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# Properties of the composite with recycled concrete manufactured by modified technology

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**Abstract.** The article describes basic mechanical, physical and durability characteristics of concrete with recycled aggregate. Recycled concrete aggregates from AZS s.r.o. are made using newly modified technology and properties for use in concrete have been tested. In this part of the research the compressive strength, tensile strength, modulus, freeze and thaw resistance are tested. The basic aim was to test two mixtures with fifty percent substitution of the coarse component of natural aggregate by recycled one (the standard EN 206 does not already allow this) and to prove that such a quantity of recycled aggregate can be used for concrete constructions. The properties were tested on 150 mm cubes and beams 100 x 100 x 400 mm after 28 days.

## 1. Introduction

Concrete, which is completely dependent on natural raw materials, is the most used building material due to its properties, whose production is about 10 billion tons a year [1]. These facts lead to over-exploitation of natural resources and high volumes of waste concrete, which constitutes around 40% of construction and demolition waste. The use of concrete waste as aggregate or admixtures for concrete is one of the most effective approaches to the recycling of construction and demolition waste. The aim of this work is to verify the properties of concrete, which can be classified as plain concrete with a minimum allowable amount of cement and the prescribed percentage substitution of recycled aggregate, which reaches acceptable material characteristics and verification of the two-cycle recycling process.

### *1.1. Percentage replacement of natural aggregates*

The possibilities of substitution of the aggregate coarse fraction in concrete with recycled aggregate and requirements for the properties of recycled aggregate are set out in valid Czech standards [2, 3]. The standards reflected the years of research into the properties of recycled aggregate concrete and its impact on concrete properties. The use of a coarse fraction of recycled aggregate concrete usually leads to a deterioration of all properties of the concrete, so the maximum possible substitution is 30% [4] or 50% [4, 5] depending on the quality of recycled aggregate concrete and concrete class as it is stated in table 1.

The standard allows a maximum of 50% substitution of coarse aggregate, although there are studies where 100% coarse fraction of aggregate is replaced by recycled aggregate concrete [6, 7]. The coarse fraction of natural aggregate (4–8 mm and 8–16 mm) was partially replaced by recycled concrete aggregate. Replacement of aggregate (30% and 50%) in the concrete mix was performed for the most frequently produced concrete classes C16 / 20 X0 and C25 / 30 XC2. Table 1 shows that for plain concrete, which is mostly specified with low exposure class, percentage substitution of recycled aggregate from an unknown source can be used. Structural concrete, which is used in load-bearing structures, must not contain a percentage of recycled aggregate.

**Table 1.** The maximum percentage of coarse aggregate replacement [2].

| | X0 | XC1,XC2 | XC3, XC4, XF1, XA1, XD1 |
|---|---|---|---|
| Type A | 50% | 30% | 30% |
| Type B | 50% | 30% | 0% |

[a] Recycled aggregates of type A from a known source can be used for the degree of environmental impact for which the original concrete was designed.
[b] Recycled B-type aggregates are not used in concrete class > C30 / 37.

## 2. Material and Methods

The cooperation was established with the recycling company AZS 98 s.r.o. To achieve the highest quality of recycled aggregate with stable properties, the recycling process and technology were modified. Undesirable components such as reinforcement and clay components are first separated from recycled concrete. Pure 63–128 mm fragments of concrete enter the second cycle when pure concrete is crushed into fractions 0–4 mm, 4–8 mm, and 8–16 mm. The recycling device is designed to capture fine particles when crushing concrete fragments, which can be further used as an admixture or substitute for cement.

The properties of recycled aggregate (figure 1, figure 2) have been verified in the previous part of the authors' research and meet conditions for use in concrete [8].

**Figure 1.** Recycled aggregate concrete fraction (8–16 mm).

**Figure 2.** Recycled aggregate concrete fraction (4–8 mm).

Six series of concrete mixtures were designed (table 2). Three series of concrete mixtures (C2, C4 and C6) were designed for concrete class C16 / 20 with cement quantity of 300 kg/m$^3$, which is the minimum allowable quantity for the structural concrete [2]. Concrete mixtures (C1, C3 and C5) were designed for concrete class C 25 / 30. Two different types of cements with the same strength grade 42.5R were used in the experiment. Concrete mixtures (C1, C2, C3 and C4) had 30% substitute for coarse natural aggregate. Concrete mixtures (C5, C6) were designed with 50% replacement of coarse recycled aggregate (table 3). Two types of cement were used in the experiment This type of cement was supplied by recycling company. Cement Mokrá has been used in our previous research and series with this cement were added for comparison. Both cements have the same strength class.

**Table 2.** Components of concrete for each mixture.

| | C1 (kg/m$^3$) | C2 (kg/m$^3$) | C3 (kg/m$^3$) | C4 (kg/m$^3$) | C5 (kg/m$^3$) | C6 (kg/m$^3$) |
|---|---|---|---|---|---|---|
| CEMENT | 380 [c] | 300 [c] | 380 [d] | 300 [d] | 380 [d] | 300 [d] |
| WATER | 149 | 149 | 149 | 149 | 149 | 149 |
| NA [a] (0-4mm) | 800 | 850 | 800 | 850 | 800 | 850 |
| NA [a] (4-8mm) | 175 | 175 | 175 | 175 | 125 | 125 |
| NA [a] (8-16mm) | 525 | 525 | 525 | 525 | 375 | 375 |
| PLASTICIZER [e] | 2 | 2 | 2 | 2 | 2 | 2 |
| RAC [b] (4-8mm) | 75 | 75 | 75 | 75 | 125 | 125 |
| RAC [b] (8-16mm) | 225 | 225 | 225 | 225 | 375 | 375 |

[a] Natural aggregate
[b] Recycled concrete aggregate
[c] Cement Mokrá (42.5 R)
[d] Cement Radotín (42.5 R)
[e] Polycarboxylate base plasticizer (Stachement 2180)

**Table 3.** Percentage replacement of coarse fraction with recycled aggregate for each mixture.

| | C1 | C2 | C3 | C4 | C5 | C6 |
|---|---|---|---|---|---|---|
| Percentage replacement | 30% | 30% | 30% | 30% | 50% | 50% |

## 3. Results and discussion

### *3.1. Compressive strength*

The compressive strength tests were performed with cube specimens 150/150/150 mm by method specified in ČSN 73 EN 12390-3 [12]. Five samples were made for each series of concrete mixtures. Average compressive strengths are given in figure 3.

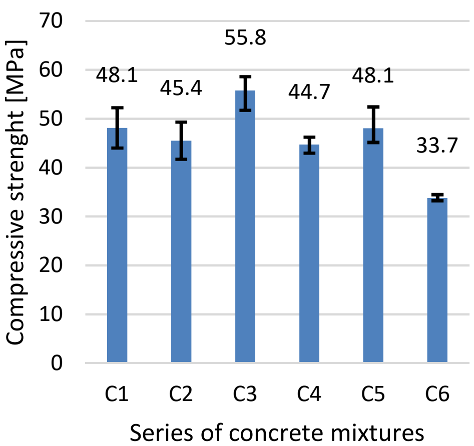


**Figure 3.** Average compressive strengths.

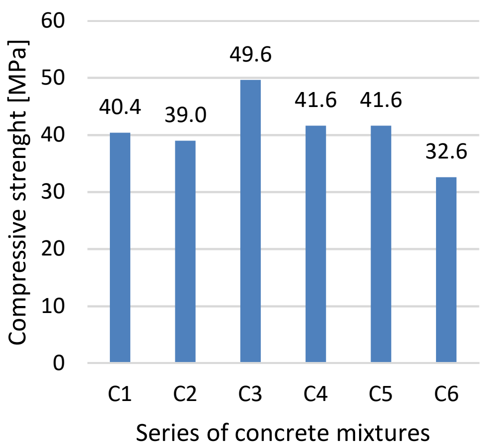


**Figure 4.** Characteristic compressive strengths.

Comparison series (C1 vs C3, C2 vs C4) of concrete mixtures showed that the mixtures with Radotín cement have higher compressive strengths and that is the reason why were used for further research.

Characteristic compressive strength of specimens are given in figure 4. All series of concrete mixtures can be classified to the C25 / 30 concrete class, including the C6 series, which was designed to meet the C16 / 20 concrete class. Comparison of results from our research with other researchers is in table 4.

**Table 4.** Comparison of compressive strength with other research groups.

| | Cement content (kg/m$^3$) | Compressive Strength (MPa) |
|---|---|---|
| Our research | 380; 300 | 48.1; 33.6 |
| [14] | 394 | 42; 41.5 |
| [15] | 575 | 33 |
| [16] | 410 | 47.4 |

Compressive strength is similar or higher to samples made [14, 15, 16] with similar or higher dosages of cement as you can see in.

### *3.2. Tensile strength*

After evaluation of compressive strength, further research was concentrated on concrete mixtures C5 and C6, where the maximum allowable substitution by recycled aggregate (50%) is allowed. Results of flexural strength are similar to obtained in other study [16] and it is showed in table 5.

**Table 5.** Comparison of flexural strength with other research.

| | Cement content (kg/m$^3$) | Flexural Strength (MPa) |
|---|---|---|
| Our research | 380; 300 | 5.32; 4.3 |
| [16] | 410 | 4.78[a] |

[a] after 56 days

### *3.3. Testing the freeze – thaw resistance of the RAC (recycled aggregate concrete)*

The freeze thaw resistance tests of RAC were performed with specimens 100/100/400 mm by method specified in ČSN 73 1322 [9].

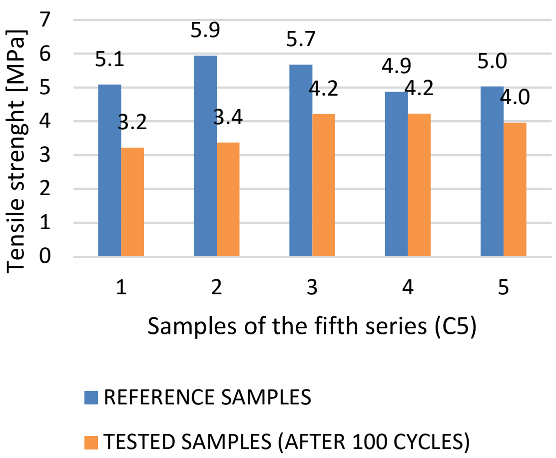


**Figure 5.** Comparing tensile strengths of concrete after 100 cycles for series C5 of concrete mixtures.

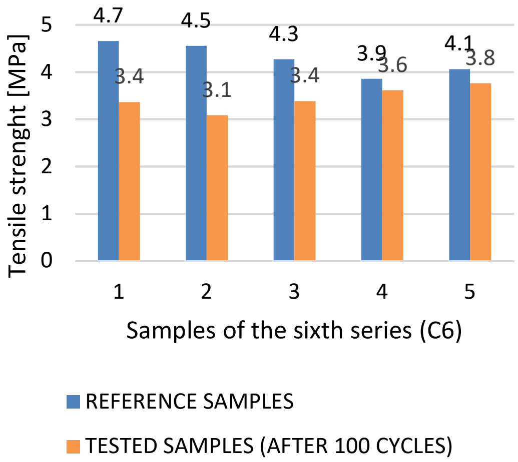


**Figure 6.** Comparing tensile strengths of concrete after 100 cycles for series C6 of concrete mixtures.

Results were compared with reference samples that were not subjected to freeze thaw cycling. Comparing tensile strengths of concrete after 100 cycles for series C5 of concrete mixtures are given in figure 5 and for series C6 of concrete mixtures are given in figure 6. Freeze thaw resistance test is evaluated according to the standard [9]. The ratio between reference samples that were not subjected to freeze cycling and tested samples is calculated. If this ratio is greater than 0.75, frost resistance is proven. According to results, the ratio is 0.79 for concrete mixture C5 and 0.72 for concrete mixture C6. Average tensile strength values of 3.8 MPa for C5 and 3.4 MPa for C6 meet the tensile strength for the C 35 / 45 concrete class and exceed their grades.

### *3.4. Modulus of elasticity*

Materials with a higher modulus of elasticity require higher stresses to achieve the same deformation. The static and dynamic modulus of elasticity was measured on 100/100/400 mm beams (figure 8) according to the standard [10, 13].

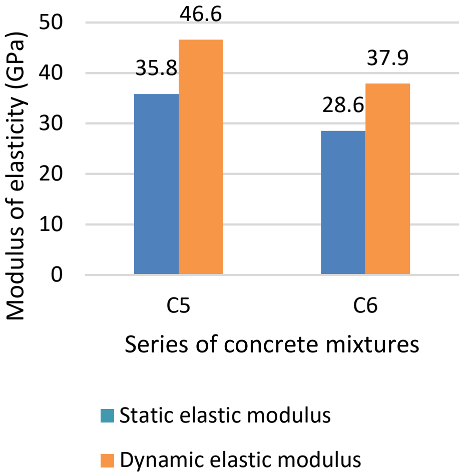


**Figure 7.** The average values of the static and dynamic modulus.

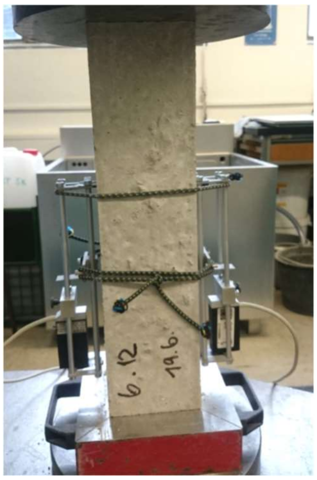

**Figure 8.** Measurement of the modulus of elasticity.

The static modulus of elasticity has similar results to the compressive strength. For concrete mixture C6, the static elastic modulus decreases by 20% compared to concrete mixture C5 (figure 7). Nevertheless, the value of 28.6 GPa is quite sufficient and measured values were also observed by another researchers (see table 6).

**Table 6.** Comparison of modulus of elasticity with other research groups.

| | Cement content (kg/m$^3$) | Modulus of elasticity (GPa) |
|---|---|---|
| Our research | 380; 300 | 35.8; 28.6 |
| [15] | 575 | 29 |
| [16] | 410 | 24.07 |

## 4. Conclusions

Two concrete mixtures which were tested in detail with fifty percent substitution of recycled aggregate concrete. Concrete mixtures were designed as C25 / 30 and C16 / 20 concrete class, both were tested for compressive strength, tensile strength, dynamic and static modulus of elasticity and frost resistance.

The results of compressive strength of concrete shows that the type of cement has an influence on properties. Significant decline in compressive strength was at 50% replacement of recycled aggregate and use the minimum amount of cement (300 kg/m$^3$). All series of concrete mixtures can be classified to the C25 / 30 concrete class, including the series, which was designed to meet the C16 / 20 concrete class. Compressive strength, flexural strength and modulus of elasticity are similar or higher to results get by other research programs (made with equal or higher dosages of cement). The average tensile strength after 100 cycles of freeze thaw resistance test had values (3.8 MPa and 3.4 MPa), which is a sufficient value for structural concrete. Achieved results can be considered very good.

Recycled aggregate concrete is better suited for lower class of concrete. The results further show that the recycling of recycled aggregate concrete by two-cycle recycling can produce significantly better results than the aggregate produced in a conventional one-cycle recycling process. It is necessary to continue in this area in order to ensure even more recycled concrete utilization, thus saving natural resources.

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