Microwave radiation absorption in heat-resistant basalt-based composites

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Motivation

Basalt fibers (BF) are capable to **withstand very high temperature** and show **low thermal conductivity, high tensile strength and modulus**. Moreover, it is known that some **BF-based composites (**particularly, BF/Ni and BF/Fe2O3) possess promising microwave absorbing properties and therefore may be good candidates for the use as **heat-resistant electromagnetic absorbers** for civil and military applications. On the other hand, it was reported that composites consisting of **carbon-based fillers** also exhibit good **microwave absorbing (MA)** properties.

Thus, in this work, we have investigated MA properties in the frequency range of 1.5-2.1 GHz for **BF/nickel** and **BF/graphite** composites having various filler concentrations. It can allow one to detect peculiarities of the interaction of microwaves with the composites, provided by the appearance **of the current percolation**, as well as to determine **optimal concentrations of the graphite and nickel fillers** in basalt-based composites for MA.

Experimental

Basalt fibers were obtained from basalts of Berestovetsk deposit (Ukraine) having a composition shown in Table 1. Melting and production of fibers were conducted in the induction oven of the technological unit “Basalt-30”. The melt is further fed to the blow head where basalt fibers form by high-speed turbulent air streams. The powder mixtures of pure BFs, pure graphite, as well as BF/nickel, and BF/graphite composites having the filler concentrations of 10, 20, 30, 40, and 50 wt% were ground in a planetary mill for 15 min and hot-pressed in a graphite die.

The study of the BF/graphite and BF/nickel composites in the microwave range was conducted with help of a R2-52/3 analyzer of circuit parameters in the frequency range of 1.5-2.1 GHz using the convenient method of measuring microwave losses. The dynamic range of the insertion loss measurement using the R2-52/3 was 40 dB. The insertion loss measurement is based on the reflectometry principle: separate selection and comparison of signals that are proportional to the power of electromagnetic waves incoming from a generator and passing through the device under test.

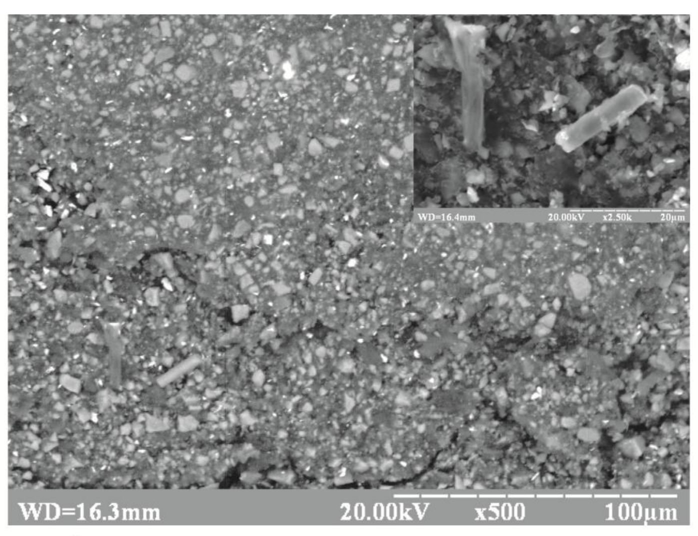
Table 1. Chemical compositions of the used basalt ore deposit and obtained basalt fibers, wt%

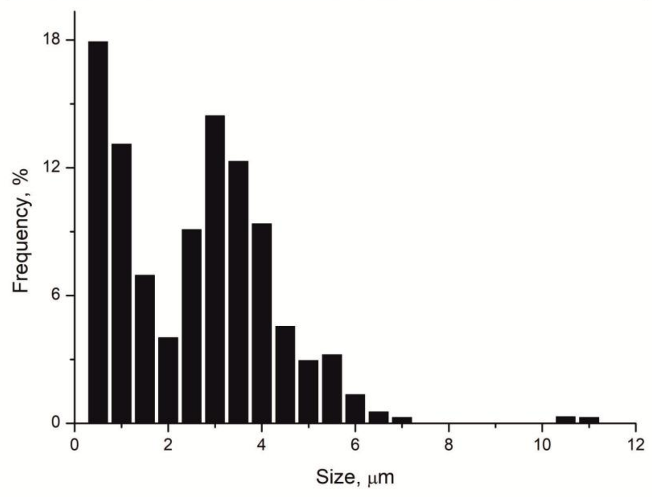
	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	MnO	SO_3
Basalt deposit	48.9	1.6	16.1	4.6	9.1	10.2	5.1	2.3	1.3	0.3	0.3
Basalt fibers	43.4	3.2	13.8	17.2		14.0	5.3	0.1	1.0	0.4	-

Structure of the composites

BF/graphite

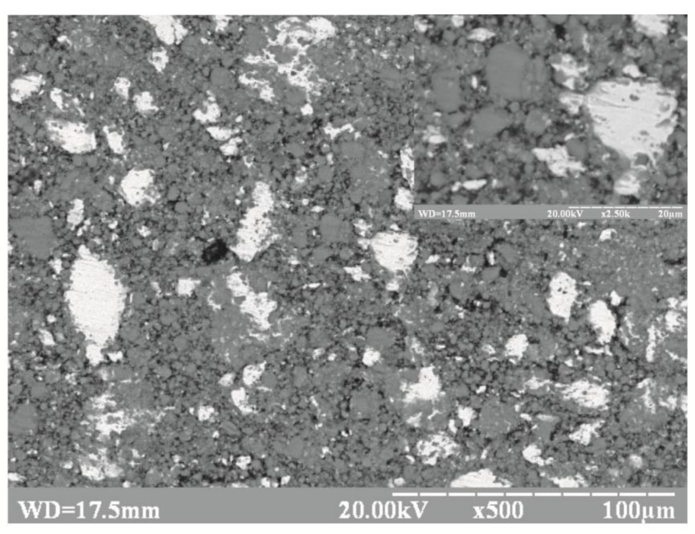
BF/graphite composite contains broken basalt fibers of 0.5-6 *μm* in length and submicrometer-sized graphite particles

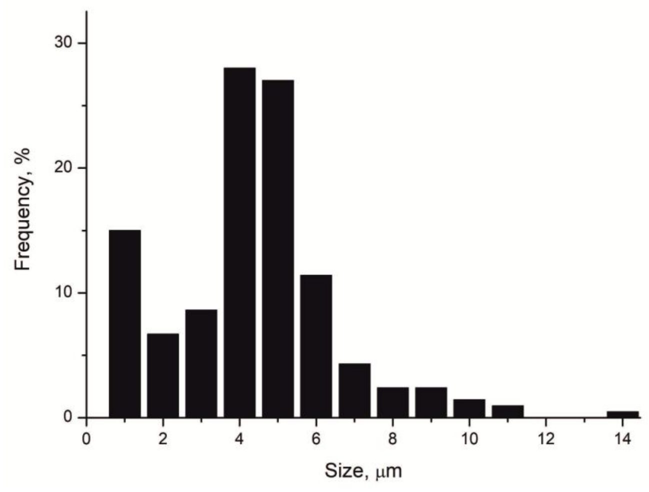




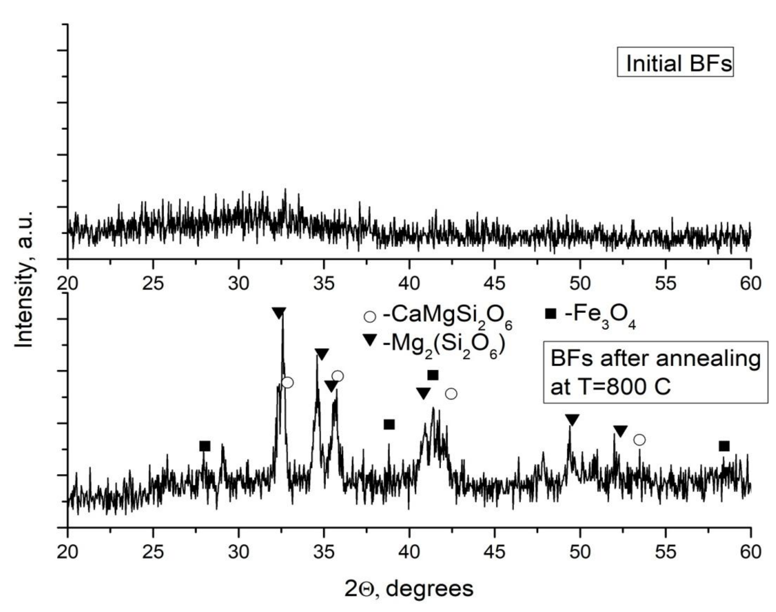
BF/Ni

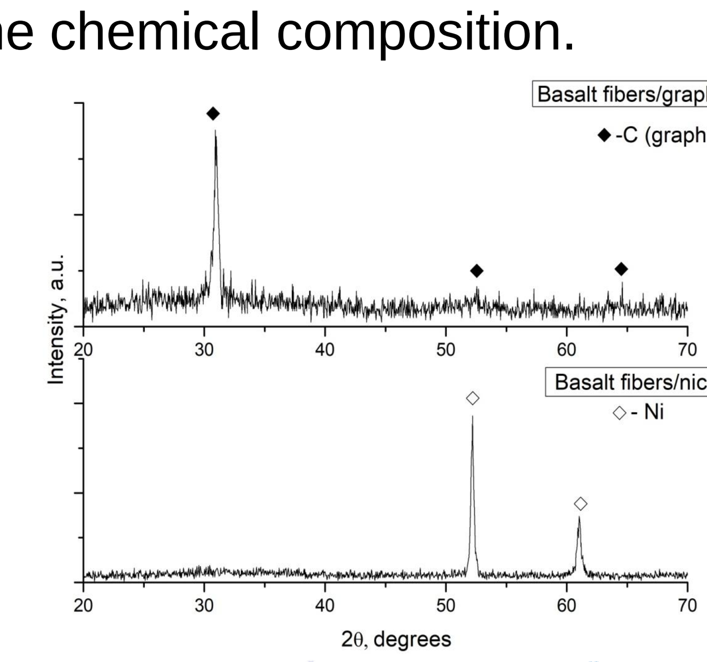
Nickel particles of 5..10 *μm* in size are distributed uniformly in the composite volume. Particles of the broken basalt fibers have a size in the range of 4-6 μm.





In the initial state the basalt fibers have an amorphous structure that crystallizes at temperatures above 800°C. XRD pattern of the basalt fibers annealed at 800°C proves the formation of crystalline SiO_2, Al_2O_3, and Fe_2O_3 phases, which is typical for basalts of the chemical composition.

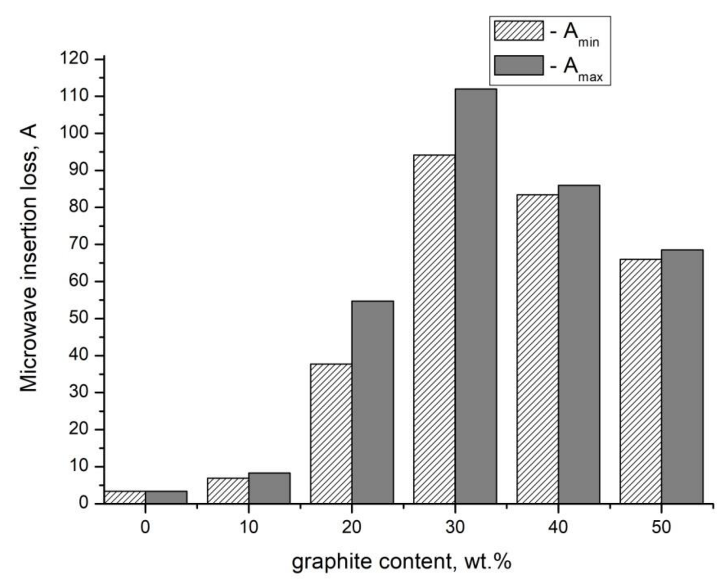




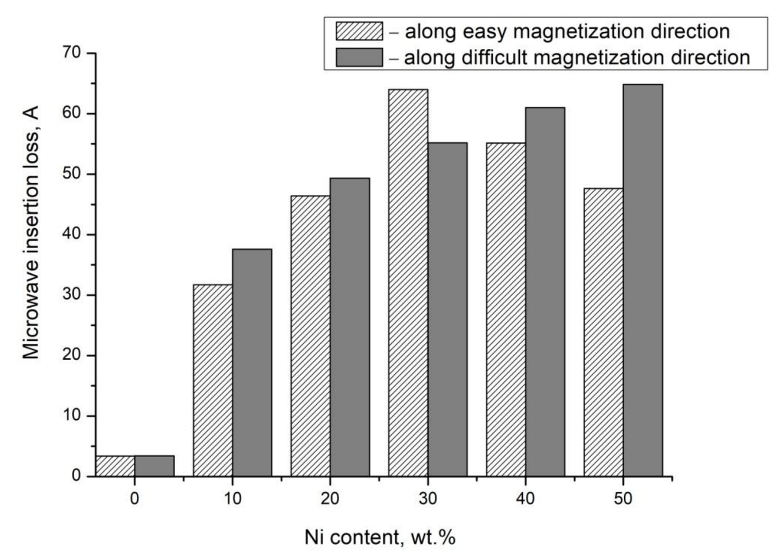
Structures of both BF/graphite and BF/nickel composites contain crystalline graphite and nickel phases, respectively, besides amorphous basalt fibers.

Microwave insertion losses in BF/graphite and BF/Ni composites

BF/graphite



BF/Ni



Experimental data of the insertion loss value *A* of microwave signal for two mutually perpendicular directions of the composite BF/graphite (a) and BF/nickel (b) structures containing various fractions of graphite and nickel microparticles, respectively

Conclusions

- The value of the MA in the BF/graphite and BF/nickel composites significantly depends on the volume fraction of the filler (nonmagnetic graphite or magnetic nickel) and its properties. The optimal content of the fillers providing maximum MA for both graphite and nickel was found to be about 30 wt%;

- It was found that there is anisotropy of MA for two mutually perpendicular directions for both BF/graphite and BF/nickel composites. This anisotropy is caused by some orientation of BF particles for BF/graphite composite and the presence of directions of easy and difficult magnetization for BF/nickel composite;

- The dependence of MA in BF/nickel composite on Ni content significantly differs for directions of easy and difficult magnetization. In the case of the easy magnetization direction, the maximum of MA was found at Ni content of about 30%, while further increase in Ni content leads to the absorption decrease (similar behavior was observed for BF/graphite composite). In the case of difficult magnetization direction, the dependence of microwave losses on Ni content has no maximum at the studied filler concentration range. Particularly MA rises with Ni content up to some threshold value at 50 wt% of Ni;

- Maximum value of MA in BF/graphite was found to exceed that for BF/Ni composite by 1.5-2 times.