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Resistance of recycled aggregate concrete to freeze-thaw and deicing salts

Karel Šeps, Josef Fládr, Iva Broukalová*

Czech Technical University in Prague, Faculty of Civil Engineering, Department of Concrete and Masonry Structures, Thákurova 7, 166 29 Prague 6, Czech Republic

Abstract

The paper aims at the topic of sustainable building concerning recycling of waste rubble concrete from demolition. The authors´ long-term concern is about utilization of recycled concrete as aggregate in fibre reinforced cementitious composite. The recent investigations aimed at the durability properties of fibre reinforced concrete made entirely from recycled aggregate. Recycled concrete aggregate resistance to freezing and thawing was performed by several methods. The recycled concrete aggregate was used for making of fibre reinforced concrete and the freeze thaw resistance and resistance to deicing salts were tested. Conclusions are drawn and proposals made for application of the fibre reinforced concrete with recycled aggregate.

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Keywords: Recycled aggregate concrete; resistance to freeze-thaw cycles; deicing chemical agents; fibre reinforced concrete

1. Introduction

Recycling is an important business for the society. A big amount of recycled material originates in construction industry. The recycled material is applicable in production of concrete composite. Nowadays, most recycled concrete is used as aggregate in base and sub-base layers and backfills. Utilization of recycled concrete aggregate in new concrete mixtures and application for structural use is rare. The recycled concrete is sometimes used as coarse aggregate, mainly in combination with natural (virgin) aggregate. Our research group focused in an investigation of

* Corresponding author. Tel.: +420-224-354-631.
E-mail address: iva.broukalova@fsv.cvut.cz

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fibre reinforced cement composite made entirely from recycled crushed concrete with a limited dosage of cement binder. Utilization of RCA (recycled concrete aggregate) and minimal cement dosage contribute to the environmentally friendly production. Minimal cement dosage ensures covering of aggregate with the binder. The interlocking in the composite structure is increased by fibres. Fibres in the mixture strengthen the structure of the composite and provide tensile strength, toughness, and ductility of the FRC.

In the recent research freeze-thaw resistance and chemicals resistance of the composite were examined as these resistances are features important for potential application of the composite in environmentally exposed elements or structures. The focus was on freeze-and-thaw resistance of recycled aggregate itself, concrete from recycled aggregate, relation of them and resistance to chloride attack.

Several studies and results of various research teams have been published on durability properties of concrete or fibre reinforced concrete with recycled aggregate [1–4].

Abbas et al tested the freeze-and-thaw resistance of concrete with coarse recycled aggregate according to ASTM C 666. The coarse aggregate content was combined from recycled and natural (63.5–100 %) and the cement dosage was 230–430 kg/m^3. The RAC (recycled aggregate concrete) was classified resistant based on measuring of the relative dynamic elastic modulus. Chloride resistance of the RAC was also tested. The specimens were soaked in 15.1% solution of sodium chloride. The results showed big differences between two examined concretes; nevertheless, both had sufficient resistance [5].

Zaharieva et al. compared the resistance of RAC determined by different testing methods and drew the conclusion that resulting resistance depends on the testing method [6].

A study [7] followed freeze-and-thaw resistance for varying saturation by water and acknowledged dependence of the freeze-thaw resistance on saturation.

Investigations of RAC made from crushed concrete, returned back to concrete plants, proved that durability properties depend on resource concrete and recommends a procedure for manufacturing of durable concrete with crushed concrete aggregate [8].

All studies and investigations show an importance of durability and research of RAC durability. However these investigations used different concretes and testing methods and their results are not fully comparable with local recycled concrete and composite materials.

2. Materials and Methods

In the research program freeze and thaw resistance of recycled concrete aggregate from local recycling centre WEKO s.r.o. was tested. Two testing methods were used. Subsequently, fibre reinforced concrete made from the same recycled concrete aggregate was examined and its freeze-and-thaw resistance and resistance to chlorides were determined. The composition of the tested fibre reinforced concrete is listed in the Table 1.

Table 1. Components of the fibre reinforced concrete.

Component	Dosage (*kg*)
Cement CEM I 42,5R	300
Water	150
Recycled aggregate 0/16	1475
Synthetic fibres PP (length = 54 mm)	4.55

Experiments were performed and evaluated by methods specified in Czech standards ČSN EN 13242+A1:2008, ČSN EN 1322 and ČSN EN 73 1326 method A.

3. Results and discussion

3.1. Test of RCA (recycled concrete aggregate)

The recycled concrete aggregate was tested with methodology commonly used for testing of freeze-and-thaw resistance of aggregate for concrete. The principle of the test is a weight decrease determination of grains with chosen range of gradation in ten freeze – thaw cycles. The temperatures were applied in compliance with curves in the Fig. 1. The RCA (recycled concrete aggregate) contained a lot of fine particles; therefore, the test was performed with gradation range 8/16 and three batches of weight 650 g.

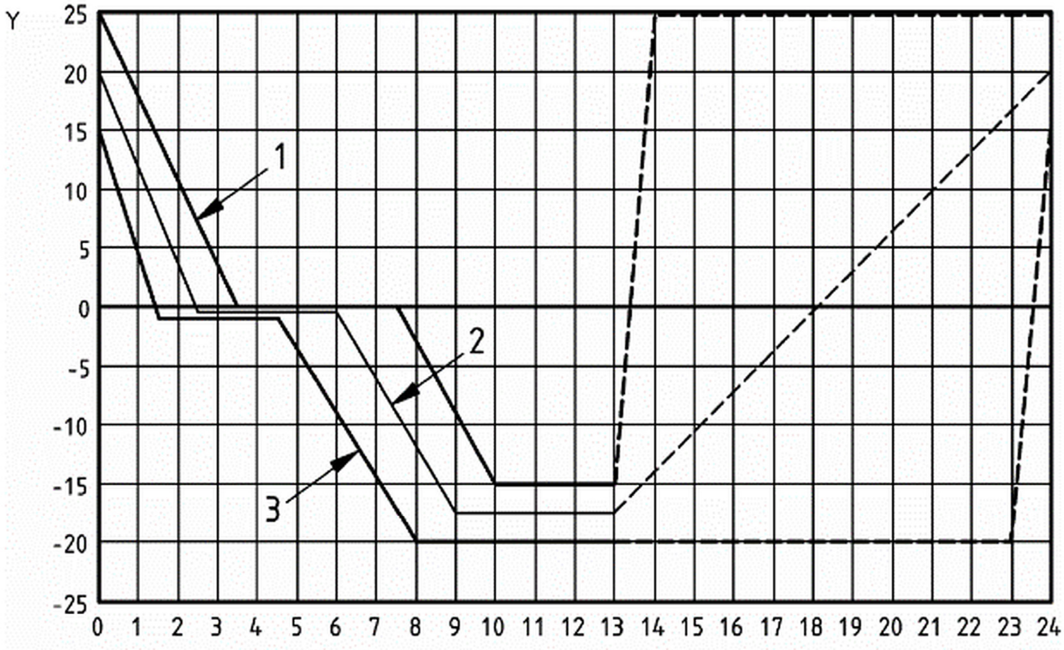

Fig. 1. Temperature course during freeze and thaw cycling (1 – minimal temperature curve, 2 – optimal temperature curve, 3 – maximal temperature curve) [9].

The resulting freeze – thaw resistance of the aggregate is then calculated from relation:

$$F = \frac{M_1 - M_2}{M_1} \cdot 100 \quad (1)$$

where: M_1 is the initial dry total weight of the batch in grams,
M_2 is the final dry total weight of the batch in grams that remained on specified sieve.

The evaluation of the experiment was performed according to ČSN EN 13242+A1:2008 that specifies 4 categories of aggregate freeze – thaw resistance (see Table 2).

Table 2. Categories of freeze and thaw resistance [10].

Mass loss (%)	Category
≤ 1	F_1
≤ 2	F_2
≤ 4	F_4
> 4	$F_{declared}$

Substitution of measured values in relation (1) gives the mass loss of tested aggregate:

$$F = \frac{2000.2 - 1085.6}{2000.2} \cdot 100 = 45.72\% \quad (2)$$

The mass loss is high. The result indicates that the recycled concrete aggregate is unsuitable for concretes subjected to freeze and thaw cycling.

In addition, the freeze and thaw resistance of RCA was verified in screening test of aggregate freeze and thaw durability where absorbability of aggregate is tested. The principle of the test is in the determination of weight increase of RCA immersed in water for 24 hours. The tested RCA had 4.9% increase of weight after treating in water.

Table 3. Categories of water absorption values [11].

Water absorption Mass percentage (%)	Categories
≤ 1	WA_{24} 1
≤ 2	WA_{24} 2

This method also showed that the tested RCA does not provide sufficient freeze thaw resistance. The water absorption significantly exceeded the code limits.

Thus a decision was taken to perform an other special test that should have given an accurate information on change of granularity due to freeze thaw cycling. The test is not covered in any code. The principle of the test is similar to the first testing method but here, wide range of gradation with known granularity is used for testing. Results of the test are in Fig. 2.

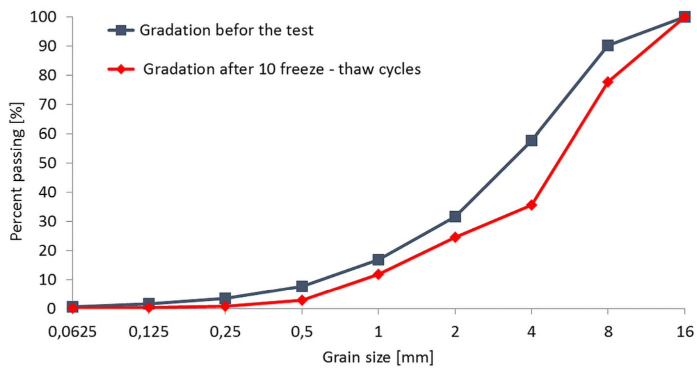

Fig. 2. Change of gradation in freeze and thaw tests.

The chart in Fig. 2 shows apparent drop of mass of grains with size from 2 to 8 mm (red line) compared to original recycled aggregate sample (blue line).

Three methods were used for testing of freeze-thaw resistance of RCA (recycled concrete aggregate). In all tests low resistance to freeze and thaw cycling of the RCA was confirmed.

3.2. Testing the freeze – thaw resistance of the RAC (recycled aggregate concrete)

The freeze thaw resistance tests of RAC were performed by method specified in ČSN EN 1322 with specimens 100/100/400 mm. Results were compared with reference samples, that were not subjected to freeze thaw cycling. Parameters recorded in regular intervals are listed in the Table 4.

Table 4. Mechanical properties after 50 cycles.

Sample	Reference samples Bulk density ($kg{\cdot}m^{-3}$)	Reference samples Compressive strength (*MPa*)	Tested samples Bulk density ($kg{\cdot}m^{-3}$)	Tested samples Compressive strength (*MPa*)
1	1813	20.8	1908	9.2
2	1883	21.3	1924	8.8
3	1829	30.3	1909	11.8
4	1854	29.9	2095	9.9
5	1829	21.4	1902	12.3
6	1846	17.4	1912	8.9
7			1934	15.0
8			1950	8.8
9			1907	14.0
10			1936	12.7
Average	1842	23.5	1938	11.1

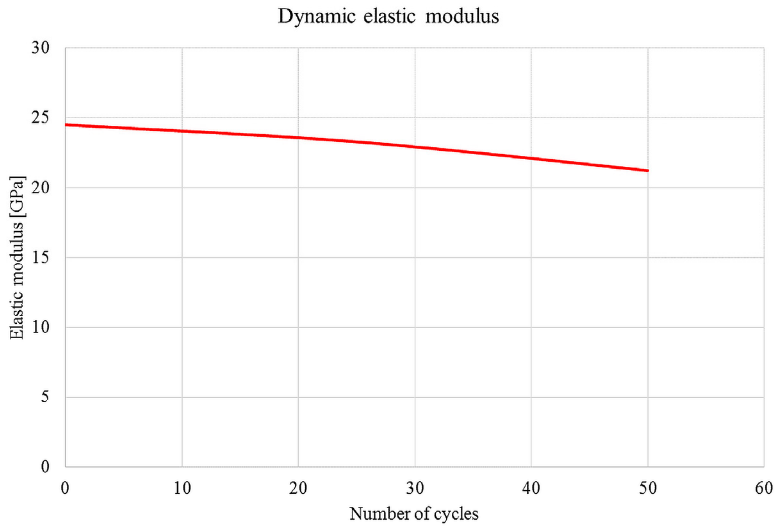

Fig. 3. Change of dynamic elastic modulus during cycling.

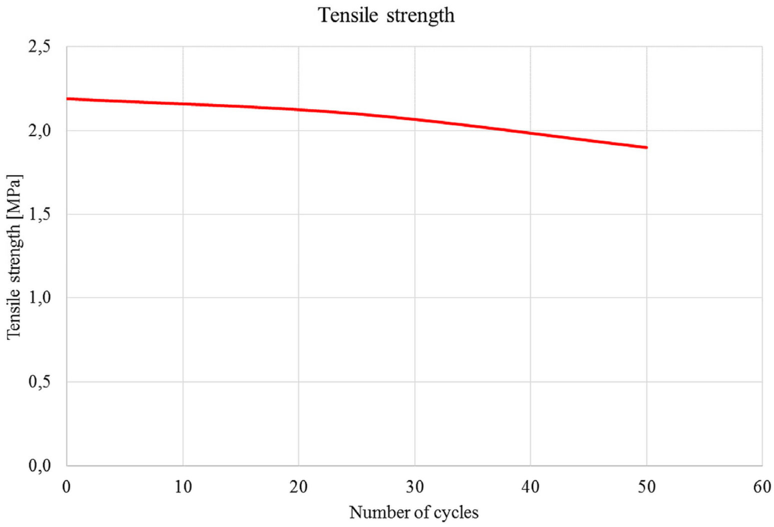

Fig. 4. Change of tensile strength during cycling.

3.3. Resistance of RAC (recycled aggregate concrete) to deicing salts

A set of test specimens was used to analyse RAC resistance to deicing salts. The tests were performed according to standard ČSN EN 73 1326 method A. Principle of the method is immersion of the cube in 3% solution of sodium chloride. The evaluation of the freeze – thaw resistance is done by measuring of weight loss regularly after 25 cycles.

Fig. 5. Surface of specimen (a) before testing; (b) after 25 cycles; (c) after 50 cycles of freezing and thawing.

Table 5. Mechanical properties after 50 cycles.

Sample	Weight (*kg*)	Mass loss after 25 cycles (*g*)	Total mass loss after 25 cycles ($g{\cdot}m^{-2}$)	Classification	Mass loss after 50 cycles (*g*)	Total mass loss after 50 cycles ($g{\cdot}m^{-2}$)	Classification
1	6400	71.90	2820		136	8153	
2	6480	45.40	1780		99.8	5694	
3	6430	76.10	2984		170.5	9671	
4	6610	60.95	2390	Strongly disturbed	101.3	6363	Disturbed
5	6770	52.85	2073		115.9	6618	
6	6545	86.75	3402		109.9	7712	
Average	6539	65.7	2279		122.2	7211	

All performed tests demonstrated that the tested composite is not suitable for applications subjected to environmental conditions. The measured results were:

- In the test of aggregate resistance to freeze and thaw the RCA exhibited mass loss 45% after ten cycles.
- Water sorption of the RCA in the simple screening test for freeze – thaw resistance was 4.9% after 24 hours of soaking in water.
- Decrease of compressive strength of RAC made entirely from crushed concrete was 47% after 50 cycles of freezing and thawing.
- Decrease of tensile strength of RAC was 10% after 50 cycles of freezing and thawing.
- Decrease of dynamic elastic modulus of RAC was 15% after 50 cycles of freezing and thawing.
- Average mass loss in the test of resistance to deicing salts was 2279 g after 25 cycles and 7211 g after 50 cycles.

There is evident correlation in change of RAC compressive strength and freeze thaw resistance of recycled aggregate. Due to low cement dosage, the compressive strength is provided mainly by aggregate that is disturbed by freezing and thawing. The tensile strength was almost not affected by freezing and thawing. It results from contribution of fibres. The tensile strength depends mainly on fibres and, as fibres are not disturbed by freezing and thawing that much as aggregate, the drop of tensile strength is small. The small decrease can be caused by worse conditions of interlocking of fibres and disintegrating aggregate.

For applications subjected to freezing and thawing the choice of suitable fibres is important. Generally the polymers behave in an increasingly brittle manner in temperatures below zero. E.g. in the choice between PP (polypropylene) and PVA (polyvinyl alcohol) fibres, more convenient are PVA fibres.

4. Conclusions

Presented results should not imply conclusion that cement composites made entirely with RCA are unsuitable for applications.

Properties of RAC are affected by type of recycled concrete aggregate, whose quality varies according to way of processing (crushing, sorting, straining out impurities etc.) and source of the crushed concrete. This information is usually not known as recycling centres do not ascertain origin of recycled materials. Scatter of material parameters of RAC is thus inevitably higher than scatter of material parameters of common concrete made from natural aggregate.

The tested RAC had compressive strength 23.5 MPa, what is favourable for designing of structures made from this material, as the RAC is cheaper and more ecology friendly than common concrete. If the tested RAC would be prevented from temperatures below zero or coincidence of moisture and low temperatures, it can be applied. The high potential of application of the RAC is utilisation it as filling grout in hollow core masonry. Considerable application field is utilisation of the RAC in earth structures, where the layer of RAC strengthened by fibres serves as stiffening layer.

Acknowledgements

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