

Effect of the addition of waste basalt fibers on concrete shrinkage

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Abstract. This article presents the issues related to using by-products and waste materials in construction and mining industry. The current applications of selected materials in various areas are presented, with particular focus on cases in the construction and mining industries, where waste-based composites sealed with various hydraulic binders are used to build new structural elements or just as fills and backfills. In the next part of the review, the methodology and selected results of shrinkage tests on concrete composite samples with the addition of various amounts of additives and price tests to reference samples without dispersed reinforcement are presented and discussed. Research has been carried out on the subject of balance between concrete and the semi-finished product used.

1 Introduction - general description of the facility

The growing demand for infrastructure and the increasing prices of building materials cause interest in new technological solutions as well as create opportunities for reusing previously produced building materials [1-5]. Steel fibres [1,2], PET [3], waste basalt rebars [4-5] and even rubber from used tyres [6,7] may be used to improve selected characteristics of composite materials in building and civil engineering. Potential reuse of CDW (construction demolition waste) is one of the leading areas of sustainable development [8] in construction and mining industry [9]. Reuse of spoil material and by-products seem to be extremely attractive idea for mining industry that produces a lot of waste and needs large amounts of backfill material for safe mining production [10-12]. In addition to the economic aspects [11-12], in some cases special attention should be paid to the durability of reused materials [13,14] as well as health aspects. At the same time regulations are being raised all over the world, imposing on companies and investors the use of recycled or reused building materials. Currently, there is a lot of research conducted on replacing the materials traditionally used so far as an intermediate, e.g. for the production of concrete mix, with alternative ones. Ubysz and Łuszczuk are conducting research on the possibility of using steel fibers from recycled tires as reinforcement for concrete as well as the use of other materials as reinforcing fibers [6,7]. In the next step researchers undertake the replacement of the seemingly indispensable component of concrete, which is aggregate, with waste composite rods [5]. Another example of attempts to replace cement binder is making mixtures based on industrial wastes dissolved in water [15].

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In addition to the use of recycled materials as semi-finished products for concrete mix, research is also conducted on the possibility of using it in the other areas. Apart from the widespread use of pieces of rubber from car tires as filling in artificial surfaces of football fields or in communication construction [6,7], research is conducted on the possibility of using construction waste in geotechnics and mining with particular emphasis on the lack of negative environmental impact [9-11,15].

The article presents selected results of tests carried out on concrete samples with the addition of waste basalt fibers used as dispersed reinforcement.

2 Shrinkage of concrete composites - conditions

Concrete shrinkage is an intrinsic phenomenon that occurs in materials with a porous structure [16,17]. It consists in reducing the volume of concrete through the loss of water contained in the pores due to physical and chemical phenomena. The total volume change of concrete consists of chemical and autogenous shrinkage resulting from the processes of setting and hardening of the cement slurry and deformations caused by the loss of water from the material (plastic shrinkage and drying out). One of the main factors determining concrete shrinkage is the thermal and humidity conditions of the environment [18]. All those factors must be considered in constitutive modelling of composites based on hydraulic cementitious binders [19].

As a porous material concrete is exposed to the risk of reducing its volume. In non-laboratory conditions, it is inevitable and the effects of its formation can only be limited [20]. In the process of designing fibro-concrete, a number of factors should be taken into account that affect the most important strength properties of the finished concrete as well as shrinkage. Below are some issues that should be taken into account when designing a concrete mix with added fibers [21] :

- the maximum grain diameter should not be greater than 1/3 of the length of the straight fibers and not more than 1/2 of hook-shaped fibers,
- maximum grain diameter should not exceed 4 or 8 mm.
- due to the deterioration of the workability of the concrete mix, it is necessary to use a plasticizing admixture. Its absence may result in increased porosity of concrete and uneven distribution of fibers,
- water-cement ratio should not exceed 0.55.

Common practices to reduce the effects of shrinkage in structural elements are the placement of additional reinforcement at the surface of the element and the use of appropriately designed concrete mixtures. The most common is steel and polypropylene dispersed reinforcement. Polypropylene reinforcement is used to eliminate the effects of autogenous shrinkage occurring during the drying of the cement. The tests of concretes with polypropylene fibers show that the increase in the volume of the fiber in the concrete in the amount of 0.25, 0.5 and 0.75% reduces the autogenous shrinkage gradually by 5, 15 and 26% compared to normal concrete will shrink after 24 hours. Steel reinforcement also is used to eliminate the effects of shrinkage from drying out. Combined polypropylene and steel reinforcement is increasingly used. This combination eliminates both autogenic shrinkage and drying out. In many cases composite reinforcement (carbon, basalt) is also used, which has no undesirable properties in some situations, such as the risk of corrosion in aggressive environments, interference with the electromagnetic field in the vicinity of precise devices.

3 Sample preparation

Concrete shrinkage as a physical phenomenon, occurs due to the loss of free water from the concrete, as well as occurs in fiberconcrete [21]. Basalt fibers reduce shrinkage due to the fact that they do not shrink themselves, and thus they resist concrete shrinkage due to the adhesion effect between these materials. As the number of fibers increases, the shrinkage decreases, although it is not proportional. Too little amount of fibers does not, or only slightly affects, the amount of shrinkage. On the other hand, too much fiber causes difficulties in workability and arrangement of the concrete mix.

The concrete mix was made in the Accredited Test Laboratory located at the Faculty of Civil Engineering at the Wrocław University of Technology. In the first stage all the components of the concrete mixture were mixed and then basalt fibers were added (figures 1a,1b). Then the ready mixture was placed in 100×100×500mm molds and stored until demoulding.



Fig. 1a Mixing of ingredients



Fig. 1b Mixing of ingredients with basalt fibers

The sample shrinkage was tested on the basis of the PN-84: B-06714/23 standard. Determination of volumetric changes by the Amsler method. It consists the change in the length of the sample, determined with the Amsler apparatus, in relation to its initial length. The test was carried out on bars with dimensions of 100×100×500mm made by using aggregates with a grain size not greater than 16mm according to the recipe in tab 1.



Fig. 2. Sample with measuring instrument

Table 1. The proportions of the ingredients used to make the concrete mix

Ingredient	Cement	Aggregate			Water	Fluidizing admixture
	CEM II 32,5	0-2mm	2-8mm	8-16 mm		
quantity[kg/m ³]	450	670	500	600	180	22,5

After concreting, the molds with bars were placed in a climatic chamber with a temperature of $18 \pm 2^{\circ}\text{C}$ and a relative humidity of over 90%. The samples were demoulded 24 hours after concreting. Then the samples were stored in a climatic chamber at a temperature of $18 \pm 2^{\circ}\text{C}$ and a relative air humidity of 65-75%. The samples were stored in a way that allowed air to enter from all sides (Figure 3).



Fig. 3. Samples in a climatic chamber

The change in beams length after n days was calculated according to the formula (1):

$$\epsilon_n = \frac{(l_n - l_1) \cdot 1000}{500}, \quad (1)$$

where: l_n – sample measurement result after time n, in mm,
 l_1 – the result of the first sample measurement after 24h of hardening, in mm.

4 Results

The table presents selected results of the tests carried out for selected samples with the content of basalt fibers in the amount of 2%.

The figure 5 presents a collective graph comparing the shrinkage of samples with the addition of basalt fibers in the amount of 1%, 2% and without the addition of fibers. By analyzing the chart it can be concluded that the lowest final shrinkage was found for the samples with the highest percentage content. Practically from the beginning of the measurements, clearly lower values of the results for particular days can be noticed compared to other samples. Considering the results for the tested samples, it can be seen that the final

value of shrinkage for samples with the addition of basalt fibers in the amount of 2% is lower than the samples without the addition of fibers by about 65%. The highest deformations occur in the time interval up to the 28 day from the moment of performing the reference measurement. This is in line with theories suggesting that concrete should be cared for in the constructed structures and with the achievement of its full strength. The study was terminated after 165 days due to the very slight deformation that appeared after 84 days.

Table 2. Shrinkage test results

Number of sample	Time	Readings		Readings after time		Readings correction	Result of the research	Result of the research - average score
		template	sample	template	sample			
-	days					mm	mm/m	mm/m
BW2001	0	6	11,54	-	-	-	-	-
BW2002			10,64		-		-	
BW2003			10,77		-		-	
BW2001	5		11,54	6	11,51	-	-0,06	-0,0533
BW2002			10,64		10,75		0,22	
BW2003			10,77		10,61		-0,32	
BW2001	7		11,54	6	11,5	-	-0,08	-0,0667
BW2002			10,64		10,75		0,22	
BW2003			10,77		10,6		-0,34	
BW2001	14		11,54	6	11,49	-	-0,1	-0,0800
BW2002			10,64		10,74		0,2	
BW2003			10,77		10,6		-0,34	
BW2001	21		11,54	6	11,47	-	-0,14	-0,1200
BW2002			10,64		10,72		0,16	
BW2003			10,77		10,58		-0,38	
BW2001	28		11,54	6	11,43	-	-0,22	-0,2067
BW2002		10,64	10,68		0,08			
BW2003		10,77	10,53		-0,48			
BW2001	84	11,54	6	11,41	-	-0,26	-0,2600	
BW2002		10,64		10,65		0,02		
BW2003		10,77		10,5		-0,54		
BW2001	165	11,54	6	11,39	-	-0,3	-0,2933	
BW2002		10,64		10,63		-0,02		
BW2003		10,77		10,49		-0,56		



Fig. 4a Cross-section of the sample



Fig. 4b Cross-section of the sample

After the raw material tests, the bending tensile strength test was also carried out. A side effect, albeit a desirable one, was the possibility of checking the distribution of fibers in the sample's cross-section. The photo 4a and 4b shows a cross-section through a damaged sample with marked fibers. Aforementioned fibers are evenly distributed across the cross-section, which also resulted in lower deformation of the tested samples.

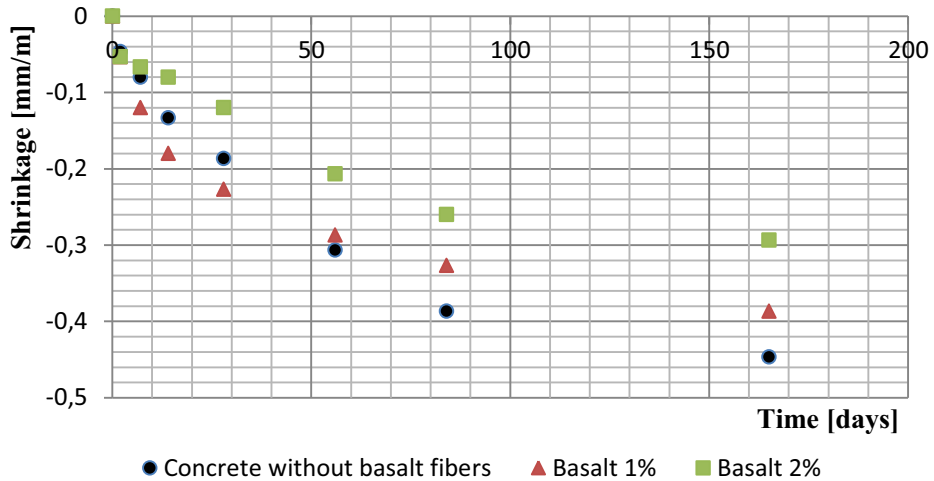


Fig. 5. Shrinkage of concrete samples - the results of the tested ones

5 Conclusions

Based on the conducted research it can be concluded that waste basalt fibers fulfill their role in the process of reducing the negative effects of shrinkage. The decrease in shrinkage stress over time for 2% fibers from the start is much lower than for samples with 1% and without added fibers. Considering the final recorded result of shrinkage stresses for samples with a content of 2% compared to samples without the addition of reinforcement, a decrease in the total shrinkage strains by about 65% can be noted. When making the concrete mix, it was found that the maximum amount of added fibers should fluctuate around 2%. With a larger amount, there were significant difficulties in workability, which consequently led to problems with the arrangement of the mixture in the molds and the exact vibration of the samples.

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