

Study on potential of fibre reinforced concrete with recycled aggregate for applications

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Abstract. The construction and demolition waste constitute a quarter of all types of waste production. Recovery of this waste in other areas of the economy is a step in the right direction to achieve sustainable development. Department of Concrete and Masonry Structures at the Faculty of Civil Engineering of the Czech Technical University is concerned in the problematic of sustainable constructions by research on recycled materials. One of the focus is on replacing of natural aggregate by rubble concrete recycled from demolished concrete structures and use of the recycled aggregate in fibre-reinforced concrete with synthetic fibres. The research focused also on possibilities of the structural design of structures from investigated material. The investigations proved usability of fibre-concrete with recycled crushed concrete in certain applications. The composite has satisfactory material characteristics and its application would consume a great deal of recycled concrete aggregate. The paper will present the material parameters and its efficiency in examples of applications.

1. Introduction

Application of recycled aggregate as a substitution for natural aggregate is well established and widespread. The use of recycled concrete aggregate (RCA) is principally same as the use of concrete with natural aggregate. Properties of the hardened RCA composite depend on the proportion of recycled and natural aggregate and on characteristics of the original concrete used for recycling.

The density does not change if the RCA content is up to 25%. The density of concrete with more than 25% of RCA is lower than density of common concrete with natural aggregate. Generally, the substitution of natural aggregate with RCA decreases the compressive strength (by 4–45%) [1–3]. Some investigations showed no changes of compressive strength [4] or even increase (by 9%) [1, 5–7], probably due to quality high-strength original concrete.

Tensile splitting strength is usually lower (by 33%) if more than 25% of natural aggregate is replaced by RCA [1, 7]. On the other hand, some investigations indicated increase of splitting tensile strength by 20% [8–10].

The article does not deal with the utilization of recycled concrete aggregate sorted to separate fractions. Therefore, it does not address potential use of recycled concrete aggregate as a partial or full replacement of natural aggregates in the production of dense concrete, classified by strength classes.

This paper shows a different, completely new way of utilizing of recycled concrete aggregate in practice. Porous fibre-reinforced concrete made entirely with RCA is applicable in appropriately selected constructions.



2. Examples of possible applications of the composite

Based on Inverse design approach and material characteristics determined in initial investigations, potential applications of the porous fibre reinforced composite with recycled concrete aggregate were proposed. The composite can be used in sub-layers, in earthworks, in earthen flood dams, noise barriers, walls and columns for low load-bearing structures.

2.1 *Fibre reinforced composite from RCA in sub-layers*

The composite can be efficiently used for stabilizing layers in pavements, cycle routes, roadways, parking areas and sports grounds. This application takes the advantage of permeability of the composite that will contribute to draining of sub-layers in these types of structures. Technology of the composite compacting complies with the road and pavements construction technology of roller compacting. Vast amounts of material are consumed in sub-layers, thus a big portion of waste material will be utilised and not deposited in the waste landfills.

2.2 *Fibre reinforced composite from RCA in earthworks*

Use of the composite as a strengthening layer in earthworks benefits from tensile strength, ductility and permeability of the composite. The pervious layer allows water from precipitation to pass through, prevents runoff and contributes to groundwater recharge.

The reduction of the embankment width by 2 x 10 m determined in the studied case would bring significant savings. Considering the purchasing price of farmland in the Czech Republic as 1 €/m², saving of 20 x 1000 = 20 000 € per one kilometre of the dam can be estimated. The savings can be even much higher in case that the structure is built on a more expensive estate such as forest or building land.

2.3 *Fibre reinforced composite from RCA in earthen flood dams*

Fibre reinforced composite with recycled aggregate can be utilized for stabilizing layers in the earthen flood dams. This application was proposed for recycled aggregate that incorporated higher amount of fine aggregate and the porosity of resulting composite was lower.

2.4 *Noise barriers*

Porous materials are generally exploited as sound absorbing materials. On the premise that sound energy will be dissipated in a series of interconnected cavities in the porous fibre reinforced composite with recycled aggregate it based the next proposed application in the noise barrier. The assumption must be verified by a laboratory test. Sound absorbing coefficient must be determined and reduction of sound pressure level must be verified for particular frequencies.

2.5 *Fibre reinforced concrete walls and columns*

Recycled aggregate can be used in a cement composite for application in walls and columns similarly to masonry walls and pillars. The walls and columns from the composite are applicable in low-storey houses with moderate loading. The composite has strength comparable to strength of clay masonry, comparable heat insulation performance and the advantage is lower labour intensity compared to clay masonry.

3. Materials and methods

In contrary to common concrete mix design, which begins by determining the requirements on concrete; setting of required concrete class, according to conditions that the concrete will be exposed to in service, a new approach was introduced, in which the procedure of the structural design and concrete mix design are inverted. In the initial phases a mixture is specified, subsequently material properties of hardened concrete are examined and identified, and application of the composite is proposed. The mixture composition is adjusted and modified for particular applications.

The composite consists of recycled concrete aggregate, which is not sorted into fractions. Maximum particles size 22 mm, gradation curve in Figure 1. Composite has a minimal dose of cement for structural application (260–300 kg/m³), polymer fibres and water. The dosage of mixing water depends on water absorption of recycled aggregate and aggregate moisture state. The mixing water is dosed to reach the mixture consistency convenient for compaction by ramming or tamping.

A composite is intended for application in walls (columns). It consisted of 1,650 kg/m³ of recycled concrete aggregate, 260 kg/m³ of Portland cement (42,5 R Mokr), 9.1 kg/m³ of polypropylene fibres (length 55 mm) and 150 kg/m³ of water. The composite properties were investigated in various tests. Parameters related to structural function of the composite were determined and, also thermal parameters were followed.

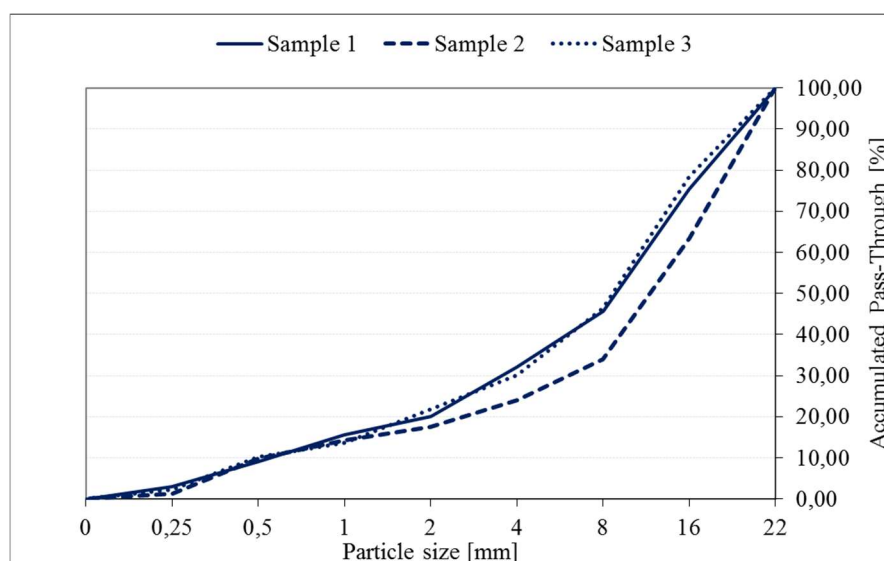


Figure 1. Gradation curve of recycled concrete aggregate.

4. Results and discussion

Common tests with cube specimens were performed to determine compressive strength (Table 1) and tensile splitting strength.

Table 1. Results of compression tests.

Specimen	Dimensions			Weight (kg)	Density (kg/m ³)	Load (kN)	Compressive strength (MPa)
	Width (mm)	Length (mm)	Height (mm)				
A1	149	149	149	6.088	1,840	276	12.43
A2	149	147	149	5.946	1,822	216	9.86
A3	149	145	148	6.032	1,887	350	16.20
A4	149	149	149	6.034	1,824	254	11.44
A5	149	150	148	6.302	1,903	282	12.62
A6	148	149	151	5.980	1,796	214	9.70
A7	149	149	149	5.972	1,805	208	9.37
A8	149	150	148	6.106	1,846	236	10.56
Mean value					1,840		11.52
Conditional standard deviation					38.1		2.25

A characteristic value of compressive strength was calculated from the measured data according to ISO 2394. General principles on reliability for structures using k- coefficient for eight specimens $k = 2$. The characteristic strength of recycled aggregate fibre reinforced composite is $f_k = 6.99$ MPa.

Mean value of tensile splitting strength is 0.7 MPa with standard deviation 0.12.

Non-standard prism specimens 150/150/600 mm and 150/150/1,200 mm were loaded in the direction of their axis in compression machine. Figures 2 to 4 show load-deformation diagrams of both specimens and the state of specimens after finishing of tests. Cracking and development of visible cracks occurred after reaching of ultimate load for both specimens.

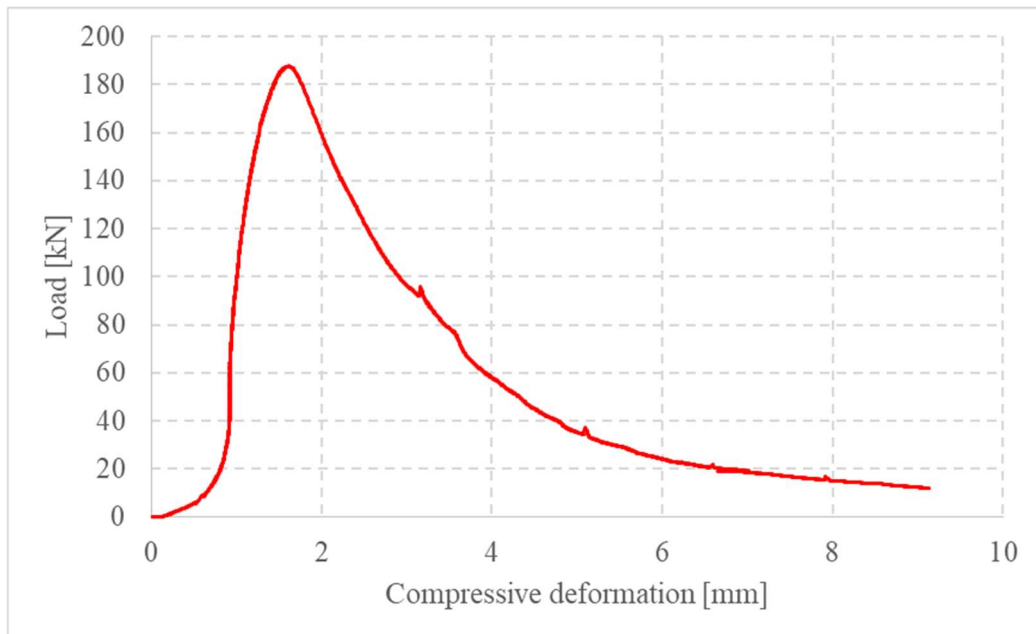


Figure 2. Load – deformation curve of specimen 150/150/600 mm.

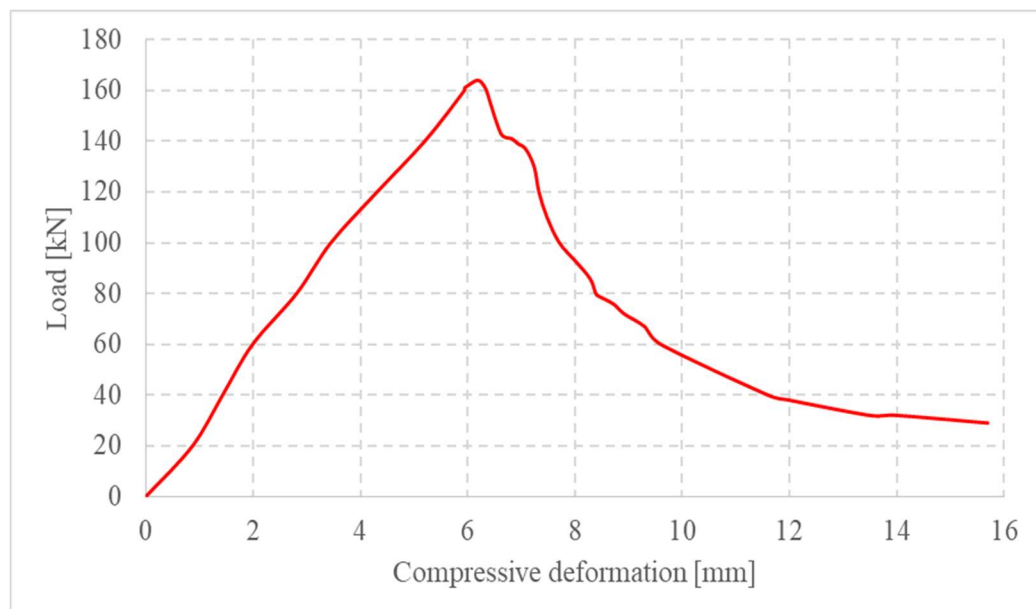


Figure 3. Load – deformation curve of specimen 150/150/1,200 mm.



Figure 4. Specimens after laboratory tests 150/150/1,200 mm.

The high porosity of the composite led to assumption of efficacious thermal properties. Volumetric thermal capacity and thermal conductivity were measured with a device Isomet on cubes 100/100/100 mm.

The measurement was based on an analysis of the temperature response of the analysed composite to heat flow impulses. The heat flow was excited by electrical heating of a resistor heater inserted into the probe which was in a direct thermal contact with the tested specimen. Evaluation of thermal conductivity and volumetric heat capacity is based on periodically sampled temperature records as a function of time, provided that heat propagation occurs in unlimited medium. Results of measurements are in Table 2.

Table 2. Thermal parameters.

Specimen	Thermal conductivity λ (W/mK)	volumetric <i>thermal</i> capacity c (10^6 J/m ³ K)
1	0.6741	1.4244
2	0.7505	1.5288
3	0.5892	1.3925
4	0.7689	1.5213
5	0.6005	1.4068
6	0.5926	1.4083
Mean value	0.6630	1.4470
Standard deviation	0.0820	0.0610

Thermal transmittance (U-value) was calculated from the measured thermal parameters. The calculation assumed wall of thickness 44 cm with 15 mm lime plaster on the interior side of wall and perlite plaster of thickness 15 mm on the exterior side of wall. The calculations were performed according to EC ISO 6946. Properties of the recycled aggregate composite wall are compared to a masonry wall of the same thickness.

U-value of the aggregate composite wall was $U = 1.0$ W/mK; the referential masonry wall had U-value $U = 1.2$ W/mK.

Material with properties described above is applicable in constructions for structures with moderate loads and non-loadbearing structures. These considerations resulted in an idea of using the recycled aggregate composite as a substitution to masonry in loadbearing walls. The thermal technical parameters of the composite are better compared to solid masonry. Nevertheless, without additional insulation, the composite wall does not meet standard requirements. Considering the thermal characteristics and required resistance capacity, the composite can be used for loadbearing walls in low-storey building.

5. Conclusions

Designing of materials for structural applications is restricted by many specifications. E.g. the dosage of recycled aggregate is limited and blends of natural and recycled aggregate are used. The investigations focused on recycled aggregate concrete made entirely with recycled aggregate. The intention of the approach is maximizing of the exploitation of secondary aggregates in concrete for structural applications and changing the perspective and offering the alternative view of designing cement composites from recycled aggregate concrete.

A new porous fibre reinforced composite was proposed, and its material characteristics were tested.

Several potential applications from the composite were suggested and their benefits assessed. The composite used for strengthening of earthen body may result in decrease of farmland occupation and reduce excavations. Strengthening layers contribute to stability of the sloping earth body and increase the resistance. In earthen flood dams the stabilizing fibre reinforced composite layers increase the bearing life in case of overflow in floods. The composite can be applied for loadbearing walls in low-storey buildings.

Certainly the limitations of the proposed composite must be considered, too. The input material – recycled concrete aggregate possesses heterogeneous properties, what affects the scatter of resulting composite characteristics. The composite is a porous low-strength material with higher dispersion of material parameters, what must be considered in the choice of appropriate application.

The limitations are balanced by favourable environmental aspects. Increased utilization of recycled concrete contributes to saving of raw materials, elimination of the need for disposal of construction waste and low carbon production. High economic and ecological effects of the composite is provided by maximising of recycled aggregate use and minimising of cement consumption. Application of the fibre reinforced composite with recycled concrete aggregate preserves primary resources of natural aggregate, decreases depletion of the environment and reduction of construction waste disposal in landfills.

Acknowledgements

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