Petrographic Analysis of Basalt from China’s Dalian Field for Making Melt and Fiber by Electric Arcing

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Abstract. This paper presents the petrological and chemical tests of basalt rock extracted from the Dalian Field, China, for further smelting in an electric-arc reactor to make melt and further produce fibrous materials. Melt was produced from basalt rock, particles sized 6 to 12 mm. Basalt and the fiber made from it were studied on a microscale by microscopy. Thus, Dalian basalt was found to be an ‘enriched’ ferroalkaline basaltoid with a characteristic high content of iron, alkali, and phosphorus. The microrelief of the basalt indicated considerable metamorphic alterations, due to which the secondary replacement structures developed during the primary phases were predominant. The presented electric-arc smelter had smooth temperature adjustment functionality and was able to maintain a constant temperature in the jet exiting the tap hole for less energy-intensive melt and fiber production.

1. Introduction

Heavy industries, construction, energy, and other manufacturing and production industries demand ever more basalt products: mineral fiber and castings. Basalt production technologies continue to advance. However, the ore mining facilities that provide high-quality basalt fail to cover the demand. This is mainly due to these raw materials not being recognized as minerals. Using construction rubble of variable mineral and chemical composition has negative impact on the production technology as well as on the final product quality. At the same time, chemical and mineral composition of basalt, in particular the presence of refractory minerals, the degree of metamorphism, etc. do affect the output of the melt as well as the produced fiber. Raw materials to be smelted should be non-refractory and easily transformable into a melt without residual primary crystalline phase [1, 3, 9].

Converting basalt into a melt is an important engineering problem; however, the primary issue persists, and that is to reduce the energy costs of making melts, as it is the energy costs that determine the cost of making mineral-based heat insulation materials.

Using electric arc plasma to melt the raw materials so as to produce heat insulation fiber is a promising new area. When heat is provided by an electric arc, its high temperature drastically reduces the melting time, as there is no delay due to induction [10, 14].

The goal hereof is to study the mineral and chemical composition of basalt from China’s Dalian Field in connection with the data on using electric arc smelting.
2. Research materials and methods
Melt production tests used technological samples of Dalian basalt, see Table 1 for particle-size distribution.

| Particle size, mm | +10 | -8+6 | -6+4 | -4+2 | -2+0 |
|------------------|-----|------|------|------|------|
| Output, %        | 60.0| 29.5 | 5.5  | 3.5  | 1.5  |

Screening the basalt showed 95% of its particles were sized 10 to 5.0 mm, with <5 mm particles accounting for ~5%.

Microscopy identified singular inclusions of silicate tuff, mainly in association with silicon-carbonate packets. Dark-colored minerals accounted for up to 90 wt%.

Analysis showed that thin-section basalt had undergone metamorphic transformations, which produced lens-shaped textures in the form of small tectonic crushing and cataclasis foci filled with chlorite, carbonate, and partly quartz [2-8].

Figure 1. Dalian basalt. Massive texture. x100 magnification;
(a) clinopyroxene replaced with chlorite in actinolite basis with epidote inclusions (nicols crossed);
(b, c) quartz, plagioclase, chlorite, and volcanic glass aggregates isolated, nicols crossed.

Thus, microscopy of the samples showed that the bulk of basalt had been decrystallized and mainly composed of metamorphic minerals: actinolite, chlorite, epidote, albite, quartz, and locally carbonates. Besides, the bulk of the mineral mass contained relic pyroxene grains encircled in narrow chlorite inclusions. The mineral mainly had an aphanite structure. Thus, primary clinoenstatite and augite-diopside were present in far less amounts than their metamorphic counterparts, namely actinolite (46.70%) and chlorite (34.30%), see Figure 1. Primary basic plagioclases were replaced with albite-oligoclase (10%), epidote (4.78%), and quartz (4.22%). Microphotography clearly identified the primary mineral components as well as small tectonic crushing foci filled with fine-grained agglomerations of chlorite and quartz, see Figure 1, as well as micrograins of accessor minerals: sphene, chrome spinels, and magnetite.

3. Experimental smelter
Conventional’ smelting units such as cupola furnaces, tank or tunnel furnaces fail to properly process basalt containing refractory minerals, as the temperatures such units can create is below 2,000ºC, which is too low; industrial processing of such materials requires electric arc furnaces (plasma furnaces) or induction (microwave) furnaces; however, the latter have very limited use due to their excessive energy consumption, strong electromagnetic radiation and related radiointerference, as well as risk of inductor explosion shall the ferrosilicate cooking process trigger a short circuit. Electroplasma units are preferable for smelting refractory substances, as plasma has such unique properties as very high...
temperature (up to 10,000 K), high specific power (per unit of reactor volume), and thus a very intense smelting process. Compared cupola or tank smelting, the electrothermal method requires less expensive and easier-to-use equipment.

To study the smelting of basalt, the research team used an electromagnetic reactor and tested multiple smelting configurations experimentally, see Figure 2.

**Figure 2.** Electromagnetic reactor in operation; longitudinal section and cross-section:
1 is the reaction chamber; 2 is the water-cooled lid; 3 is the water-cooled bottom; 4 are rod electrodes; 5 is the pickoff electrode; 6 is a pole tip; 7 is a series winding; 8 is the power source; 9 is an additional power source for heating the jet; 10 is the tap hole for releasing the melt; 11 is the lined chamber bottom; 12 is an inlet to feed the raw materials to the reaction chamber; 13 is lining

The reactor was designed to produce pure melt free of gas bubbles and reduced metals that would settle on the bottom; thus, it was able to produce a higher-quality output [10-13].

**4. Experiment results and discussion**
Beside petrographic analysis of the basalt composition, the research team also covered its elements and mineral fibers produced from the melt by rotating the material when smelting it in the electromagnetic reactor.

Basalt rubble was used to make the smelt and the fiber, see Figure 3; for composition, see Table 2.
As can be seen in the table, this basalt is an enriched ferroalkaline basaltoid with its characteristically high content of iron and alkali, specifically sodium and potassium (in terms of K$_2$O, Na$_2$O), as well as a high concentration of phosphorus (0.30 to 0.50%). Phosphorus content is the most important criterion when it comes to classifying such basalts by the element composition, as sodium and potassium content might be high due to secondary metamorphosis-related changes [4-7]. In this regard, it should also be noted that the high percentage of iron, phosphorus, and alkali made this basalt easy and quick to smelt.

The electric arc reactor did not show signs of swirling or sparking; the energy consumption was law. Electricity meters showed a consumption of 1.5 kW per kg, or 1.5 kWh/kg, which meant the smelting unit was cost-effective [16]. While pouring, the melt was pulled into fibers by unwinding and centrifugal spraying in a fiber-forming chamber.

Figure 4 shows the fibers and their predominant sizes. Size-wise, these were thin-spun fibers suitable for thermal insulation [17-20]. Figure 5 shows the spectral lines of elements (a) and their distribution (b); Table 3 shows wt% of each element present in the fiber.
Figure 5. Spectral lines of element distribution; distribution by mass.

Table 3. Chemical composition of the fiber made of the melt.

|    | O   | Na  | Mg  | Al  | Si  | K   | Ca  | Ti  | Fe  | Total |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
|    | 50.2| 2.8 | 2.65| 8.0 | 21.1| 1.0 | 5.30| 0.51| 6.29| 100.00|
| %  | 0   | 0   | 9   | 4   | 3   |     |     |     |     |       |

Table 3 makes it clear that the distribution and composition of basalt did change significantly compared to Table 2. The only exception is phosphorus, as it is highly reactive to high temperature, which might have caused it to evaporate or make a compound with the reduced iron that was removed when the melt was poured.

5. Conclusions

Micropetrography opens up great opportunities for studying basalt materials and fibers on a microscale. Thus, Dalian basalt was found to be an ‘enriched’ ferroalkaline basaltoid with a characteristic high content of iron, alkali, and phosphorus. The microrelief of this basalt indicated considerable metamorphic alterations, due to which the secondary replacement structures developed during the primary phases were predominant.

The presented electric-arc smelter is a plasma reactor; it had smooth temperature adjustment functionality and was able to maintain a constant temperature in the jet exiting the tap hole for less energy-intensive melt and fiber production. The melt thus produced is suitable for making castings and thin mineral fibers for composite materials as well as for fibrous thermal insulation for use in construction and architecture.

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