

The fibre reinforced concrete with using recycled aggregates

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Abstract—Application of recycled materials in the building industry is essential for permanently sustainable development of each country. The use of primary sources and materials is becoming unbearable both economically and ecologically, and therefore it is necessary to seek the possibility of reuse of those materials once their durability expired. Recycling them is the most effective method for dealing with the increasing volume of waste for preservation of the environment. There is whole range of applications of recycled materials in both architectural and civil engineering.

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—Fibre reinforced concrete, recycled aggregate, synthetic fibres, mechanical properties, construction & demolition waste, masonry rubble, concrete rubble.

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 land fills.

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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. Those “3R” are the positive influence on Economy, Ecology and Energy. Application of recycled materials in the building industry is important for sustainable development and keeping of primary sources of each country. Recycling and re-use of building rubble presents interesting possibilities for economizing on waste disposal sites and conserving natural resources.

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. As a recycled material, one can consider not only the construction and demolition waste but also the waste coming from the industrial production and extraction of primary materials. The restrictions in improvement of recycling principles are requiring certain criteria [1] (Fig. 1).

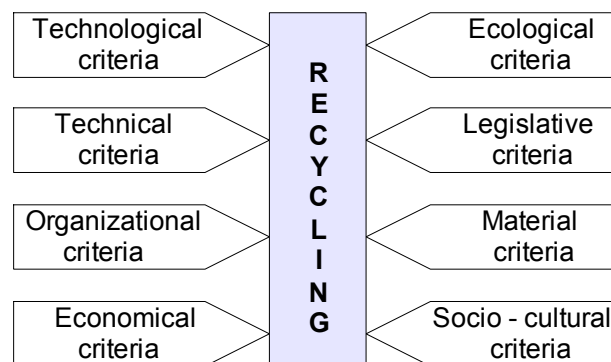


Fig. 1 Criteria in recycling process

C&DW as crushed concrete or masonry (brick) are mineral inorganic materials with inert behaviour, without dangerous properties and without significant physical, chemical or biological change. 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]-[4]. This work as thesis aims to reduce the demand for primary aggregates by using crushed C&DW as an alternative.

A. Recycled aggregates

Since there are many unsolved problems encountered in controlling the quality of recycled aggregates (RA), which include low compressive strength, wide variability of quality, high drying shrinkage, large creep and low elastic modulus, applications of are hampered. These problems are mainly resulted from the following two reasons:

- Construction and demolition waste materials are always contaminated with foreign materials (glass, wood, soil, plaster, tile etc.).
- Recycled aggregate particles are always attached with substantial amount of relatively soft cement mortar paste, making these aggregates more porous and less resistant to mechanical attacks.

Generally some modifications to the mix proportion are needed in the production of recycled aggregates, which can then be produced with the same production procedure as the conventional concrete does. However, such an approach will produce concrete with poorer quality, depending directly on the proportion of RA added. Hence, most studies recommend a limit of 30% of RA. Many researchers have successfully applied RA on pavement and roadwork or simple structures, underground structures, foundations, piles and mass concrete. However, its application to higher grade concrete is not common. These weaknesses of RA, including high porosity, high amount of cracks, high level of sulphate and chloride contents, high level of impurity and high cement mortar remains, will affect the mechanical performance of RA. The prerequisite in applying RA to high-grade concrete is to overcome these weaknesses.

The amount RA which could be recycled will depend mainly on factors such as:

- Location of the demolition site and of the manufacturing site.
- Level of contamination in the C&DW as a result of unsuitable materials used in the original construction or caused by poor segregation during the demolition process.
- Local demand for the material that varies depending on current development and infrastructure projects.

Demolition contractors typically use jaw crushers or impact crusher which will process material more slowly to produce a crushed concrete and masonry of a particle size of 0-8, 8-32, 32-64, >64 mm. Screening after the material has been crushed is necessary to control the particle size of the finished product. The particle size of material required to manufacture new

concrete will require demolition contractors to invest in new screens in order to produce the correctly graded material.

B. Recycling in the Czech Republic

At present, the mostly recycled materials in the Czech Republic come from the recycled waste of bricks, masonry, concrete, asphalt, mixed building waste, various types of aggregates and soil. There are more than 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.arms.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 and Table 1 [5].

Table 1: Construction and Demolition waste processed in recycling company in CR (The amount in thousand of tons, source ARSM)

Waste	Year					
	2003	2004	2005	2006	2007	2008
Brick	1392	1664	1711	1616	1996	1549
Concrete	1255	994	1233	1112	1611	1155
Asphalt	516	514	598	576	728	740
Mixed Building waste	59	131	122	54	40	118
Aggregat.	913	719	596	738	975	1291
Spoil	452	432	298	590	691	1026
Other	261	309	134	387	471	475
Σ	6852	6767	6697	7079	8519	8362

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.

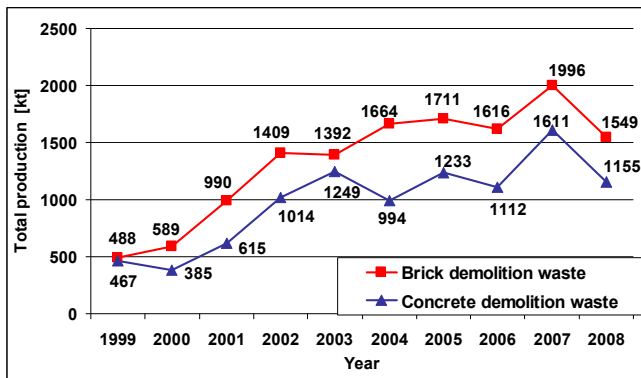


Fig. 2 Total production of crushed demolition waste in recycling centers in the Czech Republic (in thousand tons)

C. 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].

II. PROPERTIES OF THE RECYCLED AGGREGATES

Usually replacement of only 10% to 30% virgin sand is used for new concrete. It 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.

The particles of crushed brick are generally more porous and have a lower density when compared to natural and recycled concrete aggregates. It is found that concrete made with crushed brick generally has comparable compressive and tensile strengths compared to those of conventional concrete. However, the modulus of elasticity, shrinkage, creep, initial surface absorption and chloride diffusion are inferior compared to those of natural concrete. Though, successful applications of crushed brick as the aggregates in the production of concretes are possible.

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 than that of similar concrete mix with natural aggregate. These facts are certified in many research studies.



Fig. 3 Masonry rubble in recycling centers

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. 4, 5).



Fig. 4 Masonry rubble (fraction 0/32 mm) tested in experimental program

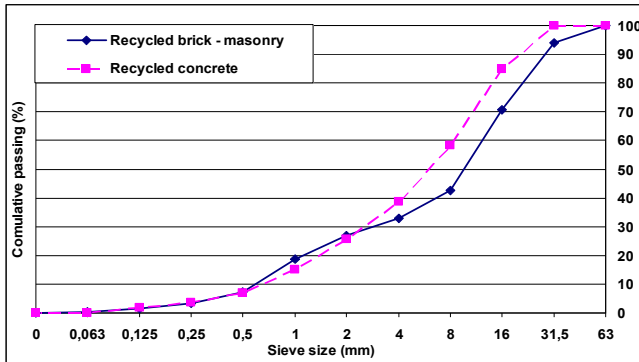


Fig. 5 Grading of recycled aggregates – brick (masonry) and concrete

In figure 6 is show grading size curve of virgin sand and pure and impure crushed bricks in fraction 0/8 mm. A good correspondence among the aggregate grading curves for fine natural aggregate and recycled masonry aggregated was proved.

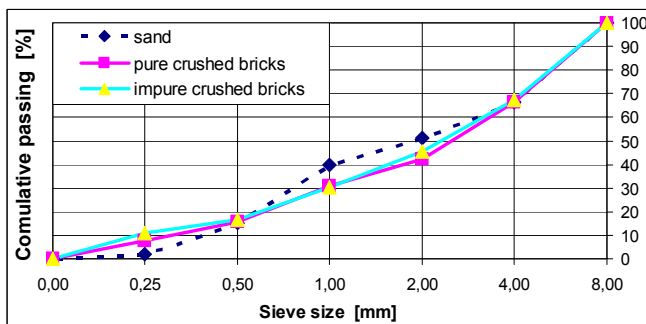


Fig. 6 Grading of recycled brick (pure) aggregates, masonry (impure) aggregates and sand

III. 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 (Fig. 7, 8) can be considered as optimal structural concrete for various applications.



Fig. 7 Specimens with recycled masonry aggregate and synthetic fibres



Fig. 8 Specimens with recycled concrete aggregate and synthetic fibres

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 proved and its applicability in building industry sought.

The porous structure of fibre concrete with masonry rubble is shown in Fig. 9.



Fig. 9 Grading The porous structure of fibre concrete with masonry rubble

IV. 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.

V. 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. 4) 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 polypropylen 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 (Fig. 10) 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.



Fig. 10 Tested fibres from PET-bottles

Tensile strength of fibres cut from waste PET bottles is 50-80 MPa. Fig. 11 shows the diagram - load-deflection from the flexural test of fibre from waste PET bottle.

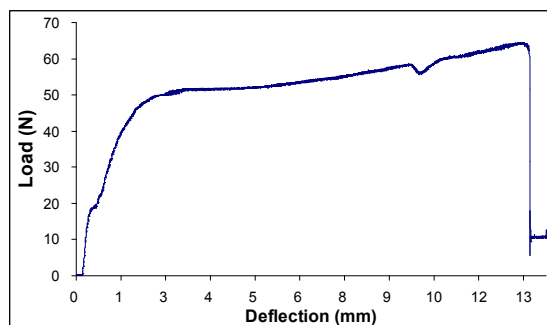


Fig. 11 Load-deflection diagram from the flexural test of fibre from waste PET bottle

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 2-4 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. 2 Summary of the fundamental mechanical-physical characteristics of the fibre reinforced concrete

Characteristics		Concrete rubble	Brick rubble
Bulk density	[kg/m ³]	2000-2200	1800-2100
Compressive strength	[MPa]	12-30	12-28
Tensile-splitting strength	[MPa]	1,6-2,5	1,5-3,3
Flexural strength	[MPa]	1,6-2,5	1,5-2,8
Modulus of elasticity	[GPa]	13-18	11-15

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

Samples	Recycled aggregate	Type of fibres	Volume of fibres	Bulk density
			[%]	[kg/m ³]
FM 1	MR	Forta Ferro	0,0 %	2034
FM 2	MR	Forta Ferro	0,5 %	2041
FM 3	MR	Forta Ferro	1,0 %	1842
FM 4	MR	Forta Ferro	1,0 %	2082
FC 1	CR	Forta Ferro	0,0 %	2085
FC 2	CR	Forta Ferro	0,5 %	2099
FC 3	CR	Forta Ferro	1,0 %	2084
PM 1	MR	PET	1,5 %	2080
PM 2	MR	PET	3,0 %	2013
BM 1	MR	Benesteel	1,0 %	2028
BM 2	MR	Benesteel	0,5%	2002

Tab. 4 Selected mechanical-physical characteristics of the fibre reinforced concrete (average value from 3 samples)

Samples	Compressive strength	Tensile-splitting strength	Modulus of elasticity	Flexural strength
	[MPa]	[MPa]	[MPa]	[MPa]
FM 1	21,85	2,14	13,6	1,60
FM 2	21,97	2,22	14,7	1,85
FM 3	19,11	1,82	13,6	2,44
FM 4	25,84	2,97	-	-
FC 1	12,71	1,58	15,9	1,81
FC 2	13,75	1,69	14,6	2,09
FC 3	13,83	1,71	15,3	2,16
PM 1	28,67	3,07	-	2,61
PM 2	27,36	3,23	-	2,57
BM 1	26,96	2,62	-	2,32
BM 2	27,02	2,89	-	2,24

The basic mechanical properties in tension of the tested fibre concrete (Fig. 11 - 15) can be derived according to TP FC 1-1 [11] edited at Czech Republic.

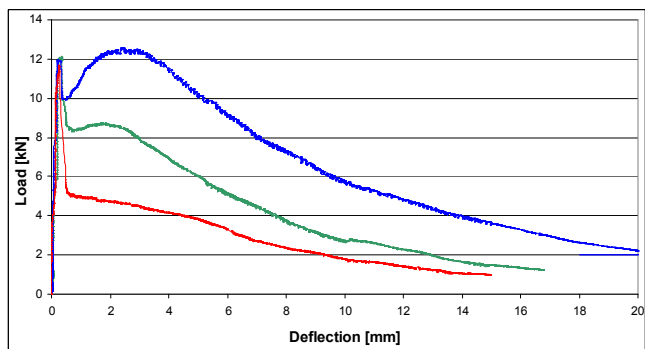


Fig. 11 Pseudo-working diagram of three specimens FC3

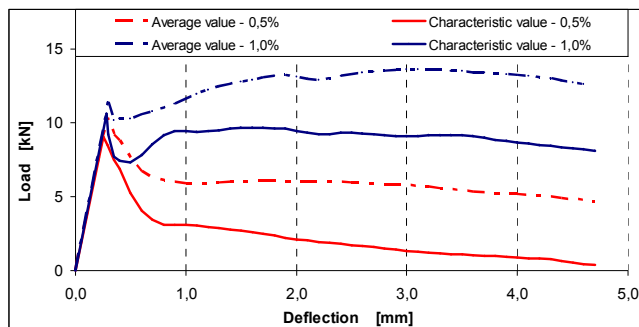


Fig. 12 Average and characteristic resistance diagrams of specimens with 0,5 and 1,0% vol. fibres FORTA FERRO and masonry rubble (average value from 3 samples)

The main characteristics of fibre concrete are derived from the standardised testing procedure (standard bending test). The stress – strain diagram is a basic for the design process of fibre concrete structures.

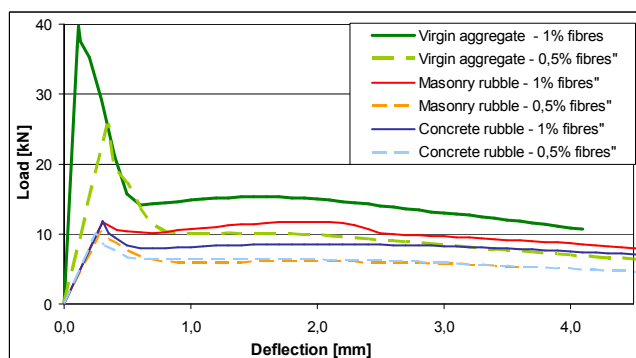


Fig. 13 Average resistance diagrams of specimens with 0,5 and 1,0% vol. fibres FORTA FERRO and masonry or concrete rubble and virgin aggregate (average value from 3 samples)

The compressive strength and tensile splitting strength (Fig. 16) 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 strengths by 13% higher than four-points bending test. That is why a three-point flexural test performed to compare result.

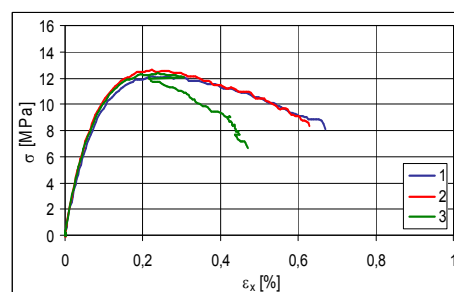


Fig. 14 Linear strain of specimens (concrete rubble, without fibres)

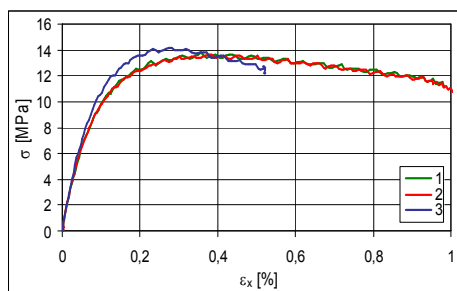


Fig. 15 Linear strain of specimens (concrete rubble, 1% fibres Forta Ferro)

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.

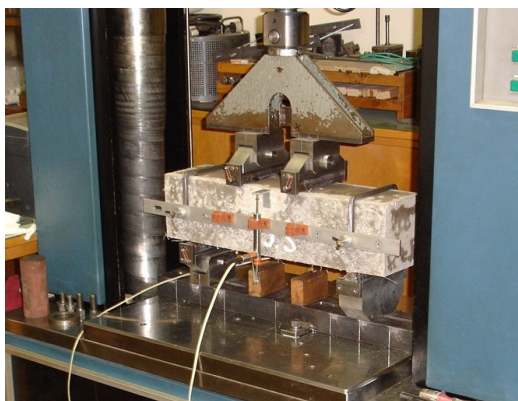


Fig. 16 Tensile strength of specimen

VI. 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.

VII. 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 applicable for fibre reinforced concrete and improve the properties of concrete

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.

The main purpose of this research was to investigate the addition of construction waste (masonry and concrete) material in concrete production and establish the effects of polypropylene fibres on mechanical-physical properties of new concretes. In terms of this research were used standard test methods for determination of mechanical-physical properties as initial bulk densities, compressive strengths, flexural strengths and tensile-splitting strengths. Results are presented from the laboratory test results showing how recycled crushed aggregate can be recycled and experiment testify that utilization of concrete with fibres in every-day life is possible and more it is useful without plasticizer and other admixtures. Thus will be attractiveness of this composite material achieved as cement is the most energy demanding component in concrete mixture manufacturing and changes of the brickconcrete material properties will not be dependent on cement dosage increase.

The recycling of C&D waste material in building production contributes to sustainable development in the construction sector and so helps to protect the environment. The viable technology of the construction material recycling could be considered an easy reference for future applications. A sprayed, pumpable or normal brickconcrete with fibres are suitable in highway construction, namely layers of pavement, slope stabilization, in hydraulic engineering for the strengthening of dam crests and in structural engineering for layers of floors in commercial halls. In general are appropriate for structures where restriction of cracking is required.

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

This will show more definitive trend of the effect of the level of replacement primary aggregates on the properties

concretes. 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 only the mechanical, physical and rheological properties of recycled concrete, but also ecological deficiency or, on the contrary, the benefits and attainable economical effect.

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