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MATERIAL PROPERTIES OF FRC WITH RECYCLED AGGREGATE

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ABSTRACT

The sustainable ecology belongs to the most important issues today. In this field a use of recycled materials is of great interest to people. Consequently, incorporation of industrial waste, concrete and brick scraps and other rubbish into products for civil engineering use is very important. Certain results from experiments carried out in laboratory on standard samples are emerged in this paper. Since the material is not yet enough approved, three main targets are addressed. The first involves the behaviour of fiber reinforced concrete based on aggregates from various recycled material. Then the influence of distance among two or more fibers is observed. For completeness the results from shear tests are presented in the end of this paper.

KEYWORDS: recycled aggregate, concrete composite, pullout test, shear test, effect of number of fibers

1. INTRODUCTION

One of a possible application of waste material of concretes, bricks and industrial rubbish reveals in fabricating concrete slabs with the above mentioned waste (Tam and Tam, 2008). Before the aggregate can serve as a reasonable stiffening of concrete it has to be crushed and granulated in order to win a set of grains of necessary spectrum. This is prescribed by standards devoted to the side distribution curve of various concretes. It appears that the self-sustained concrete with recycled aggregate obeys very restrictive material properties and can only be uses in a short range of applications. On the other hand the fiber 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. Certain papers have been concentrated on the topic in the past, such as (Vodička et al., 2007; Trčková and Řezba, 2009) and (Trčková and Procházka, 2009). In these papers some important material properties have been discovered, like the mutual effect of concrete composite based on cement matrix and metallic fibers (adhesion, tension, toughness, etc.). The influence of elevated temperature on the behaviour of the concrete composite with polypropylene fibers is discussed in (Mahasneh, 2005; Procházka et al., 2010). The comparison of measured results from experiments and the outputs from computation, improvements of the physical models and input data; all this can be carried out using coupled modelling, (Procházka and Trčková, 2008). The idea of measurement of the shear strength is developed in (Attom and Tamimi, 2010). Since the soil considered in the latter publication is weaker than the concrete material certain improvements have been done and the special apparatus for obtaining results about shear strength is fully described. Also special measurement device had to be built up before conducting the pullout tests with recycled material.

In the second chapter a study of the behaviour of concrete with several sorts of aggregate materials is addressed. In order to get larger information on adhesive properties of steel fibers the samples are created as a unit cell of cylindrical shape. Five fibers are always imbedded into the matrices of various assemblage and sort of the waste material.

In order to get more information on the behaviour of the effect of various numbers of steel fibers the samples with one, two and three fibers are tested in the third chapter. In all cases Dramix type fibers and straight steel fibers are used.

The last chapter is devoted to the shear strength. The tests are conducted on standard beams with rectangular cross-sections, reinforced by polypropylene fibers.

2. STUDY OF FORCES NEEDED TO PULLOUT STEEL FIBRES FROM CONCRETE SPECIMENS MADE FROM VARIOUS SORTS OF WASTE RECYCLED MATERIALS

In the laboratory conditions the forces needed to pullout steel fibers from the specimens made from mixtures of recycled materials in dependence of number fibers in the specimen and their distance were studied.

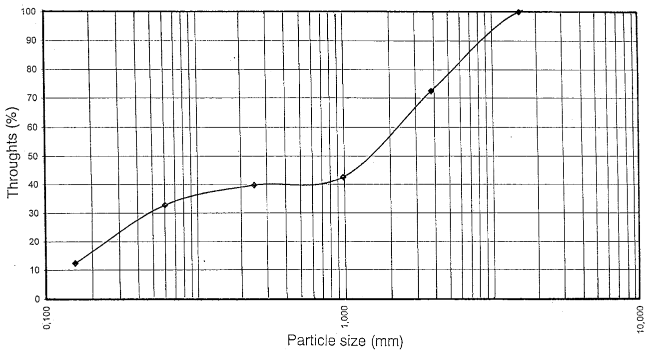


Fig. 1 Size distribution curve – siliceous sand (mixture NS).

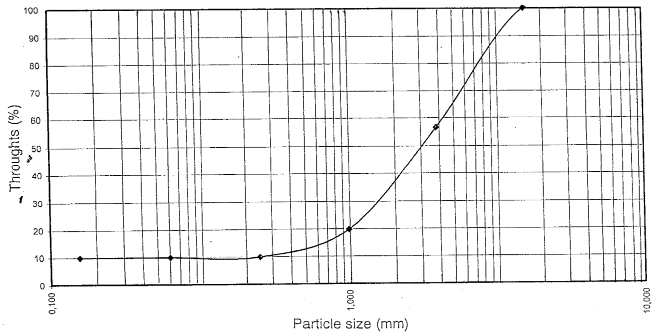


Fig. 2 Size distribution curve – concrete recycled material.

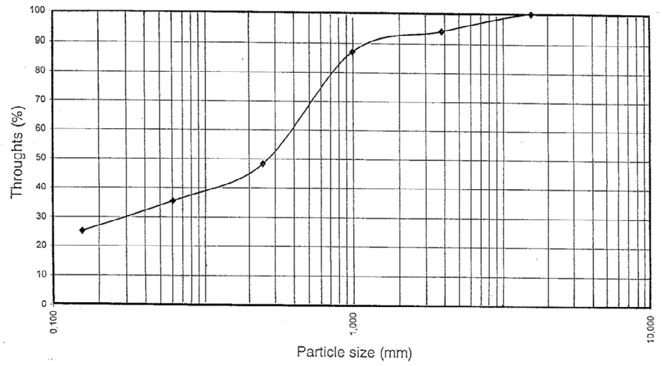


Fig. 3 Size distribution curve – brick recycled material.

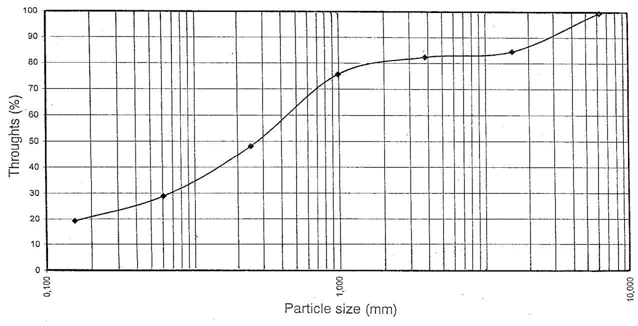
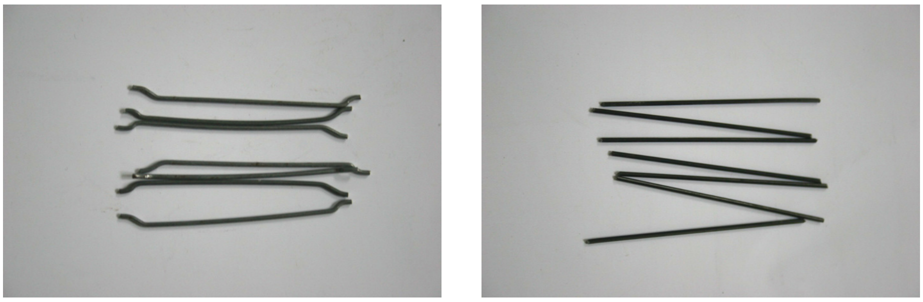


Fig. 4 Size distribution curve – industrial recycled material.

Table 1 Properties of the filling masses.

Filling mass	Bulk density (g/cm^3)	Particle density (g/cm^3)	Water absorption (%)
Siliceous sand (mixture NS)	2.08	2.63	1.86
Concrete recycled material	1.74	2.52	10.26
Brick recycled material	1.79	2.67	15.41
Industrial recycled material	1.55	2.76	50.43



a **b**

Fig. 5 Type of fibers.

For this study, following material was used:

- Brick recycled material crushed from pulling down old bricks
- Concrete recycled material crushed from old concrete floor
- Industrial recycled material processed in recycling company WEKO, s.r.o.
- Siliceous sand (mixture NS: ⅓ of fine siliceous sand with grain size 0-0.25 mm, ⅓ of siliceous sand with grain size 0.25-2.0 mm, ⅓ of siliceous sand with grain size 2.0-4.0 mm)
- Portland cement CEM II/B-M (V-LL) 32,5 R

Particle size fraction of used filling mass for tested samples was chosen 0-4 mm (industrial recycled material has a particle size fraction up to 8 mm). Size distribution curves, determined in compliance with standard ČSN CEN ISO/TS 17892-4, are given in Figures 1-4 and the basic physical properties of the filling mass are put forward in Table I. Each of these curves is in a good compliance with the requirement of the appropriate standard, which is valid for the particular concretes.

Specimens were made from mixtures which were mixed in ratio 3 parts of filling mass and one part of cement. The portion of water changes as follows: 0.45 of part for mixture from siliceous sand, 0.8 for concrete crushed material, 0.9 for brick crushed material and 1.2 of part for industrial recycled material, in dependence of their water absorption.

Specimens of cylindrical shape with diameter 50 mm and height of 50 mm were made from mentioned mixtures. Mixtures were placed into the form and vibratory compacted. During the preparation of specimens, five fibers were placed into the mixtures to get more accurate and fine results. Partly steel fibers DRAMIX with diameter of 0.90 mm, length of 50 mm and with bending on both ends (Fig. 5a), partly steel fibers with a diameter of 0.80 mm, length of 70 mm (Fig. 5b) are used. Fibers were placed in the plane passing through the centre of the specimen, symmetrically to the centre. Dramix fibers so as a 30 mm of the fiber lied in the mixture, second type of fibers so as a 50 mm of the fiber lied in the mixture and the remaining part of fibers served for fixation in the grip installed on the measuring device. The distance between fibers was 5 mm (Fig. 6).

Minimum of 12 specimens were made for each test. Specimens were tested 28 days after preparation. Samples curing and maturation was conducted in the room temperature.

Mechanical loading machine, with maximal loading force of 25 kN was used to measure the distribution of forces needed for the pullout of steel fibers from specimens, which are in relation with displacements (Fig. 7). A specimen was placed in the lower jaw and fibers were fixed in the grip of the upper jaw installed in the loading machine. The jaws became moving and the distance between them determined the displacements; the fiber was pulled out from the specimen.

The resulting pullout forces are derived as an arithmetic average from 12 tests. From Table 2 and graph in Figure 8 one get the force needed for complete pull out of the fibers, i.e. the admissible force. It always depends on used filling mass, its stiffness, on the interface conditions between the steel fibers and the cement mixture, which appears to be influenced by quantity of the fine particles in the filling mass, among others. From the size distribution curves one has conclusion that the industrial recycled material has a large share of the fine particles and the admissible pullout force in the case of steel fibers is the biggest, on the other hand the concrete recycled material has the minimum share of the fine particles.

3. STUDY OF FORCES NEEDED TO PULLOUT STEEL FIBERS FROM CEMENT MIXTURE

Table 2 Average limit pullout forces

Filling mass	Pullout force (kN)	
	Steel fiber	Steel fiber Dramix
Siliceous sand (mixture NS)	327	708
Concrete recycled material	140	220
Brick recycled material	220	390
Industrial recycled material	267	595

The admissible forces needed to pullout steel fibers from the cement mixture specimens in dependence of the number of fibers in the specimen and their mutual distance are studied in order to get the information on interaction among fibers and the cement matrix.

Considering the possibility of the laboratory equipment, especially tested specimens' dimensions, cement mixture with lower grain size distribution was selected. The cement mixture was prepared from following ratio:

1 part by weight of cement CEM II/B-M (V-LL) 32.5 R

3 parts by weight of siliceous sand with grain size 0.25 – 4.0 mm

½ part by weight of water

The steel fibers with a diameter of 0.95 mm, length of 80 mm were used for laboratory tests.

The same specimens of cylindrical shape with diameter 50 mm and height of 50 mm as mentioned above were made. During the preparation of specimens, one to three steel fibers were placed into a cement mixture cylinder, considered as a representative volume element, so as 50 mm of fiber lies in the specimen and remaining part of 30 mm serves for the fiber fixation in the grip installed on the measuring device. If one fiber was used, it was placed in the centered at the specimen; two and three fibers were placed in the plane passing through the centre of the specimen, symmetrically to the centre. Distances between the fibers were chosen 0 (side by side) (Fig. 9), 5 mm (Fig. 10) and 10 mm (Fig. 11).

The specimens were prepared and tested successively for one, two and three steel fibers and various distances. The resulting pullout forces are derived as an arithmetic average from 20 tests. The results for two and three fibers in the setup of the concrete composite are shown in Table 3.

The same results are depicted in the form of graph in Figure 12. From there it is seen that till the distance of approximately 4 mm the number of fibers stiffens the composite while in case of larger distance is considered the limit pullout force decreases. Consequently, the larger distance among fibers the smaller interaction among them.

Table 3 Numerical results of limit pullout force in kN for two and three fibers.

Distance between fibers (mm)	Number of fibers	
	2	3
0	54.7	105.0
5	182.7	146.7
10	142.3	173.9

Due to the small dimensions of specimen and technical abilities of the testing device, it was impossible to increase the number of steel fibers placed in one specimen and also heighten the distance between the fibers.

4. SHEAR STRENGTH OF CONCRETE WITH RECYCLED AGGREGATE

It appears that there is a wide range of applications in geomechanics the shear strength of composites based on aggregates from waste material plays an important role. From a large number of tests conducted in laboratory conditions on samples their geometry is in compliance with the current standards, specimens with a rectangular cross-section of 40 x 40 mm and length of 160 mm, a typical result is presented in this chapter. The industry waste is the aggregate and the polypropylene fibers BeneSteel are the reinforcement. Fibres BeneSteel, ribbons with a length of 27 mm, width of 1.5 mm and thickness of 0.4 mm, laterally shaped, are high strength synthetic fibres patterned for higher cohesion with fresh concrete mixture. They have high tensile strength (about 610 MPa) and are very easy folded in concrete mixture and do not gather rust. The testing device is shown in Figure 13 together with a sample beam being partly broken in Figure 14.

An average force – displacement diagram is depicted in Figure 15. It is seen that the shape of the graph is very similar to the bending tests, but the part right after the saddle in the damage section. There a sudden refreshment of the material is obviously seen and a new peak in the damage section occurs. In this way a greater toughness is registered in the shear test.

5. CONCLUSIONS

In conclusion let us sum up the results, which follow from a large spectrum of experiments targeted on the study of concrete composites, their matrix is created from various waste materials, such as brick recycled material crushed from pulling down old bricks, concrete recycled material crushed from old concrete floor, industrial recycled material processed in recycling company WEKO, s.r.o., and siliceous sand. The matrix was prepared from recycled aggregate and Portland cement CEM II/B-M (V-LL) 32.5 R. Although tests on cubic samples have been carried out previously, a detailed interaction between the steel fibers (Dramix and straight) and the concrete matrix has not been carried out so far. This is why the tests are concentrated on this lack of information. Through the pullout tests it has been proved that the effective material properties are very reasonable and the recycled material used in this paper can be used as a structural element in civil engineering and underground construction.

Surprising result was attained in the study of effects of number of fibers positioned next to each other. It appeared that there is a peak (optimum) in the relation between the number of fibers and the admissible force, see Figure 12. Also of great importance is the shear test, which provides a bigger toughness and an additional significant peak in the damage section of the relation force – displacement. It seems that this peak is due to a kind of refreshment of the composite material.

The experimental program carried out in the frame of this study is also a starting point for the assessment of theoretical models, which can be used in computer programs, (Procházka and Šejnoha, 1995).

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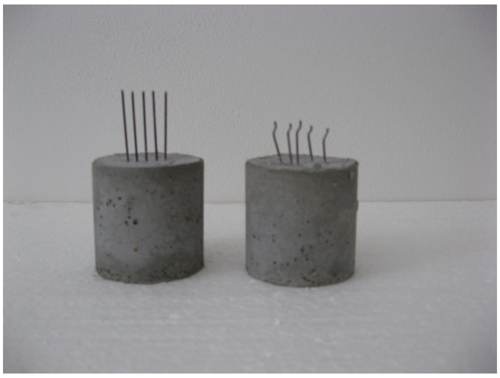

Fig. 6 Tested specimens.

Fig. 7 Loading machine with adapted jaws.

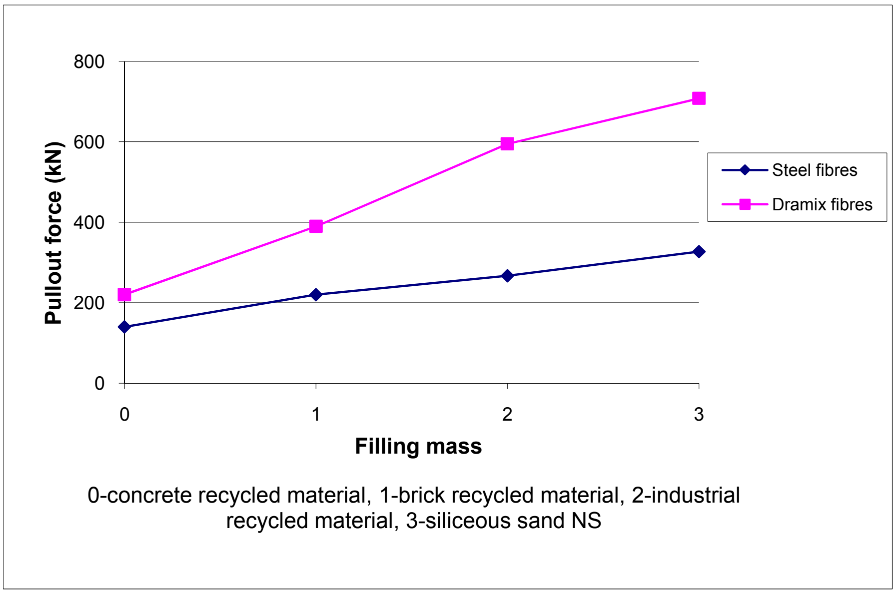

Fig. 8 Average pullout forces for various materials.

Fig. 9 Setup of fibers in the sample with the distance between adjacent fibers of 0 mm.

Fig. 10 Setup of fibers in the sample with the distance between adjacent fibers of 5 mm.

Fig. 11 Setup of fibers in the sample with the distance between adjacent fibers of 10 mm.

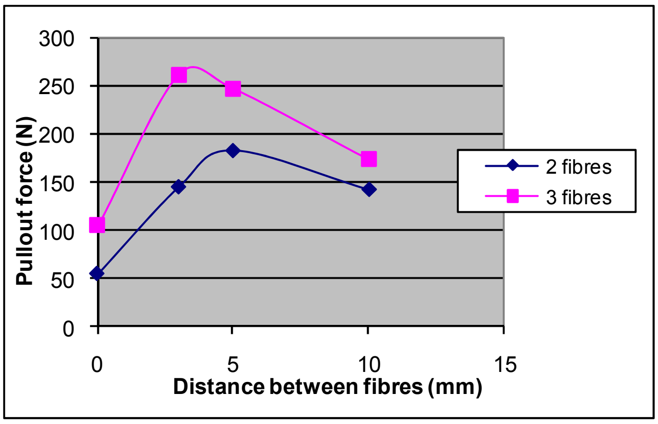

Fig. 12 Dependence of the pullout force on the distance between fibers.

Fig. 13 The apparatus for shear stress assessment.

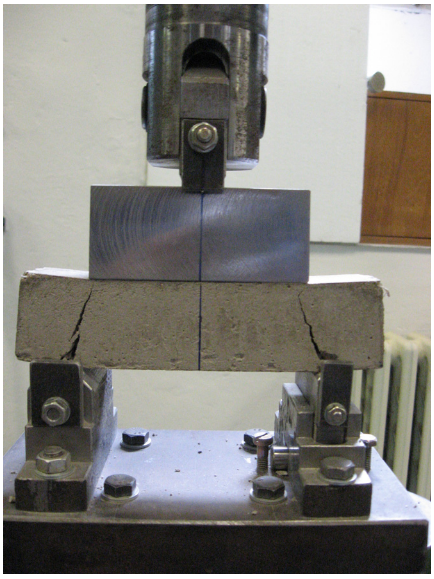

Fig. 14 Detailed view of broken sample.

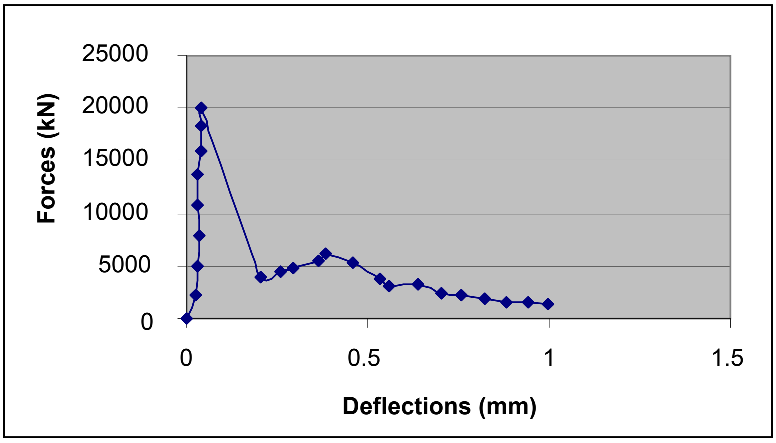

Fig. 15 Distribution of deflections for industrial recycled material.