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Quality evaluation of the Kuluevskaya basalt outcrop for the production of mineral fiber, Southern Urals, Russia

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Abstract

More recently, a significant growth is observed in the manufacture of composite materials. Intensively developed polymer composite materials (PCM) are used in different sectors of industry and technology. They are successfully replacing traditional construction materials and also permit the conditions that exclude use of metals. Basalt fiber is one of these materials, it have caught come into the spotlight due to their superior physical and chemical properties in which they only rank below expensive carbon and silicon carbide fibers. The suitability of raw material for basalt fiber production is mainly determined by the mineral composition and crystallization properties of basalt melts.
In this article, we present the results of an integrated petrographic and mineralogical investigation of melanocratic basalts of the Kuluevskaya volcanic complex from the Southern Urals, in order to assess their suitability for the production of high quality basalt fiber. The low acidity and viscosity parameters indicate the possibility of producing brittle fibers with a poor chemical resistance. Moreover the redox state and content of iron in the basalt glasses determine high crystallization ability of basalt fibers, it limits their application temperature and leads to low productivity of the BCF production process, but keeping acceptable insulation properties, hence their significance in the construction industry is high.
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1. Introduction

Basalt a mafic extrusive rock, is the most widespread of all igneous rocks, and comprises more than 90% of all volcanic rocks. It is usually fine-grained due to its rapid crystallization as lava on the Earth's surface. It has a crystalline structure that varies based on the specific conditions during the lava flow at each geographical location. Basalt combines three silicate minerals plagioclase, pyroxene and olivine. Plagioclase describes a number of triclinic feldspars that consist of sodium and calcium silicates. Pyroxenes are a group of crystalline silicates that contain any two of three metallic oxides, magnesium, iron or calcium. Olivine is a silicate that combines magnesium and iron $(Mg, Fe)_2SiO_4$. For many years, basalt has been used in casting processes to make tiles and slabs for architectural applications. Additionally, cast basalt liners for steel tubing exhibit very high abrasion resistance in industrial applications. In crushed form, basalt also finds use as aggregate in concrete. In the last decade, basalt has emerged as a contender in the fiber reinforcement of composites. These fibers perform more highly than other fiber types in certain areas such as: thermal stability, heat and sound insulation, vibration resistance and durability [1-6]. In general, basalt products have a non-toxic reaction with air or water, are non-combustible and are explosion-proof. Basalts are also more stable in strong alkalis than glasses, while their stability in strong acids is slightly lower [7]. Thus, basalt fibers and materials made from them have the best relationship between quality and cost in comparison with other types of fiber such as glass and carbon fibers. One of the most important advantages of CBF technology is the almost unlimited amount and cheapness of raw material both in Russia and all over the world as well as the possibility of using single raw materials such as the rocks of certain chemical and mineralogical composition [2,8-11].

In Russia basalt technologies are widely used in industry and the Perm Region is a leader in this direction. Unfortunately, companies are forced to import raw materials from other places because the possibility of using local raw materials has not been sufficiently investigated. Moreover, a regional metamorphism of basalts occurs in this area, changing geological texture and minerals content. This investigation could give an important contribution on natural resource management for new materials.

Nomenclature

BCF	Basalt Continuous Fibers
PCM	Polymer Composite Materials
XRD	X-Ray Diffraction analysis
XRF	X-ray Fluorescence

2. Materials and methods

During summer field campaigns in July 2011 and June-July 2012 were collected twenty-one representative rock samples from the melanocratic basalt outcrops of the Kuluevskaya volcanic complex. The selection was based on availability of outcrops and sample freshness. Thirty-two thin-sections were prepared using the impregnation method for petrography and scanning electron microscopy. All thin-sections were analyzed with standard petrographic techniques and examined under a polarizing microscope to identify mineral phases and classify groundmass textures. The mineralogical composition was investigated by X-ray diffractometry (XRD), using a Philips PW1730/3710 automated diffractometer with a graphite monochromator and CuKα radiation, operating at 40 kV and 30 mA. The measuring range was from 2° to 40 ° 2θ with a step size of 0.041 and a 4 s counting time. Major oxide compositions were determined through X-ray fluorescence (XRF) spectroscopy on fused glass beads by using an EDX-900HS spectrometer, in the FHMI laboratory of the Geology and Geochemistry Institute, at the Ural Branch of the Russian Academy of Sciences. About 30 g of basalt was prepared by first removing any visibly altered material. These samples were then crushed into 2-3 mm particles, and grains showing traces of alteration were also removed under a binocular microscope. Samples were then treated with ultrasonic waves in a 0.2 N HCl solution for 15 min. and in distilled water for 45 min. They were then washed with distilled water and left to dry at

60 °C for 12 h before being pulverized with an agate mortar. The glass beads were prepared by combining samples with $Li_2B_4O_7$. The sample to $Li_2B_4O_7$ ratio was 1:5. The accuracy of the XRF analysis is estimated to be better than 1% for all major oxides.

2.1 Geological and tectonic settings

The Uralian orogenic belt is located between the East European platform and the Kazakhstanides in the East. It is the result of the Collisional magnamatism that started in the Silurian and persisted untill the Permian. The examined area is located in the Island-Arc Continental sector represented by the transition from oceanic to continental environments in the middle and south Urals. The collision-related magmatism started during the Silurian and finished during the Permian, and shows a progressive displacement of the peak age from west to east. The magmatic activity, therefore, migrated eastward so that each new active magmatic sequence in both island arcs, from the low-K tholeitic in the west to the high-K calc-alkaline rock in the east, in the the subducted oceanic slab dipped toward the east during Silurian and Devonian. The Kuluevskaya volcanic complex includes basalts from the tholeiitic series [12], which include gradual transitions to andesite and melanocratic basalts. We focused the investigation on melanocratic basalt outcrops from the Kuluevskaya volcanic complex (D1 - 2kv), located in the Southern Urals within the Chelyabinsk Graben (Fig.1), in order to assess its suitability for the production of basalt fiber. Uralian magmatism, despite its considerable scientific and economic interest, is still poorly understood.

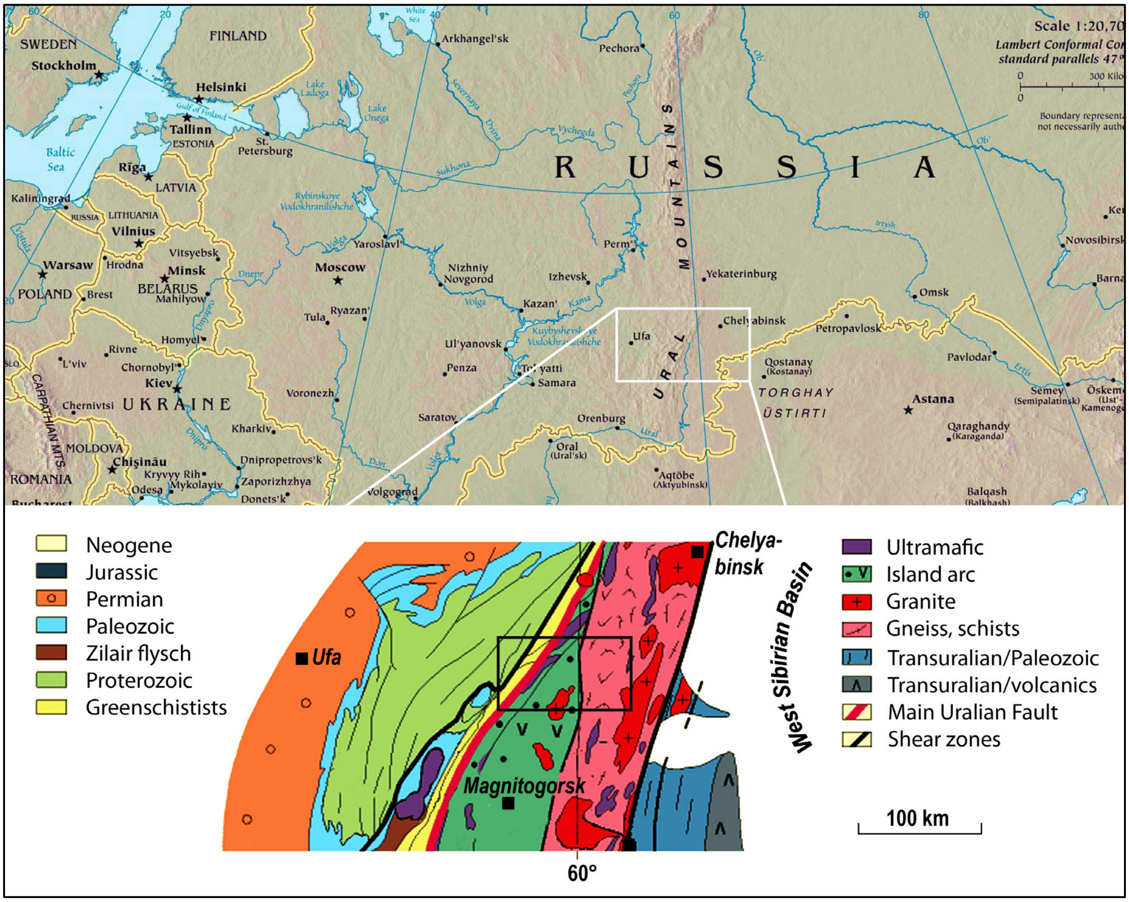

Fig 1. Simplified distribution map of geological domains in the Urals and the location of the study area.

3. Results and discussion

3.1 Chemical and petrographic features

The thin sections taken for the microscopic investigation of the melanocratic basalts showed that they had undergone intensive metamorphism. The small zones of tectonic crushing and cataclasis had a shale and lenticular texture filled by chlorite, carbonate, and some quartz. Porphyry and glomeroporphyritic structures are preserved. The size of the porphyry selections of clinopyroxene and plagioclase is 0.5-1.0 mm, and rarely up to 2.5 mm. The bulk of plagioclase and pyroxene phenocrysts is up to 10-15%, so the basalts can be considered small and seldom porfiritic. Porphyritic clinopyroxene and plagioclase are replaced by chlorite along fractures and in marginal areas. They are surrounded by an inner rim of small-scale black and dark gray chlorite, and an outer rim of white and bluish- gray actinolite (Fig 2).

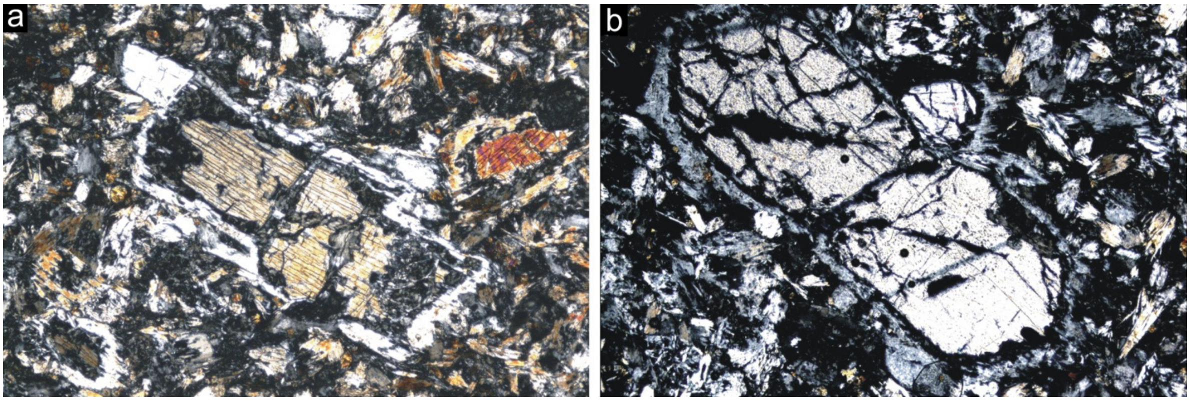

Fig 2. (a) first picture - porphyry allocation clinopyroxene with high relief and bright interference colours, partially substituted by chlorite (dark gray, gray scales with a brown tint) and white actinolite; (b) second picture - glomeroporfirovoe selection plagioclase with dark chlorite borders and light gray actinolite border

The main bulk of the basalts is crystallized and is mainly composed of metamorphic minerals: actinolite, chlorite, epidote, albite, quartz, and locally carbonates. Moreover, the relict grains of pyroxene size 0.05-0.17 mm are in the main substrate surrounded by a narrow rim of chlorite. The structure of the main bulk is aphanic granonematolepidoblastic. The chemical compositions of the basalts from the Kuluevskaya volcanic deposits were determined by the classical weight method, as well as by using x-ray spectral microprobe analysis. For reference purposes, we also analyzed the chemical compositions of the andesitic basalt outcrops of the Kuluevskaya volcanic complex. Table 1 reports the average of the chemical compositions of the main basalt deposits of Kuluevskaya. The melanocratic composition is reflected in the high content of FeO, MnO, MgO and a reduced amount of SiO_2, Al_2O_3, CaO, Na_2O, K_2O. Kuluevskaya basalts are very different in their chemical composition and acidity module compared to andesitic ones as well as island arc basalts [12]. Instead, the chemical compositions of Kuluevskay andesitic basalts and calcareous-alkaline series basalts showed great similarity. Table 1 also reports the acidity modulus M_a and the viscosity modulus M_v, which are calculated according to Eqs. 1 and 2:

$$M_a = \frac{m_{SiO_2}+m_{Al_2O_3}}{m_{CaO}+m_{MgO}} \tag{1}$$

$$M_v = \frac{x_{SiO_2}+x_{Al_2O_3}}{2x_{Fe_2O_3}+x_{FeO}+x_{CaO}+x_{MgO}+x_{Na_2O}} \tag{2}$$

where m is the mass content of oxides (%); x is the molar content of oxides in mineral rocks (%). The high content of CaO and MgO in the andesitic basalt increases its crystallizing capacity and the smaller content of Al_2O_3 and a similar content of SiO_2 decrease the values of the modules. Therefore, the viscosity of that basalt melt should be lower than that of the calcareous-alkaline basalt series, which points to the possibility of producing fine staple basalt fibers with a small diameter. The acidity modulus (M_a) of the basalt raw material is the main parameter to define the quality of the final fiber products. If the M_a is < 1.8, the fiber is considered to be a mineral wool, the base materials of which are basic volcanic rock and cinder. These fibers are brittle, but have acceptable insulation properties. If the M_a > 1.8, the fiber is called rock wool and if its base material is basalt then it is called basalt wool (basalt fiber, BF).

The higher acidity module indicates that the basalt fibers are of good quality with excellent properties; they have a high strength, corrosion resistance, temperature resistance, along with an extended operating temperature range. The moisture regains and moisture content of basalt fibers is less than 1% and they have a high resistance to alkaline environments, withstanding a pH up to 13-14. However they are relevantly less stable in strong acids.

The acidity moduli calculated indicates that the andesitic basalt composition matches the requirements for quality basalt fibers with a M_a of 3.51. Whereas the lower value of 1.91 for the melanocratic basalt is too close to the limit, indicating the possibility of low basalt fiber quality.

Table 1. Average chemical composition of main basalt deposits.

	Mass content (%)													Modulus	
Deposit	SiO_2	AL_2O_3	CaO	MgO	Fe_2O_3	FeO	K_2O	Na_2O	TiO_2	MnO	Sox	H_2O	Total	acidity	viscosity
Melanocratic Basalt	44.78	8.81	9.88	18.22	3.65	7.52	0.08	1.51	0.54	0.31	0.04	4.82	100.16	1.91	1.20
Andesitic Basalt	49.92	15.96	10.52	8.22	2.85	6.54	0.64	2.21	0.68	0.13	0.03	2.24	99.94	3.51	1.98

Other important parameters to determine the fundamental possibility of forming a continuous fiber from a melt are the viscosity, surface tension, density, and crystallizability. Regarding the stability of the fiber-forming process, the melt stream must keep its shape in a certain range of temperatures. The operating temperature range is determined by the ratio of viscosity to surface tension (η/σ). This parameter is also called fiberizability in the technology of continuous silicate fibers [2,13]. The greater the η/σ ratio is, the more stable the process is. The chemical and mineralogical compositions of basalts, as a single natural raw material, determine their glass and fiber forming ability. The high crystallizability of single igneous rocks in melts is due to the high content of iron oxides and the presence of titanium, magnesium, and calcium oxides [8,9,14]. During their quenching, the rapid formation of crystallization centers and the high linear growth rate of crystals are the basic causes of defects at the stage of filament drawing [2,14]. High crystallization adversely affects the stability of the fiber-forming process, reducing the operating temperature range by increasing its lower limit [2,8,14]. Basalt melts with higher viscosity are less crystallizable and more suitable (than low-viscosity melts) for making continuous fibers. Therefore, the low viscosity value of the melanocratic basalt revealed that it isn't suitable for the production of continuous BF and roving.

4. Conclusion

The results obtained in this study show that the chemical and mineralogical composition of melancratic basalt outcrops of the Kuluevskaya volcanic complex are are unsuitable for producing fine staple and continuous basalt fibers. The low acidity and viscosity parameters indicate the possibility of producing brittle fibers with a poor chemical resistance. Moreover the high content of iron oxides and the presence of magnesium, and calcium oxides determine high crystallization ability of basalt fibers, it limits their application temperature and leads to low productivity of the BCF production process (many yarn breaks and narrow production temperature range).

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