Forming Fibres from Basalt Rock

NEW APPLICATION FOR A WELL-ESTABLISHED PROCESS

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Basalt, a rock which results when molten lava from deep in the earth's crust rises up and cools sufficiently to solidify is found in many parts of the world. In some notable instances it covers areas of many thousands of square miles. This paper describes work carried out to produce commercially useful fibre from the basalt which occurs as an enormous outcrop in Idaho, Oregon and Washington in the United States of America.

Basalt is the name given to a wide variety of volcanic rock. The specific gravity of this material is nearly 3 and it can be extremely hard, ranging from 5 to 9 on the Mohs' scale. As a result of this hardness, it has a superior abrasion resistance and is often used in its natural form as a paving and building stone. This igneous rock may be classified into two main groups, the calc-alkali and the alkali basalts. The calc-alkali show a silica content ranging from 45 to 52 per cent. This variety predominates among the lavas of orogenic belts and covers many thousands of square miles in the states of Idaho, Oregon, and Washington. Figure 1 shows the typical columnar formation in which basalt rock often appears, this view is from the White Pass region in Western Washington, U.S.A.

While the commercial applications of cast basalt have been well known for a long time, it is less well known that basalt could be formed into a continuous or staple fibre having unique chemical, mechanical and economic properties (1).

Numerous recent articles describe Eastern European plants as producing basalt fibre superior in many applications to more traditional materials such as glass fibre, rock wool, or asbestos (2). Basalt fibre is being used as an insulation material, especially at high temperature (to 900°C), formed into paper and cardboard, and used as an inexpensive building board with unique properties (3, 4). Basalt is an attractive raw material for fibre forming because of its relatively homogeneous chemical structure, its large-scale availability throughout the world, its freedom from impurities and, of course, its ability to form fibres in the molten state. A recent extensive review from available literature concluded that production of basalt fibres in the U.S.A. was potentially a profitable industry (5), hence the reason for this investigation.

Fibre Forming Characteristics

In many ways basalt fibre technology is similar to glass fibre technology. The ability of a glass to form a fibre is strongly dependent on its viscosity, which in turn has a strong temperature dependence. For this reason very close temperature control of the molten material is necessary. Slayter in 1941 obtained a patent for "Mechanically Drawing Fibres", in which the concept of using a resistance-heated rhodium-platinum crucible or bushing was described (6). The molten stream of glass was drawn through a carefully shaped orifice in the bottom of the bushing, then attenuated into a fine, solid fibre by mechanically drawing or blowing with air or steam. The rhodium-platinum alloy has fairly good electrical conductivity (about 0.10 that of copper) requiring the use of a very high-amperage, low-voltage power supply. Similar

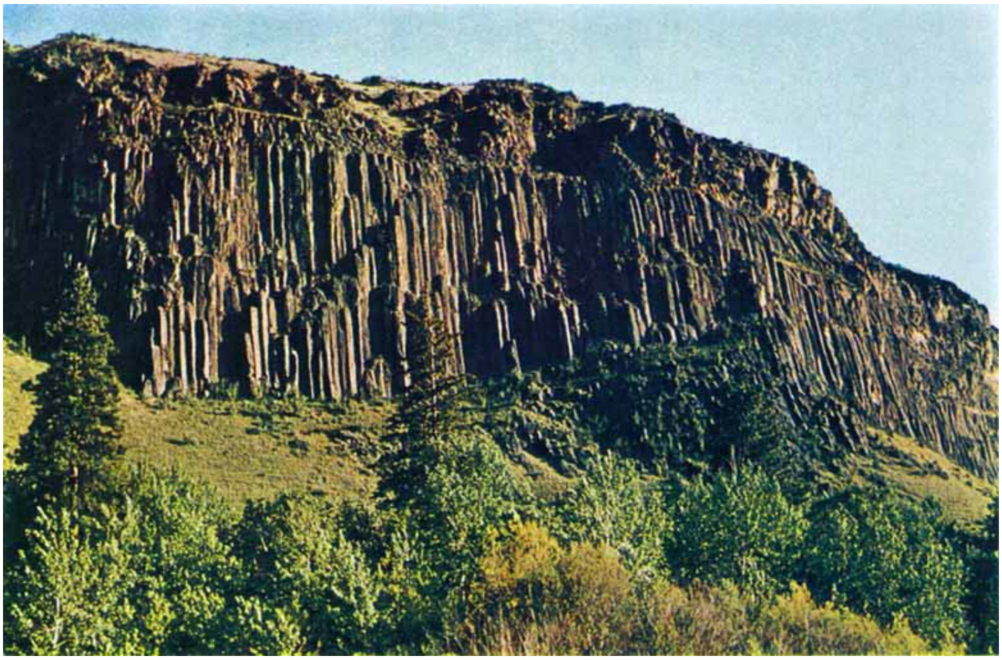

Fig. 1 This outcrop of basalt in the White Pass region of Western Washington, U.S.A., shows the typical columnar structure which results from the cooling and contraction of the molten lava. In homogeneous rocks the columns are generally hexagonal and may be divided into short lengths by ball and socket cross-jointing, a spectacular European example of this occurring at the Giant's Causeway in Antrim, Ireland

glass-forming techniques described by Slayter in 1941 are in use today, and in fact are also being adapted by European basalt fibre manufacturers.

Platinum and rhodium-platinum alloys have physical characteristics which make them uniquely suitable for fibre production bushings. Platinum alloy bushings are resistant to the corrosive and erosive effects of molten glass, they have adequate mechanical strength at the operating temperatures used, and they are actually the least expensive choice (7, 8).

Generally for fibre drawing, the molten glass must be in the viscosity range of 500 to 1000 poise—at a lower viscosity the glass is too fluid and droplets form at the nozzle, at a higher viscosity, the glass flow rate is too low and tension in the fibre during drawing is too high. Equally important in fibre forming are the crystallisation characteristics of the melt. Crystallisation phenomena are intimately related to the liquidus temperature, the temperature of maximum rate of crystal growth, viscosity at and near the liquidus temperature, as well as other factors. The liquidus temperature is important because formation of fibres is difficult or impossible when crystallisation is taking place while a fibre is being drawn. Crystals may form in the bushing or orifice, causing clogging, and may also occur on the outside of the orifice in the molten fibre. In the latter case they will then be contained within the solid fibre, creating a weak spot or discontinuity which causes the fibre to fail later during processing. In addition, if the viscosity of the glass is only 100 to 200 poise at the liquidus temperature, other difficulties occur; very rapid formation of crystals occurs and mechanical drawing of the fibre will be very difficult. On the other hand, if the melt viscosity is around 1000 poise at the liquidus temperature, crystal formation will be impeded and favourable drawing conditions will exist.

The surface tension is also an important fibre-forming parameter. If the surface tension is too high, a spherical bead will form at the nozzle and it will be impossible to draw a fibre. If the surface tension is too low, the material will not have enough strength to form a molten fibre while it is being drawn. Fortunately, silica additions to glass usually solve both the viscosity and surface tension problems simultaneously, and the glass industry uses silica amounts of 55 per cent and above to control these effects.

If the glassy material does not meet these requirements for drawing of fibre, a fibre can still be formed by steam or air blowing of the thin molten stream. It seems basalt often fails to meet the viscosity requirements; consequently, basalt fibres may be formed by blowing. The viscosity during blowing is usually about 100 poise for a fine long fibre.

The Russian literature recommends using a basalt with a viscosity of at least 90 poise at 1700°C, and at least 350 poise at 1250°C (4). In addition, a liquidus temperature below 1250°C is required. It appears, however, that useful staple fibres are being produced with materials of lower viscosity than these recommendations and with a less pronounced viscosity temperature dependence. It happens, as will be discussed later, that several Pacific Northwest, U.S.A., basalts seem to meet these requirements for good fibre forming.

Summary of Important Physical Properties of Basalt

The table gives chemical analysis of basalts from our local Whitlow Quarry, another basalt from Vantage, Washington area, as well as analysis of basalt from two Russian sites. Chemical analysis of high- and low-silica glass is also included. It is noted that the basalt materials have a somewhat varying composition, with silica content in the range of 48 to 50 per cent—sometimes as high as 53 per cent—with considerable amounts of iron oxides and aluminum oxides, as well as calcium and sodium oxides. Most of these oxides are not present in normal glass compositions. Our local Whitlow Quarry basalt is probably similar in viscosity to the Russian Yanova basalt, while the basalt from the Vantage, Washington, area seems to be similar in some respects to the E-glass composition.

Fibre Formation

A single orifice bushing of 20 per cent rhodium-platinum alloy was used. The shape

Chemical Composition of Local and Russian Basalts as Well as Two Glasses Used in Fibre Forming
(References shown in parenthesis)

	Whitlow Quarry, Pullman, Washington (11)	Grant County, Vantage, Washington (9)	Yanova, U.S.S.R. (4)	Armenia, U.S.S.R. (4)	Low-alkali E-Glass (10)	Soda-lime Glass (10)
SiO_2	49.10	54.30	51.0	45.4	55.2	73.0
Al_2O_3	13.90	14.30	15.2	16.6	14.8	2.0
Fe_2O_3	2.00	14.60	5.9	9.7	0.3	0
FeO	11.98	9.80	8.0	1.3	0	0
MgO	5.25	4.60	5.6	11.1	3.3	3.5
CaO	9.43	8.30	9.3	13.0	18.7	5.5
Na_2O	3.09	2.80	2.9	3.6	0.3	11.0
K_2O	1.26	1.20	?	?	0.2	0.5
H_2O	0.60	1.55	?	?		
TiO_2	3.16	1.75	1.6	0.6		

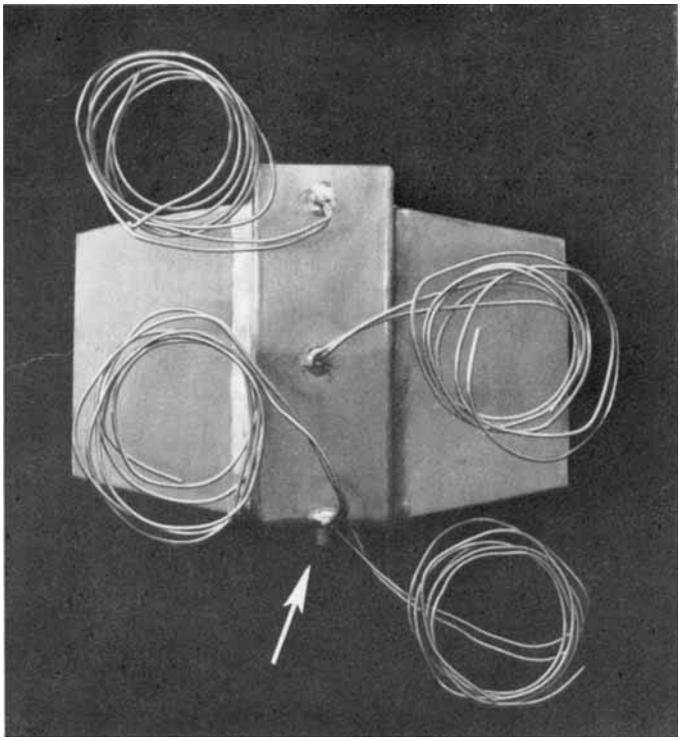

Fig. 2 The rhodium-platinum alloy bushing used for fibre forming consists of containment vessel with large tabs on the side for electrical connections and a single orifice, indicated by the arrow, at the bottom. Three thermocouples measure temperature distribution along the bushing and a fourth near the orifice is used for temperature control

of the bushing is shown in Figure 2. The bushing has a vessel size of 2.5 cm square by 6.5 cm long, with a wall thickness of 1 mm. It is important to minimise the wall thickness in order to increase the over-all resistance of the bushing, thus decreasing the average electrical current level. An orifice size of 1 mm in diameter by 1.5 mm long was used. An additional counterbored length terminating in a final wall thickness at the exit of 0.25 mm was used to preclude any tendency of the molten basalt to climb up the outside of the nozzle.

Four thermocouples are used on the bushing; three for measuring the temperature distribution along the length of the bushing, and a fourth located near the orifice for temperature control purposes.

Electrical power to the rhodium-platinum bushing is from a 15 kVA transformer with voltage taps at 0.8 to 2.5 volts. The transformer supplies current to the bushing up to a maximum of 2000 amps. The power of the bushing is controlled on the input side of the transformer by a 240 volt, 60 amp S.C.R. power controller, and one of the bushing thermocouples provides feedback control to this controller. A digital thermocouple indicator indicates bushing temperatures. Voltage and current (0 to 5 volts and 0 to 2000 amps) to the bushing were also continuously measured. The bushing itself is insulated and supported in a high-temperature iron-free refractory ceramic jacket cast around it.

Electrical connections to the bushing must be flexible to permit bushing expansion and they must be cooled to prevent forming a low-melting platinum-copper alloy at the bushing connection junction. Three strands of 4/0 cable connected in parallel are used to connect each transformer bus to each bushing electrode. This gives a total current-carrying capacity of 1800 amperes. A water-cooled copper clamp makes the actual connection between the cable and the bushing electrode as is shown in Figure 3. Located below the

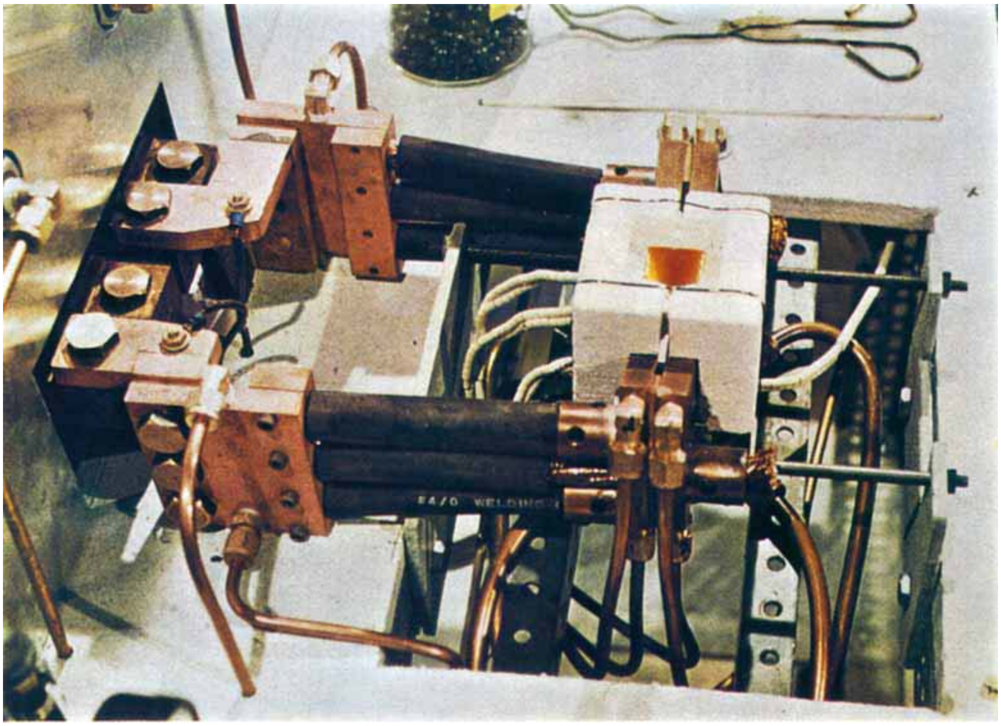

Fig. 3 In the experimental set-up for basalt fibre forming the bushing is insulated with a high purity porous refractory. Heavy, flexible, water-cooled conductors connect the power supply to the bushing while the fibre blowing nozzle and fibre winding drum are located below the bushing

bushing is a fibre blowing nozzle and a winding drum for continuous fibres. The molten stream of basalt passes through the centre of the nozzle and a high pressure cone of gas blows on the stream forming it into fibre.

To begin the actual formation of fibres, degassed marbles of basalt were first formed by melting crushed rock, taken from the

Fig. 4 Basalt fibre being drawn from the bushing orifice. Fibres having a wide size range can be produced in the laboratory by varying the speed of drawing and the temperature of the melt

Fig. 5 Fibre produced from some of the basalt rock which covers vast areas in the Pacific Northwest of the U.S.A. While not all basalts readily form fibres those that have been produced have good physical properties

Whitlow Quarry site, in an alumina crucible. These marbles were used to charge the platinum alloy bushing. At a temperature of 1250 to 1300°C a droplet formed on the tip of the nozzle could easily be drawn into the fibre by extending it with an alumina rod. The fibre being drawn from the nozzle is shown in Figure 4. The fibre tip was attached to a revolving drum and a quantity of continuous fibre formed. By varying the drawing speed of the fibre and temperature of the melt, fibres of a wide size range could be produced. For example, at a drawing speed of 12 metres per second and a nozzle temperature of 1325°C a fibre of 7 microns was produced, while at 4 metres per second and 1285°C a fibre of 17 microns was produced. It was found that very fine fibres could also be formed by situating an air nozzle about 10 cm below the bushing and blowing fibres with a core of high pressure air. This process resulted in a matte of staple fibres which was collected on a screen.

It is interesting to note that using basalt marbles of the composition obtained from the Vantage, Washington site and the same bushing orifice size, fibres could be drawn only with great difficulty.

The different chemical composition of this material, principally the higher silica content, resulted in a much higher viscosity. It required a bushing temperature of 1385°C to obtain even slow flow through the single orifice, and the drawing characteristics were also rather poor.

Mechanical Properties of Basalt Fibres

Shown in Figure 5 is a quantity of drawn fibre. The finished fibre has a silk-like sheen and, due to the high iron content, is brown in colour. Electron microscope studies carried out on fibres drawn at a temperature of 1175°C indicated the presence of a large number of crystalline inclusions, while fibres drawn at the higher temperature of 1285°C were beautifully smooth.

Fibres were tested for strength in a micro-tensile tester. Fibres in the size range of 8 to 18 microns and drawn at 1285°C exhibited average tensile strength of 1330 MN/m^2 while fibres in the size range of 9 to 11 microns and drawn at 1175°C exhibited average tensile strengths of only 660 MN/m^2. This large reduction in strength reflects, of course, the effects of crystal inclusions at the lower drawing temperature.

The modulus of elasticity for fibre as measured using elastic stress wave propagation time measurements was 95 GN/m^2, considerably higher than that of E-glass, usually reported to be 70 GN/m^2.

Conclusions

Glass fibre technology has been adopted to form fibres from some basalt rock located in the Pacific Northwest of U.S.A. Not all basalts in this area seem to be good fibre formers, but those fibres that are produced have good physical characteristics.

It is anticipated that there exists several commercial applications which could, with benefit, draw upon the unique properties of this fibre. An insulation material for normal and elevated temperature use, a reinforcement fibre for concrete and a replacement for wood fibre to form building board or panelling are a few diverse applications which come readily to mind.

The question of whether the basalt fibre can compete economically with the extensively developed glass fibre industry in the U.S.A. remains to be seen.

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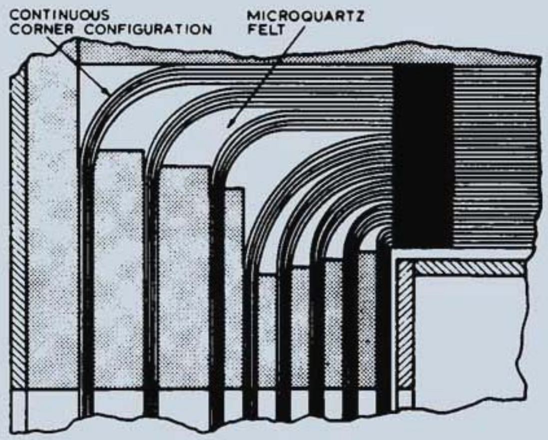
Platinum for High-Temperature Insulation

The properties of platinum have been utilised for a novel application, the thermal insulation of high-temperature systems, in work done by Andrew J. Parker of Hittman Associates Inc. for Goddard Space Flight Centre, Maryland, U.S.A. and outlined in *NASA Tech. Briefs*, 1976, **1**, (1), 74.

In the application, for which platinum was chosen because its high emissivity is stable at temperatures up to over 900°C in both air and vacuum, as well as being resistant to oxidation, forty layers of platinum foil 0.00025 inch thick are arranged as shown in the accompanying figure to form a laminated insulation. By such careful grouping it is possible to produce a linear temperature gradient through the thickness of the insulation.

While cost considerations are likely to restrict the use of platinum for this purpose it is probable that there are situations in the advanced technology industries where its use would be technically and economically viable.



Platinum foil used to form laminated insulation