Probabilistic Analysis of Structural Member from Recycled Aggregate Concrete

To cite this article: I Broukalová and K Šeps 2017 IOP Conf. Ser.: Mater. Sci. Eng. 246 012035

View the article online for updates and enhancements.

Related content
- Study on potential of fibre reinforced concrete with recycled aggregate for applications
  K Šeps, I Broukalová, J Fládr et al.
- Aspects Concerning the Use of Recycled Concrete Aggregates
  I Robu, C Mazilu and R Deju
- The influence of kind of coating additive on the compressive strength of RCA-based concrete prepared by triple-mixing method
  K Urban and A Sicakova
Probabilistic Analysis of Structural Member from Recycled Aggregate Concrete

I Broukalová† and K Šeps†

†Department of Concrete and Masonry Structures, Faculty of Civil Engineering, Czech Technical University in Prague

E-mail: iva.broukalova@fsv.cvut.cz

Abstract. The paper aims at the topic of sustainable building concerning recycling of waste rubble concrete from demolition. Considering demands of maximising recycled aggregate use and minimising of cement consumption, composite from recycled concrete aggregate was proposed. The objective of the presented investigations was to verify feasibility of the recycled aggregate cement based fibre reinforced composite in a structural member. Reliability of wall from recycled aggregate fibre reinforced composite was assessed in a probabilistic analysis of a load-bearing capacity of the wall. The applicability of recycled aggregate fibre reinforced concrete in structural applications was demonstrated. The outcomes refer to issue of high scatter of material parameters of recycled aggregate concretes.

1. Introduction
Growing demand for cutting carbon emissions, reduction of pollution emitted from building industry, saving natural resources and raw materials should target to reduction of construction waste disposal in landfills, re-use of construction materials, utilization of non-traditional materials or non-traditional use of common materials.

Recycled aggregate accounts for ca 8% of aggregate use in the European production (European Aggregates Association, 2013). Our efforts aim to increase this ratio and consume a significant quantity of crushed concrete from construction and demolition waste (CDW) in production of recycled aggregate concrete (RAC) and minimizing of natural aggregate depletion.

Use of RCA (recycled concrete aggregate) in concrete is restricted by code prescriptions on aggregate testing, quality of aggregate and limits of maximal amount of recycled aggregate which can be used as a substitution of natural aggregate. The restrictions are caused by the reason of worse quality and high dispersion of recycled aggregate characteristics.

The purpose and target of our aspirations was to change the understanding in attempts to apply RCA in concrete. In our opinion, it should not be regarded that RCA is used to make concrete with downgraded properties compared to common concrete. Under a new perspective RCA is used to make a new composite, which is relevant in certain applications.

The keynotes of the new composite design are maximizing of recycled aggregate consumption, minimizing of cement consumption (low cement dose), simplification of the composite manufacturing by minimizing the demanded pre-treatment of recycled aggregate and minimizing required accompanying tests. These provisions are supposed to provide competitive advantage of the composite made from recycled concrete.
As a result of this approach in the concrete mix designing, a low-strength porous composite is manufactured. Efficiency of the composite for application in a load-bearing member was studied in the testing program and probability analysis.

2. Mixture composition
The governing intention of the mixture proposal is maximising of the recycled aggregate consumption. Basis of the mixture design was the grain size distribution curve of the delivered recycled aggregate. Natural aggregate was added to replenish missing fractions of recycled aggregate so that the ideal grain size distribution was approximated.

2.1. Aggregate. The dose of 1 310 kg of recycled concrete aggregate was combined with 200 kg of greywacke and 150 kg of sand per cubic meter.

2.2. Cement binder. Dosage of cement relates to economic and ecology aspects of the research project and it was determined with respect to the European Standard EC 206-1 requirements for minimal cement content.

Type I hydraulic Portland cement was used, with 95 % of Portland cement clinker (chemical composition is in the table 3). Specific surface area of cement binder was 381 m$^2$/kg.

### Table 1. Main chemicals in the cement binder

| Component | Content [%] |
|-----------|-------------|
| CaO       | 64.2        |
| SiO$_2$   | 19.5        |
| Fe$_2$O$_3$| 3.2         |
| MgO       | 1.3         |
| SO$_3$    | 3.2         |

2.3. Fibres in the mixture strengthen the structure of the composite and provide tensile strength and toughness. Activation of fibres after macrocracking increases the ductility of the composite.

In the choice of materials for fibres, high porosity and permeability of hardened concrete should be considered. To prevent deterioration of fibres due to penetrating moisture, synthetic fibres should be selected; here 4.55 kg of polypropylene macrofibres with strength ca 600 MPa were used.

2.4. Water. The water absorption capacity of aggregate influences the properties of the fresh concrete such as its workability.

The dosage of mixing water depends on water absorption of recycled aggregate and aggregate moisture state. The mixing water was dosed to reach the mixture consistency convenient for compaction by ramming or tamping (vibration cannot be used because of the high porosity of composite).

### Table 2. Fibre reinforced composite from recycled concrete aggregate mixture design

| Component                             | Dosage [kg/m$^3$] |
|---------------------------------------|------------------|
| Portland cement 42,5 R                | 310              |
| water                                 | 150              |
| recycled concrete aggregate           | 1 310            |
| natural aggregate 8/16                | 200              |
| natural aggregate 0/4                 | 150              |
| polypropylene macro-fibres            | 4.55             |
3. Testing program

Material parameters were determined in common tests used for concretes. Cubes 150/150/150 mm were used for determination of compressive strength (table 3). Tensile strength was specified in a three-point bending test of prisms 100/100/400 mm (table 4).

### Table 3. Compressive strength of the composite

| Specimen | Weight g | Density kg.m⁻³ | Compression Load kN | Strength MPa |
|----------|----------|----------------|-------------------|--------------|
| 1        | 6 985.0  | 2 052          | 843.33            | 37.2         |
| 2        | 6 420.0  | 1 876          | 427.85            | 19.2         |
| 3        | 6 730.0  | 2 050          | 784.13            | 35.7         |
| 4        | 6 465.0  | 1 890          | 369.62            | 16.6         |
| 5        | 6 905.0  | 2 017          | 815.80            | 35.9         |
| 6        | 6 780.0  | 2 003          | 611.53            | 27.2         |
| Average value |        | 1 981          |                   | 28.6         |
| Standard deviation | | 79            |                   | 9.1          |

### Table 4. Tensile strength of the composite

| Specimen | Weight g | Density kg.m⁻³ | Tensile Load kN | Strength MPa |
|----------|----------|----------------|----------------|--------------|
| 1        | 8 055.0  | 1 986          | 9.09           | 2.69         |
| 2        | 7 865.0  | 1 978          | 9.06           | 2.74         |
| 3        | 7 475.0  | 1 934          | 7.20           | 2.30         |
| 4        | 7 780.0  | 1 921          | 8.16           | 2.40         |
| Average value |        |                | 2.53           |              |
| Standard deviation | |               | 0.22           |              |

4. Analysis of the structural member

One of the targets of the investigations was a feasibility study of the proposed composite in a structural element.

For application of any material in load-bearing structural elements a reliable design is an essential condition. Reliability is defined as ability of the structure to withstand loads with corresponding reliability level and fulfil given requirements during the whole lifetime of the structure. The reliability level is assessed on a statistical basis, by defining the probability of collapse that is reputed acceptable as a function of the consequences of the collapse itself and the nominal lifetime of the construction.

Present designing and verification of reliability are based on limit state methodology that includes randomness of actions, material parameters, geometry of the structure and uncertainties in structural
models. The stochastic nature of material parameters and actions on structures in common design approach is covered in partial safety factors. Entirely probabilistic approach to the design is advanced method of structure assessment.

4.1. Probabilistic analysis

The proposed fibre reinforced composite is a novel material; hence it is essential to prove its reliability for structural applications in thorough probability analysis. The probabilistic verification was performed for a wall made from recycled concrete composite of 30 cm thickness and 2.8 m height. The choice of the wall dimensions and a manner of loading and its eccentricity relates to referential masonry wall from solid bricks.

The probabilistic analysis was performed with software system SARA – FREET – ATENA. FREET (Feasible Reliability Engineering Tool) is multipurpose probabilistic software tool for statistical, sensitivity and reliability analyses. ATENA is a program developed especially for non-linear analyses of concrete and reinforced concrete structures. SARA (Structural Analysis and Reliability Assessment) is computing environment providing communication between FREET and ATENA. Randomness and uncertainties are described as random variables by probability functions. Random input parameters are generated by LHS method (Latin hypercube sampling). The stochastic analysis refers to deterministic simulation of the composite wall behaviour assembled in ATENA program, which modelled behaviour of a wall loaded vertically with eccentricity 15 mm until failure. The simulations in ATENA stemmed from material model “Nonlinear Cementitious 2” implemented in the software tool and material parameters measured in laboratory tests.

In the probabilistic analysis the material characteristics of the composite were chosen as random variables. The mean values, variance, standard deviation and variation coefficient were derived from scatter of laboratory tests results. Table 5 shows material parameters assumed as random variables in the probabilistic analysis.

| Material parameter     | Distribution | Mean value | Standard deviation |
|------------------------|--------------|------------|--------------------|
| Elastic modulus        | normal (Gauss) | 25 GPa     | 8.25               |
| tensile strength       | normal (Gauss) | 2.5 MPa    | 0.22               |
| compressive strength   | normal (Gauss) | 28.5 MPa   | 9.24               |
| fracture energy        | normal (Gauss) | $3 \times 10^{-5}$ MN/m | $1 \times 10^{-5}$ |

Figure 1: Distribution of random variable (elastic modulus)
Twenty simulation tasks were analysed with random material parameters. The scatter of resistance calculated in particular tasks is rather high (figure 2).

![Figure 2. Bundle of load – deformation diagrams from probabilistic analysis](image)

Summary of random resistance of the wall loaded with vertical load applied with eccentricity equal to 15 mm assessed in probabilistic calculation is shown in table 6.

| Table 6 Statistical resistance of recycled aggregate composite wall |
|---------------------------------------------------------------|
| Mean value of the maximum load                              | 9 105 kN/m |
| Variation coefficient                                        | 0.23       |
| standard deviation                                           | 2 110      |
| distribution function                                        | normal     |

Based on the results of analysed simulation tasks statistical evaluation of resistance was performed. The action applied on wall was assumed with normal distribution and variance 0.1. The results in terms of reliability index are plotted in the figure 3. The diagram shows decreasing reliability index related to increasing value of load in kN/m plotted on horizontal axis.
Figure 3: Reliability index of the recycled aggregate composite wall determined in probabilistic analysis

As the wall is described with structural resistance function with its mean value and standard deviation and the load effect function can be described in a similar manner, the structure can be designed to have a prescribed reliability index. A target value of the reliability index is specified in Eurocode 1990, annex B according to reliability classes table 7.

| Reliability Class | Minimum values for $\beta$ at ultimate limit state |
|-------------------|---------------------------------------------------|
|                   | 1 year reference period | 50 years reference period |
| RC3               | 5.2                    | 4.3                     |
| RC2               | 4.7                    | 3.8                     |
| RC1               | 4.2                    | 3.3                     |

The reliability class level relates to dividing of structures to consequence classes according to type, function of the building and damage, injury impacts or loss of lives caused by failure of the structure. The structural member investigated in the feasibility study is intended for use in simple buildings as family houses and small office or agricultural buildings. Thus it was classified RC2 according to the table 8 given in EC 1990.
Table 8 Consequences classes in Eurocode, EN 1990

| Class | Description | Examples |
|-------|-------------|----------|
| CC1   | Low consequence for loss of human life, and economic, social or environmental consequences are small or negligible | Agricultural buildings where people not normally enter (e.g. storage buildings), greenhouses |
| CC2   | Medium consequence for loss of human life, economic, social or environmental consequences are considerable | Residential and office buildings, public buildings where failure consequences are medium (e.g. office building) |
| CC3   | High consequence for loss of human life, or economic, social or environmental consequences are very great | Grandstands, public buildings where the consequences of failure are high (e.g. concert hall) |

The target reliability index is reached for load 1 000 kN/m, what signifies quite satisfactory resistance for a loadbearing wall. The value of resistance is bigger compared to resistance of common masonry walls. (Design resistance of 30 cm thick masonry wall from solid bricks determined by Eurocode 1996 calculation procedure is ca 360 kN/m.)

Undesirable factor is a big divergence of the maximum load value and targeted resistance. For the investigated composite wall the ratio of the mean resistance and targeted satisfactory resistance is 9.

The high variance of resistance determined in the probabilistic analysis is caused by high scatter of material properties measured in laboratory tests. It is evident that the scatter of compressive strength relates to scatter of density; specimens with the lowest compressive strength have at the same time the lowest value of density (table 3). The small strength is caused by bad compaction of the composite; consequently technology discipline should be the principal focus in manufacturing of the fibre reinforced composite with recycled concrete aggregate for structural use.

5. Conclusions

The resistance, safety and the economic aspects are the most important factors in the decision-making process when the construction material for the planned structure is selected. However, new aspects of the designing process such as environmental issues and depletion of natural resources are becoming more and more important. Increased utilization of recycled concrete would contribute to saving of raw materials, elimination of the need for disposal of construction waste and low carbon production.

The analysis proved feasibility of recycled aggregate concrete in structural applications. On the other hand confirmed commonly known issue of the high scatter of material parameters of recycled aggregate concrete. It is a challenge for the future investigations to overcome the drawbacks, benefit from features of the fibre reinforced composite with recycled concrete aggregate and consider the material properties in the choice of appropriate application. Only approaches that will embrace challenges and overcome obstacles, can tribute to wider application of wastes and reduce the amount of C&D waste being diverted to landfill.

Acknowledgement

This outcome has been achieved with support of the Technology Agency of Czech Republic, project No. TH02030649 Environmentally Efficient Construction and Demolition Waste for Structures (EESDOK).
References

[1] Sagoe-Crentsil, K. K., Brown, T., & Taylor, A. H. Performance of concrete made with commercially produced coarse recycled concrete aggregate. Cement and Concrete Research 2001, 31, 701–712

[2] Ajudkiewicz, A., Kliszczewicz, A.: Influence of recycled aggregates on mechanical properties of HS/HPC, Cement and Concrete Composites, Volume 24, Issue 2, April 2002, Pages 269-279, ISSN 0958-9465

[3] ISO 2394, General principles on reliability for structures

[4] Broukalová, I. - Šeps, K. - Vodička, J. - Novák, J.: A Feasibility Study on the Structural Use of Fibre Reinforced Concrete with Recycled Aggregate. In Proceedings of the Fifteenth International Conference on Civil, Structural and Environmental Engineering Computing. Stirling: Civil-Comp Press Ltd, 2015, ISSN 1759-3433. ISBN 978-1-905088-63-8.

[5] Bílý, P.; Fládr, J.; Ryjáček, P.; Vodička, J.: Development of special fibre reinforced concrete for exposed concrete pavements on bridges, In: Fibre Concrete 2015 - Technology, Design, Application. Praha: České vysoké učení technické v Praze, Fakulta stavební, 2015. ISBN 978-80-01-05683-7.

[6] Novák, J.; Brejcha, V.; Kohoutková, A.; Fládr, J.; Broukalová, I.: Precast Fibre Reinforced Concrete Element of Retaining Wall, In: Fibre Concrete 2015 - Technology, Design, Application. Praha: České vysoké učení technické v Praze, Fakulta stavební, 2015. ISBN 978-80-01-05683-7.

[7] Bílý, P.; Fládr, J.: Verification of compressive strength on different sized hsc specimens, In: Fibre Concrete 2013 - Technology, Design, Application. Praha: České vysoké učení technické v Praze, Fakulta stavební, 2013, pp. 47-52. ISSN 2336-338X. ISBN 978-80-01-05240-2.