INFLUENCE OF FIBRES AND RECYCLED AGGREGATE ON PROPERTIES OF FIBRE REINFORCED CONCRETE

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Abstract

The article presents findings from an experimental programme focused on the production of fibre reinforced concrete in which natural aggregate has been fully substituted with masonry or concrete recyclates. The objective of this study is to investigate the effect of different recycled aggregates and various kinds of polymer fibres on the strength characteristics of the composite.

Keywords: Fibre reinforced concrete, recycled aggregate, polymer fibres, strength construction and demolition waste

1. Introduction

Great quantities of construction and demolition waste materials are produced annually all over the world. Due to the depletion of high quality aggregate in many parts of the world and the desire for sustainability, recycled aggregate derived from construction and demolition waste is an alternative as partial replacement for natural aggregate in concrete mixtures. According to the final report of Service contract on management of construction and demolition waste – SR1, the amount of C&D waste in the EU-27 ranges from 310 to 700 million tones per year [1]. The volume of all C&D waste without stone and soil in the Czech Republic (according to data obtained ARSM and ISOH) is between 10 to 12 million tonnes/year [2]. In the Czech Republic, apart from some European Union countries, do not yet exist a unified technical standard of general application to the quality of recycled materials. Detailed amount of production and recycling cannot be simply determined because of insufficient declaration in present legislation. Big mass of non-elaborated C&DW still ends on illegal stocks, speculative sanitations or recultivations.

Construction and demolition waste arising in the production of building materials and construction activity covers a whole range of materials which, thanks to their typical properties, offer a wide scale of exploitation. Waste Catalogue in the Czech Republic harmonizes separation of the waste material with the European Waste Catalogue. Construction waste is given as a separate group of 17 00 00 - Construction and demolition waste. Especially subgroups 17 01 00 – concrete, masonry, ceramics waste are most suitable for use in new constructions in the form of recycled concrete. Recycled aggregate arises by crushing of C&D waste and then is divided by the coarseness into different fractions, usually 0-8, 8-16, 16-32, 32-63, 63-120, 0-63 mm. These are mineral inorganic

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materials of mostly inert nature without hazardous properties in which no significant physical, chemical or biological transformations occur.

It appears that the concrete with recycled aggregate obeys very restrictive material properties and can only be uses in a short range of applications. 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. The fibre reinforced concrete of the mentioned sort can find applications in a large scale of structures, starting from underground structures to selected elements of civil engineering complexes.

The performance of a wider range of recycled aggregate it can be further enhanced by the replacement of primary aggregate with recycled materials and the use of low cement combinations in concrete. The cost benefit assessment showed that using recycled materials in concrete instead of primary aggregate could lead to significant cost savings represented by [3]. In addition, virgin aggregate deposits have already been depleted in many areas, and hauling aggregate over long distances can be much more expensive than using free or low-cost sources of local recycled aggregate. [4] has concluded that a 25-30% recycled may not have significant effect on concrete properties based on these Recycled concrete is being used as a road fill, which is better than land fill but is "low-cycling" in the sense that virgin aggregate continues to be used for making new concrete.

In these papers some important material properties have been discovered, like the each other effect of concrete composite based on cement matrix and fibres. The influence of recycled aggregate on the behaviour of the concrete composite with polypropylene fibres is discussed in [5-7]. This paper summarizes the findings of cement composites together with synthetic fibres in the research department.

2. Experimental research

A new sphere for utilisation of the recycled materials in cement based composites open polymeric fibres of high strengths. Fibre reinforced concretes are more and more used in construction and many research institutes in the Czech Republic and abroad are engaged in the investigation of their properties and behaviour. The fibres stiffen the structure of concrete, restrict cracking, change the failure mode, affect strength and elastic modulus enhance durability, deformability and many other properties. As it is known, the final properties of FRC composition are influenced by the type and origin of the fibre, its parameters and used dosages. Material and geometry of fibres can affect the properties according to demands of the particular application. Influence of fibres is characterized by higher ductility, toughness and their higher bearing capacity after first crack appearance.

Different types of synthetic fibres (polypropylene fibre) with various volume fractions were added to the composite, which was calculated by the weight of the cement. An optimal dosage of this polypropylene fibres was determined as 0.5% – 1.5% of volume content. In this paper are presented selected results of experimental research which included three types of fibres.

- Fibres FORTA-FERRO® is used to reduce plastic and hardened concrete shrinkage, improve impact strength, and increase fatigue resistance and concrete toughness. These fibres are non-corrosive and 100% alkali proof. The fibres are 54 mm in length and their tensile strength is 570-660 MPa. Their specific gravity is 910 kg/m^3.

- Fibres BeneSteel are made from the mix polypropylene and polyethylene with tensile strength about 610 MPa and modulus of elasticity about 5170 MPa. Fibre diameter is 0,48 mm. Their specific gravity is 910 kg/m^3. The length of this tested fibre was 55 mm.
- Fibres cut from waste PET bottles are alternative for a price reduction of fibre reinforced concrete and contribute to solution of PET waste problems too. Applicable are fibres with length 60-110 mm depending on maximal size of aggregate. Width of this fibre was tested 0,7-2,5 mm. Thickness of fibres is 0,25-0,28 mm. Applicable are fibres with length 60-90 mm. Tensile strength of fibres cut from waste PET bottles is 80-140 MPa. Their specific gravity is 950 kg/m^3.

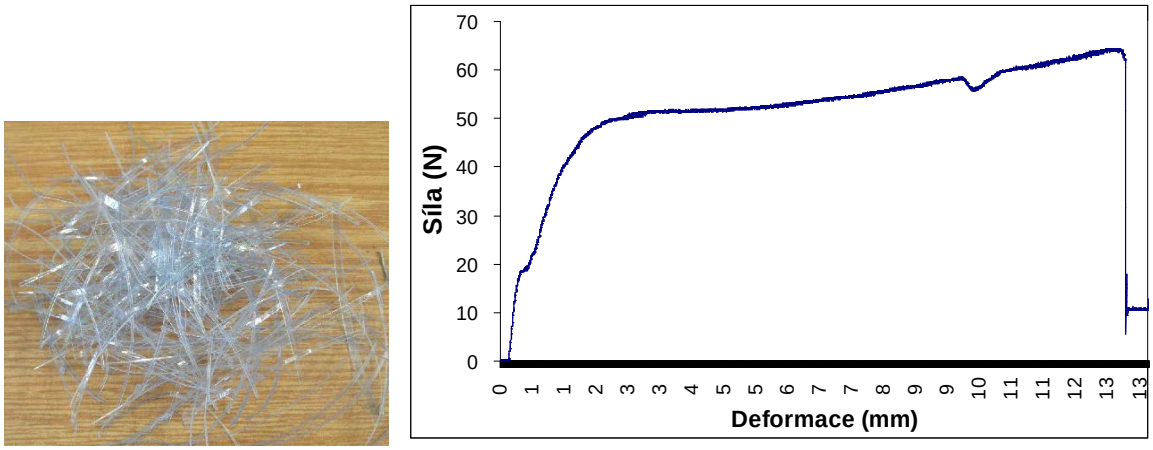

Fig. 1 Fibres cut from waste PET bottles and load-deflection diagram from the flexural test of fibre from waste PET bottle

A series of laboratory trials were carried out to establish the practical viability of using construction & demolition waste material as replacement for virgin aggregates in fibre reinforced concrete. Use of concrete or masonry recycled gravel (concrete or brick (masonry) rubble) in newly made concrete is rare and restricted (usually in amount max. 30 % of the filling as this amount does not significantly change properties of concrete). With proper production technology can be used also to replace 100% natural recycled aggregates while achieving sufficient characteristics. The advantage of the wide grading curve of the used recycled aggregate is apparent in the design of fibre concrete (0/32 mm). The recycled aggregate graded according to this limitation can be characterized as to be of the so-call wide grading curve. Utilisation of recycled aggregate in 1 fraction without use of other admixtures leads to porous structure of the composite.

In a mixture proportion the amount of cement was given on minimum for structural concrete according to Code EN 206-1 (260 kg/m^3 – 300 kg/m^3). 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.

The measurement of properties was performed according to standard test methods the Standard ČSN EN. Series of mechanical-physical experiments were carried out with test

samples 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.

In the following table 1 and 2 are show the selected results of basic mechanical-physical properties as initial bulk densities, compressive strengths, flexural strengths and tensile-splitting strengths.

Tab. 1 Results of mechanical-physical properties of samples with masonry recyclates

Type of fibres	Volume of fibres	Bulk density	Compressive strength	Tensile-splitting strength	Flexural strength
	[%]	[kg/m3]	[MPa]	[MPa]	[MPa]
-	0,00%	2034	21,85	2,14	1,6
Benesteel	0,50%	2002	27,02	2,89	2,24
Benesteel	1,00%	2028	26,96	2,62	2,32
Forta Ferro	0,50%	2041	21,97	2,22	1,85
Forta Ferro	1,00%	2082	25,48	2,97	2,44
PET	1,50%	2080	28,67	3,07	2,61
PET	3,00%	2013	27,36	3,23	2,57

Tab. 2 Results of mechanical-physical properties of samples with concrete recyclates

Type of fibres	Volume of fibres	Bulk density	Compressive strength	Tensile-splitting strength	Flexural strength
	[%]	[kg/m3]	[MPa]	[MPa]	[MPa]
-	0,00%	2026	18,24	1,77	2,25
Benesteel	0,50%	2065	18,05	1,75	1,88
Benesteel	1,00%	2052	17,32	1,78	1,98
Forta Ferro	0,50%	2023	18,1	1,55	2,13
Forta Ferro	1,00%	2017	18,22	1,67	2,21
PET	1,00%	2104	19,55	1,95	2,38
PET	1,50%	2044	18,54	1,63	1,89

The results of the project proved that properties of the concrete with void structure with full substitution of the natural gravel by masonry rubble and/or concrete rubble together with fibres are sufficient for particular practical applications [5-7].

Accepting of the fact that concrete with recycled aggregate has pores and voids and adding of inert component in the form of polymeric fibres would bring enhancement of the composite properties in such extent that these composites can be considered structural

materials; of course with restriction of possible use with respect to given material properties.

The target of the project was a complex analysis of void structure and behaviour of the composite affected by fibres. The residual strength – detectable for example in a flexural test of prisms – is affected by fibres both in composites with voids and dense composites; more expressive is in composites with voids. Nevertheless the effect of fibres depends on the grain size and length of fibre. For example for composite with grain sizes 0/32 mm the length of fibres shall be up to 100 mm.

The capability of transferring tensile stresses even after crack occurs up to significant strains is among the beneficial specific characteristics (Fig. 2-4 Resistance diagrams from bending test). Also, the regulation of tensile strength by controlling the weight dosage of synthetic fibres, which is not possible in the case of common dense fibre reinforced concrete, is beneficial. This can be explained by the hypothesis based on the structure of such fibre concrete, which shows high porosity.

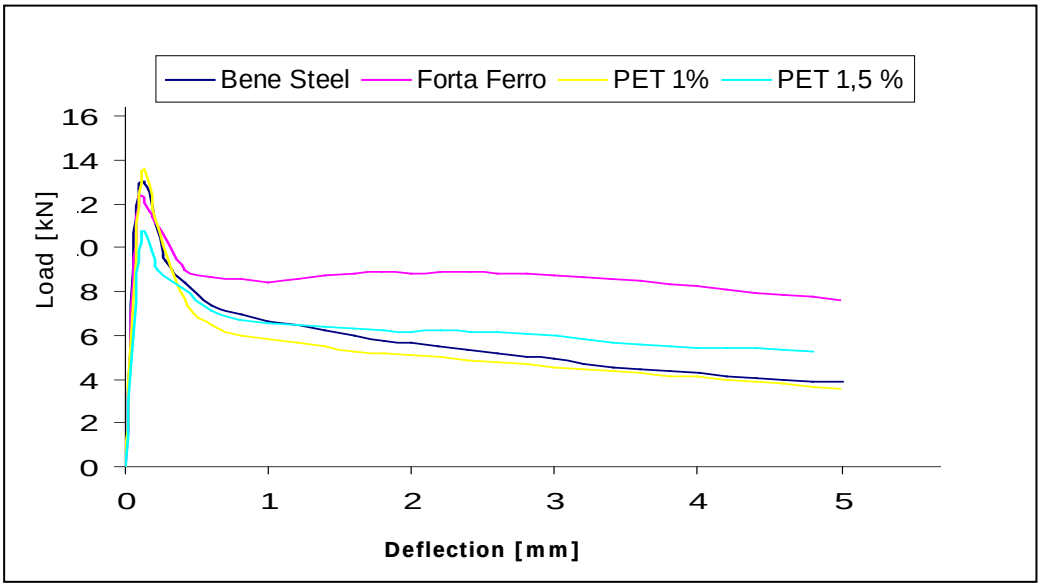

Fig.2 Tensile test of fibre reinforced concrete with different fibres

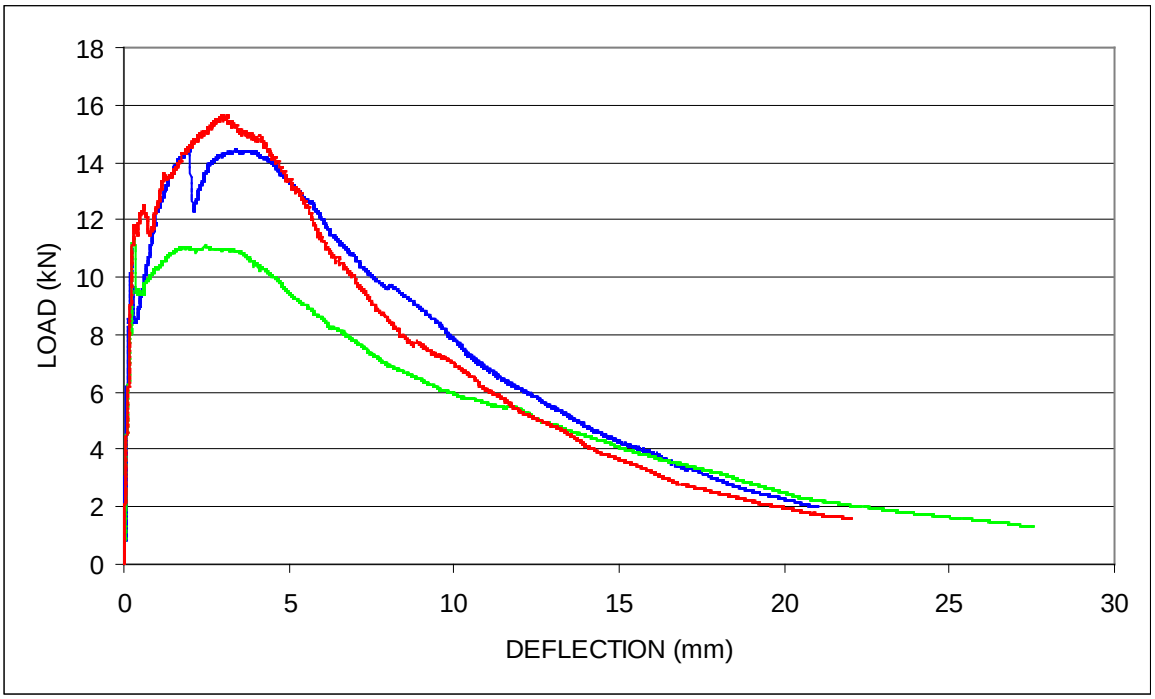

Fig. 3 Resistance diagram from bending test for 3 samples with masonry recyclates and Forta Ferro fibres (1%)

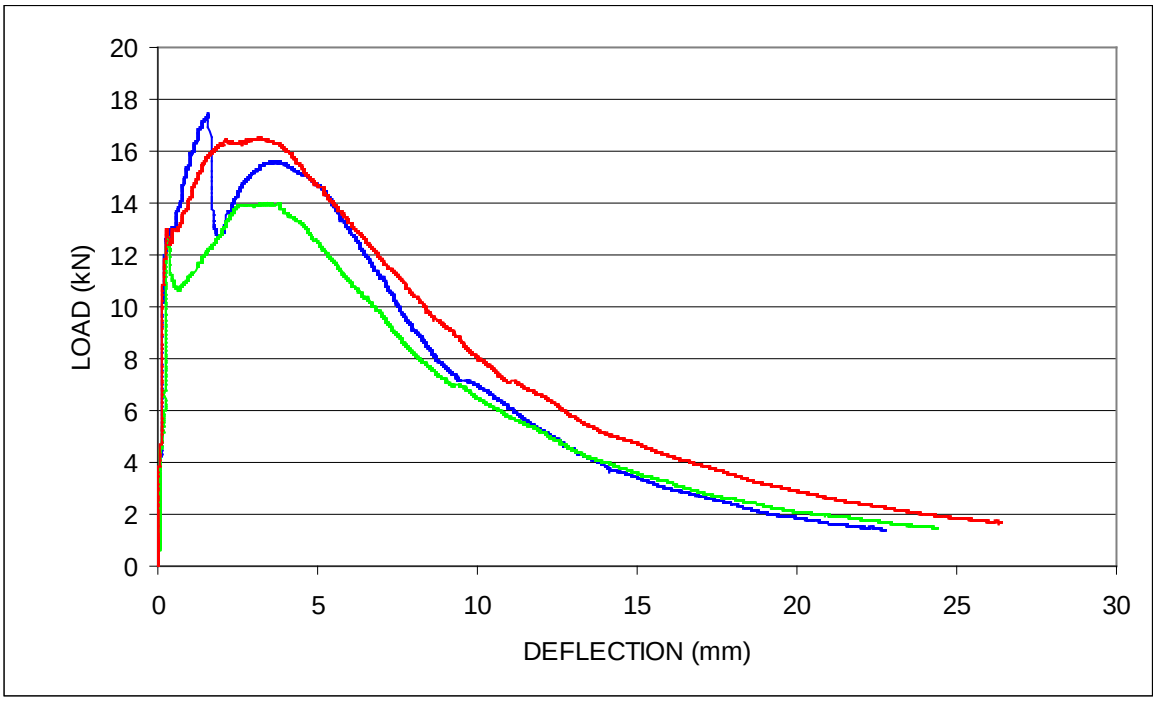

Fig. 4 Resistance diagram from bending test for 3 samples with concrete recyclates and Benesteel fibres (1%)

3. Conclusions

Results of experimental tests of fibre reinforced concrete with recycled aggregate are compared in the paper for three chosen types of fibres – synthetic polypropylene fibres FORTA FERRO, BeneSteel and fibres cut from waste PET bottles. Monitored characteristics were measured on cubes 150mm. Previous tests of fibre concrete with aggregate from recycled bricks or concrete proved efficacious characteristics of the composite. The advantageous properties are utilised in appropriately chosen applications mainly in earth structures. The application of fibre concrete is limited by the high cost of the composite due to price of the manufactured fibres. The efforts to decrease the resulting cost led to investigation of the substitution of fibres manufactured in mass production in plants by fibres cut from waste PET bottles. Results confirmed possibility of utilisation of fibre concrete made from waste PET bottles and aggregate made from construction waste. The application of fibre concrete slabs made from waste materials in earth structures (e.g. dams and embankments) would be a benefit both from the ecological and economic points of view.

One of the specific characteristics of this fibre concrete is its increased porosity, which is caused by use of unsorted recycled aggregate which is limited only by the maximum particle size in relation to the size of the designed structure. The capability of transferring tensile stresses even after crack occurs up to significant strains is among the beneficial specific characteristics. Also, the regulation of tensile strength by controlling the weight dosage of synthetic fibres, which is not possible in the case of common dense fibre reinforced concrete, is beneficial. This can be explained by the hypothesis based on the structure of such fibre reinforced concrete, which shows high porosity.

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