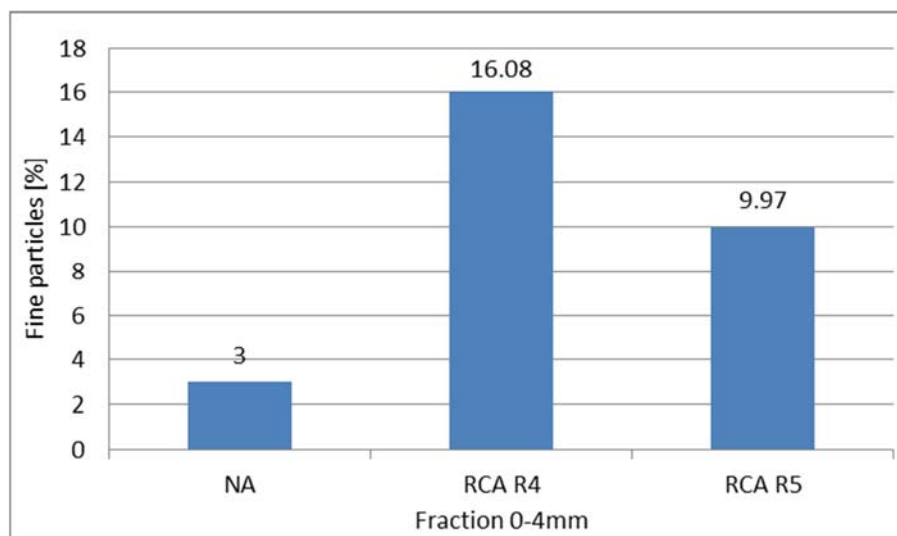
Figure 5. Graphical part of content of fine particles in fraction 0-4mm.

Water absorption was detected higher in fractions of 0-4 mm, as expected, where it moved from 9.2% to 9.6%. Higher water absorption is caused by content of crushed cement paste and in case of R4 by content of crushed lightweight granule slug aggregates. Water absorption of RCA R4 is almost in all cases higher than water absorption of RCA R5 which is again probably caused by content of lightweight granule slug aggregates. These aggregates as they are crushed have high surface and open pores which can easier hold water in their structure. Water absorption for each fraction and type of aggregate is presented in Figure 6.

Density of oven dried particles is directional for RCA to avoid distortion of results by higher water absorption. Standard CSN EN 12 620+A1 [8] states minimum density value of oven dried particles 2,000 kg/m^3 for production of all concretes in conformity with CSN EN 206-1 [14], in A1 of mentioned norm is also covers recycled aggregates with densities between 1,500 and 2,000 kg/m^3.

From results of density evaluation can be stated that density of oven dried particles of RCA R4 is comparable for all fractures and range from 1,997 to 2,083 kg/m^3 in case of fraction 4-8 mm. Lower density was expected as testing RCA originates from light weight concrete. In case of R5 values of density of oven dried particles were in wider range from 2,076 kg/m^3 for fracture 0-4 mm up to 2,272 kg/m^3 for fracture 4-8 mm. Aggregates in maternal concrete for production R5 were denser than the one in R4 and therefore density is higher for bigger fractures which contain more aggregates than fracture 0-4 mm. By visual control it was visible that the aggregates in R5 stayed intact and crucks were formed only through cement past. Results for measurements of density are presented in Figure 7.
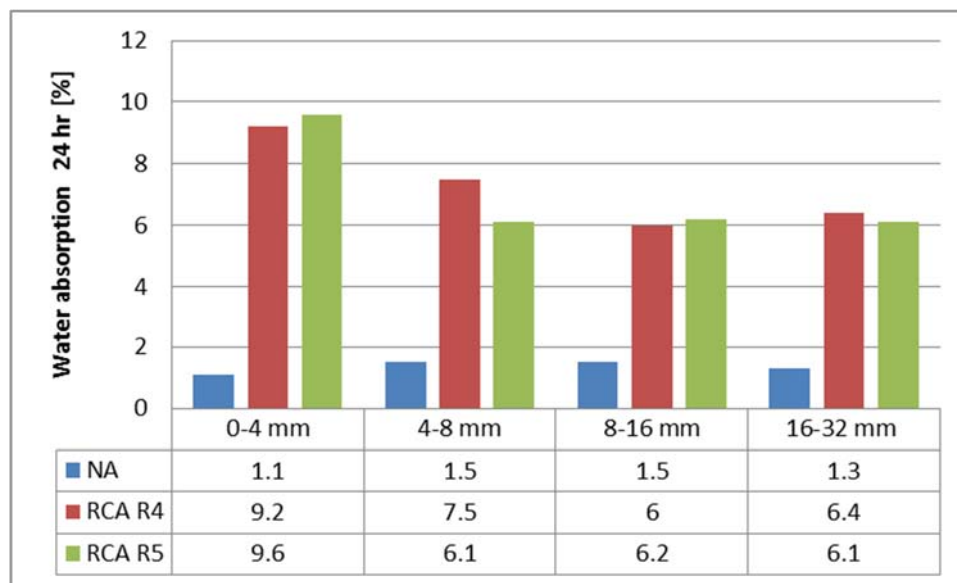
Figure 6. Graphical representation of water absorption of tested aggregates NA, RCA R4 and RCE R5.
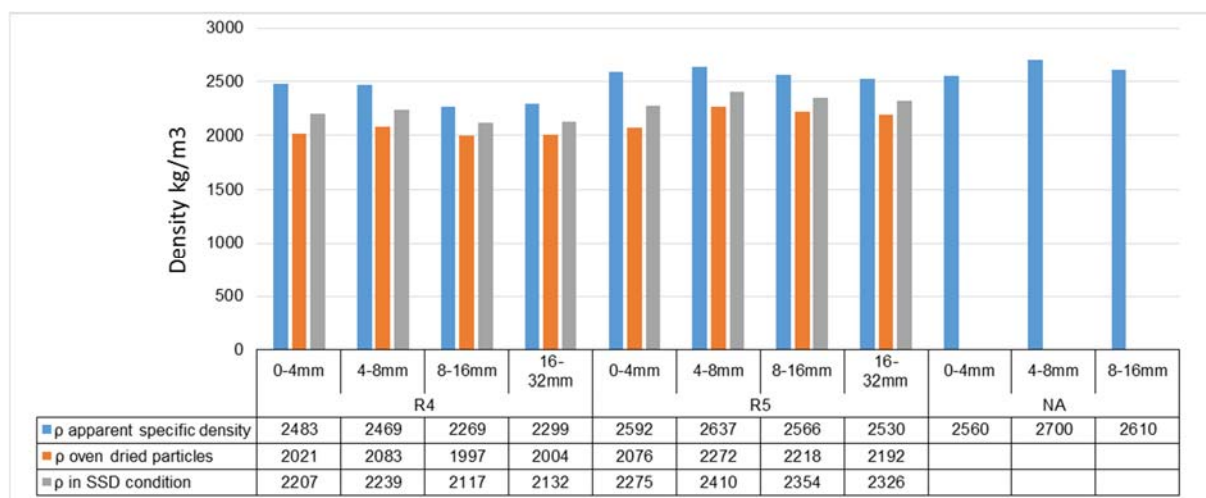
Figure 7. Specific density of the NA, RCA R4 and R5

4. Conclusions

The study presents the results from testing of two different kinds of recycled concrete aggregates and the test from one kind of natural aggregate for the comparison of the results. The sources of construction and demolition waste for recycled concrete aggregates were taken from the demolition of a concrete precast slab block building made by precast production in 1981.

It should be noted that the characteristics of RCA depend also on the maternal concrete. The quality of the maternal concrete mixture, i.e. the mix design, the quality of raw materials, the maximum aggregate grain size, transportation type, processing methods, etc. can affect properties of the maternal concrete and subsequently the RCA. Unfortunately, it is often difficult to obtain this information from the past.

Results from testing of two kinds of RCA showed particle size distribution of RCA is similar to sieve curve of NA with small difference of fire particle content under 0.125 mm. Tested R4 had much

higher content of fine particles (16.08%) which is causing higher water absorption and in case of using it as an aggregates into new concrete it is required to add extra water for wetting of RCA. Water absorption of tested RCA did not exceed the value of 10% which would make very difficult or impossible to use it for new concrete production. Density of oven dried particles was in all cases over 2,000 kg/m^3 and fulfil requirements of European standard for aggregated and concrete. Even the RCA R4 were produced from light weight concrete their density is still over 2,000 kg/m^3 or very close to 2,000 kg/m^3 for fracture 0-4 mm which is 1,997 kg/m^3.

The subject of future research will be application of RCA into concrete mix, determine its physical and mechanical properties and impact of the quality of the RCA on concrete with recycled concrete aggregates. It would also be useful to better define the empirical relationship between the maternal concrete and RCA. This can be achieved by e.g. newly created test samples, as was already presented in another paper [13].

Acknowledgment

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