Fine-grained concrete fibre-reinforced by secondary mineral wool raw material

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Abstract. Fibre concrete is one of the most promising materials for load-bearing structures. Studies in this area are mainly concerned with improving running abilities of new materials. This work deals with studying the usage capability of the waste from basaltic fibre-heat insulation material as a fibre. It was shown that the introduction of secondary mineral wool raw material in the range of 0.5-1.0 mass % concentration inside the matrix of fibre-grained concrete leads to improving the breaking strength of a sample up to 34 %, and the compression strength up to 10 %. Research results allowed establishing that samples reinforced by fibre made of secondary mineral wool raw material have homogeneous and dense contact zones at the fibre-matrix boundary. Processes of fibre components corrosion, being in contact with alkaline aqueous media formed by the interaction of cement and water, were considered and substantiated taking into account chemical properties of oxide components of basaltic fibre. Conducted research allows improving the production and solves the problem related to recycling ecologically harmful large tonnage construction materials.

1. Introduction

Among different kinds of concrete widely used in the construction in dusty fibre concrete, having in its composition micro rein for cement consisting of different components, is of special interest for research. They can be conventionally divided into two groups. The first one is metallic produced from tee land and the second is non-metallic represented by fibrous materials. The introduction of fibre-reinforced filling materials leads to improving some operating abilities like strength of a concrete to tensile load and breaking force, chemical durability, crack growth, cold, heat and water resistance [1-8]. Some special attention should be paid to basaltic fibre. It is distinguished by some valuable operating characteristics, availability, raw material cheapness and simplicity of production. However, in spite of its chemical durability, basaltic fibre is exposed to degradation in a strong alkaline medium formed in compositions on the basis of cement.

It is to be mentioned that nowadays one of the urgent problems is recycling and utilization of anthropogenic bulk waste formed by reconstruction and renovation of industrial buildings and communication networks, where one of the main waste products is mineral and glass wool. However, the issue related to the use of mineral wool heat insulation material as a fibre has not been studied yet. The use of advantages obtained by this research can result not only in the reduction of fibre wool use produced at special enterprises, but also solve partly the ecological problem.
This study is concerned with the impact of fibre produced from secondary mineral wool raw material on physic-engineering properties of heavy fine-grained concretes.

2. Materials and methods.
This paper focuses on physical-mechanical properties of a fibre concrete obtained from the secondary raw material in the form of mineral wool residues. Portland cement I 42.5N satisfying all requirements was used as a cementing (binding) material for producing fibre concrete [9].

Fine-grained sand meeting all the demands was used as filler [10,11]. Basaltic fibre produced from secondary raw material was used as a reinforcing component. Its main parameters and chemical composition are presented in Tables 1 and 2 below.

Table 1. Main parameters of basaltic fibre (BF) from mineral wool raw material

| Mean diameter of a fibre, mm | Mean fibre length, mm | Humidity, not more than, % | Colour          |
|-----------------------------|-----------------------|---------------------------|----------------|
| 0.01-0.012                  | 0.03-0.15             | 2.0                       | yellow-and-brown|

Table 2. Qualitative and quantitative composition of basaltic fibre from secondary mineral wool raw material

| Qualitative and quantitative composition (% mass.) of basaltic fibre |
|---------------------------------------------------------------|
| Na₂O   | MgO   | Al₂O₃ | SiO₂ | K₂O | CaO | Fe₂O₃ |
| 1.27   | 1.74  | 4.53  | 50.61| 0.81| 33.78| 7.26  |

Since the secondary mineral wool raw material was obtained after reconstruction of a building site in a form of small pieces (blocks), it was necessary to crush and grind it in a rotor cutting mill before introducing in a concrete mixture. Electronic microscope JCM-6000 was used to determine (measure) the diameter and length of BF made of secondary mineral wool raw material. The humidity of BF made of secondary mineral wool raw material was determined by means of a special method used for specific humidity estimation and mass concentration of substances removed by their calcination (ignition). A visual method was used to determine the color of BF made of secondary mineral wool raw material.

The test of concrete mixture properties was carried out in compliance with State Standard methods 7473-2010 [12].

The mobility of concrete mixture was assessed through the slump test and was calculated as the arithmetical mean value of two test results with round-off up to 1.0.

Mean density of the concrete mixture was determined through the ratio of consolidated (compacted) concrete mass to its volume and was calculated as the arithmetical mean value of three test results from the same sample.

Sample-beams of the size 40×40×160 mm were produced to determine the bending strength. Sample-cubes of the size 70.7×70.7×70.7 mm were produced to determine ultimate compression strength. The produced samples were placed in special moulding boxes inside a bath with a hydraulic valve (seal) for a period of 24 hours. Relative air humidity in the bath was not less than 90 %. After stripping, the samples were exposed to hardening under normal conditions. On the expiry of storage time samples were tested [13,14].

Ultimate bending strength was calculated as the arithmetic mean value of two small test results of three production samples.

Structural features of the cement stone with BF made of secondary mineral wool raw material were determined by scanning electron microscope JCM-6000.
Fiber was introduced in a concrete premix for a uniform distribution of the basaltic fibre produced from secondary mineral wool raw material. To prepare this concrete mixture, a special proportion of 1:3 of cement and sand was used. The ratio of water-cement (WC) was 0.5 with adding fibre in the amount of 0.5, 1.0, 1.5 and 2.0 mass %.

3. Results and discussion.

The properties of concrete mixture and the results of bending and compressive strength are shown below in Tables 3 and 4.

Table 3. Properties of concrete mixture with different amount of basaltic fibre produced from secondary mineral wool raw material

| Samples | Composition nomenclature | Fibre amount, % from cement mass | Slump, cm | Mean density, kg/m³ |
|---------|---------------------------|----------------------------------|-----------|--------------------|
| 1       | Check composition         | -                                | 8.0       | 2250               |
| 2       | Using BF from secondary   | 0.5                              | 8.0       | 2253               |
|         | mineral wool raw material | 1.0                              | 7.6       | 2256               |
| 4       |                            | 1.5                              | 6.6       | 2260               |
| 5       |                            | 2.0                              | 5.0       | 2259               |

As it can be concluded from Table 3, the introduction of secondary mineral wool raw material of more (greater) than 0.5 mass % will result in worsening place ability of concrete mixture. If fibre contains 2 mass %, the slump of mixture decreases from 8 cm to 5 cm. The increase of BF content made of secondary mineral wool raw material from 1.0 mass % causes troubles to mixing the concrete since the fibre tends to lump. The specified shortcomings can be removed by the increase of concrete mixing time or the increase of water-cement ratio.

Table 4. Results of sample tests on bending and compression strength that various time of hardening

| Samples | Composition nomenclature | Amount fibre, mass.% | Ultimate bending and compressive strength (MPa) |
|---------|--------------------------|----------------------|-----------------------------------------------|
|         |                          |                      | 7 days                                     | 14 days                      | 28 days                      |
| 1       | Check composition        | -                    | 8.0/31.6                                    | 8.6/34.8                     | 9.3/38.8                     |
| 2       | Using BF from secondary  | 0.5                  | 9.5/34.2                                    | 10.3/36.5                    | 11.8/39.5                    |
| 3       | mineral wool raw material| 1.0                  | 11.4/35.9                                   | 11.7/38.3                    | 12.5/42.7                    |
|         |                          | 1.5                  | 8.5/33.3                                    | 9.0/35.2                     | 10.3/39.0                    |
| 5       |                          | 2.0                  | 7.6/30.5                                    | 8.1/34.5                     | 9.0/37.1                     |

It is obvious from Table 4 that the introduction of BF made of secondary mineral wool raw material up to 1.5 mass % results in the improvement of bending strength indices compared with the test composition within 7 days from 18.8 mass % (BF =0.5 mass %) up to 42.5 mass % (BF =1.0 mass %). Thus, it can be assumed that the introduction of the filler in the concentration which approximates to 1.0 mass % is optimal.

The same tendency is observed within 14 days, but the stabilization of bending strength improvement has been observed by 28 days and makes up 26.8 mass % (BF =0.5 mass %), 34.4 mass % (BF =1.0 mass %). The bending strength of composition 4 has increased to a very little degree and decreased up to 3% in composition 5. Thus, the best results demonstrates concrete mixture with 1 BF mass %, especially in the early periods of hardening. With the introduction of BF made of secondary mineral wool raw material from 0.5 to 1.5 mass % in the concrete mixture, the compression strength increases within 7 days from 7.6 % (BF = 0.5 mass %) up to 13.6 % (BF = 1.0 mass %) compared with the test composition. The bending strength in composition 4 has increased but not sufficiently and has decreased
in composition 5 by 3 %. The same tendency is displayed within 14 days of hardening and the stabilization of bending strength improvement has been observed over 28 days.

The analysis of experimental data showed that the main increment of bending and compressive strength is in the composition containing 1.0 mass % of BF made of secondary mineral wool raw material over the period of 7, 14 and 28 days. When the mass of BF is greater than 1.5 %, there is a decrease of strength indices. Moreover, it is difficult to mix concrete, and some fibre accumulation is observed. It is necessary to emphasize that the increase of fibre dosage causes the increase of water consumption of a concrete mixture.

The introduction of the reinforcing component made of mineral wool waste causes some changes in a structure of hardened concrete. The photos below demonstrate the microstructure of check samples reinforced by secondary mineral wool raw material (Fig.2) at the age of 28 days (Fig. 1a, 1 b)

![Microstructure of samples](image1.png)

**Figure 1.** Microstructure of samples with testing composition: a – magnification ×1000; b – magnification ×2000.

Fig. 1 shows that the control composition for a sample is heterogeneous and there are some little pores and cracks. Some hydrated formation of a needle-shaped type in the form of plates typical for ettringite and Portland are identified in this sample.

Photos of the sample microstructure reinforced by BF made of secondary mineral wool raw material are presented in Fig. 2.

![Microstructure of a sample](image2.png)

**Figure 2.** Microstructure of a sample reinforced by BF made of secondary mineral wool raw material. (Magnification ×2000).
As it can be seen from Figure 2, the sample reinforced by BF made of secondary mineral wool raw material has a homogeneous lamellar microstructure. Besides, compared to the reference specimen, the number of micro pores and the volume of new formation have increased which can be explained by large quantity of crystallization centers. Due to differently directed fibre, a tight contact area between basaltic micro wool and cement-sand matrix is formed.

Elemental composition in a cement-sand matrix was determined through ski graphing in the area of fibre\matrix contact and compared with basaltic fibre. The results are shown in Figures 3,4 and Table 5.

**Figure 3.** Microphotos of the X-ray patterns of a reinforced BF sample. 003 – highlighted area for analysis.

**Figure 4.** X-ray pattern of the elemental composition of the fibre\matrix contact boundary \
Table 5. Qualitative and quantitative composition of the cement-sand matrix on the boundary contact fibre\matrix (sample 1) compared with basaltic fibre (Table 2)

| Sample | Na₂O | MgO  | Al₂O₃ | SiO₂ | K₂O | CaO  | Fe₂O₃ |
|--------|------|------|-------|------|-----|------|-------|
| 1      | 1.25 | 1.953| 3.38  | 31.06| 0.83| 60.45| 1.09  |

In accordance with the obtained data the most significant changes are in calcium and silicon oxides. The concentration of SiO₂ decreases from 50.60 to 31.06 mass %, while the concentration of CaO increases from 33.78 to 60.45 mass %. From our point, it can be explained by processes of chemical interaction, the solution of near-surface area and selective boundary adsorption of chemical reaction products. It is well known that BF contains different oxides: acid (SiO₂); amphoteric (Al₂O₃, Fe₂O₃) and basic (FeO, MgO, CaO, Na₂O and K₂O) [15]. The following reactions can take place in an alkaline medium (pH~ 12) formed by the interaction between cement and water. As the result of these reactions very soluble, poorly soluble and low soluble compounds are formed.

1. Very soluble compounds:
   \( \text{Al₂O₃} + 2\text{OH}^- = 2\text{AlO}_2^{2-} + 2\text{H}^+ \) (1)
   \( \text{Fe₂O₃} + 2\text{OH}^- = 2\text{FeO}_2^{2-} + 2\text{H}^+ \) (2)
   \( \text{SiO}_2 + \text{OH}^- = 2\text{HSiO}_3^- + \text{H}^+ \) (3)
   \( \text{Na}_2\text{O}(\text{K}_2\text{O}) + \text{H}_2\text{O} = 2\text{Na(K)}\text{OH} \) (4)

   The reaction (4) with sodium and potassium oxides is hardly probable since the chemical equilibrium in the alkaline medium is strongly off-set to the left, while hydrosilicate formation is an indisputable fact.

2. Compounds that are poorly soluble in water:
   \( \text{CaO} + \text{H}_2\text{O} = \text{Ca(OH)}_2 \) (5)

   Despite the basic nature of CaO, the presence of high calcium hydroxide concentration is the result of the interaction between cement and water.

3. Low soluble compounds: hydroxides, silicates and ferric and magnesium carbonates. Thus, from the above presented chemical compounds, it can be concluded that only calcium hydroxide ions are able to diffusion in a liquid medium while all other compounds sludge.

From the above presented results, the following process of interaction between BF and cement-sand mixture can occur.

By mixing the compound with water, the pH medium can increase up to 12, which results in the solution of a silica-alumina carcase in the near-surface fibre, and the diffusion removal of reaction products in the form of very soluble ammonium, silicon and iron salts. Their concentration must decrease, which is reflected in the variation of quantitative composition (Table 2 and 5). Calcium hydroxide moves up in the in the phase boundary between fibre and liquid medium as a result of gradient area formation of concentration in a near-surface layer of BF and due to its diffusive mobility. It is known [15] that there are some broken bonds of a silicate carcase on the fresh surface of basaltic fiber for med due to alkaline corrosion. Calcium hydroxide allows compensating broken bonds by completing their building till \( \text{Si} – \text{O} – \text{H} \) condition with selective adsorption of calcium ions on the near-surface fiber area. These processes lead to the increase of ion concentration on the interface boundary and ensure a more homogeneous and dense contact area. Consequently there is an increase of physical-mechanical properties of the composition on the whole.

4. Conclusion

The possibility to use secondary basaltic mineral wool raw material in the production of concrete structures exposed to dynamic load was shown in the given paper.
Physical-technical characteristics of concrete mixtures with various content of basaltic fibre were investigated. It can be concluded that the best results are achieved by introducing in the mixture secondary mineral wool raw material with the concentration range of 0.5-1.0 % mass. It should be mentioned that the compressive strength increases by 34 % within the period of 28 days of samples hardening and bending strength up to 10 % compared with a check (reference) sample. The development of strength is more efficient in early periods of hardening.

The development of interaction processes between mineral wool raw material and components of cement composition was suggested and substantiated.

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