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Basalt-boron fiber as reinforcement of composites for nuclear energy applications

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Outline

- Composite material based on concrete + basalt&boron fiber
- The radiation shielding modelling of basalt-concrete materials
- Investigations for degradation level of basalt fiber in concrete environment
- The shrinkage tests for composite concrete reinforced by basalt fiber with different dosages

Composite material based on concrete + basalt&boron fiber

Cracking

“Cracking is the main reason for degradation of concrete structures on NPP”

(*Naus D.J. 2007, Primer on Durability of Nuclear Power Plant Reinforced Concrete Structures - A Review of Pertinent Factors. NUREG/CR-6927, ORNL/TM-2006/529, Oak Ridge National Laboratory, U.S. Nuclear Regulatory Commission, USA)*

Cracking leads to moisture penetration which may lead to gradual destruction

Best available solution in civil engineering is the use of „fiber reinforcements“

(*Abrishambag, A, Barros, J. A.O., Cunha, V. M.C.F., 2013 Relation between fibre distribution and post-cracking behavious in steel fibre reinforced self-compacting concrete panels. Ce-ment and Concrete Research. 51, 57-66.*

Graeff, A.G., Pilakoutas, K., Neocleous, K., Peres, M.V. N.N., 2012. Fatigue resistance and cracking mechanism of concrete pavements reinforced with recycled steel fibres recovered from post-consumer tyres. Engineering Structures. 45, 386-395.

Haddad, R.H., Smadi, M.M., 2004. Role of fibers in controlling unrestrained expansion and ar-resting cracking in Portland cement concrete undergoing alkali-silica reaction. Cement and Concrete Research. 34 (1), 103-108)

Fiber Reinforcement

Metallic fiber reinforced concrete is the most common type

Also, for fiber reinforced concrete used:

- glass fiber
- polymer fiber
- copolymer fiber
- etc.

We study the use of basalt fiber as reinforcements in various aspects

Basalt fiber

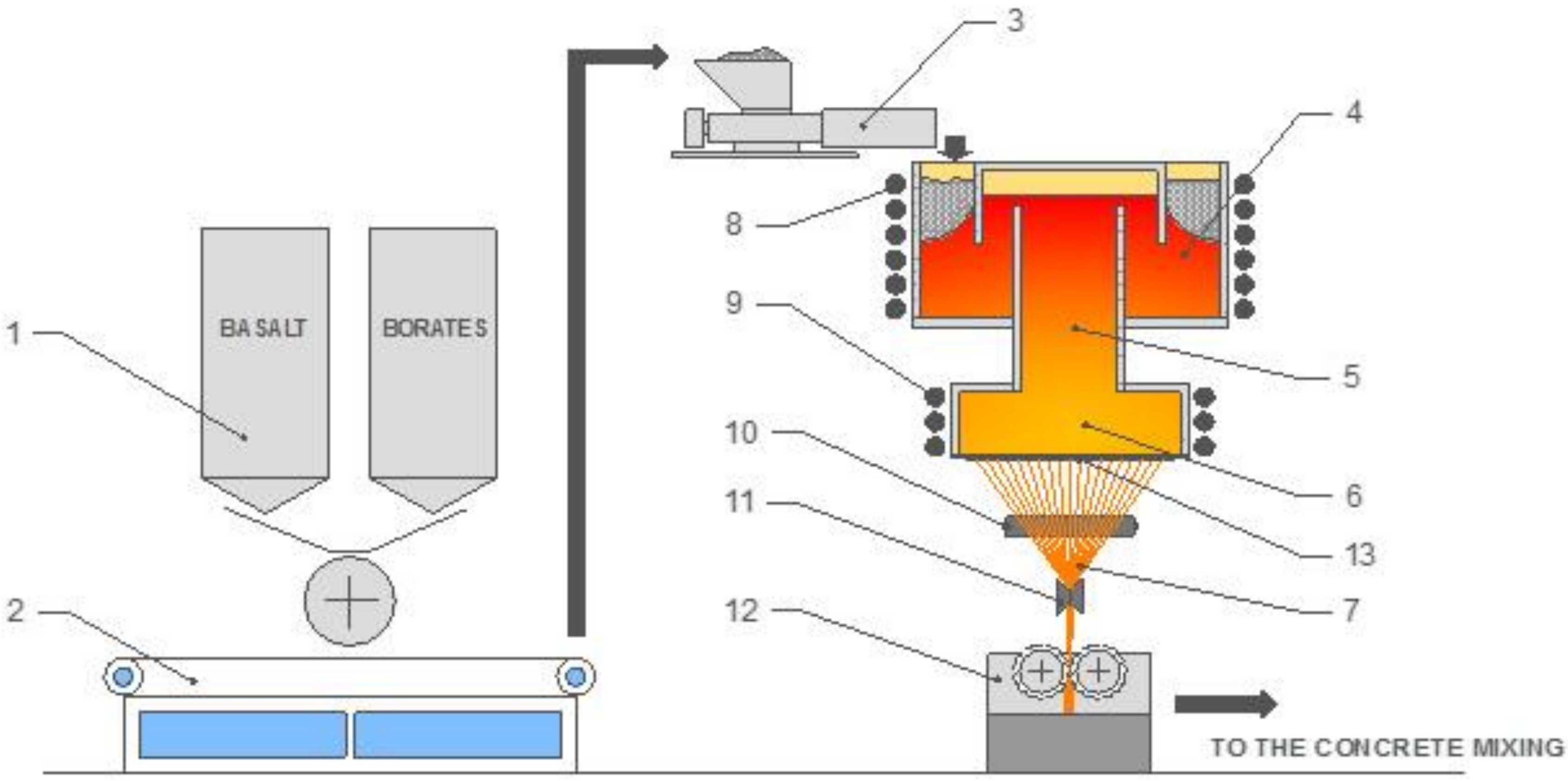
Advantages of basalt fiber for concrete reinforcement

The reinforced concrete with basalt fiber has the following advantages:

- High chemical and corrosion resistance;
- Longevity;
- High abrasion resistance;
- High shock resistance;
- High water resistance;
- High frost-resistance
- Workability
- Reducing of level of cracks
- Low cost

Specialty Enhanced Basalt Fiber Production

Main idea: The basalt fibers infused with natural and enriched boron in different proportions



The radiation shielding modelling of basalt-concrete materials

Calculation of gamma-ray radiation shielding: Method

For the investigation of gamma radiation, we need the following:

- The mean electron density $\langle N_e \rangle$ (1)
- The effective atomic number , $Z_{PI,eff}$ (2)
- The effective electron density $N_{e,eff}$ (3)
- The effective atomic number $Z_{M,eff}$ (4), by Murty (1965) (for comparison)
- (μ/ρ), the mass attenuation coefficient

$$\langle N_e \rangle = N_A \frac{\sum_i f_i Z_i}{\sum_j f_j A_j} = N_A \frac{\langle Z \rangle}{\langle A \rangle} \quad (1)$$

$$Z_{PI_{eff}} = \frac{\sum_i f_i A_i \left(\frac{\mu}{\rho}\right)_i}{\sum_j f_j \frac{A_j}{Z_j} \left(\frac{\mu}{\rho}\right)_j} \quad (2)$$

$$N_{e,eff} = N_A \frac{n Z_{eff}}{\sum_i n_i A_i} = N_A \frac{Z_{eff}}{\langle A \rangle} \left({electrons}/{g} \right) \quad (3)$$

$$Z_{M,eff} = \left[\sum_i W_i Z^{3.1}{}_i \right]^{1/3.1} \quad (4)$$

Calculation software

We have one calculation „software“, which is in essence a database

This software is called XCOM, developed by Hubbell and Seltzer (1995) and available from NIST (National Institute of Standards and Technology)

This software is also adapted to the Windows Platform under the name WinXCom by Gerward et al. 2001

With this software we are able to compute the total cross sections, attenuation coefficients as well as partial cross sections for various interaction processes, such as incoherent and coherent scattering, photoelectric absorption and pair production, for elements, compounds and mixtures

The working principle is the input the weight fractions of the constituent elements

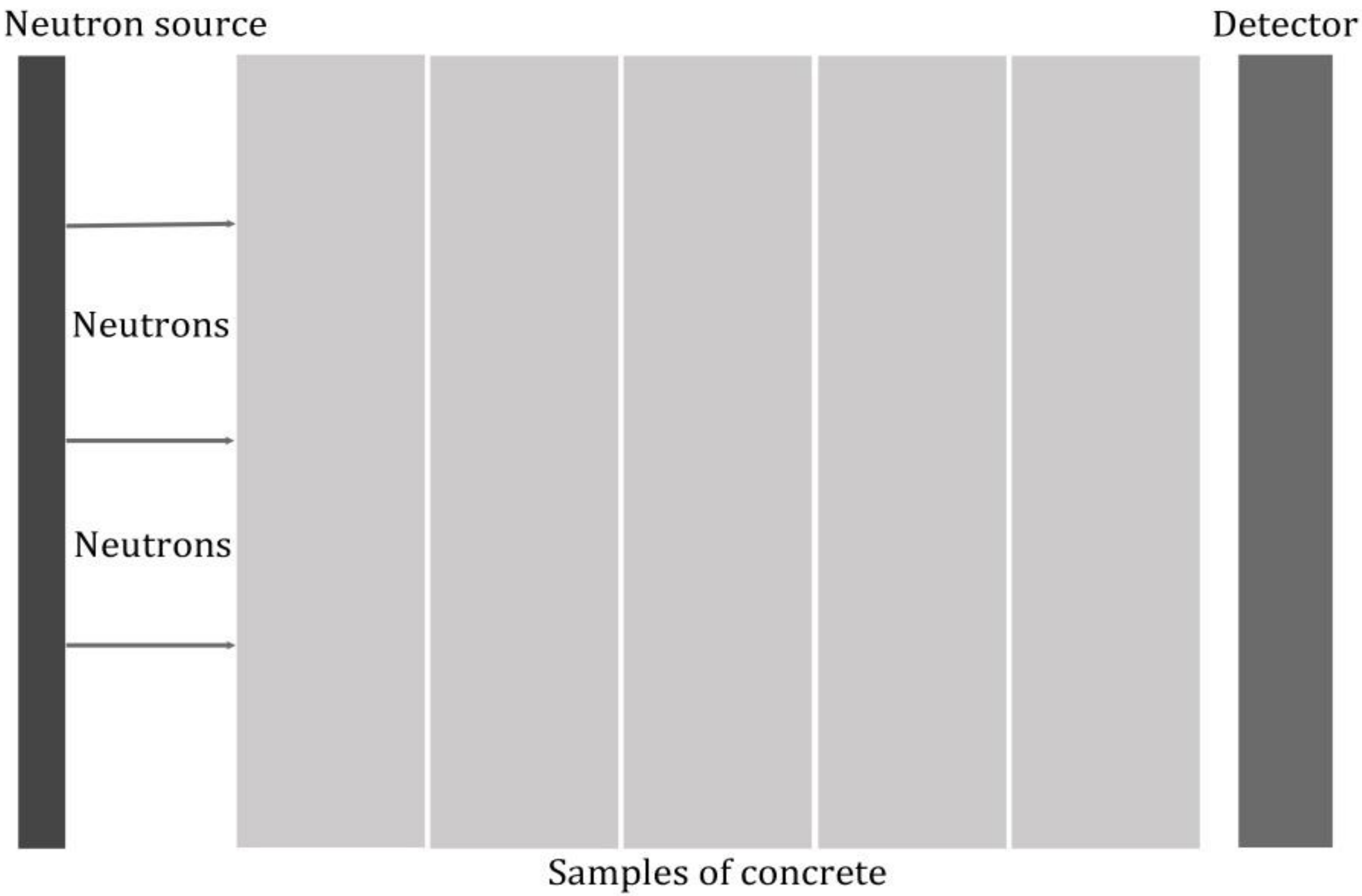
Results

	<Z>	<A>	Z_{ef} min	Z_{ef} max	N_{ef} min	N_{ef} max
1	7,09	13,93	5,68	13,33	2,46E+23	5,76E+23
2	7,09	13,93	5,68	13,33	2,46E+23	5,76E+23
3	7,10	13,93	5,68	13,33	2,46E+23	5,76E+23
4	7,10	13,93	5,68	13,34	2,46E+23	5,76E+23
5	7,10	13,94	5,69	13,34	2,46E+23	5,76E+23
6	7,10	13,94	5,69	13,34	2,46E+23	5,76E+23
10	7,11	13,96	5,70	13,36	2,46E+23	5,76E+23
15	7,11	13,96	5,70	13,36	2,46E+23	5,76E+23
20	7,11	13,97	5,70	13,37	2,46E+23	5,76E+23

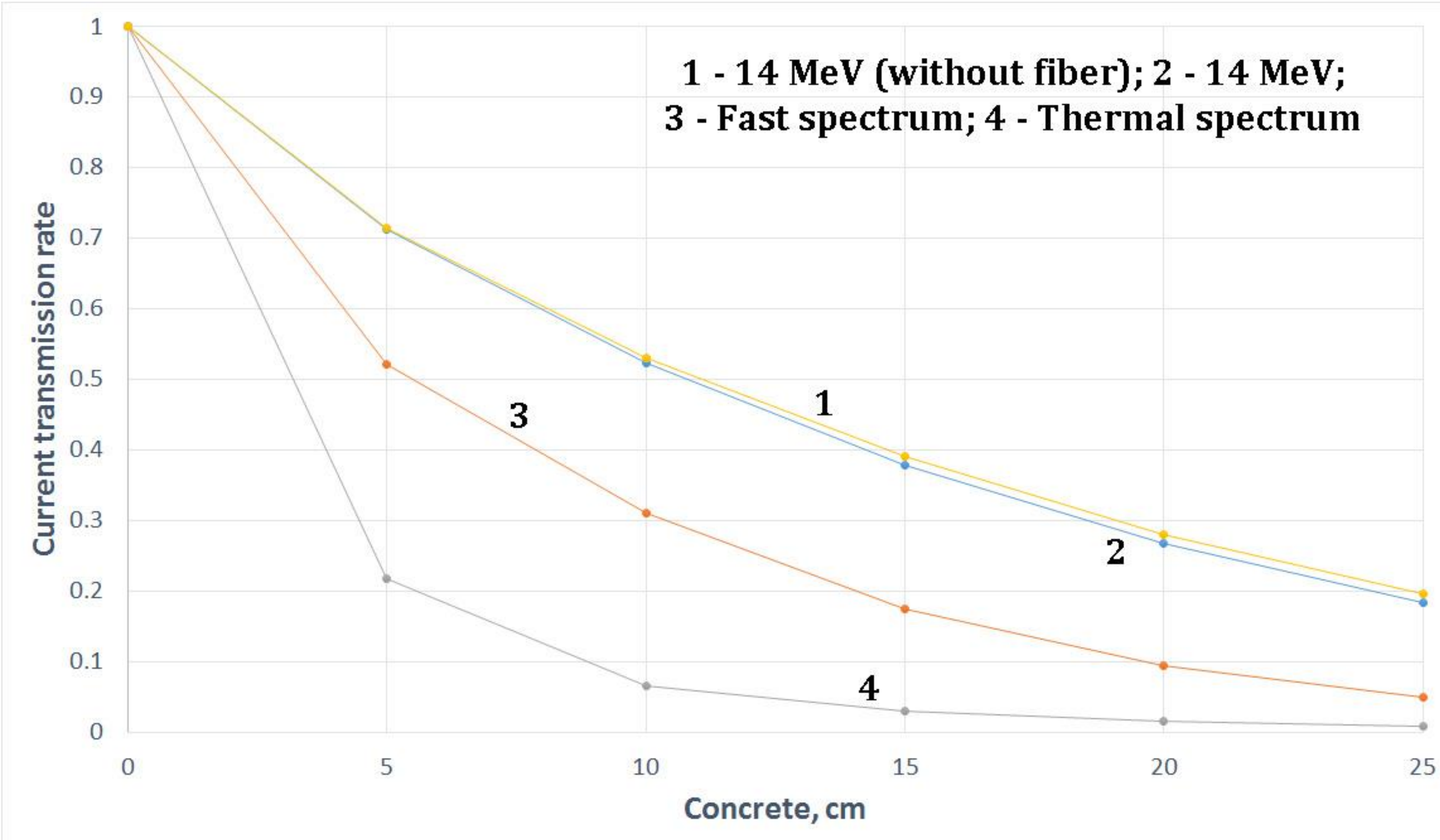
The variation is very small but it is observed that all parameters increase with the addition of basalt fiber into the mixture

Calculation of neutron radiation shielding

Serpent code is a new Monte Carlo code and is able to simulate the passage of neutrons in matter

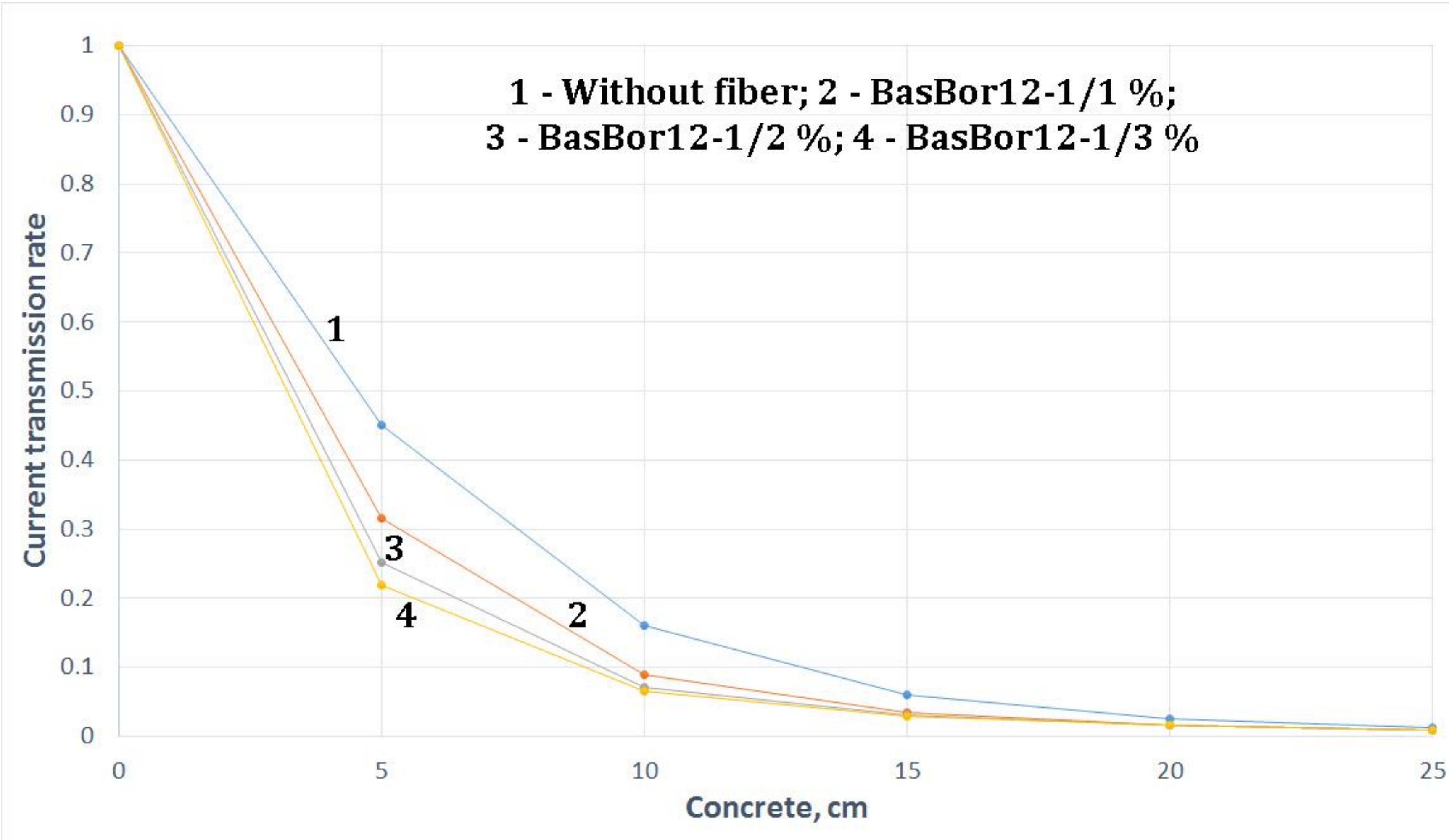


Results



The current transmission rate for neutron sources with different spectra for case BasBor12-1/3 %

Results



The current transmission rate for thermal neutron spectrum

Conclusions for radiation shielding investigations

It is found that even though the addition of basalt-boron fiber in concrete has negligible effects for very fast neutrons with energy 14 MeV, considerable shielding improvements are observed for fast fission spectrum neutrons, which means that the use of basalt-boron fiber as reinforcing material in concrete could in fact be a viable shielding material for nuclear reactor facilities both for reactors with fast fission spectrum and for conventional reactors with light water moderator.

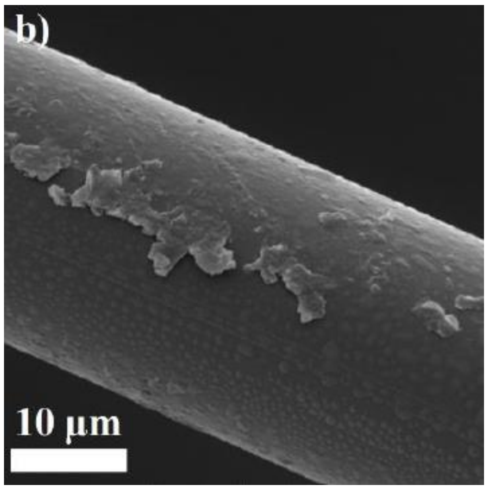
Investigations for degradation level of basalt fiber in concrete environment

Two types of basalt fiber were considered: type A – ordinary basalt fiber with standard chemical composition; type B – “alkaline” basalt fiber based on alkaline mines of basalt rock

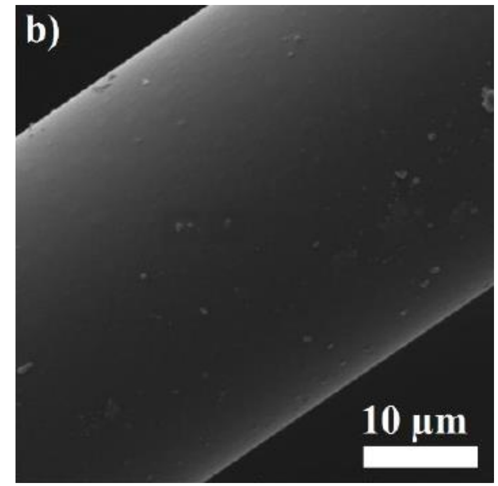
type A

type B

The basalt fiber samples for types A and B were investigated before and after concrete environment (28 days) for SEM inspection, AFM surface roughness measurements, Young’s modulus test, tensile strength test and bending modulus test.

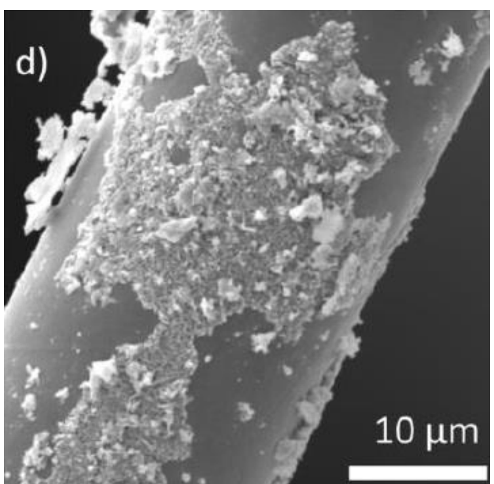


type A

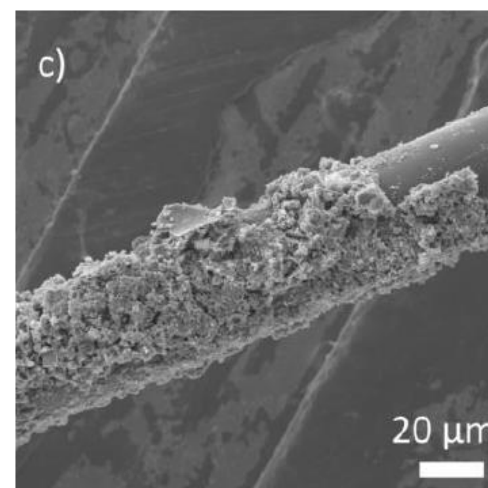


type B

Before concrete



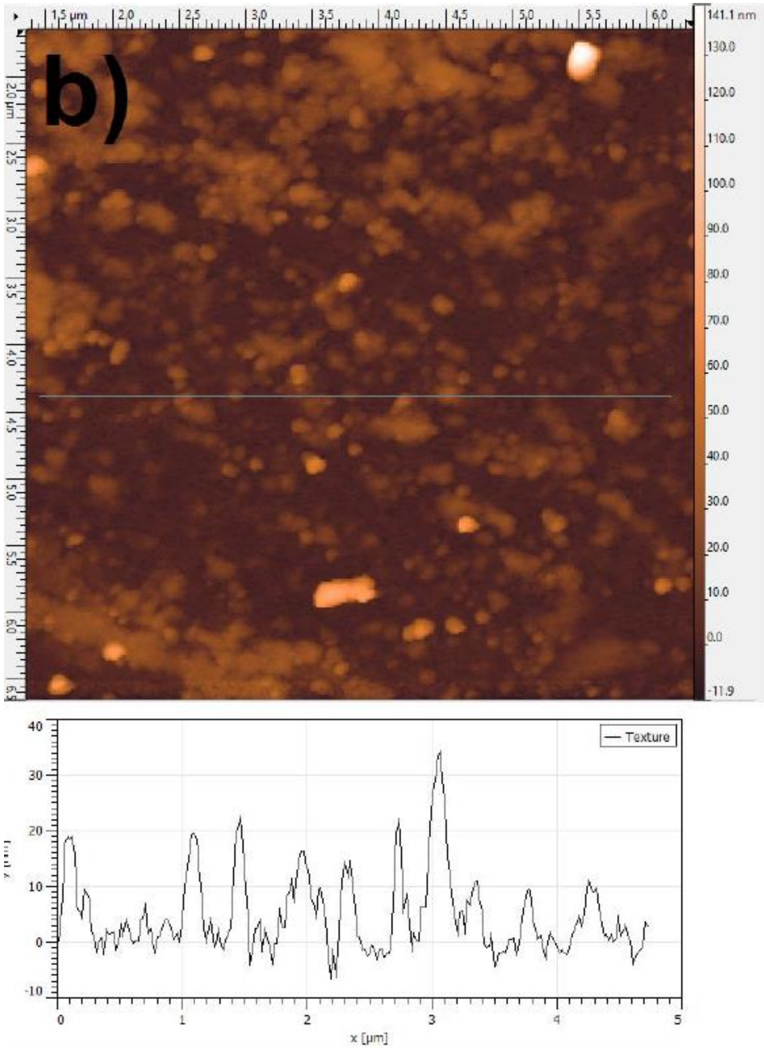
type A



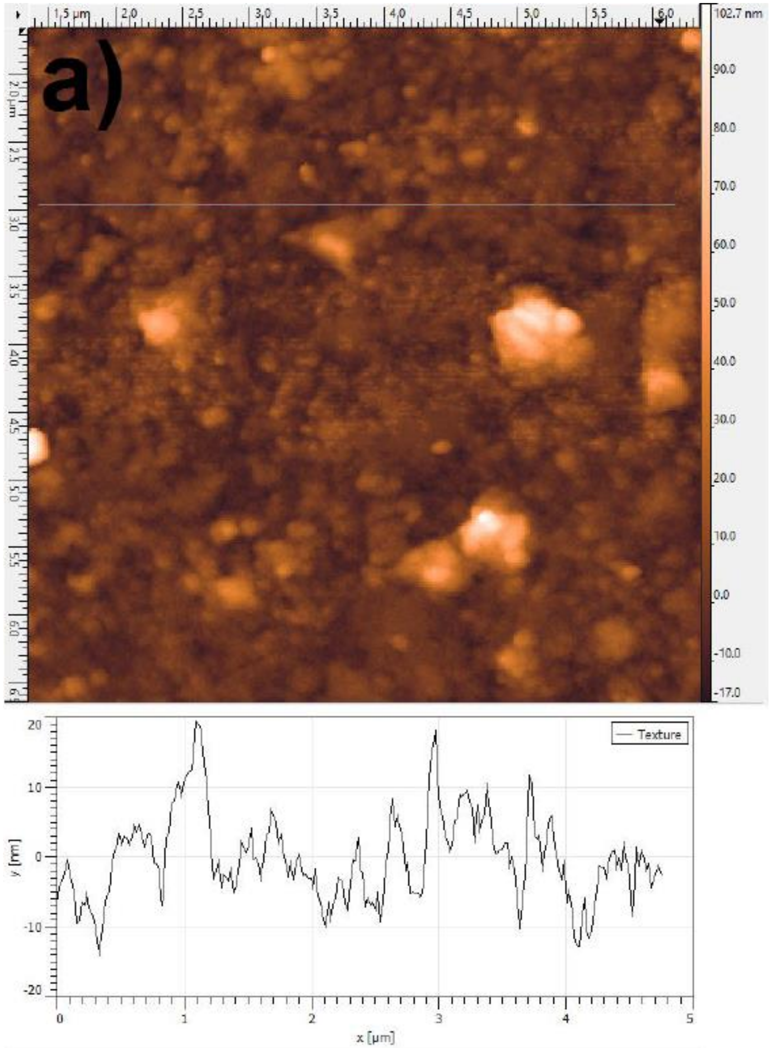
type B

After concrete

type A



type B



AFM images and line profile of two different sample micro-fiber surface after concrete with scanning area of 5x5 µm

Main results

Type FB	Diameter, µm	Surface roughness, nm	Young's modulus, GPa	Tensile strength, MPa	Bending modulus, GPa
"A"	-5 %	+56 %	-32 %	-29 %	-22 %
"B"	-0.5 %	+76 %	+20 %	-22 %	-2 %

Relative changes for structural and mechanical properties of different basalt fiber samples after concrete environment (alkaline medium)

The shrinkage tests for composite concrete reinforced by basalt fiber with different dosages

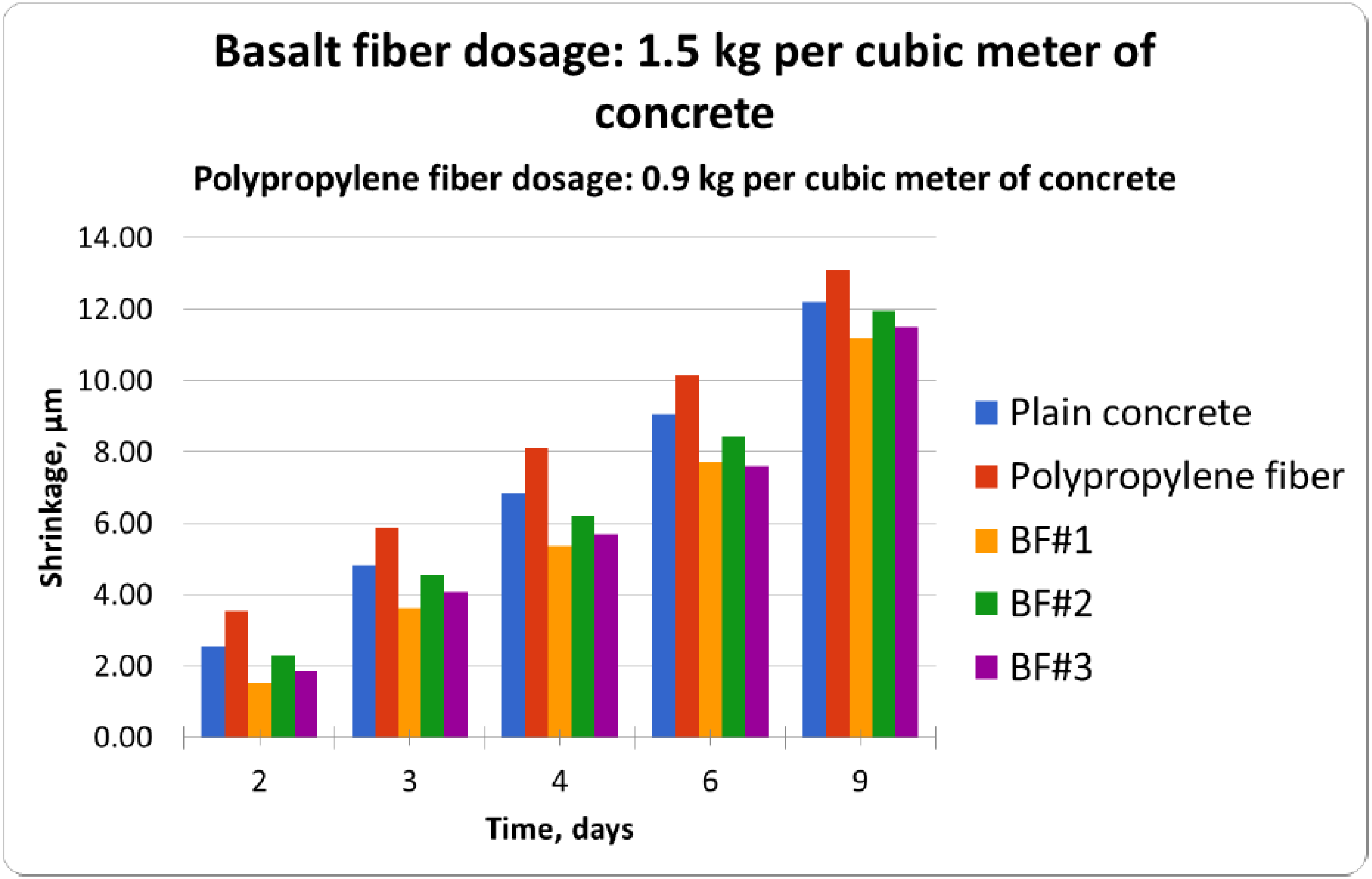
Description of experiment

Three types of basalt fiber were considered for this test. Dosages of basalt fiber: 0.5; 1.0; 1.5; 2.0; 3.0 kg/m^3



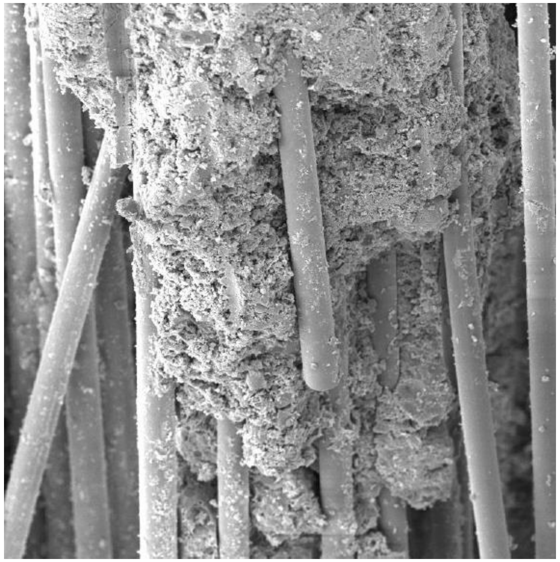
The standard GOST24544-81 “Concretes. Methods of shrinkage and creep flow determination” was used as base standard for current investigations. Also, BS EN1367-4:2008 “Tests for thermal and weathering properties of aggregates, Part 4: Determination of drying shrinkage”, ISO 1920-6 “Testing of concrete. Part 6: Sampling, preparing and testing of concrete cores”, ISO 1920-8:2009 “Testing of concrete - Part 8: Determination of drying shrinkage of concrete for samples prepared in the field or in the laboratory” were used for present work as well.

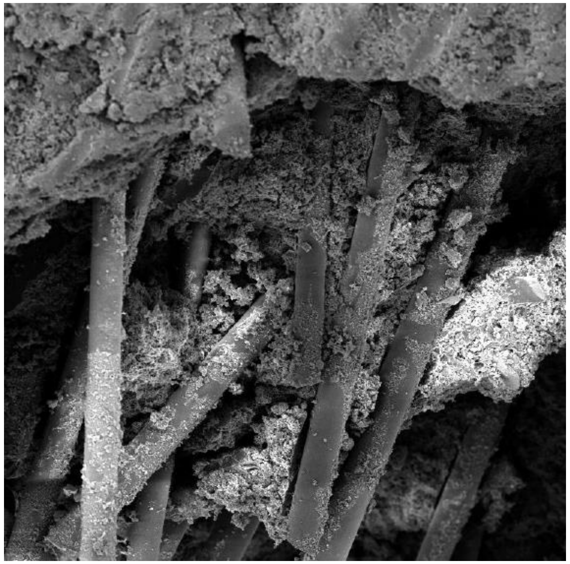
Results for shrinkage tests



Conclusions:

- With this study, authors intend to draw attention to the prospect and use of cement–basalt and cement-boron&basalt mixtures as structural material in nuclear energy applications and for storages of nuclear waste
- Concrete composite with basalt-boron fiber as reinforcement could significantly improve neutron radiation shielding characteristics for neutron sources with thermal neutron spectrum
- The degradation study of the basalt fiber has shown that there is a possibility for the improvement of degradation level of concrete due to selection of raw basalt material for basalt fiber production





The journal and conference papers

- ***V.I. Gulik**, A.B. Biland*. The Use of Basalt, Basalt Fibers and Modified Graphite for Nuclear Waste Repository, Proceedings of International Waste Management Conference (WM2012), Phoenix, Arizona, US: 26 February - 1 March, 2012
- *H. Nulk, C. Ipbüker, **V. Gulik**, A. Biland, A. H. Tkaczyk*. The investigation of gamma and neutron shielding properties of concrete including basalt fiber for nuclear energy applications. Proceedings of 2nd International Symposium on Cement-based Materials for Nuclear Wastes (NUWCEM2014), Avignon, France: 3-6 June, 2014
- *C. Ipbüker, H. Nulk, **V. Gulik**, A. Biland, A.H. Tkaczyk*. Radiation shielding properties of a novel cement-basalt mixture for nuclear energy applications. Nuclear Engineering and Design, 284, 27 – 37, 2015
- *C. Ipbüker, E. Zorla, **V. Gulik**, S. Kovaljov, M. Kiisa, A. Biland, A.H. Tkaczyk*. Optimization of basalt fiber in concrete composite for industrial application in Estonia. Fresenius Environmental Bulletin, 25 (1), 355 – 364, 2016
- *E. Zorla, C. Ipbüker, A. Biland, M. Kiisk, S. Kovaljov, A.H. Tkaczyk, **V. Gulik***. Radiation shielding properties of high performance concrete reinforced with basalt fibers infused with natural and enriched boron. Nuclear Engineering and Design, 313, 306 – 318, 2017

Thank you for your attention

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