Benefits of aggregates surface modification in concrete production

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Abstract. In our study, recycled concrete aggregates (RCA), which surfaces had been modified by geopolymer material based on coal fly ash, were used to produce the concrete samples. In these samples, fraction 4/8 mm was replaced by recycled concrete aggregate with a range of 100%. To modify the surface of RCA was "Solo" and "Triple stage" modification used. On these samples real density, total water absorption and compressive strength were examined after 28, 90, 180 and 365 days of hardening. The highest compressive strength 56.8 MPa, after 365 days hardening, reached sample which had improved RCA surface by "Triple stage mixing".

1. Introduction

At present, sustainable development is a priority for all spheres of society. Important role in the sustainable development of the built environment, reduction of pollution, conservation of natural resources and energy savings certainly has the entire civil engineering, especially construction materials industry [1].

The manufacture of traditional concrete is one of the most pollutants industries. About 80–90% of GHG (Greenhouse gas) emissions and energy used in the fabrication of concretes derives from the high temperatures required for cement production and the decomposition of the calcium carbonate [2]. One of the main reasons to use Recycled concrete aggregate (RCA) in structural concrete is to make construction more "green" and environmentally friendly. Some major environmental issues associated with construction, are that construction "takes 50 % of raw materials from nature, consumes 40 % of total energy, creates 50 % of total waste." The use of RCA on a large scale may help to reduce the effects of the construction on these factors by reusing waste materials and preventing more natural aggregates from being harvested [3].

Many studies have focused on the physical, mechanical and durability properties of concrete employing recycled aggregates [4] and their findings have concluded that when compared with natural aggregates the lower properties of the recycled aggregates have a detrimental effect on the physical, mechanical and durability properties of the Recycled aggregate concrete (RAC) [5].

It is important to improve the interface between cement matrix and coarse aggregate of low-quality recycled aggregates to promote their application in concrete mixes. Qualitative improvement will in turn enhance the mechanical performance such as the modulus of elasticity and strength, and it will be possible to manufacture concrete with improved durability in terms of drying shrinkage, neutralization, and freezing-thawing. One possibility is a surface modification through the use of an inorganic material on crushed concrete aggregates [5,6].


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However, the use of RCA has successfully developed since its initial use via the strict following of minimum qualities, maximum replacement ratios, particular mixing methods or mixing designs using mineral admixtures [5,7].

In our study, construction and demolition wastes (C&DW), namely RCA with modified surface were used to produce the experimental concrete cubes. On these samples real density, total water absorption and compressive strength were after 28, 90, 180 and 365 days tested.

2. Material and methods

Cement, natural aggregates, recycled concrete aggregates, coal fly ash and water were used in our research.

The binder used in the study were Portland cement CEM I 42.5 (according standard STN EN 197-1 Cement. Part 1: Composition, specifications and conformity criteria for common cements, while its specific weight is 3100 kg/m^3.

Two types of aggregates were used in our experiment, natural aggregates - NA and recycled concrete aggregates - RCA. Two different fractions, 0/4 mm and 4/8 mm of natural aggregates for concrete samples preparing were used. Natural aggregates were evaluated according to the standard STN EN 12 620 Aggregates for concrete.

The recycled concrete aggregates in a platform of recycling by crushing concrete waste of demolished buildings were produced. They are composed of old paste and natural aggregates and are free of other materials like bitumen. Separated concrete blocks were fed into crushing unit, then sieved to achieve required sizes. We used only fraction 4/8 mm, in our experiment.

Original coal fly ash (OFA) from Heating plant, Kosice – Slovakia, were used as the main component of geopolymer slurry, in our experiment. The results of chemical analysis and original particle size of the investigated coal fly ash are shown in table 1. The results of this analyses are expressed by following parameters - grain diameters: d (0.1) - indicates that 10% of the whole amount of investigated sample is under measured value of the particle size (μm) and the like parameters d (0.5) – 50% and d (0.9) – 90%. The calcium oxide content of fly ashes is less than 10%, hence they can be classified as Class F according to ASTM 618 standard.

Table 1. The results of chemical and granulometric analysis of coal fly ash.

	Oxide Composition (%)						Grain size (μm)		
Materials	MgO	Al_2O_3	SiO_2	CaO	Fe_2O_3	CaO/SiO_2	d(0.1)	d(0.5)	d(0.9)
OFA	1.18	23.21	51.11	2.58	6.4	0.051	3.97	20.44	84.73

To prepare concrete mixtures drinking water (STN EN 1008 Mixing water concrete) and superplasticizer additive Stachement 2353 was used. Stachement 2353 (Stachema Company) is a high-activity water reducing/superplasticising additive based on polycarboxylates. According to the technical data, this additive can reduce the water content of the fresh concrete while maintaining workability and improving its strength, durability and shrinkage. Table 2 shows basic composition of concrete to 1m^3.

Table 2. Reference concrete mix proportion per cubic meter.

Composition	1 m^3
Cement (kg)	370
Aggregates 0/4 mm (kg)	1100
Aggregates 4/8 mm (kg)	695
Water (l)	205
Plasticizer (%)	0.5

The amount of water in the mixture was indicative. For mixture resulting consistency required slump grade was followed (S2). The total amount of water was composed form effective water and 10% absorbed water of the aggregates and its shown in table 3.
In this experiment four series of mixes were considered (table 3). The first series was the control mix containing 100 % natural aggregates in both fractions. The second mixes were concretes containing 100% RCA as full replacement for natural coarse aggregates in fraction 4/8 mm. The third and fourth mixes were similar to the second series in every respect except the type of used RCA. Recycled concrete aggregates used in these samples had improved surface by coating.

Table 3. Details of experimental mixtures converted to 1m^3.

Sample	Aggregate 0/4		Aggregate 4/8		RCA aggregate surface modification		Plasticizer (%)	Total Water (l)
	NA	RCA	NA	RCA	Solo	"Triple stage" mixing		
B0	●	-	●	-	-	-	0.5	210
B1	●	-	-	●	-	-	0.5	220
B2	●	-	-	●	-	●	0.5	210
B3	●	-	-	●	●	-	1.5	220

To RCA surface modification geopolymer slurry based on coal fly ash in two ways was used. Geopolymer slurry consisted of coal fly ash, liquid glass, 10M NaOH solution and water. In "Solo modification" firstly was the coating of RCA by geopolymer slurry. After coating the aggregates at ambient conditions for 28 days were cured. Then, like this RCA aggregates into concrete mixture were applied. In the second way ("Triple stage mixing") RCA aggregates directly during mixing of concrete were coated. First, fraction 4/8 of RCA was coated by geopolymer slurry and it was curing. After 30 minutes the concrete mixing continued – gradually the other components were added. After a careful mixing of the all components concrete samples were prepared.

All the samples were elaborated under laboratory conditions and demolded after 24 h. Then, they were immersed in water under constant temperature at 20 ± 3 °C during the corresponding curing time. Real density, total water absorption and compressive strength were tested after 28, 90 and 180 days. The compressive strength was tested using a hydraulic press ELE International and was determined by using the standard (STN EN 12390-3 Testing hardened concrete. Part 3:Compressive strength of test specimens) on specimens 150x150x150 mm. Same specimen dimensions were used for determining the real density in accordance with STN EN 12390-7. Total water absorption by following the standard (STN EN 73 1316 Determination of moisture content, absorptivity and capillarity of concrete) specifications on prism 40x40x160 mm was measured.

3. Results and discussion

Table 4 shows results of real density of tested samples. The highest values of real density were presented in reference sample B0 prepared with natural aggregates only, from 2290 kg/m^3 to 2340 kg/m^3. The lowest density reached sample B1, contained staring RCA with specific gravity 1960 kg/m^3.

Table 4. Average values of density after 28, 90, 180 and 365 days of curing.

Sample	Real density (kg/m^3)			
	28 days	90 days	180 days	360 days
B0	2340	2290	2310	2300
B1	2160	2130	2190	2180
B2	2290	2280	2290	2280
B3	2190	2140	2200	2190

Values observed in samples with surface modified RCA (samples B2 and B3) were quite similar, and observed density values are caused by low density of RCA. Average density of all samples is in the range from 2130 kg/m^3 to 2340 kg/m^3.

Table 5 shows the results obtained in total water absorption test analysis for each mix according STN EN 73 1316. Water absorption of reference sample was about 3% during all periods. Total water absorption other samples with time gradually decreased, firstly values ranged about 9%, after 28 days and got to the level of 3%, after 365 days curing. This value of 3% is at the level of the comparison sample. In the sample prepared with starting RCA total absorption was reduced from 9% to 6%, only.

Table 5. Total water absorption of tested samples after 28, 90, 180 and 365 days of hardening.

Sample	Total water absorption (%)			
	28 days	90 days	180 days	365 days
B0	3.1	2.9	2.7	2.8
B1	9.1	7.8	6.0	6.3
B2	8.8	7.8	3.3	3.4
B3	8.3	7.5	3.0	3.1

Based on the results, we can conclude that both tested methods of aggregates surface modification ("Solo" and "Triple stage mixing") have brought significant results. The values of the measured total water absorption were different at least for both methods, but namely about 0.3%, afterr 180 and 365 days hardening in the same way.

Compressive strength development of concrete mixes which were produced by substitution of natural aggregates with recycled concrete aggregates is shown in table 6.

Table 6. Compressive strength samples prepared with recycled concrete aggregate after 28, 90, 180 and 365 days of curing.

Sample	Compressive strength (MPa)			
	28 days	90 days	180 days	360 days
B0	38.7	45.1	53.1	55.1
B1	29.6	35.5	36.5	40.0
B2	33.5	41.3	55.7	56.8
B3	32.8	43.4	52.8	54.9

The values in the table are the average values of minimum three cubes 150x150x150 mm. No differences in type of failure were witnessed. From the results is clear, that in all samples the compressive strength values increased over time. However, the largest increase can be observed in the sample B2, which contained aggregates with improved surface by "Triple stage" mixing. In this sample, compressive strength increased from 33.5 MPa (after 28 days) to 56.8 MPa (after 365 days hardening). This is also the highest compressive strength reached among the tested samples. It should be noted, however, that high compressive strengths even using "Solo modification" have been achieved (54.9 MPa). The lowest compressive strength, 29.6 MPa, after 28 days reached sample B1, which contained RCA with unmodified surface.

4. Conclusion

To reduce the absorption of the RCA fraction 4/8 mm, the surface of aggregate was activated by a multi-stage mixing and using of geopolymer phases, in our experiment. Experimental concrete samples with using these activated RCA were prepared, while w/c ratio was from 0.52 to 0.56. For mixture resulting consistency required slump grade S2 was followed.

Average density of all samples were in the range from 2160 kg/m^3 to 2340 kg/m^3. The highest values of real density were presented in reference sample with natural aggregates prepared, 2340 kg/m^3. The lowest density reached sample, which contained unmodified aggregates with specific

gravity 1960 kg/m^3. Values observed in samples with surface modified RCA were quite similar, about 2200 kg/m^3.

Total water absorption of reference sample was about 3% during all periods, but water absorption samples prepared with improved surface RCA with time gradually decreased, from 9%, after 28 days to 3%, after 365 days hardening. This is a similar value like reached a reference sample. Only in the sample containing starting RCA total absorption was reduced at least, and thus from 9% to 6%.

Compressive strength testing intervals for experimental samples with RCA were 28, 90, 180 and 365 days. Based on the results, we can conclude that all of the tested samples had the same compressive strength development - evenly increasing. However, the largest increase can be observed in the sample which had improved RCA surface by "Triple stage mixing", from 33.5 MPa, after 28 days to 56.8 MPa, after 365 days hardening.

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