Basalt reinforcement in concrete beams in

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Synopsis

Basalt reinforcement is a relatively new type of reinforcement, used as an alternative to steel. As the name implies, the bars are made of basalt, which is a naturally occurring volcanic rock. The reinforcement is tested by placing the bars in concrete beams and bending the beams in flexure. Basalt reinforcement was found to have several beneficial properties: the bars are lightweight, possess a high tensile strength and are resistant to fire. Nevertheless, basalt reinforcement has a low elastic modulus and therefore the test beams exhibited high deflections. Anchorage problems were also evident, characterised by substantial bar slippage. Here, this type of reinforcement is critically evaluated and possible applications are suggested.

Introduction

The development of basalt reinforcement is somewhat shrouded in mystery. Although originally discovered in the 1920s, the technology was suppressed, since the material was thought to have military applications. Despite the technology having been 'declassified' by the US, Russian and European governments by the mid-1990s, the use of this material has gained little popularity in the last 20 years or so. As a result, basalt reinforcement is largely unknown among structural engineers.

Basalt rock exists in vast quantities and is volcanically formed. Reinforcement rods are formed by crushing the rock into a powder. The powder is heated to its melting point (approx. 1450°C). The molten material is then extruded through a fine nozzle, to produce a thin continuous strand, ranging in diameter from 9-13μm. In this state, the basalt strands are highly flexible, resembling hair. The strands are then bundled and bound together with a polymeric compound into long straight bars. Commonly, additional basalt strands are wound around the bar transversely, forming spiral ribbing. The ribbing provides containment, adds rigidity and improves the mechanical anchorage between the bar and the concrete. The diameter of the bars match conventional reinforcement sizes, and is intended to be an alternative reinforcement for concrete. A typical basalt reinforcing bar is shown in Figure 1.

Figure 1
Basalt reinforcing bar

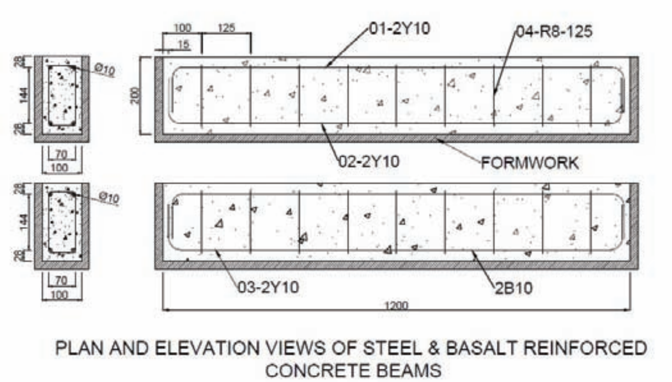


Figure 2
Reinforcing details of test beams

To explore the properties and application of basalt reinforcement, 12 reinforced concrete bending tests were performed. The construction of the beams, the testing procedure, and the results of the tests are presented. A discussion is also provided, detailing some of the possible applications and shortcomings of the material.

Construction of the test specimens

The testing programme consisted of 12 reinforced concrete beams. Six were constructed with basalt reinforcement while the remaining six were constructed with ordinary steel reinforcement. All of the beams measured 100 x 200 x 1200mm (b x h x L). The six steel reinforced beams were used as the control beams, to enable a direct comparison. Both the steel and the basalt reinforcements were 10mm in diameter. The testing programme was devised with only one parameter of difference - the material of the reinforcing bars located at the bottom of the beams. The reinforcing details are given in Figure 2.

As illustrated, the only difference in the two details is the bottom reinforcement – six beams are reinforced with high-yield reinforcing steel (f_y = 450MPa) and the other six with basalt reinforcement. The top steel, in both sets of tests, were two 10mm high-yield steel reinforcing bars, identified by the symbol Y10. Likewise, the shear reinforcement in both sets of beams were 8mm mild steel reinforcing bars (f_y = 250MPa), identified by the symbol R8 and spaced at 125mm. The reinforcing cover was 20mm.

flexure

In practice, it is common to 'close-off' the ends of the concrete beam with reinforcement, by detailing a 90° bend. For this reason, the top and bottom steel were lapped, thus closing-off the ends of the beam. The purpose of the lapped bends is to both provide rigidity to the reinforcing cage during construction and anchorage to the main reinforcement, as well as to assist in resisting shears or bending moments at the supports. This practice is easily accommodated in steel reinforced beams, but basalt reinforcement cannot be bent. Therefore, short 'L' shaped steel bars were lapped to the ends of the basalt reinforcement.

The configuration of the test beams were designed to fail in bending, where the basalt bars are located. Due to space and construction limitations, the test beam's span/depth ratio was lower than commonly occurring proportions for simply supported beams. However, preliminary tests (not recorded here) indicated that flexural failure dominated, thus enabling the use of the test results. In beams with low span/depth ratios, shear stresses tend to dominate the mode of failure - no indication of shear failure occurred in any of the test beams.

Mechanical properties of the reinforcement

Determining the tension strength of the basalt reinforcement proved to be difficult. The clamps of the testing machine crushed the ends of the basalt reinforcement, precipitating premature failure. After several disastrous attempts, the only successful tests were carried out when the bars were placed in tight fitting tubes. The basalt specimens were 400mm long, with 150mm stainless steel pipes placed at either end. The pipes were internally threaded to improve the mechanical bond between the pipe and reinforcement. Grease nipples were also placed at the ends of the pipes and an epoxy resin was pumped into the pipes to chemically bond the basalt to the inside of the threaded pipes. After the resin set, the specimens were placed in the clamping wedges of the testing machine and loaded to failure. As the load was applied, some slippage occurred, but the failure load was achieved. As a result of the slippage, two sets of tests were required to determine the modulus of elasticity and the tensile strength. The results are given in Table 1 while a failed tension bar is shown in Figure 3. The properties of basalt reinforcement are taken from a variety of sources[1-3] and compared to the test results (Table 2).

Table 1: Results of basalt tension tests

Test number	Failure load (kN)
1	87.0
2	92.0
3	90.0
Average	89.7

Table 2: Material properties of basalt and steel reinforcement (10mm diameter)

Properties	Basalt published values	Basalt test	Steel published values	Steel tests
Weight (kg/m³)	1900-2100	1909	7800-7900	–
Tensile strength (MPa)	≥ 700	1143	450	525
Young's modulus (GPa)	≥ 40	52	210	206
Poisson's Ratio	–	~4*	0.30	–
Elongation (%)	≥1.8	–	≥18	–
Coefficient of thermal expansion ($x10^{-6}$/°C)	9-12	–	≥ 11.7	–
Residual strength of bars subjected to heat	20°C – 100% 200°C – 95% 400°C – 82% 600°C – 76%	–	20°C – 100% 200°C – 81% 400°C – 42% 600°C – 18%	–

* See text on Poisson's ratio

Figure 3 Failure of basalt reinforcement bar during tension test

From Table 2, basalt reinforcement can be seen to have several promising characteristics:

- *Light weight* - the weight of the basalt bars is only a quarter of the weight of steel. Thus, the cost of transportation is significantly less and the reinforcement is easier to work with on site.
- *Tensile strength* - the tensile strength of basalt bars is double that of high yield steel reinforcement. Thus, only half of the required reinforcement is necessary to meet strength requirements.
- *Residual strength under fire conditions* - Manufacturers have reported that the loss in strength is significantly reduced under fire conditions, compared to steel reinforcing[4]. This characteristic is a definite advantage in structures which are susceptible to fire damage. Basalt is volcanic rock, and therefore fire resistant. The loss in strength is due to the breakdown of the polymeric compound; the binding material used to form the bars. However, the fire resistance may vary, depending on the binding compound used by the manufacturer. The coefficient of thermal expansion of concrete[5] and basalt reinforcement is similar, which is an important consideration when bearing in mind fire conditions. If dissimilar, debonding of the two materials is possible, resulting in a loss in strength.
- *Oxidation* - basalt reinforcing is free of oxidation, and therefore increased durability can be expected. The concrete is also free of unsightly discolouration, frequently caused by rusting of the steel reinforcement.
- *Energy consumption* - the lower energy

Table 3: Cube results at time of tests

Cube results for steel reinforced beams		Cube results for basalt reinforced beams	
Cube	**Compression strength (MPa)**	**Cube**	**Compression strength (MPa)**
1	29.6	1	29.7
2	30.2	2	28.5
3	29.4	3	30.0
Average	29.7	Average	29.4

Figure 4
Test arrangement

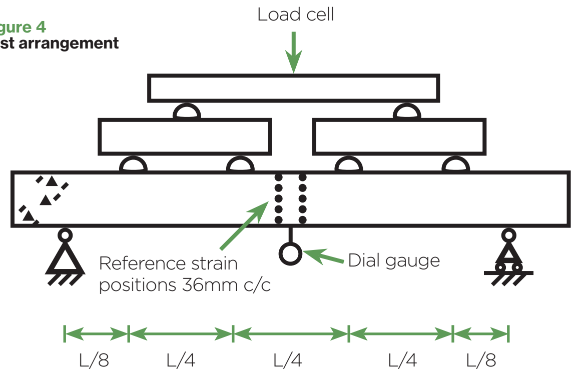


Figure 5
Load arrangement, location of DEMEC targets and deflection gauge

consumption in the production of basalt reinforcement, and the subsequent effect this has on cost, are additional advantages. Fazio[6] has reported that the energy required to produce basalt reinforcement is about a third of what is required for steel reinforcement (per kg). As a result, the cost of basalt reinforcement is about half the cost of steel (per metre length of similar size steel bars). At present, very few factories in the world produce basalt reinforcement; for this reason, the price varies substantially and is greatly influenced by the cost of shipping.

Despite these positive characteristics, basalt also has some evident disadvantages:

- *Elastic modulus* - the elastic modulus (Young's modulus) is only about a quarter of reinforcing steel's (50GPa compared to 200GPa). Concrete, subjected to flexure, will crack at a low tensile strain. Once cracked, the tensile force is transferred to the reinforcing bars and subsequent deflections are directly related to the elastic modulus of the reinforcement - significantly increased deflections are expected. To counteract this problem, as much as four times the amount of basalt reinforcement is required to achieve the same stiffness of steel reinforcement.
- *Ductility* - the elongation at failure is only a tenth of steel's. The mode of failure tends to be brittle, with little or no ductility. A lack of ductility reduces the overall strength of a structural member, since hinges, or yield-lines, are not able to form. Furthermore, basalt reinforced beams are less able to absorb energy, which is an important consideration in earthquake zones.
- *Constructability* - basalt bars are manufactured as straight bars and cannot be bent or shaped in any way. This will severely limit the usefulness in reinforced concrete design. In the test specimens, ordinary steel reinforcement was lapped onto the basalt bars near the ends of the beams.
- *Poisson's ratio* - strangely, this ratio is not readily available in published sources; it was therefore necessary to determine this value experimentally to explore the material in its entirety. However, the experimental values were so high and seemingly out of the ordinary, the tests were repeated numerous times, using different measuring techniques. The material responded to load in an unstable manner, with a large variation in lateral strain. Poisson's ratio was determined as approximately equal to 4. In most structural materials, Poisson's ratio ranges from 0.1 to 0.3. However, and subsequent to the tests, it was found that Poisson's ratio is similarly high for unidirectional glass fibre, bound together by an epoxy resin[7]. Basalt strands are also unidirectional and orientated along the axis of the bar. In the longitudinal direction, the stresses are resisted by the basalt stands, but in the lateral direction, the polymeric compound is the resisting material (which contracts significantly under a tensile load). Excessive 'necking', or contraction of the reinforcement about the diameter, provides a clear explanation for why the reinforcement debonded from the concrete (see 'Test results' section). Admittedly, Poisson's ratio will vary greatly, depending on the manufacturer, the quality of the binding compound and configuration of the strands. Nevertheless, debonding seems to be a common feature[8] and therefore an unusually high Poisson's ratio is most likely a related problem among most basalt products.

Concrete mix design

The beams were tested when the concrete reached a compression strength of 30MPa, which is a typical design strength for many reinforced concrete structures. The concrete mix, however, was designed at 40MPa. A higher strength mix is often used as a means to pinpoint, with higher accuracy, the target strength of the concrete. Numerous cubes were cast and the compressive strength was tested daily, to monitor precisely the progression of strength. When the cube strength reached 30MPa, the beams were tested (Table 3).

The same materials and mix were used in both sets of tests (i.e., steel and basalt). The basic proportions of the mix are given below:

Cement (C) (Afrisam 42.5N)	= 445.00kg
Water (W)	= 262.55litres
Stone (6.7mm Andesite)	= 703.00kg
Sand	= 1118.00kg
W/C (ratio)	= 0.59
Fineness modulus (FM)	= 3.22
Average slump	= 102mm

Testing setup and procedure

The beams were tested under four point loads to simulate a uniformly distributed load (UDL). The support conditions were simply supported and the span of the test beams was 1100mm. The load arrangement is shown in Figures 4 and 5. An Amsler testing machine was used to apply the load, and readings were taken in increments of 20kN. All of the tests were load controlled i.e. at each load step, the load was maintained until the deflections stabilised until the creeping of deflection terminated. The loading was applied at a rate of 4kN/minute.

At each load step, the strains along the depth of the beam and deflections were measured at mid-span (Fig. 5 shows the location of DEMEC targets and the deflection gauge).

Figure 6
Load-deflection curves for test specimens

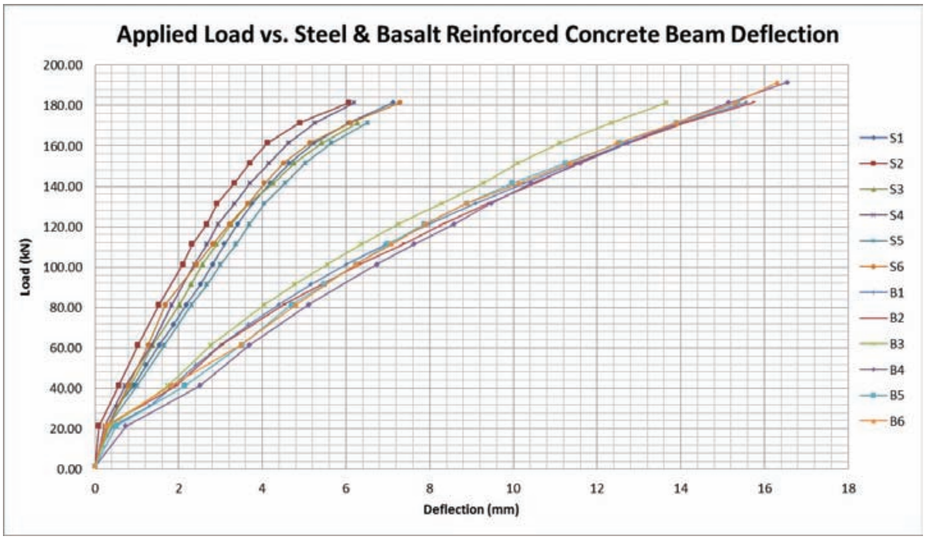


Figure 7
Strains along height of basalt reinforced beams

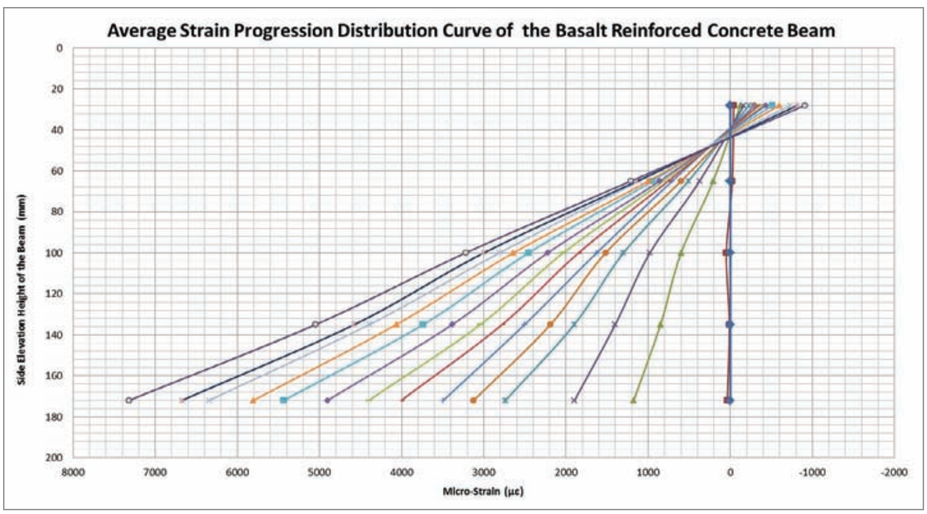
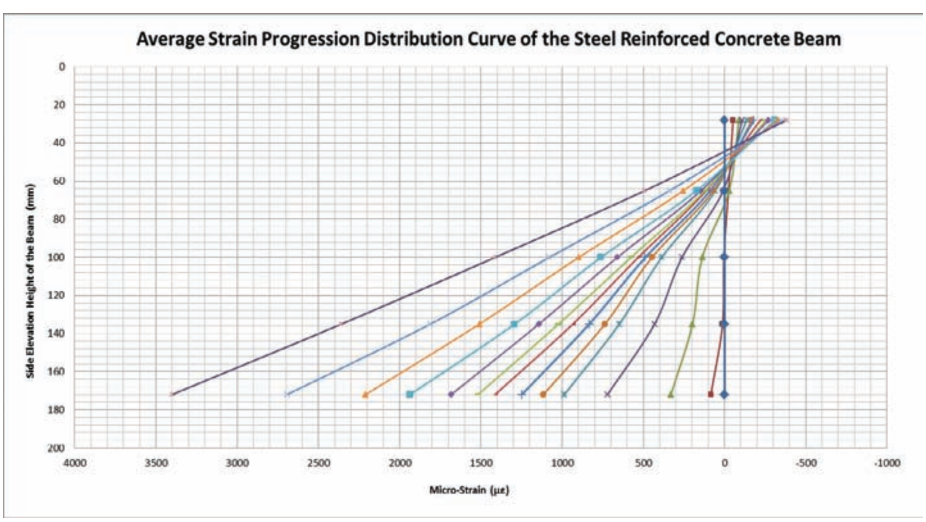


Figure 8
Strains along height of steel reinforced beams



Test results

The load-deflection curves for the 12 tests are given in Figure 6, and the mid-span strains through the height of the basalt and steel beams are shown in Figures 7 and 8 respectively. As illustrated in Fig. 6, the graphs are compact and consistent, indicating reliability of test data.

Load was incrementally applied to each beam until the deflections began to 'run'. The term 'running of deflections' is used to describe the behaviour of the beams at the end of the test - when the beams undergo a substantial increase in deflections (relative to the deflections in the elastic range) and are concurrently unable to carry additional load. When this occurs, the beam is deemed to have failed. In the beams that were reinforced with ordinary steel, failure was precipitated by yielding of the flexural steel and the failure pattern was typical and predictable (vertical cracks near mid-span and sloping cracks towards the supports). However, in the beams reinforced with basalt, failure was atypical – being precipitated by slippage of the reinforcing bars and cracks forming on the underside of the beams, spanning along the length (Figures 9-11). A dissection of the beams, revealed that the chemical and mechanical bonding of the basalt was inadequate to develop the full tension capacity of the bars, and substantial slippage was detected at the end of the beams. The slippage was identified by the formation of cavities, located directly behind the reinforcing bars. Furthermore, the crack pattern differed from ordinary reinforcement. Fig. 10 shows the underside of a beam reinforced with basalt reinforcing; cracking occurred at the location of the basalt and extended along the length of the beam. Horizontal cracks also occurred near the bottom of the beam at the location of the bars (Fig. 11). The bars seem to have debonded and then pushed downwards, causing a linear crack along its length (directly below and horizontally). The basalt reinforcement tests are also characterised by having substantially increased deflections – the deflections were more than twice those of an equivalent cross-sectional area of steel reinforcement (Fig. 6 and Table 4).

Poor adhesion of the basalt to the concrete has been previously reported, substantiating the test results[8]. Although Ramakishnan's test was limited to one beam, slippage of the basalt was the dominant mode of failure and pre-empted subsequent experiments. The other experiments included tests with end anchors and mixtures of cables and fibres to resolve the slippage problem;

Figure 9
Signs of slippage in basalt reinforced beams

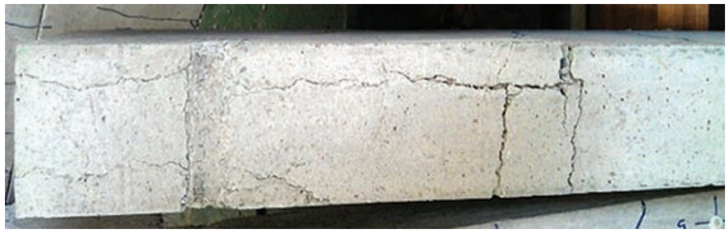


Figure 10
Crack propagation on underside – spanning length of beam

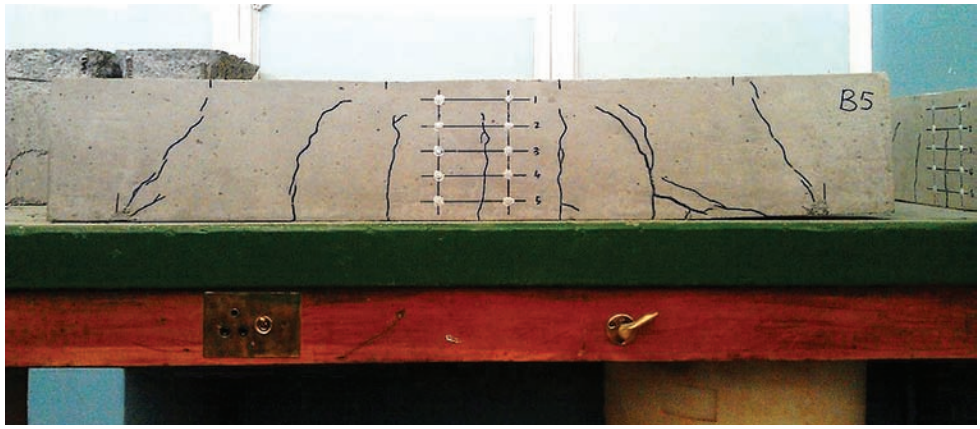


Figure 11
Crack pattern on side of basalt beam

Table 4: Maximum loads and deflections

Steel reinforcement			Basalt reinforcement		
Beam	Max. load (kN)	Max. deflection (mm)	Beam	Max. load (kN)	Max. deflection (mm)
S1	197	7.13	B1	197	15.56
S2	195	6.07	B2	202	15.72
S3	195	7.90	B3	213	13.66
S4	205	6.20	B4	196	16.55
S5	201	7.75	B5	191	15.37
S6	195	7.29	B6	211	16.31
Average	198	7.06	Average	202	15.53

Ramakishnan provided several creative solutions to the debonding problem.

The pattern of strains along the depth of the basalt beams were similar to the beams reinforced with steel. However, the magnitude of strains in the basalt bars was double that of the strains of the steel beams.

Adaption of steel reinforcing theory

Since the strain distribution of both the basalt and steel reinforced beams are similar for a range of loading (Figs. 7 and 8), flexural theory (associated with steel reinforcement) was applied, to predict the flexural strength of beams reinforced with basalt. An older version of the South African concrete code[9] was utilised to predict the moment capacity, since later versions of the code (although more accurate) determine the required cross-sectional area of the reinforcement, rather than the moment capacity. The flexural theory of the South African code is based on BS 8110[10].

It is assumed coincidental that the experimental moment capacities of both sets of tests are similar. In both cases, the experimental values far exceeded the predicted moment capacities (Table 5). However, the basalt reinforced beams should have a moment capacity approximately double that of steel (based on the tensile strength). Slippage of the basalt bars has substantially reduced the capacity to levels similar to steel reinforcement. Thus, no benefit in strength was realised.

Discussion

A brittle failure was predicted, since basalt reinforcement possesses little ductility. However, although the beams did not fail abruptly, they had the appearance of a ductile failure due to bar slippage. Slippage was evidenced by gaps, or cavities, located directly behind the ends of the bars. Basalt strands are wrapped around the bars in a spiral to improve the mechanical bonding, but the tests have illustrated this was not sufficient to prevent slippage. Nevertheless, the contraction of the reinforcement, due to Poisson's effect, was most likely the greatest contributor to bar slippage. In fact, the slippage was so severe that the failure load of the basalt beams approximated the failure of the steel beams (no gain in strength, despite basalt having a tensile strength that is double that of steel reinforcement). This problem became self-evident at the very start of the testing programme, when trying to determine the tensile strength of individual bars.

The basalt reinforced beams had shown significantly more deflections (indeed, twice the amount as were evidenced with steel reinforced beams). The cause is the low elastic modulus and slippage of the reinforcement. Even if slippage did not occur, approximately four times more basalt bars are required to achieve the same stiffness.

Constructability is also a major problem - the bars cannot be bent without damaging the material. This severely restricts the application of basalt reinforcement, since only straight bars can be used.

Although basalt reinforcement has been around for many years, the technology is not sufficiently developed. The polymeric compounds, used to bind the basalt fibres, may not be the most suitable material. The matrix (i.e., the binding compound and basalt fibres) is relatively weak and exhibits an extremely large Poisson's ratio, leading to bar slippage within the concrete.

Despite the poor experimental results, several favourable properties cannot be ignored and basalt reinforcement will have definite application. The material is light, the tension strength is high and the bars are resistant to heat.

A possible application is in post-tensioned slabs. These types of slab are vulnerable to fire and damage to the anchored ends. Some designers add unstressed reinforcing steel to post-tensioned slabs as safety steel, to counteract the possibility of localised failure, or fire damage. Basalt reinforcement is therefore an appropriate material, due to its excellent resistance to heat. Another possibility is to design a hybrid system, a mixture of steel and basalt (basalt for strength and steel for ductility) or apply a combination of different forms of basalt, i.e. basalt fibre and cables[8]. Some newer products weave the basalt fibres into sheets, which are used to repair damaged concrete structures[11]. Basalt fibres have also been investigated as an energy-absorbing material to resist impact loads, despite the material's small ductility range beyond yielding[12]. Also noteworthy, is the fact that basalt doesn't break down in an alkaline environment (a common problem with glass fibres), it is not as expensive as carbon fibres and has superior strength to many polymer based fibres (FRP).

The potential of basalt is evident, but the development is lacking.

Table 5: Prediction of moment capacity

	Basalt reinforcement		Steel reinforcement	
	Eqn. (kN.m)	Average experiment (kN.m)	Eqn. (kN.m)	Average experiment (kN.m)
Moment capacity	15.58	27.22	8.68	27.78

References

► 1 Brik V. B. (1997) 'Basalt fiber composite reinforcement for concrete', *Transportation Research Board, Research Report NCHRP-IDEA Project 025,* Washington DC: TRB

► 2 Colombo L. V. (2012) 'Static and fatigue characteristics of new basalt reinforced composites', *Composite Structures*, **94** (3), pp. 1165-1174

► 3 Czigany T., Vad J. and Poloskei K. (2005) 'Basalt fibre as a reinforcement of polymer composites', *Periodica Polytechnica Ser. Mech. Eng.,* **49** (1), pp. 3-14

► 4 Kowalski R. and Kisielinski R. (2011) 'On mechanical properties of reinforcing steel in RC beams subjected to high temperature', *Architecture Civil Engineering Environment*, (2), pp. 49-56

► 5 Portand Cement Institute (1994) *Fulton's Concrete Technology,* (7th ed.), Ed. Addis B. J., Johannesberg: Natal Witness and Publishing Co.

► 6 Fazio P. D. (2011) 'Basalt fibra: from earth an ancient material for innovative and modern applications', *Studi & Ricerche Technical Papers, Energia, Amblente e Innovazione,* (3), pp. 89-96

► 7 Craig P. D. and Summerscales J. (1988) 'Poisson's ratio in glass fibre reinforced plastics', *Composite Structures*, **9** (8), pp. 173-188

► 8 Ramakishnan V. and Panchalan R. K. (2005) 'A new construction material - non-corrosive basalt bar reinforced concrete', *American Concrete Institute*, 229, pp. 253-270

► 9 SABS 0100-1 (1980) *The structural use of concrete, Part 1: Design,* The South African Bureau of Standards

► 10 British Standards Institution (1997) *BS 8110: Part 1: 1997, 'Structural use of Concrete, Part 1: Code of Practice for design and construction'*, London: BSI

► 11 Sim J., Cheolwoo P. and Moon D. Y. (2005) 'Characteristics of basalt fiber as a strengthening material for concrete structures', *Composites Part B: Engineering*, **36** (6-7), pp. 504-512

► 12 Li W. and Jingu X. (2009) 'Mechanical properties of basalt fiber reinforced geopolymeric concrete under impact loading', *Material Science and Engineering: A*, **505** (1-2), pp. 178-186