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Basalt fiber bar

Reinforcement of concrete structures

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Abstract

This paper is review of state of art of knowledge of basalt fiber, the production methods and review of tests on basalt fiber as a strengthening material for concrete structures.
There are several types of basalt fiber strengthening methods used to strengthen concrete. In this paper three types are mentioned: External strengthening, fiber matrixes, and rod type material.
Basalt composite bars are made by utilizing basalt fibers and a resin epoxy binder. They are non-corrosive, consist of 80% fibers and have a tensile strength three times that of the steel bar normally used in building construction. Wherever corrosion problems exist, basalt fiber composite bars have the potential to replace steel in reinforced concrete. Compared to FRP bar as they are use for small amount in building industry the basalt bar are cheaper and have better durability under extreme conditions. It is concluded that basalt bars are of great interest for the building industry and can be used for example in bridge decks, offshore structure and in element buildings.

Key words:
Basalt, basalt rock, basalt fiber, basalt fiber bar, basalt fiber rod, fiber reinforced polymer

Introduction

The need for non-corrosive reinforcement of the construction industry has developed in the last decades. There have been several researches and tests of integrating basalt fibers into concrete structures, mainly concrete beams. The tests have shown improvements in strength and durability. In this review paper the focus is on the basalt fiber bars, the possible usage of such bars instead of the common steel reinforcement rebar. One of the benefits of using Fiber Reinforced Polymer (FRP) as a strengthening material in concrete is that it is non corrosive. In places where concrete structures are close to the sea, like houses or bridges, the maintenance of the concrete is needed on regular basis. In such conditions the common rebar is in constant danger of corrosion and therefore could become weak and hazardous in a short period of time.

Basalt rock can be used to make not only basalt bars but also basalt fabrics, chopped basalt fiber strands, continuous basalt filament wires and basalt mesh. Some of the potential applications of these basalt composites are: plastic polymer reinforcement, soil strengthening, bridges and highways, industrial floors, heat and sound insulation for residential and industrial buildings, bullet proof vests and retrofitting and rehabilitation of structures (Ramakrishnan, V. & Panchalan, R., 2005).

There is very little published information available on the behavior of the basalt fiber composite bars as reinforcement for concrete.

Properties of Basalt

Basalt is the most common rock type in the earth's crust (the outer 10 to 50 km). Basaltic magma is commonly produced by direct melting of the earth's mantle, the region of the earth below the outer crust. The ocean floor is mostly made of basalt. Huge outpourings of lava called "flood basalts" are found on many continents. Basalt is composed mainly of silica and alumina with lime, magnesium oxide and ferric oxide found in lesser percentages (Ramakrishnan, V. & Panchalan, R., 2005).

Basalt fiber

Fabrication

Basalt fiber is a material made from extremely fine fibers of basalt. The manufacture of the basalt fiber is by melting the quarried basalt rock. The molten rock is then extruded through small nozzles to produce continuous filaments of basalt fiber. The basalt fibers do not contain any other additives in a single producing process, which gives additional advantage in cost. It is known that basalt fibers have better tensile strength than E-glass fibers, greater failure strain than carbon fibers as well as good resistance to chemical attack, impact load and fire with less poisonous fumes (Sim, J., C., & Moon, D. Y., 2005).

Basalt having a high modulus of elasticity and excellent heat resistance, the fibers made of it has significant capability of heat and acoustic resistance and are outstanding vibration isolators. Basalt fibers are produced with the Junkers technology by melting the basalt rock and then forming fibers out of it. (Fig. 1.)

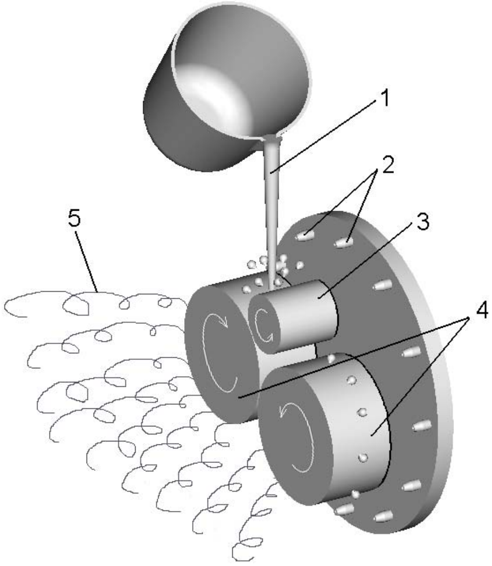

Figure 1. Junkers type basalt production (1 – basalt lava, 2 – blowing valves, 3 – accelerating cylinder, 4 – fiberization cylinder, 5 – basalt fibers)

The essence of the method is that the melt of 1580 ºC coming from the gas-heated furnace is transmitted to a horizontal shaft fibrising machine that has three centrifugal heads. The lava adhered to the heads flies off due to the centrifugal force and as a result of blowing 60-100 mm long fibers of 6-10 µm diameter are formed from the viscous liquid (Czigany, T., Vad, J., & Poloskei, K, 2005).

Basalt fibers compared to other FRP

To compare basalt fiber to other FRP, several experiments have been made. In this paper, reference is made to a research that was performed by *Sim, J., Park, C., & Moon, D. Y. Characteristics of basalt fiber as a strengthening material for concrete structures. Composites Part B: Engineering* where glass fiber and carbon fiber are compared to the basalt fiber.

Mechanical properties of the basalt fiber in this test

Density	2,593 g/cm³
Fiber diameter	10,6 µm

The tensile strength of the basalt fiber is close to 1000 MPa and about 30% of the strength of carbon fiber and 60% of the strength of high strength glass fiber.

Durability of basalt fiber

To test the durability, three different experiments were performed:

- Alkali resistance

- Weathering resistance
- Thermal stability

Carbon fiber and glass fiber were also tested for comparison.

Alkali resistance

When fiber rods are used as reinforcement inside concrete the importance of alkali resistance is high. The test involves immersing the rod into a 1 M NaOH solution for 7, 14, 21 and 28 days.

The test showed that both basalt fiber and glass fiber start to lose the strength and volumetric stability after seven days. The loss after seven days was about 50% and about 80% after 28 days. On the other hand the carbon fiber only showed 13% strength reduction after 28 days. From the alkali resistance perspective the basalt and glass fibers proofed to be much weaker than the carbon fiber. However, according to tests in Canada on an existing bridge reinforced by glass fiber, there is no evidence of such volume and strength reduction (Mufti, A.A, Bakht, B., Banthia, N., Benmokrane, B., Desgagné, G., Eden, R., Erki, M.-A.,Karbhari, V., Kroman, J., Lai, D., Machida A., Neale, K., Tadros, G., & Täljsten, B., 2007).

Weathering resistance

In order to verify the resistance against weathering such as ultra-violet exposure, three different fibers were tested according to the test method specified in JIS A 1415,
Recommended practice for accelerated artificial exposure of plastics building materials. Under the specified exposure condition, 200 h of exposure in the test is equivalent to 1 year of natural sunshine exposure so that 4000 h of exposure in the test may represent 20 years of exposure under natural conditions. The strength of the carbon fiber was merely affected by the exposure. The glass and the basalt fibers tended to lose their strength as the exposure time increased. The rate of the strength reduction in the glass fiber was about twice as fast as in the basalt fiber.

Thermal stability

The fiber samples were heated for 2 hours at 100, 200, 400, 600 and 1200°C. After 1 day of cooling at a laboratory condition, the tensile strength of the fibers was measured along with a visual inspection. When the heat was under 200°C there was not much difference between the fiber types but when the heat was increased over 200°C the difference became visible. The strength reduction of the carbon and glass fiber became distinctive as the heating temperature increased but the basalt fibers retained about 90% of the normal temperature strength up to

600°C. The exposure to 1200°C for 2 hours may be high enough to represent a fire event. After such a condition, the carbon fibers looked completely molten having lost all volumetric stability while the glass fibers lost it partially. The basalt fibers still maintained their shape and seemed to have retained their mechanical integrity.

Basalt material as strengthening method

There are several types of basalt fiber strengthening methods used to strengthen concrete. Here three types are mentioned: External strengthening, , fiber matrixes, , and rod type material.

1. The external strengthening:

A fiber sheet layer is applied to the lower part (tension side) of the concrete beam as seen on fig.2. This method increases the strength considerably since it holds the concrete together.

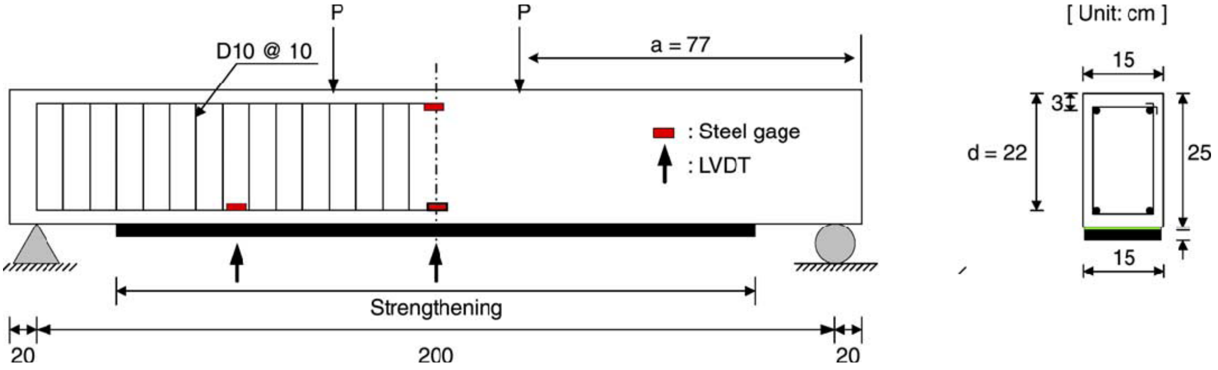

Figure 2. Fiber strengthening under the beam (Wiberg, A., 2003)

2. Fiber matrixes:

Fiber matrixes are put in the concrete to increase strength in typical steel reinforced beams. The matrixes are placed in the concrete beam in such a way as to maximize the shear strength and prevent cracks. Shear cracks usually form 45° cracks from the foundation and to the direction of the force. The fiber matrixes are placed in such a way that they try to prevent shear cracking, which is the fibers are placed perpendicular to the possible crack. This will give extra strength to this area of the beam and prevent the shear cracking.

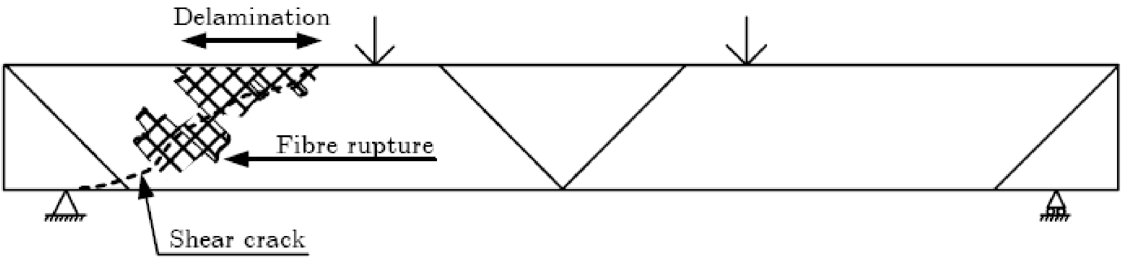

Figure 3. Fiber matrix set in the concrete (Wiberg, A., 2003)

3. The rod/bar type:

In this paper the rod type is of the most interest. Basalt fiber rod can be considered a good choice for reinforcement of concrete where for example weather conditions are such that corrosion is likely. The danger is usually to structures close to the sea or salty environment, houses and bridges are in that category. When using typical rebar close to salty environment special consideration of the concrete cover needs to be kept in mind, but with FRP rebar too little concrete cover is of no danger to the strength of the structure.

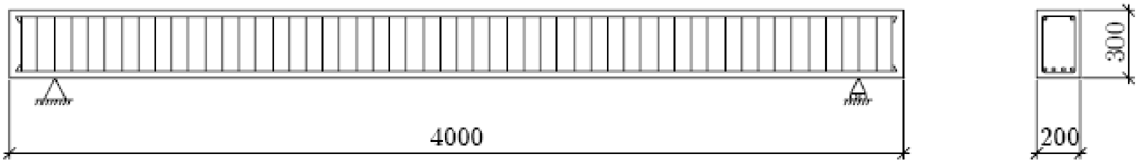

Figure 4. Typical concrete beam reinforced with bars (Wiberg, A., 2003)

Basalt fiber bar

Basalt composite bars are made by utilizing basalt fibers and a resin epoxy binder. They are non-corrosive, consist of 80% fibers and have a tensile strength three times that of the steel bar normally used in building construction. Wherever corrosion problems exist, basalt fiber composite bars have the potential to replace steel in reinforced concrete. Currently there are many FRP bar manufacturing companies which market their products. Most of these bars are made of E-glass fiber and thermosetting resin. However FRP bars lack sufficient durability under extreme conditions. These bars are costly and are also non-resistant to alkalis. Basalt bars do not possess these disadvantages and can be effectively used in various applications such as highway barriers, offshore structures, and bridge decks.

The above mentioned advantages alone could warrant a sufficient argument for substitution of steel bars with basalt bars on a large scale. Other advantages of the basalt bar are that its weight is one-third of the weight of steel and the thermal expansion coefficient is very close to that of concrete. The high mechanical performance/price ratio of basalt fiber composite bar, combined with corrosion resistance to alkaline attack, are further reasons for replacing steel in concrete with basalt fiber composite bars.

This paper refers to the first experimental investigation which was carried out to evaluate the performance of concrete beams reinforced with basalt fiber composite bars. This test was made by V. Ramakrishnan and R.K. Panchalan. (Ramakrishnan, V. & Panchalan, R., 2005).

The experiment was split up in five phases for testing different aspects of the basalt fibers:

Phase I: Flexure Test on Plain Basalt Bar Reinforced Concrete Beams

A total of six beams reinforced with basalt bars were tested. The beams were tested in flexure after a 14-day curing period. The beams failed with a single crack instead of multiple cracking, which indicated slip of the reinforcing bars.

Phase II: Flexure Test on Concrete Beams Reinforced with Plain Basalt Bars and Discontinuous Basalt Fibers

Eight beams were tested with different reinforcement. Five beams were reinforced with basalt composite bars. Four of these beams were also 3-dimensionally reinforced with basalt fibers and three beams were plain concrete (control) beams. A ductile failure was observed for the four beams with extra fibers, but the beam with only basalt bar had brittle failure. All three plain concrete beams failed instantaneously at the appearance of the first crack.

Phase III: Bond Test on Basalt Bars and Cables

The results from Phase I and II revealed that the actual ultimate moments of basalt bar reinforced concrete beams were less than the theoretically calculated ultimate moments. This was due to bond failure between bars and concrete. To avoid this type of failure, basalt cables with corrugations, rods with slots, barriers, and anchors were developed for improving the bond between the bars and the concrete.

First the plain basalt bar reinforced specimens were tested for the bond strength. As the load was applied the plain basalt bars started slipping and there was no bond between the reinforcement and the concrete

Then the 4-slot basalt bar was tested. The 4-slot basalt bar did not slip and hence there was no bond failure. But the basalt bar itself failed due to tension failure. The failure was brittle. The 8-slot basalt bar also failed in a similar manner to that of the 4-slot basalt bar.

Phase IV: Determination of Cracking and Ultimate Loads for Extremely Under-Reinforced Beams

Two extremely under-reinforced beams, reinforced with modified basalt bars, were tested to see whether an adequate bond had developed between the bar and concrete. The reinforcement provided for one beam was less than the minimum required according to ACI (American Concrete Institution) code 318. Another beam was provided with the ACI recommended minimum reinforcement.

Beam 1: The first crack occurred at the calculated cracking moment. After the first crack, the beam failed suddenly breaking into two pieces, because the beam was extremely under-reinforced. The bar broke without slipping, which indicated that there was a good bond between the bar and the concrete.

Beam 2: The beam first had a flexural crack at 85% of the calculated cracking moment, but ultimately the beam failed in shear. Even though the beam failed in shear, it took 88% of the calculated ultimate moment. The beam did not fail due to slip of the bar, which indicated that there was a good bond between the 4-slot bar and the concrete.

Phase V: To Determine Cracking and Ultimate Loads for Five Under-Reinforced Beams

A total of five beams reinforced with basalt bars were tested. The beams were designed according to ACI-318 Building Code recommended design procedures. All the beams were designed as under-reinforced beams with the normal range used in construction. All beams were tested in flexure after a 28-day curing period.

Beam 3 was designed as a lightly under reinforced beam with one corrugated basalt rod 9 mm. The first crack occurred at 95% of the calculated cracking moment. After the first crack the beam took 2,7 times more moment than the cracking moment indicating very good bond strength between the bar and the concrete. The beam failed at 98% of the calculated ultimate moment. The beam failed primarily in flexure and secondarily in shear.

Beam 4 was also under-reinforced. Two cables of 1.524 mm length and 8 mm diameter were used as reinforcing bars. These cables were made in the laboratory by twisting three individual basalt wires into one. The beam first had a flexural crack at 76% of the calculated cracking moment. After the first crack the beam took 4,9 times more moment than the cracking moment indicating very good bond strength between the bar and the concrete. The beam failed at 97% of the calculated ultimate moment. The beam failed purely in flexure. The cables did not slip even after the ultimate load was reached.

Beam 5 was made of three basalt cables of 1.041 mm length and 3 mm diameter. The beam was under-reinforced. The beam first had a flexural crack at 95% of the calculated cracking moment. After the first crack the beam took 2,4 times more moment (less than the other beams because it was under-reinforced, and the tensile strength of the bar was also less) than the cracking moment indicating very good bond strength between the bar and the concrete. The beam took 49% more than the calculated ultimate moment. The beam failed primarily in flexure and secondarily in shear. The cables did not slip even after the ultimate load was reached.

Beam 6 was made with two basalt bars of 1.219 mm length and 10 mm diameter. The beam was lightly under-reinforced. The rods were provided with 1 Fe-Mn-Ni anchors (smart alloys) on each end of the bar to prevent slip. The actual cracking moment exceeded the calculated moment by 4.5%. After the first crack the beam took 5,1 times more moment than the cracking moment indicating very good bond strength between the bar and the concrete. The beam took 12% more than the calculated ultimate moment. The beam failed primarily in flexure and secondarily in shear.

Beam 7 was made with two basalt bars of 1.219 mm length and 10 mm diameter. The beam was lightly under-reinforced. The rods were provided with 2 Ti-Ni (50/50) anchors (smart alloys) at each end of the bar to prevent slip. A strain gauge was placed on the compression side of the beam and another strain gauge was also placed on the bar in the slot to measure the strain in the bar. The actual cracking moment exceeded the calculated moment by 7%. After the first crack the beam took 5,9 times more moment than the cracking moment indicating very good bond strength between the bar and the concrete. The beam took 21% more than the calculated ultimate moment. Of all the beams, this beam performed very well basically because of the anchors and the slots that were provided on the bar. The beam failed primarily in flexure and secondarily in shear. The bars did not slip even after the ultimate load was reached.

The conclusion of these tests presented in the paper by V. Ramakrishnan and R.K. Panchalan is as follows:

Phase I:

The beams reinforced with plain basalt composite bars failed in flexure by pull-out of the bars, due to inadequate bond between the rod and the concrete. All the actual ultimate moments were much less than the calculated ultimate moments due to the bar pull-out failure.

Phase II:

The beams supplied by the manufacturer reinforced with 3D-fibers and bars exhibited a primary failure in flexure and shear followed by a secondary failure in splitting. The 3D-fibers caused a ductile failure of the beam and also increased the actual cracking moment capacity of the beam. All the actual ultimate moments were much less than the calculated ultimate moments due to bar pull-out failure.

Phases III to V:

The bond between all the modified basalt bars and concrete was extremely good. The experimental ultimate moments nearly matched or exceeded the calculated moments, for all the beams tested. The experimental ultimate moment was much higher than the first crack moment in all the Quality of Structures and Advances in Materials 261 beams tested, indicating a good bond between bar and concrete. The deflections were considerable indicating adequate ductility. All the beams had primary flexural failures and a few beams had secondary shear failures. There was no slip of the bars in any of the beams tested and there was no evidence of bond failure between the concrete and the modified basalt bars and twisted cables. The limited testing conducted indicated the feasibility of using basalt bars to reinforce concrete structures in place of steel bars. However the authors are conducting additional testing, including durability tests, so that positive recommendation could be made.

Conclusion

Based on the above mentioned tests it is concluded that basalt bars are of great interest for the building industry. This is still quite new and needs to be researched further. There are several masters and doctors thesis available on the usage of basalt fiber, but few with research and testing of basalt fiber bars.

Pros and cons

Pros: The benefit of using basalt fiber or other FRP material is that it is non-corrosive, this means it is a good choice for reinforcing concrete structure located close to the sea such as bridges and houses. The strength is very good, about three times the strength of the common steel rebar. The heat resistance is very good which is extremely important for buildings. Basalt is the most common rock on earth so there is no lack of sources, which means this material is much cheaper than other rock material, like for example carbon fiber.

Cons: One of the problems using FRP material is to get the bondage to the concrete, but that can be solved by using anchors fastened to the cable or bar ends to prevent slip in the concrete. The alkali effect on the basalt bars needs to be looked into, since laboratory tests have shown that basalt and glass fiber do not withstand alkali well, but bridges in Canada with glass fiber bars as reinforcement have shown otherwise after eight years of usage.

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