29th International Conference
ENGINEERING MECHANICS 2023
Milovy, Czech Republic, May 9 – 11, 2023

THE USE OF RECYCLED AGGREGATES IN CONCRETE STRUCTURES

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Abstract: *At present, the existence of concrete will be achieved first by the challenge of its arrival, which is its sustainability for the next generations, in connection with the growing population. With the passage of time, there is an increasing deficit of non-renewable resources. Because of this, most informed people agree with the transition from a linear to a circular economy. Of course, concrete must keep up with this significant paradigm shift. What are the most important data to assess the potential for concrete recycling? Is it possible to use recycled concrete in the construction of supporting structures of buildings, and what will affect its final properties? This paper will deal with the dispersion of the mechanical characteristics of recycled concrete depending on the type of recycled aggregate and the size of the water/cement ratio.*

Keywords: Recycled concrete, recycled concrete aggregate, mechanical properties of recycled concrete, the applicability of recycled concrete.

1. Introduction

As a result of population growth worldwide and increased population migration, there has been a development in the construction industry associated with the construction of new buildings, which has also been associated with the creation of construction and demolition (C&D) waste. The amount of C&D waste is already so large, that it is necessary to think about the possibilities of reuse in the construction industry. This would also save the environment itself - there will be no need to create new landfills and extract new raw materials to produce building materials. In addition, such reuse of C&D waste would positively impact the economy, as C&D waste is cheaper than mining new raw materials.

Since this article will deal with the usability of recycled concrete, it will be interesting to mention the materials suitable for its production. In 2004, 1.79 billion tons of C&D mineral waste were produced, which represented roughly 68.5% of the total waste production. In 2018, according to EUROSTAT (Eurostat online data), the production was 375 million tons of mineral C&D waste, which represents 13.5% of the total waste production of the registered countries. The largest amount of mineral C&D waste produced in 2018 was recorded in Germany (roughly 86.5 million tons) (Eurostat online data).

Due to the development of the generation of C&D mineral waste, it is necessary to deal with its reuse in the construction industry, not only in non-load bearing but also load-bearing structures, on a larger scale than is the case today.

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ISSN: 1805-8256, doi: 10.21495/em2023-179

2. Mechanical properties of recycled concrete

2.1. Compressive strength

To be able to fully use recycled concrete in load-bearing structures, it is necessary to guarantee its mechanical and chemical properties. As with normal (ordinary) concrete produced from natural aggregate, also in concrete produced from recycled concrete aggregate, its main predisposition is its compressive strength.

Many available studies show a decrease in the strength of recycled concrete compared to normal concrete when using similar recipes (Hansen, T.C., 1986; Hansen, T.C.,1992a; Hansen, T.C., 1992c; Müller, A., 2004; Roos, F., 2002) Guaranteeing the compressive strength of concrete made from recycled aggregate is not such a big problem, and it is possible to produce almost all strength classes, just like normal concrete. The strength of concrete from recycled aggregate will primarily depend on the recycled aggregate's strength class, the amount of natural aggregate replaced by the recycled aggregate, the grain size of the recycled aggregate, the amount and type of cement used, and the water/cement ratio used.

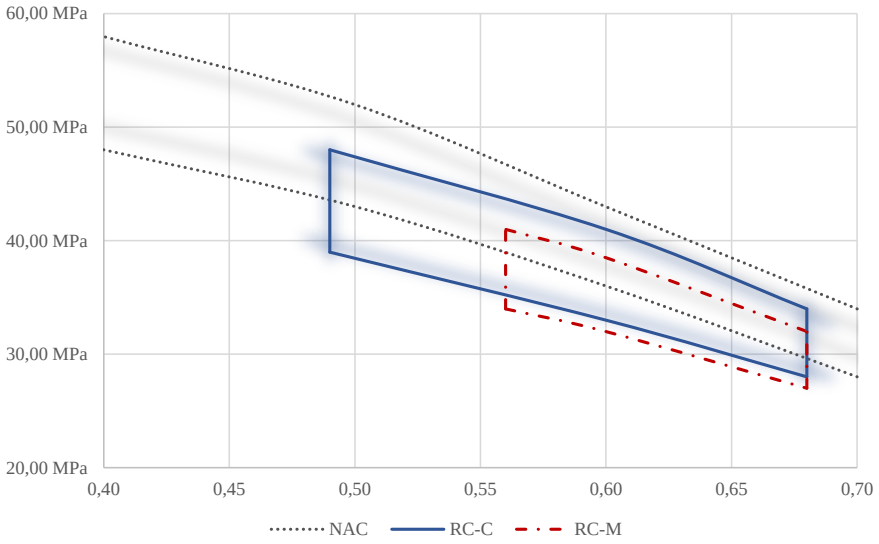

Fig. 1: Strength of concrete considering to the water/cement ratio and type of aggregate; NAC – natural aggregate concrete, RC-C – concrete from recycled concrete aggregate, RC-M – concrete from mixed recycled aggregate (Hoffmann, C., Moser, K., 2010; Hoffmann C., 2014).

Tab. 1: Decrease in RC strength depending on the exchanged fractions.

Quotation	Fraction < 4 mm	Fraction > 4 mm	Decrease in strength [%]
(Wainwright et. al., 1993)	RA	RA	20%
(Dillmann, R., 2002; 19.Wesche, K. and Schulz, R.R., 1982a, b)	NA	RA	10-25%
(Beckerová, L., 1998)	NA+RA	NA+RA	25%
(Fraaij et. al. 2002)	NA	RA	10%
(Fraaij et. al. 2002)	RA	NA	20%
(Gómez-Soberón, J.M.V., 2002)	RA	RA	10%

2.2. Modulus of elasticity

In comparison to the compressive and tensile strength of RC, there is consensus in the available literature that the use of recycled aggregates reduces the modulus of elasticity, while the data on the modulus of elasticity decrease and its variance vary widely (Dillmann, R., 1999; Khedar, G.F. and Al-Windawi, S.A., 2004; Wesche, K. and Schulz, R.R., 1982a; Wesche, K. and Schulz, R.R., 1982b). According to available research, the use of natural sand instead of recycled aggregate has a beneficial effect on the modulus of elasticity.

Tab. 2: Decrease of modulus of elasticity of RC depending on the type of RC.

Quotation	Type of RC	Decrease of modulus of elasticity of RC [%]
(Salem, R.M. and Burdette, E.G., 1998)	RC-M	16 %
(Jianzhuang, X., Li, J. and Zhang, C., 2004)	RC-M	45 %
(Grübl, P. et. al. 1999b)	RC-M	50 %
(Lukas, M., 1994)	RC-M	30 %
(Grübl, P. and Rühl, M., 1998)	RC-C	20 %
(Hansen, T.C. and Boegh, E., 1985)	RC-C	15 - 30 %
(Lukas, M., 1994)	RC-C	+26 %

In general, the modulus of elasticity is subject to greater variance than the compressive strength, regardless of whether the concrete was made from the natural or recycled aggregate. A fluctuation of ± 10,000 MPa is not unusual in concrete with natural aggregates. In the case of concrete with recycled aggregate, the modulus of elasticity can vary even more depending on the recycled aggregate used (Bergmeister, K. and Wörner, J.-D., 2005). Based on the summary of tested concretes, published in available publications, it can be observed that the relationship between concrete compressive strength and modulus of elasticity of concrete made from recycled aggregates is in the range of concrete from natural aggregates and lightweight concretes (Bergmeister, K. and Wörner, J.-D., 2005).

3. The use of recycled aggregates in concrete structures

3.1. Use based on recommendations

Tab. 3: Material composition of aggregates for concrete (Hoffmann, C., Moser, K., 2010; Hoffmann C., 2014).

Type of		Category of aggregate components					
Concrete	**Aggregate**	**R_U+NA**	**R_C**	**R_B**	**R_A**	**X+G**	**FL**
C ../..	Natural aggregate	≥ 75 %	< 25 %	≤ 5 %	≤ 1 %	≤ 0,3 %	≤ 2,0 cm^3/kg
RC-C	Concrete recycled aggregate	< 75 %	≥ 25 %	≤ 5 %	≤ 1 %	≤ 0,3 %	≤ 2,0 cm^3/kg
RC-M	Mixed recycled aggregate	< 95 %	< 95 %	≥ 5 %	≤ 1 %	≤ 0,3 %	≤ 2,0 cm^3/kg

*For RC-C and RC-M the following must be met: $R_C+R_B \geq 25$ % mass fraction

R_C – concrete, mortar, concrete products etc., R_B – burnt clay bricks and tiles, limestone masonry, aerated concrete (non-floating) etc., R_U – unconsolidated aggregate, natural stone etc., R_A – materials containing asphalt, X – other materials like clays, soil, ferrous and non-ferorous materials, gypsum etc., G – glass, FL – floating materials (by volume)

3.2. The use of recycled concrete on a real structure

Fig. 2: Reinforced load-bearing slab made of recycled concrete (Trnava SK).

Acknowledgment

This work was supported by the Scientific Grant Agency VEGA under the contract No. VEGA 1/0310/22.

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