Properties of fiber reinforced concrete using recycled aggregates

V. Vytačilová, J.Vodička

Abstract—Application of recycled materials in the building industry is essential for permanently sustainable development of each country. This paper is focused on the experimental program aimed at verifying selected material properties of fibre reinforced concrete in which all of the natural stone aggregates is replaced by recycled aggregates – masonry and concrete.

The combination of recycled construction and demolition waste, synthetic fibres and binder creates an unusual fibre reinforced concrete; new composite, which offers a wide field of possible use in construction industry.

The paper presents experimental program and shows results on this composite - mechanical and physical characteristics – density, compressive strength, splitting tensile strength and flexural tensile strength and modulus of elasticity of fibre reinforced concrete. Based on a large series of acquired experimental results on different characteristics of the tested material, it can be judged on the behavior of this composite, which is sufficient enough to be used in ground structures as intended.

The application of this composite material is ensured by the synthetic fibres, which along with the other components constitutes the tough structure of the composite favourable especially under tensile loading due to its high ductility.

Keywords—Fiber reinforced concrete, recycled aggregate, synthetic fibres, mechanical properties.

I. INTRODUCTION

Construction and demolition waste (C&D) constitutes a major portion of total solid waste production in the world, and for the present most of it is used in landfills. The most effective way to reduce the waste problem in construction is agreed in implementing reuse, recycling and reduced the use of a construction material in construction activities. Application of recycled materials in the building industry is important for sustainable development and keeping of primary sources of each country.

There is whole range of applications of recycled materials for civil engineering structures and it is necessary seek the other possibility in re-use of those building materials whose live-span has been finished. The restrictions in improvement of recycling principles are requiring certain criteria [1] (Fig. 1).

Because of the difference in properties of recycled material and possible uncertainties in origin of the recycled rubble it might be difficult to provide and guarantee considered properties in concrete. This is probably reason that recycled aggregate is used mainly for non-structural applications at present such as a road base or a backfill.

The idea to add fibres to a concrete mixture with recycled aggregate may change material properties of such concrete, improve behaviour, bring about new types of applications and enables saving sources of natural aggregate [2, 3, 4].

II. RECYCLING

A. Recycling in the Czech Republic

At present, the mostly recycled materials in the Czech Republic come from the recycled waste of bricks, concrete, asphalt, mixed building waste, various types of aggregates and soil. There are more then 200 recycling centers (static and mobile) and deposits, in the Czech Republic which process construction and demolition waste. The total yearly capacity of all the recycling centers in the Czech Republic is about 7.5 million tons, which is 50% more than the actual production of recycled materials. Recycled masonry and concrete waste,
which is the product of these centers, can be graded according to the customer’s requirements at the most strict grading when the recycled material should be used as aggregate in ordinary concrete. As is in the rest of the world, as a result of the construction industry is growing at a great pace in our country as well.

The Association for development in recycling of building materials (www.armc.cz) summarizes the yearly output C&D waste since 1999. The production of masonry and concrete demolition waste in recycling centers is documented in Fig. 2 [5]. The debris from these demolished buildings is thrown away, causing environmental pollution, or is used as filling material. If the rubble material is sorted and if the presence of all the foreign material that could be introduced in the recycling operation especially deleterious content is checked thoroughly, the utilization of concrete and masonry rubble for mixing of structural concrete is possible and eligible. Only very little of C&D waste is recycled for high specification applications because potential users are deterred by the perceived risks involved.

Recycling in the European Union
The use of C&D waste as a source of aggregate for the production of a new concrete has become more common in the recent decade. From 3 billion tonnes of wastes of all kinds annually produced in the European Union, about 31% are coming from C&D area. They are mainly composed of concrete, asphalt and masonry [6].

III. PROPERTIES OF THE RECYCLED AGGREGATES
Usually replacement of only 10% to 30% virgin sand is used for new concrete. Is approved using 100% recycled coarse aggregate produces acceptable quality concrete. Use of recycled fines, however, in a new mix requires close examination. Recycled fine aggregate is angular, with a high porosity and low specific gravity. Using recycled fines further reduces strength compared with virgin sand, so its use in new concrete mixes should be carefully controlled. Concrete produced with recycled aggregate has lower of the strength of a comparable natural aggregate concrete. The most marked difference in the physical properties of the recycled concrete aggregate is higher water absorption, lower bulk density, porous and rough surface texture and lower resistance to mechanical action on compare to natural aggregate. Workability of recycled aggregate concrete is lower that that of similar concrete mix with natural aggregate. These facts are certified in many research studies.

In the case of preparation of fibre concrete for the intended reinforcing slabs, which are inserted in the earth structures[7, 8], the recycled material can be limited by the maximum particle size according to the thickness of the design slab and the length of the synthetic fibres, whose use in the fibre reinforced concrete is anticipated. The recycled aggregate graded according to this limitation can be characterized as to be of the so-call wide grading curve. The fibre reinforced concrete with the recycled aggregate with this characteristic is beneficial in the presented applications both in the fresh and hardened state.

Recycled brick (masonry) or concrete aggregates were produced in a recycling facility from construction and demolition waste. This aggregate was supplied by local demolition company where it was passed through a jaw crusher and was transported to a laboratory. After using a jaw crusher only one fraction 0/32 mm of recycled masonry or concrete were obtained and used for recycled concrete mix design in this experimental program (Fig. 3).

Fig. 2 Total production of crushed demolition waste in recycling centers in the Czech Republic (in thousand tons)

B. Recycling in the European Union
The use of C&D waste as a source of aggregate for the production of a new concrete has become more common in the recent decade. From 3 billion tonnes of wastes of all kinds annually produced in the European Union, about 31% are coming from C&D area. They are mainly composed of concrete, asphalt and masonry [6].

IV. FIBRE REINFORCED CONCRETE WITH RECYCLED AGGREGATE
Concrete with aggregate from recycled materials, which enables saving sources of natural aggregate, is considered to have generally worse mechanical properties than common concrete. But the idea to add fibres to a concrete mixture with recycled aggregate may change material properties of such concrete, improve behaviour and bring about new types of applications. Fibre reinforced concrete with recycled aggregate can be considered as optimal structural concrete for various applications.

The approach to design of fibre reinforced concrete with recycled aggregate is defined by this method, or the philosophy, of the design. While in the case of ordinary, or plain, concrete the material characteristics are defined by its application, which is reflected in the composition of fresh
concrete, in the case of fibre reinforced concrete this process is its complete opposite. The composition is given in advance and subsequently its properties are proofed and its applicability in building industry sought.

V. MIX DESIGN

The general procedure of testing of composites mostly follows the economic criteria (cost minimization) with respect to simplicity of technology and possible applicability in practice, which would contribute to the building sustainability.

The advantage of the wide grading curve of the used recycled aggregate is apparent in the design of fibre concrete. The design can be based only on determination of the density of the compacted recycled aggregated regardless to its saturation, and the remaining components can be just added. The amount of cement should ensure the bond between the fibres and the recycled aggregate, and the amount of fibres should ensure the required uniaxial tensile strength. The amount of water should be decided according to workability requirements.

The mix composition is based on the following principles:
- recycled aggregate of wide grading curve (a single grade, e.g. 0/32 mm),
- constant minimum amount of binder (cement)
- weight of fibres according to the requirement of fibre concrete properties,
- amount of water according to required workability.

VI. EXPERIMENTAL PART

In this article is presented the experiments focused on the assessment of the basic mechanical-physical characteristics of composites with recycled aggregate and fibres. A series of laboratory trials were carried out to establish the practical possibility of using (C&D waste) material as replacement for virgin aggregates.

Recycled aggregates consisted in 100% content of natural aggregates. Unclean brick (masonry) and concrete rubble were shattered in recycling company. The recycled aggregate – masonry and concrete (Fig. 2) arising from demolition may be contaminated with mortar and plaster, as well are often mixed with other materials such as timber or glass. The advantage of the wide grading curve of the used recycled aggregate is apparent in the design of fibre concrete (the best was 0/32 mm). The recycled aggregate graded according to this limitation can be characterized as to be of the so-call wide grading curve.

For experimental tests was used synthetic polypropylene fibres FORTA FERRO® and BeneSteel. In order to minimize cost an optimal dosage of this polypropylene fibres was determined as 0,5 % - 1,5 % of volume content. FORTA-FERRO® are non-corrosive, non-magnetic, and 100% alkali proof fibres with length 54 mm, specific gravity 910 kg/m3 and tensile strength is 570-660 MPa.

Polymer fibres BeneSteel are made from the mix polypropylene and polyethylene with tensile strength about 610 MPa and modulus of elasticity about 5170 MPa.

Fibres cut from waste PET bottles are alternative for a price reduction of fibre concrete and contribute to solution of PET waste problems too [12-14]. Polyethylene terephthalate analyzed in the present study belongs to the polyester group. Applicable are fibres with length 60-90 mm and width 1-2 mm. Tensile strength of fibres cut from waste PET bottles is 50-80 Mpa. Fig. 4 shows the diagram - load-deflection from the flexural test of fibre from waste PET bottle.

In a mixture proportion the amount of cement was given on minimum for structural concrete according to Code EN 206-1 (260 kg/m3) from Portland fly-ash cement CEM II/B – V 32,5R, whereas this quantity is sufficient for unpretentious engineering construction.

The amount of water should be decided according to workability requirements. Values of water-cement ratio of the mixture was between 0.5 - 0.6. Was tested that for improvement technological properties isn't necessary (but possible) apply additives.

The main purpose of this program was to obtain a larger amount of experimental data on fibre concrete with masonry (MR) and concrete (CR) recycled aggregate characterizing its properties.

In the following table 1-3 are show the selected results of experiments. Basic mechanical-physical properties as initial bulk densities, compressive strengths, flexural strengths and tensile-splitting strengths, pseudo-working diagram force – deflection, modulus of elasticity are determined.

Tab. 1 Summary of the fundamental mechanical-physical characteristics of the fibre reinforced concrete

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Concrete rubble</th>
<th>Brick rubble</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk density [kg/m³]</td>
<td>2000-2200</td>
<td>1800-2100</td>
</tr>
<tr>
<td>Compressive strength [MPa]</td>
<td>12-30</td>
<td>12-28</td>
</tr>
<tr>
<td>Tensile-splitting strength [MPa]</td>
<td>1,6-2,5</td>
<td>1,5-3,3</td>
</tr>
<tr>
<td>Flexural strength [MPa]</td>
<td>1,6-2,5</td>
<td>1,5-2,8</td>
</tr>
<tr>
<td>Modulus of elasticity [GPa]</td>
<td>13-18</td>
<td>11-15</td>
</tr>
</tbody>
</table>
characteristic value - 1,0% point flexural tests. An annex A of a code ČSN EN 12390-5:2001 says that a flexural test with three-point bending show examined on halves of specimens remaining after the four-point flexural tests. An annex A of a code ČSN EN 12390-5:2001 says that a flexural test with three-point bending show

The basic mechanical properties in tension of the tested fibre concrete (Fig. 5) can be derived according to [11].

The compressive strength and tensile splitting strength were examined on halves of specimens remaining after the four-point flexural tests. An annex A of a code ČSN EN 12390-5:2001 says that a flexural test with three-point bending show

The measurement of properties was performed according to standard test methods the Standard ČSN EN. Series of mechanical-physical experiments were carried out with beams of the valid standard dimension 150 x 150 x 150 mm and 150 x 150 x 700 mm. The specimens were tested after 28 days after mixing.

VII. APPLICATION OF FIBRE CONCRETE IN EARTH STRUCTURES

The previous experimental program has proved that the properties of this concrete are sufficient enough to be used in ground structures as intended.

Fibre concrete with recycled aggregate is looking for potential usage in present. One of possible applications of fibre-concrete composite is strengthening of layers in earth structures as levees, dams or dikes. Inserting of slabs in the body of the earth structures contribute to stability and higher resistance of the structures. The slope or dam may have steeper sloping, what reduce earthmoving work [7, 8]. Inserting of fibre-concrete slabs into dam enhanced resistance of the dam in case of spill-over that may happen during floods.

VIII. CONCLUSION

Based on a large series of acquired experimental results on different characteristics of the tested material, it can be judged on the behaviour of this composite. The new findings from the experiments with recycled aggregated will be used for definition of the not yet existing standards and provisions related to recycling of structures in the Czech Republic.

The following conclusion may be drawn from the present investigation:

- C&D waste material can be recycled and experiment testify that utilization of recycled concrete with fibres in every-day life is possible and more it is useful without plasticizer and other admixtures.
- However, the use of recycled aggregate is possible only for that with acceptable grading in the range of 0/32 mm on account of a technology simplification. Suitable technology of construction material recycling could be considered an easy alternative for future applications. The recycling of this waste will reduce environmental damages caused by incorrect disposal, extend the useful life of landfills and preserve finite natural resources.
- Recycled PET fiber are aplicable for fibre reinforced concrete and improve the properties of concrete

Studies are continuing with the aim of obtaining more information about concretes made with C&D waste materials and reinforced with fibres and modeling situation construction with this composite.

The next task of the research and development in application of recycled concrete is determination of characteristics and production procedures of concrete using recycled concrete aggregate. The team will investigate not

<table>
<thead>
<tr>
<th>Samples</th>
<th>Recycled aggregate</th>
<th>Type of fibres</th>
<th>Volume of fibres (%)</th>
<th>Bulk density [kg/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>FM 1</td>
<td>MR</td>
<td>Forta Ferro</td>
<td>0,0%</td>
<td>2034</td>
</tr>
<tr>
<td>FM 2</td>
<td>MR</td>
<td>Forta Ferro</td>
<td>0,5%</td>
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<tr>
<td>FM 3</td>
<td>MR</td>
<td>Forta Ferro</td>
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<td>1842</td>
</tr>
<tr>
<td>FM 4</td>
<td>MR</td>
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<td>1,0%</td>
<td>2082</td>
</tr>
<tr>
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<td>Forta Ferro</td>
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</tr>
<tr>
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<td>CR</td>
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</tr>
<tr>
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<td>CR</td>
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<td>2084</td>
</tr>
<tr>
<td>PM 1</td>
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<td>PET</td>
<td>1,5%</td>
<td>2080</td>
</tr>
<tr>
<td>PM 2</td>
<td>MR</td>
<td>PET</td>
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<td>2013</td>
</tr>
<tr>
<td>BM 1</td>
<td>MR</td>
<td>Benesteel</td>
<td>1,0%</td>
<td>2028</td>
</tr>
<tr>
<td>BM 2</td>
<td>MR</td>
<td>Benesteel</td>
<td>0,5%</td>
<td>2002</td>
</tr>
</tbody>
</table>

Tab. 2 Identification of samples and bulk density of the fibre reinforced concrete (average value from 3 samples)

Tab. 3 Selected mechanical-physical characteristics of the fibre reinforced concrete (average value from 3 samples)

<table>
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<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>FM 1</td>
<td>21,85</td>
<td>2,14</td>
<td>13,6</td>
<td>1,60</td>
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<tr>
<td>FM 2</td>
<td>21,97</td>
<td>2,22</td>
<td>14,7</td>
<td>1,85</td>
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<tr>
<td>FM 3</td>
<td>19,11</td>
<td>1,82</td>
<td>13,6</td>
<td>2,44</td>
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<tr>
<td>FM 4</td>
<td>25,84</td>
<td>2,97</td>
<td>-</td>
<td>-</td>
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<tr>
<td>FC 1</td>
<td>12,71</td>
<td>1,58</td>
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<td>3,23</td>
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<td>2,57</td>
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<tr>
<td>BM 1</td>
<td>26,96</td>
<td>2,62</td>
<td>-</td>
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<tr>
<td>BM 2</td>
<td>27,02</td>
<td>2,89</td>
<td>-</td>
<td>2,24</td>
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The basic mechanical properties in tension of the tested fibre concrete (Fig. 5) can be derived according to [11].

Fig. 5 Average and characteristic resistance diagrams of specimens with 0,5 and 1,0% vol. fibres FORTA FERRO and masonry rubble (average value from 3 samples)
only the mechanical, physical and rheological properties of recycled concrete, but also ecological deficiency or, on the contrary, the benefits and attainable economical effect.

Several areas of application have been recognized however full-scale use of such fibre concrete is still hindered by the high cost, which is unacceptable for investors. The examples of application of such fibre concrete, which would help to meaningfully utilize the demolition waste, are so far based on numerical simulations and developed laboratory models.

REFERENCES


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