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VERIFICATION OF THE BASIC PROPERTIES OF RECYCLED AND NATURAL AGGREGATES

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Abstract. In the future, it is planned to use up to 50 % of construction and demolition waste (C&DW) for the production of new building structures. This leads us to think about how we can use recycled concrete aggregate (RCA) as a substitute for natural aggregate (NA) in concrete mixtures. This is why we compare the two typical representatives of recycled aggregates with a representative of natural aggregates. As a representative of recycled aggregates, we chose pure concrete recycled from the cutting of concrete and mixed recyclate from the demolition of the apartment building. As a representative of natural stone, we chose the extracted aggregate.

Keywords: Construction and demolition waste (C&DW), recycled concrete aggregate (RCA), natural aggregate (NA), stone testing.

1. Introduction

Aggregates form the supporting framework of the concrete mixture, occupying almost 80 % of the volume in the concrete. Because of this, the issues of sustainability of construction and recycling come to the subconscious. Although there is currently a very rapid development in the field of building materials, concrete remains a building that has one of the widest applications in the construction industry. The composition of the concrete can be very varied depending on the filler, additives or additives used. However, the filler function always forms aggregates. Depending on the properties of the structures, it is possible to modify the concrete composition to meet individual requirements, eg strength, compactness, resistance to the influences. One of the requirements may also be its subsequent recycling.

Concrete as a composite material consists of two components, aggregate and cement slurry. However, the third component, which is a layer at the interface of the cement slurry and aggregate, is thin, about 10 - 50 microns, and we call it the transit zone. It is formed by the fact that the grains of cement are distant from the grain surface of the aggregate and thus the grain is covered only with a layer of water and a small amount of cement particles. The effort of cement to deviate from the aggregate is also supported by the homogenization process in the mixer. [1]

Plain concrete from recycled concrete does not reach the original concrete properties. Recycled concrete often has less strength and more creep and shrinkage than the original concrete. Improvement of these properties can occur with the use of epoxy dispersions without the presence of a solvent. This improves the adhesive properties of cement bonding cement recyclates and, if the dispersions are applied to dry recycled material, have an effect on reducing the water absorption value.

The characteristics of concrete from recycled aggregate are affected by impurities that contain recycled aggregate. Using the dirt will be transferred to a new material or construction. These are impurities in the form of clay, glass, plaster, plastics, textiles, papers, etc. The importance of dirt and their percentage of recycled concrete is not negligible, reflecting the quality of the newly developed material. [2]

The use of modified construction and demolition waste (C&DW) as a partial substitute for natural aggregates (NA) saves not only natural resources, but at the same time contributes to the reduction of the amount of construction waste in landfills. Reasons for using recycled aggregate (RCA), however, are not only these stated benefits that correspond to the objectives of sustainable construction, but also its cost and affordability, which is more favorable in many states than natural aggregates.

The disadvantage of recycling, however, is that secondary material no longer achieves the precise properties of the primary raw material, in our case, natural aggregate. Methods of testing, sorting and classification are covered by European standards EN 12620 + A1 Aggregates for concrete [3] and EN 933-11 Testing of the geometrical properties of aggregate - Classification of components of gross recycled aggregate. [4] Therefore, it is not used to a greater extent. An important aspect in the production of recycled aggregate is also the economic aspect, it is important that the production of recycled aggregate is not more expensive than the extraction of natural raw materials, thus the importance of recycling would be lost.

Because the durability of the concrete is limited, we need to anticipate its decay and subsequent demolition as soon as a new concrete structure is built. Therefore, we should think about the solution of the concrete afterwards when it stops performing its function.

It is, however, appropriate to say that RCA has not yet been widely used in the construction industry due to the diversity of individual recycled concrete mixtures. For this reason, several physico-mechanical properties such as bulk density, porosity, water absorption, frost resistance, reactivity of unhydrated cement in RCA, leachability of pollutants, purity of RCA itself, alkaline silicate reaction, etc. are observed in RCA. [5]

2. Materials and methods

To verify the basic properties of recycled aggregates, we chose two types of slightly different concrete recyclates. RCA 1 is the concrete recycled from the cutting of the outdoor concrete surface. On the other hand, RCA 2 comes from the demolition of a residential building and contains a wide range of different materials from the concrete - ceramic shards, glass pieces. As a reference natural stone for our needs was selected directly from the water extracted rock.

In order to achieve the same input conditions for all the aggregates compared, we chose the gravel fraction of 0 - 16 mm for testing. We subjected to the tests and measurements described below.

Grain. Determination of granularity, or screening of aggregates, is one of the basic tests performed on aggregates according to EN 933-1 Testing for particle size distribution - Sieving method. [6] The principle is to sort and separate the material by means of a set of sieve into several fractions with a descending size of holes. The result is graphical representation of the representation of individual fractions in the aggregate sample. The sample size of the test specimen depends on the maximum grain size D. In our case, we used a fraction of 0 - 32 mm for all tested aggregates. At the same time, we determined the percentage of fine particles < 0.063 mm in the form of nozzles.

Density. The RCA bulk density depends on the residual mortar. Since the residual mortar has a lower density than aggregate, the bulk density of the recycled aggregate is lower than natural aggregate. Its value is from 2100 - 2500 kg/m^3, natural aggregate has a bulk density of about 2400 - 2900 kg/m^3. Other dependencies are grain size. The smaller the grain, the lower the bulk density, but also the strength of the concrete. Bulk density has an effect on water absorption, resistance to CHRL. The smaller the concrete is more absorbent and less resistance to CHRL. [5] Testing of the bulk density of aggregates as described in EN 1097-6 Tests for mechanical and physical properties of aggregates - Part 6: Determination of particle density and water absorption. [7]

Suffocation. The surface of the recycled aggregate is dusty and cracked, causing bumps and crushing when recycling concrete slabs. The cement is more porous and more absorbent in the area of the transit zone, leading to the formation of larger $Ca(OH)_2$ particles and thus the increased permeability of the concrete. [5] Therefore, we tested 24 hours of water absorption on the samples according to EN 1097-6 Tests for mechanical and physical properties of aggregates - Part 6: Determination of particle density and water absorption. [7]

Shape index. This test is determined only for rough aggregate according to EN 933-4 Tests for geometrical properties of aggregates - Part 4: Determination of particle shape - Shape index. [8] Principle is the distribution of individual grains according to the ratio of their length to thickness (L/E), where the shape index is calculated as a grain fraction with a ratio greater than 3.

Bulk density. This is the mass of the aggregate unit of aggregate with cavities and pores, including spaces and between grains. We distinguish bulk density of loose and shattered aggregate. For this post, we tested the first property we determined according to EN 1097-3 Tests for mechanical and physical properties of aggregates - Part 3: Determination of loose bulk density and voids. [9]

3. Results

This part of the paper summarizes the measured results of our tested samples of two recycled concrete aggregates (RCA 1 and RCA 2) with one reference mined aggregate (NA reference). The results are written in the enclosed tables.

In the first step, we first determined the percentage of fine particles, when this test went freely to the screening of the test samples. This basis specification is introduced in Table 1. The detailed particle size distribution of studied materials in shown in Table 2. Resulted gradation curve is subsequently depicted in Figure 1.

A further test was the comparison of volumetric weights to avoid variations due to the different moisture content of the aggregates, we determined the bulk density on samples dried to a steady state. The results obtained are summarized in Table 3.

We used samples from the bulk density test to determine the 24-hour water absorption so that the conditions for all samples were the same. The results of water absorption test are shown in Table 4.

The shape index was determined on a limited fraction of 4 - 8 and 8 - 16 mm using a special sliding scale with a ratio of 1:3. The result is an L/E ratio where grains with a greater than 3 ratio are not suitable for use in the concrete mixture due to the unevenness of the material, which could occur during compaction of the concrete mixture to form caves or to break these non-conforming grains. The detailed results are introduced in Table 5.

The final test was to determine the bulk density of loose aggregate using a standard vessel of known volume, in our case 10 liters. Obtained results of single studied aggregates are well visible in Table 6.

Sample identification	Percentage of fine particles ($< 63\,\mu$m) [%]
reference NA	0.23
RCA 1	0.45
RCA 2	1.38

Table 1. Determination of percentage of fine particles.

Mesh sizes [mm]	Total fall [%]		
	reference NA	RCA 1	RCA 2
0.063	0.0	0.0	0.0
0.125	0.1	0.2	1.6
0.25	0.6	0.7	5.2
0.5	2.9	1.4	15.1
1	6.2	2.0	25.9
2	9.4	2.3	34.4
4	14.3	2.5	44.2
5.6	23.3	3.1	51.1
8	50.9	14.7	58.4
11.2	76.8	58.2	65.3
16	98.1	97.7	71.7
22.4	100	100	76.1
31.5	100	100	85.6

Table 2. The results of the screening analysis of aggregates.

Sample identification	Faction [mm]	Density of the dried sample ρ_{rd} [kg/m^3]
reference NA	0 – 4	2630
	4 - 16	2580
RCA 1	0 – 4	2080
	4 - 16	2270
RCA 2	0 – 4	2240
	4 - 16	2230

Table 3. Determination of bulk density in the dried state.

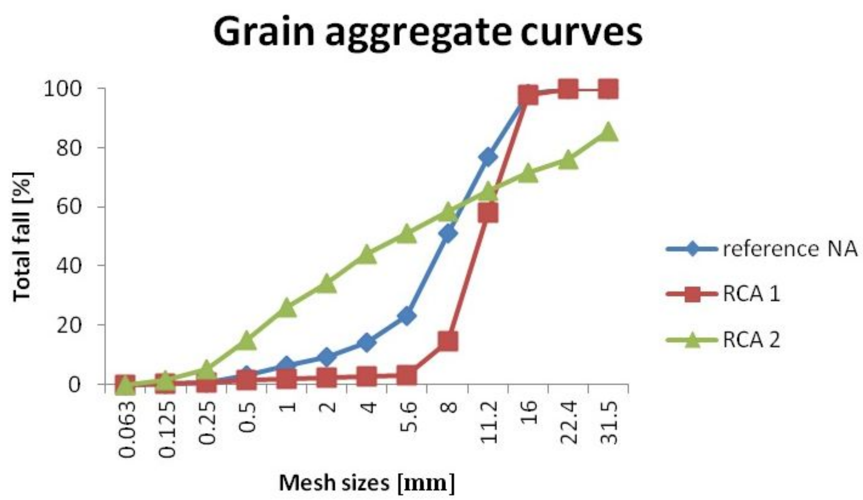

Figure 1. Graphical determination of the results of screen analysis of aggregates.

Sample identification	Faction [mm]	Weariness after 24 hours WA_{24} [%]
reference NA	0 – 4	1.2
	4 - 16	0.75
RCA 1	0 – 4	9.5
	4 - 16	5.7
RCA 2	0 – 4	5.9
	4 - 16	5.3

Table 4. Determination of 24 hours water absorption.

Sample identification	Faction [mm]	Shape index SI
reference NA	4 - 8	10
	8 - 16	13
RCA 1	4 - 8	10
	8 - 16	4
RCA 2	4 - 8	6
	8 - 16	9

Table 5. Determination of the shape index.

Sample identification	Faction [mm]	The bulk density of the loose sample [kg/m^3]
reference NA	0 - 16	1580
RCA 1	0 - 16	1120
RCA 2	0 - 16	1550

Table 6. Determination of bulk density of loose aggregate.

4. Conclusion

The largest proportion of fine particles and a significant fraction of particles below 4 mm had RCA 2, the resulting value being about 3 times higher than for RCA 1 and even 6 times higher than for NA reference. The screen analysis itself showed that RCA 2 contains almost 45% of grains below 4 mm, whereas RCA 1 has only 2.5%. This result was probably due to the different jaw setting of the crushing machine.

Determination of bulk density has shown that both recycled concrete aggregates have a similar bulk density of approximately 2250 kg/m^3, ie about 350 kg/m^3 lower than the reference NA 2600 kg/m^3.

24 hours of water absorption has highlighted the most common problem in using recycled concrete aggregates, ie water absorption. This is about 5 times higher for recycled concrete and for RCA 1 fraction 0 - 4 mm even 9 times higher than for reference NA (about 1%). As a result, a higher proportion of cement dust may be present in the fraction.

When evaluating the shape index test best suited to 8 - 16 mm RCA 2 fractions with 4, we can see why the lowest bulk density of 1120 kg/m^3 was measured for RCA 1 compared to approximately 1550 kg/m^3 for reference NA and RCA 2 .

Acknowledgements

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