Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 151 (2016) 360 – 367

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Ecology and new Building materials and products, ICEBMP 2016

Properties of concrete with partial replacement of natural aggregate by recycled concrete aggregates from precast production

Iveta Nováková*, Karel Mikulica

Brno University of Technology, Veveří 331/95, Brno 602 00, Czech Republic

Abstract

Recycled concrete aggregates (RCA) can be used as a replacement of natural aggregates for a concrete production to save natural sources and also to decrease amount of demolition waste which has to be landfilled. Precast production generates some percentage of defected elements which are carted off and recycled with other demolition waste. In this study defected elements are separately recycled into RCA with beneficial properties and used directly into new mixtures for precast elements. Results from testing of RCA and application into new concrete mixtures are presented. It was proved that the replacement of raw aggregates by RCA up to 20% has no negative influence on physico-mechanical properties of concrete.

Peer-review under responsibility of the organizing committee of ICEBMP 2016

Keywords: Concrete recycling; recycled concrete aggregates (RCA); defected elements from precast production; mechanical performance

1. Introduction

Trend of the last decade is recycling of waste materials into secondary raw materials, waste separation and ecological disposal of unrecyclable waste. Modernization of old buildings and new constructions of structures which are higher, larger and with high tech equipment is accompanied by rising amount of demolition waste from old structures and obsolete technical equipment. This construction and demolition waste (C&DW) has to be stored on landfills which doesn't have inexhaustible volume capacity and therefore we have to search for new solutions in reuse of old building materials such as concrete or mortar are. Construction industry in EU is sector with highest

* Corresponding author. Tel.: +420-721-569-065.
E-mail address: novakova.i@fce.vutbr.cz

Peer-review under responsibility of the organizing committee of ICEBMP 2016
doi:10.1016/j.proeng.2016.07.387

consumption of natural resources and also with the greatest production of waste, around 900 million tons of waste per year [1]. Landfills for C&DW are reaching their volume capacity limits and it is not allowed to store C&DW with municipal refuse. Fundamental problems of recycling are the clearliness and quality of sources. Impurities in demolition waste for production of secondary raw materials play a main role in sense of quality of new secondary raw materials. Concrete is the most used building material in the world and aggregates constitute around 70% of its volume. Natural aggregates (NA) can be easily replaced by recycled concrete aggregates (RCA) generated from C&DW and lead toward savings of natural resources. Ecological aspects of RCA usage are savings of NA and space on landfills and economical aspect is presented by the price of recycling and separation process in comparison with price of aggregate exploitation which is more significantly energy-intensive.

As it was already mentioned, the quality of the recycled concrete aggregates is based on quality and source of construction and demolition waste from which are the RCA produced. Commonly C&DW from different places is collected in recycling plant, mixed and from such a mixed C&DW is produced RCA with relatively high percentage of impurities, for instance bricks, plastic and asphalt. Such RCA is not allowed to be used as aggregates for a concrete production, because the properties do not comply with the conditions given in European Standard ČSN EN 12 620+A1 [2]. If the RCA want to be used for a concrete production, it has to contain 90% or more crashed concrete, bulk density higher than 2,000 kg/m^3 and maximum absorption capacity 10% or less. These conditions are valid for Czech Republic, for other countries it can vary, see Table 1. Solution how to obtain RCA with suitable properties is recycling in-situ or separation of C&DW by source and content on a recycling plant. First suggested solution is much more valuable, because the RCA can be directly used in same place and cut down costs of transportation. This first solution can be also applied in precast production where defected elements can be crushed, assorted into fractions and directly used in new mixtures.

Table 1. Regulations for RCA for concrete production in selected European countries. [3]

Property	Belgium	Germany	Netherlands	Portugal	Czech Republic
Composition (*% by weight*)	≥ 95% crashed concrete	≥ 90% crashed concrete	≥ 95% crashed concrete	≥ 90% crashed concrete	≥ 90% crashed concrete
Bulk density (*kg/m^3*)	≥ 2,200	≥ 2,000	-	≥ 2,200	≥ 2,000
Absorption capacity (*%*)	≤ 10 ± 2	≤ 10	-	≤ 7	≤ 10
Content of fines particles (*%*)	1.5	-	1.0	4.0	-

Properties of the recycled concrete aggregates depend on the source, quality of the waste material, percentage ratio of components and also on the sieve-fraction of aggregates. Bulk density is lower by 10 to 15% in comparison to natural aggregates, water absorption capacity is higher by 5 to 10% in comparison to NA for coarse fraction and from 7 to 12% in case of fine fraction 0–4 mm. Fractions with maximum grain size of 4 mm content usually around 20% of fines (particles smaller than 0.25 mm), which can be beneficial for production of self-compacting concretes. Pavlů [3] proved by her research, that RCA from different sources have different properties, which was further supported by our research where the results showed that properties of demolition concrete has influence as well. Other research carried by Abbas et al. [4] reported that approximately 20% particles of RCA fraction size 4.75–9.5 mm are composed of residual mortar, and in case of coarse fractions more than 50% is constituted by less than 15% residual mortar.

Many studies present results from testing of concrete with partial or total replacement of natural aggregates by recycled concrete aggregates, but the practical use of such a concrete is rare to find. As the properties of RCA differ from NA it is necessary to make some changes in composition of mix design, mixing method and curing of RC (concrete with recycled concrete aggregates). Due to higher water absorption capacity of RCA it is advice to increase water-cement ratio (w/c ratio) or minimalize the time of mixing and moulding of fresh RC. Second option of production is similar to preparation of light weight concrete with light weight aggregates, which has even higher water absorption capacity. [5,6] Study from Amorim, Brito and Evangelista [7] proved only slight influence of curing conditions on further strength properties of RC and verified that dry curing conditions are not positive for RC neither for conventional concrete (CC). Decrease of the strength and durability of RC is caused mostly by weak interfacial transition zone (ITZ) which can be avoided by enhancement of the strength of bond between old mortar and new mortar with application of fly ash, nano-silica or other fine materials. [5,8,9] Salomon and Helene [10] attributed the positive changes of carbonation depth in case of RC with 20% of replacement of NA by RCA. Durability is strongly related to percentage of NA replacement, w/c ratio and water absorption capacity which is closely linked with porosity of concrete structure. [7,10,11]

The most suitable source for RCA might be the one, which has equal composition as the concrete in which the RCA will be used. In other words, precast concrete production is not waste-free and defected elements are stored in area of precast concrete plant. Waste of such a plant is composed by defected elements, fresh/hardened concrete with faulty composition and dust from polishing of the paving elements. The waste is mostly stored in area of precast concrete plant until the storage capacity of the plant is exceeded. There are several ways how the precast concrete plants deal with the waste:

- In-situ recycling – mobile jaw crusher is used in plant and the crushed concrete is transported to other place for further use.
- Recycling in recycling plant – whole defected elements are loaded on truck bed and taken to recycling plant where are later on crushed with other concrete waste.

If the in-situ recycling is used, it would be beneficial to use RCA straight into new mixtures for the precast elements and omit carting of generated RCA. Composition of this RCA is 100% pure concrete with same raw materials, which are used for production of new concrete. The aim of this study is to verify the properties of RCA produced out of precast concrete production waste and compare them with other kinds of RCA from various sources. Properties such as bulk density, water absorption capacity, porosity and grain size distribution of three different kinds of RCA were examined and results from measurements evaluated. These tests are followed by application of RCA as a replacement of NA in new concrete. Test specimens with 20% replacement of NA by RCA from precast concrete production waste were prepared, analyzed physico-mechanical properties and first durability tests were undertaken.

2. Experimental program

2.1. Recycled concrete aggregates (RCA)

In this study, three kinds of recycled concrete aggregates in various fractions were analyzed to obtain valuable results and make assessment of their properties. Selected RCA were defined by source, origin, approximate strength and age of crushed concrete, amount of impurities and fraction in which RCA was available. Labelling for the RCA is R1, R2 and R3.

- R1 – RCA produced out of precast concrete production waste were obtained from recycling plant close to precast concrete plant. Strength class of concrete for precast concrete industry is C 40/50 and an age of RCA was about 5 months. The amount of impurities in crushed concrete was negligible and RCA was available in fractions 0–20 mm and 16–32 mm.
- R2 – RCA produced out of defected precast prestressed concrete elements SPIROLL were obtained directly from production. Strength class of concrete for precast concrete industry is in this case C 45/55 and an age of RCA was about 2 years. There was no content of impurities in crushed concrete, because it was intentionally produced for scientific purposes. RCA was available in fractions 0–4 mm, 4–8 mm and 8–16 mm.
- R3 – RCA produced out of demolished concrete road surface were obtained from temporary recycling plant close to the renovated road. Strength class of concrete for road structures is usually C 30/37 and an age of RCA was about 1.5 years. The amount of impurities in crushed concrete was about 2%, mainly asphalt and timber. RCA was available in fraction 0–32 mm.

By the sieving method were prepared uniform fractions 0–4 mm, 4–8 mm and 8–16 mm for all three test RCA and their properties compared with natural aggregates of same fractions. Particle size distribution of fraction 0–4 mm and 4–8 mm are presented in Fig. 1, for further production of concrete were used fractions 0–2 mm and 0–4 mm.

Selected properties of four tested aggregates in various fractions such as specific gravity, water absorption capacity and porosity were carried out according to European Standard [2]. Equation (1) was applied for evaluation of porosity, n, with use of data for calculation of specific gravity. Equation (1) was taken over from publication of Abbas et al. [4] and states as follows:

$$n = \left[(1 - W_{OD} / W_{SSD}) \times SG_{SSD}\right] \times 100 \quad (1)$$

where W_{OD} and W_{SSD} are the weights of oven-dried and saturated surface dry (ODD) aggregates samples, and SG_{SSD} is the SSD specific gravity of the aggregates.

2.2. Concrete with RCA

Aggregates testing was followed by application of R1 recycled concrete aggregates into concrete mixture as a partial replacement of natural aggregates. Two mix compositions were designed in accordance to mix designs commonly used within precast concrete industry. These mixtures are designed as dry cast concrete mixes with low water content. Elements are casted into moulds and finished by vibro-compaction. Reference mixture contains only natural aggregates and second mixture is with 20% replacement of natural aggregates by recycled concrete aggregates R1 (from precast production waste). Replaced fractions were 0–2 mm and 0–4 mm; fraction 4–8 mm was in all cases 100% natural aggregates.

Raw materials for production of test specimens were supplied by local factories and providers. Cement CEM I 42.5 R was used because of its rapid gain of initial strength, which is necessary for precast production, where the elements are taken from mould directly after casting. Natural aggregates as a mined sand 0–4 mm, fine mined sand fraction 0–2 mm and mined aggregates fraction 4–8 mm were used. To increase amount of fine particles in mixture, fly ash was added. Even if the requested consistency is relatively dry, plasticizer in dose 0.4% of cement weight was used to reduce water content. Mix design is given in Table 2.

Mixing method for production of test specimens was inspired by Kong et al. [5], who presented several mixing methods to enhance properties of concrete with recycled concrete aggregates. In this study following mixing design was applied: 30 seconds of dry mixing (aggregated and cement), addition of water with plastisizer and continue mixing for 90 seconds to obtain appropriately homogenized mixture. Casting of the specimens in laboratory conditions may cause decreases of strength due to imperfect vibro-compaction. For casting of test specimens was use vibrating table and moulds were loaded by 11.5 kg weight. Test samples were stored in climate chamber (23 °C, 65% r.h.) for 28 days and thereafter conducted tests.

Table 2. Test concrete mix design for 1 m^3.

Materials (*kg*)	Ref 1	Rec R1
Cement CEMI 42.5 R	250	250
Natural aggregate 0–4 mm	1,150	920
RCA 0–4 mm, R1	0	230
Natural aggregate 4–8 mm	600	600
Natural aggregate 0–2 mm	280	224
RCA 0–2 mm, R1	0	56
Filler	80	80
Plasticizer (0.4% of m_c) (*l*)	1	1
w/c ratio (-)	0.5	0.5
Water	125	125

Test concrete was examined in fresh and hardened state. VeBe test method was used for determination of consistency of fresh concrete and density of fresh concrete was measured. For determination of strength properties of hardened concrete was used hydraulic press. Density and absorptivity was measured according the European Standards. Durability of tested concrete was examined by freeze-thaw durability test according to Czech standard ČSN 73 1236 "Resistance of cement concrete surface to water and defrosting chemicals" [16].

3. Results and discussion

3.1. Recycled concrete aggregates (RCA)

Strength of concrete for production of RCA has influence on absorptivity and specific gravity of RCA. With increasing particle size of RCA the absorptivity is decreasing, therefore is more common to use coarse fraction of RCA. RCA R1 and R2 fraction 0–4 mm have similar content of fines particles (under 0.25 mm), while R3 has about 22% of fines particles, which has significant impact on water absorption. Fraction 4–8 mm of all RCA have almost same grain size distribution as a natural aggregates and therefore their use mind not influence the properties of concrete mixture in greater scale.

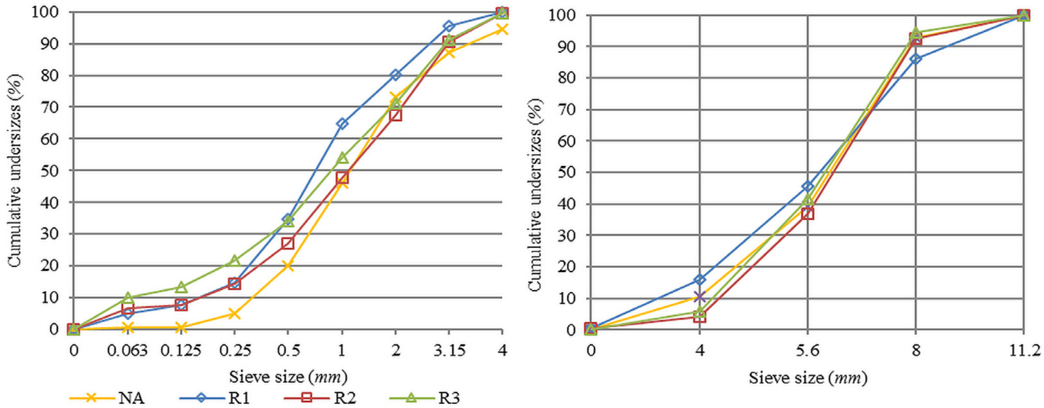

Fig. 1. Particle size distribution curves of tested aggregates (left) fraction 0–4 mm; (right) fraction 4–8 mm.

Table 3. Average physical properties of the natural and recycled concrete aggregates (SSD: saturated surface dry).

Aggregates	Fraction	Absorption (24 h) (%)	Specific gravity (*kg/m³*)			Porosity (%)
			Bulk	SSD	Oven-dried	
NA	0–4 mm	1.1	2,560	-	-	-
	4–8 mm	0.8	2,700	-	-	-
	8–16 mm	0.8	2,610	-	-	-
R1	0–4 mm	9.8	2,440	2,160	1,970	19.31
	4–8 mm	5.8	2,620	2,400	2,270	13.23
	8–16 mm	5.7	2,540	2,340	2,220	12.56
R2	0–4 mm	10.1	2,640	2,300	2,090	21
	4–8 mm	6.1	2,660	2,430	2,290	13.97
	8–16 mm	6.6	2,580	2,350	2,200	14.57
R3	0–4 mm	12.1	2,580	2,210	1,970	23.75
	4–8 mm	6.7	2,570	2,340	2,190	14.76
	8–16 mm	6.3	2,560	2,350	2,210	13.81

Water absorption of RCA R1 is relatively high, 9.8% but still lowest within all tested RCA. Fractions 4–8 mm and 8–16 mm had similar water absorption for all three tested RCA and the value ranged from 5.7 to 6.7%. Bulk density of all three fractions of RCA R1 was lowest within the others, even though the water absorption was lowest as well. This fact might be caused by production method of concrete used for production of RCA. Vibro-compaction of dry cast concrete can create higher amount of greater pores in structure of elements which do not tend to retain water. Porosity is closely linked with water absorption and the results showed, that the porosity of RCA R1 fraction 0–4 mm is 19.31% which is very high. Due to this fact, it is required to add extra water into produced concrete and let aggregates soak without influencing the hydration process of cement.

3.2. Properties of concrete with 20% of RCA

In tested concrete were replaced fractions 0–2 mm and 0–4 mm by 20% of RCA R1. Used fractions were sieved in laboratory sieving equipment from fraction 0–20 mm. The fine particles contained in RCA R1 are mostly constituted by crashed cement mortar and have higher water absorption and are more susceptible to grinding than natural sand. RCA R1 was available in fraction 0–20 mm, which contained 61.4% of fraction 0–2 mm and 71.8% of fraction 0–4 mm. As there was only 23.8% of fraction 4–8 mm, we did not use it for replacement, because in practice, it might case the problems due to lack of this fraction. Higher content of fine particles in fraction 0–4 mm RCA R1 can lead to omitting of the fraction 0–2 mm, which is commonly more expensive than standardly used fractions.

Table 4. Properties of fresh concrete.

	Consistency (VeBe)	Density (*kg/m³*)
Ref 1	25 s - V1	2,240
Rec R1	33 s - V0	2,230

As there was no addition of extra water in mixture Rec R1 for soaking the RCA R1, the workability was reduced and evaluated as VeBe V0. Density of fresh and hardened concrete was not influenced by addition of RCA R1. Value of density of fresh concrete was around 2,240 kg/m^3 and for hardened concrete 2,160 kg/m^3 for both tested mixtures. Water absorption of concrete with RCA R1 was negligibly higher (0.32%) which is positive, if we consider that the water absorption of RCA is much higher that water absorption of NA. No negative influences of RCA R1 on strength properties of tested concrete were detected. The flexure strength reminds same, 4.7 N/mm^2, for both mixtures and the compressive strength of the mixture Rec R1 rise by 1.8 N/mm^2 in comparison to Ref 1 mixture. The rice of the compressive strength might be cause by additional hydration of residual unhydrated cement particles from RCA R1. Our laboratory is not appropriately equipped for vibro-compaction of the concrete specimens and therefore the results from freeze-thaw durability test were rather poor. The results from freeze-thaw durability testing showed very high level of scaling for both tested mixtures and therefore we conclude that the compaction of concrete was insufficient. There are no any similar studies, which deals with application of RCA in to precast elements, only application of RCA in dose up to 45% into concrete pavements was carried out in Washington State, USA [17].

Table 5. Properties of hardened concrete (W&DIS: water with de-icing salt).

	Density (*kg/m³*)	Absorption (72 h) (*%*)	Flexure strength (*N/mm²*)	Compressive strength (*N/mm²*)	Resistance of concrete to W&DIS (*g/mm²*)
Ref 1	2,160	7.48	4.72	29.12	3,769.1 - 100
Rec R1	2,160	7.81	4.74	30.90	4,010.7 - 100

4. Conclusion

Study presents results from testing three different kinds of recycled concrete aggregates and subsequent application in concrete as a replacement of natural aggregates. Sources of construction and demolition waste for RCA were from precast production plants for R1 and R2, and RCA R3 was prepared from concrete road surface. The properties as grind size distribution, bulk density, water absorption and porosity were evaluated. These tests were followed by application of RCA R1 into concrete. Two different mixtures were designed according to dry cast concrete mix design for precast concrete production. Ref 1 mixture content 100% of natural aggregates and Rec R1 was with 20% replacement of NA by RCA R1 in case of fractions 0–2 mm and 0–4 mm.

Results of the testing met our expectations and showed, that the replacement of natural aggregated by recycled concrete aggregates from precast concrete production by 20% have no negative influence on physico-mechanical properties of concrete. The rise of compressive strength by 5.8% (1.8 N/mm^2) was detected and it could be caused by additional hydration of residual unhydrated cement contained in RCA. Fine particles can also enhance the strength of cement mortar and contribute to stronger interfacial transition zone. Both tested concretes failed the freeze-thaw durability test due to insufficient compaction of specimens.

It would be appropriate to prepare the specimens in precast concrete production plant by the proper vibro-compaction equipment and carry out the same tests, which were performed on laboratory condition prepared specimens. After such testing, it would be possible to make a final decision, if it is possible to use RCA as a partial replacement of NA in precast production. Separate cement matrix (max. aggregates size 2 mm) testing is also recommended to verify, if the high content of fine particles in RCA has influence on cement matrix properties.

Acknowledgements

The outcome has been achieved with the financial support of project FAST-J-15-2809 „ Usage of waste from precast production as a recycled concrete aggregates “ Brno University of Technology and project GACR 15-23219S ” Study of methods of nanoparticles dispersion, determination of conditions for preventing their re-agglomeration for application in cement composites “.

References

[1] Eurostat, environment and energy, Generation and treatment of waste, Available in <http://ec.europa.eu/eurostat/ (2010).
[2] European Standard ČSN EN 12 620+A1: Aggregates for concrete, ČNI, 2008.
[3] T. Pavlů, Testing and properties of recycled aggregate for using to concrete, stavba.tzb-info.cz 10265, Czech Republic, 2013.
[4] A. Abbas, G. Fathifazl, B. Fournier, O.B. Isgor, R. Zavadil, A.G. Razaqpur, S. Foo, Quantification of the residual mortar content in recycled concrete aggregates by image analysis, Mater. Charact. 60 (2009) 716–728.
[5] D. Kong, T. Lei, J. Zheng, Ch. Ma, J. Jiang, J. Jiang, Effect and mechanism of surface-coating pozzalanics materials around aggregate on properties and ITZ microstructure of recycled aggregate concrete, Constr. Build. Mater. 24 (2010) 701–708.
[6] L. Bodnarova, R. Hela, M. Hubertova, I. Nováková, Behaviour of lightweight expanded clay aggregate concrete exposed to high temperatures, International Journal of Civil, Environmental, Stuructural, Construction and Architectural Engineering 8 (2014) 181–184.
[7] P. Amorim, J. de Brito, L. Evangelista, Concrete made with coarse concrete aggregate: Influence of curing on durability, Aci. Mater. J. 109–120 (2012) 195–204.
[8] S.C. Kou, C.S. Poon, Enhancing the durability properties of concrete prepared with coarse recycled aggregate, Constr. Build. Mater. 35 (2012) 69–76.
[9] H. Zhang, Y. Zhao, T. Meng, S.P. Shah, The modification effects of a nano-silica slurry on microstructure, strength, and strain development of recycled aggregate concrete applied in an enlarged structural test, Constr. Build. Mater. 95 (2015) 721–735.
[10] S.M. Levy, P. Helene, Durability of recycled aggregates concrete: a safe way to sustainable developmen, Cement Concrete Res. 34 (2004) 1975–1980.
[11] M. Bravo, J. de Brito, J. Pontes, L. Evangelista, Durability performance of concrete with recycled aggregates from construction and demolition waste plants, Constr. Build. Mater. 77 (2015) 357–369.
[12] M. Joseph, L. Boehme, Z. Sierens, L. Vandewalle, Water absorption variability of recycled concrete aggregates, Mag. Concrete. Res. 67 (2015) 592–597.
[13] S. Lotfi, M. Eggimann, E. Wagner, R. Mróz, J. Deja, Performance of recycled aggregate concrete based on a new concrete recycling technology, Constr. Build. Mater. 95 (2015) 243–256.
[14] A. Ajdukiewicz, A. Kliszczewicz, Influence of recycled aggregates on mechanical properties of HS/HPC, Cement Concrete Comp. 24 (2002) 269–279.

[15] M.B. Leite, P.J.M. Monteiro, Microstructural analysis of recycled concrete using X-ray microtomography, Cement Concrete Res. 81 (2016) 38–48.
[16] Czech Standard ČSN 73 1236: Resistance of cement concrete surface to water and defrosting chemicals, ČNI, 1984.
[17] H. Wen, D. McLean, S. Boyle, T. Spry, D. Mjelde, Evaluation of recycled concrete as aggregate in new concrete pavements, Research report, Washington State, Department of Transportation (2014).