Sustainability of RCC Structures Using Basalt Composite Rebars

Dr. N. Subramanian, Consulting Engineer, Gaithersburg, MD, USA

The deterioration of reinforced concrete structures due to corrosion of steel reinforcements is well documented. Several improvements (e.g., galvanizing and coating) and alternate reinforcements (like carbon and glass fiber reinforced polymer bars) and have been tried in the past. The recent introduction of Basalt composite rebars, offers a number of advantages over the conventional steel bars as well as FRP bars. The details and properties of these bars are discussed in this paper along with their advantages and drawbacks. It is hoped that these light weight, non-corroding bars will be used in our constructions of the future, to attain sustainability of resources.

The Romans first invented what today we call hydraulic cement-based concrete. They built numerous concrete structures, including the Pantheon in Rome, one of the finest examples of Roman architecture that survives to this day, a 42 m diameter dome made of poured concrete. The name concrete comes from the Latin "concretus", which means to grow together. Today, concrete is one of the most widely used construction materials, besides steel and wood. About five billion tonnes of concrete are used around the world each year, enough for close to one tonne for each person per year, at a volume of about 400 liters per person (Garboczi , et al. 2010).

The main ingredients of concrete are cement, fine aggregates (e.g., sand), and coarse aggregates (e.g., gravel or crushed stone). When they are mixed with water, cement reacts chemically with water, called hydration, to form a hard, solid concrete composite. Concrete mix recipes vary, but most have compositions (in volumetric terms) in the range of about: 7%15% cement powder, 15%20% water, 0.5%8% air, 25%30% fine aggregates, and 30%50% coarse aggregates (Kosmatka et al. 2002).

It has always been known that concrete is a porous material, whose properties depend on its pore space. There are many different kinds of pores in concrete, ranging from the air voids that are entrapped in the mixing process, which can be quite large, up to a few millimeters in diameter, to the nanometer-scale capillary pores, which are essentially the space occupied by the leftover water from mixing[1].

Plain concrete has two major deficiencies: a low tensile strength and a low strain at fracture. The tensile strength of concrete is very low because plain concrete normally contains numerous micro-cracks. It is the rapid propagation of these micro-cracks under applied stress that is responsible for the low tensile strength of the material. These deficiencies have led to considerable research aimed at developing new approaches to modifying the brittle properties of concrete.[2] Reinforcements in the form of steel rods are often used to resist the tensile stresses developed in concrete, due to the applied forces.

It has been recognized that much of the concrete in the infrastructure in the U.S., India, and elsewhere has been deteriorating faster than expected, with much of this deterioration due to the corrosion of reinforcing steel coming from the ingress of chloride and other ions from road salts, marine environments, and ground soils. Corrosion costs U.S. industry and government agencies an estimated $276 billion/year (approximately 3.1 % of GDP), according to the study by CC Technologies for the Federal Highway Administration (Koch et al 2002). The corrosion map of India prepared by the Corrosion Advisory Bureau, Metals Research Committee (Council of Scientific & industrial Research) Jamshedpur is shown in Fig.1 (Subramanian 2000). A corroded reinforced concrete element in a typical marine application and a bridge structure is shown in Fig. 2. With more than 7000 Km of coastline, India has significant issues with salt water corrosion of its infrastructure. Air pollution and the resulting carbonation of concrete also contribute to corrosion. Humid climate in much of the country aids metallic corrosion. The cost of corrosion in India has been estimated to be 3% of its GDP $30 Billion.

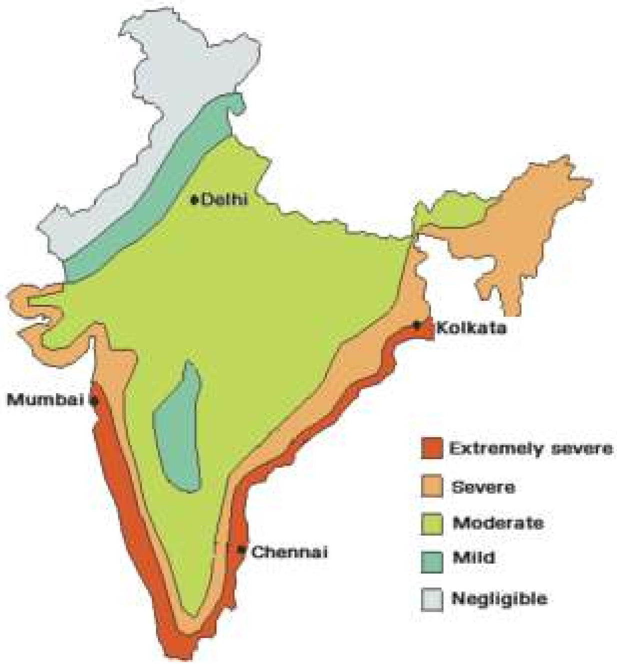

Fig.1 Corrosion Map of India

Fig. 2 Heavily corroded reinforcements in a typical marine structure, (b) Chloride-induced corrosion damage to a beam of the Brush Creek Bridge, USA

There are a wide variety of corrosion controlling technologies available in the world today each with its own special advantages, and economics. They include the following:

- Protective coatings and linings
- Metallic coatings and claddings
- Corrosion resistant alloys
- Corrosion inhibitors
- Cathodic & Anodic protection
- Corrosion resistant composites

DO YOU KNOW?

There are 583,000 bridges in the United States (1998). Of this total, 200,000 bridges are steel, 235,000 are conventional reinforced concrete, 108,000 bridges are constructed using prestressed concrete, and the balance is made using other materials of construction. Approximately 15 percent of the bridges are structurally deficient, primarily due to corrosion of steel and steel reinforcement. The annual direct cost of corrosion for highway bridges is estimated to be $8.3 billion, consisting of $3.8 billion to replace structurally deficient bridges over the next ten years, $2.0 billion for maintenance and cost of capital for concrete bridge decks, $2.0 billion for maintenance and cost of capital for concrete substructures (minus decks), and $0.5 billion for maintenance painting of steel bridges. Life-cycle analysis estimates indirect costs to the user due to traffic delays and lost productivity at more than ten times the direct cost of corrosion maintenance, repair, and rehabilitation.
Source: www.corrosioncost.com

With all these technologies, except the use of corrosion resistant composites, it is important to have periodic maintenance.

This article describes a new type of reinforcing bars, developed from basalt rocks, which are stronger than steel rods and at the same time are not prone to corrosion.

Basalt Composite Reinforcement (BCR)

Basalt Stone

Basalt is one of the most common rock types in the world. Basalt is a dark-colored (green or black), fine-grained, igneous rock composed mainly of plagioclase, pyroxene and olivine minerals and often has a glassy

Fig.3 Typical basalt stone and the Roman theatre in Bosra, Syria; the dark building stone is basalt.

appearance. The name "basalt" is usually given to a wide variety of dark-brown to black volcanic rocks, which form when molten lava from deep in the earth's crust rises up and solidifies. Basalt differs from granite in being a fine-grained extrusive rock and having a higher content of Iron and Magnesium. The ocean floor is almost completely made up of basalt. Most of the basalt found on Earth was produced in just three rock-forming environments: 1) oceanic divergent boundaries, 2) oceanic hotspots, and 3) mantle plumes and hotspots beneath continents (www.geology.com). Basalt rock has long been known for its thermal properties, strength and durability. The density of basalt rock is between 2.8 and 2.9 g/cm³. It is also extremely hard - 5 to 9 on Mho's scale. It is commonly crushed for use as an aggregate in construction projects. Crushed basalt is also used for road base, concrete aggregate, asphalt pavement aggregate, railroad ballast, filter stone in drain fields and may other purposes. Due to its superior abrasion resistance, thin slabs of basalt are cut and sometimes polished for use as floor tiles, building veneer, monuments and other stone objects (see Fig.3).

Basalt Fiber

Basalt fiber is made from extremely fine fibers of basalt, which is composed of the minerals plagioclase, pyroxene, and olivine. It is similar to carbon fiber and fiberglass, but having better physical and mechanical properties than fiberglass, and significantly cheaper than carbon fiber.

Basalt filaments are made by melting crushed volcanic basalt rock of a specific mineral mixture to about 1,400 to 1700 °C for 6 hours. The molten rock is then extruded through special platinum bushings to produce continuous filaments of basalt fiber. There are three main manufacturing techniques, which are centrifugal-blowing, centrifugal-multiroll and die-blowing. The fibers cool into hexagonal chains resulting in a resilient structure substantially stronger that steel or fiberglass. Its production creates no environmental waste and it is non-toxic in use, or recycling. The fibers typically have a filament diameter of 6, 9 and 13 µm.

The first attempts to produce basalt fiber were made in the United States in 1923. These were further developed after World War II by researchers in the USA, Europe and the Soviet Union especially for military and aerospace applications. The first industrial production of basalt continuous fiber (BCF) was launched in Kiev, Ukraine, during 1985. In 2000 the joint Ukraine-Japanese enterprise of BCF production was established. In addition to Japan, South Korea, China, Austria and USA are working on BCF technology. The EU and some other countries have basalt fiber research programs. The current annual production of BCF is about 3000-5000 tons (www.basaltfm.com).

Basalt Composite Rebars (BCR)

Basalt Composite Rebars are manufactured from continuous Basalt filaments, epoxy and polyester resins using a pultrusion process. It is 80% basalt rock fiber by weight, and balance is epoxy, Dacron winding and sand (www.withconcrete.com). It is a low-cost, high-strength, high-modulus, and corrosion-resistant alternative to steel for concrete reinforcement. BCR is a bar with continuous spiral ribbing, formed by a rolling basalt or kevlar thread, for better adhesion with concrete. Some of its properties are compared with Fe 415 steel bars in Table 1. The chemical composition of BCR is given in Table 2.

Steel is an isotropic material and hence the properties in the transverse and longitudinal direction are similar. But BCRs are anisotropic materials which imply the variation of mechanical properties in longitudinal and transverse direction. The anisotropy of the BCRs is the result of the fact that the longitudinal properties are governed by the fiber-properties whereas the transverse and shear properties are governed by the resin-properties.

Sl.No	Characteristics	SR (IS 1786:2008)	BCR	Comments
1	Density, g/cm^3	7.8	1.95	
2	Weight of 1 linear meter, kg 10mm diameter 12mm diameter	 0.617 0.888	 0.15 0.221	BCR in 4 times lighter than SR
3	Ultimate strength, N/mm^2 Tensile Compressive	 485 485	 1200 420	BCR is more than 2 times stronger than SR
4	Young's Modulus, GPa	200	52-57	
5	Thermal conductivity coefficient, kcal/(hr m °C)	38	0.35-0.59	BCR has 66-111 times less heat conductivity than SR
6	Coefficient of linear thermal expansion, 10^{-6} m/m K	12	1.0	Expansion of BCR is 12 times less than SR
7	Amount of 1 metric ton of rebars, linear meters 10mm diameter 12mm diameter	 1 621 1 126	 5 848 4 330	With BCR we can transport 4 times more rebars at a time
8	Percentage elongation	14.5	2.2	BCR not suitable for EQ zones
9	Poisson's Ratio	0.3	NA	

Table 1 Comparison of Steel Rebar (SR) with Basalt Composite Rebar (BCR)

Element	%
SiO_2	58.7
Al_2O_3	17.2
Fe_2O_3	10.3
MgO	3.82
CaO	8.04
Na_2O	3.34
K_2O	0.82
TiO_2	1.16
P_2O_5	0.28
MnO	0.16
Cr_2O_3	0.06

Table 2 Chemical composition of BCR

Advantages of BCR Over Steel or FRP Rebars

The advantages of BCR over steel or even FRP reinforcement are given below:

1. Much higher tensile strength than steel or fiberglass rebar of the same diameter: BCR is well over twice as strong in tension to prevent concrete cracking as grade 60 steel!
2. Strength + Zero rusting allows for thinner, lighter panels and decks: Since BCR does not rust or absorb water, the thickness of concrete cover can be reduced. This allows for thinner concrete sections, resulting in savings of materials and cost. Due to these properties BCR is an ideal choice for applications such as marine structures (see Fig.2), off-shore structures, parking structures, bridge decks, highway under extreme environments, and structures highly susceptible to corrosion (paper and chemical industries) and for pervious concrete pavements, which are used to reduce water retention or run off (Subramanian, 2008).
3. BCR is 89% lighter in weight than steel rebar (see Table 1); one tonne of basalt reinforcement rods provides the reinforcement of 9.6 tonnes of steel rebar. One man can easily lift a 150 m (500') coil of 10 mm BCR. Thus, we may not require hoists or forklifts to handle BCR supplies in many projects. Moreover, this results in much less fatigue for installation workers (compared to steel), and a reduction in injuries and medical expenses. Yet BCR is at least 2.2 times stronger than steel in tension.
4. BCR's light weight allows for much faster fabrication, installation, handling, and a better overall job.
5. Very high strength allows for smaller diameter reinforcement rods. In many cases, the diameter of the rebar may be reduced when using BCR. Smaller diameter rods allow more rods to be installed in critical structural designs.
6. BCR has the same thermal coefficient of expansion as concrete. Thus they Expand and contract at a rate very close to that of concrete.
7. BCR is naturally resistant to corrosion, rust, alkali, and acids (see Fig.4). Basalt Rebar is inert to a pH of 13. Since BCR cannot rust, spalling of concrete from moisture penetration is totally eliminated! Unlike FRP bars, BCR does not need a special coating to resist the high pH from exposure to concrete.
8. Basalt fibers do not absorb and transfer moisture like glass fibers. Hence, exposed fibers will not create a path for water to penetrate and destroy concrete.
9. BCR does not conduct electricity. This prevents electrolysis in marine applications.
10. BCR is non-magnetic and does not induce magnetic fields when exposed to electromagnetic or radiofrequency (RF) energy. Hence, it can be used in applications like magnetic resonance imaging (MRI) rooms and around Radio Frequency Identification (RFID) readers.

Fig.4 BCR bars compared with steel bars after exposure to environment

11. Basalt can be used in a wider temperature range, -260/-200 oC to about 650/800 oC, as the melting point is 1450 oC. Though, the resins in the BCR, limit the working temperature range as -70 °C to +100 °C, BCR is useful in applications that demand fire resistance. BCR also has low heat conductivity (Thermal conductivity is the quantity of heat transmitted through a unit thickness in a direction normal to a surface of unit area, due to a unit temperature gradient under steady state conditions), inflammable and does not emit any harmful substances on fire.
12. BCR can be cut easily to length in the field with common tools.
13. Use of BCRs, increases the life of reinforced concrete structures, resulting in sustainable structures. With these bars as reinforcements, we can now design RCC for a life span of 100 years or more.

Drawbacks and Field Handling Considerations

1. BCRs are brittle in nature (they do not stretch as far as steel bars before breaking); hence not suitable for use in earthquake prone areas.
2. Field bends are not allowed in BCR, and it is not-weldable.
3. BCRs are designed to be used in tension only, as their compressive and shear strengths are low.
4. As compared to steel, BCR has a lower Modulus of Elasticity. Panel deflection will be the limit to application. When pushed to its bending limit, it will just snap off cleanly. From a practical stand point, when installed in a properly engineered pour, the bending limit will be much higher than the crushing limit of the concrete, so in a properly engineered pour BCR's lower modulus is NOT an issue.
5. Unrolling BCR coils: Substantial kinetic energy is stored during the coiling process. Care must be exercised when uncoiling to prevent tangling and uncontrolled movement of ends. Coils are shipped with U clamps to allow uncoiling from the inside of the coil for safety reasons.
6. Cutting in the field: Bolt cutters are not recommended as they dull quickly and break themselves resulting in shattered steel. Cable cutters do work well on sizes 12mm and smaller, however frequent sharpening is required. Hacksaws or abrasive wheels will work. The best choice is an inexpensive, 4" battery circular saw with common inexpensive diamond tile blade. They last a long time for the money. Bulk cuts may be done with chop saw, or gas saw with a masonry blade, but wet saw is preferred.
7. Unlike steel, BCR are not ductile, and failure will be brittle, once the ultimate tensile strength is reached. It is therefore important to keep the (sustained) loads below the ultimate strength by an adequate margin of safety.
8. The cost of these bars may be higher than steel bars. The sales price of BCR is slightly more than that of FRP bars and less than that of epoxy coated steel.

Availability of BCR Rebars

Basalt/epoxy rebar is currently being pultruded in the Ukraine, and is in the process of being certified for U.S. construction. A few manufacturers have already started manufacturing Basalt rebars in USA. One of the products, with the name Rock RebarTM is marketed by Southwestern Composite Structures Inc. Another company, Sudaglass Fiber Technology (Houston, Texas), a basalt fiber producer with facilities in Russia and the Ukraine, has broken ground on a U.S. production facility in northern Texas.

Research and Specifications

The ACI Specification, ACI 440.6-08, does not cover BCR, as BCR has been introduced in the market only recently. However, ASTM testing of BCRs indicates that this material will easily meet the minimum performance requirements of ACI 440.6-08. Note that the specifications of BCR change as the diameter increases, with smaller-diameter rods generally having higher tensile strength and modulus of elasticity.

Under the sponsorship of the National Cooperative Highway Research Program (NCHRP), of Transportation research Board, USA, Prof. Ramakrishnan and his associates initiated a research project to study the performance of Basalt Fiber Reinforced Concrete and Basalt Rod Reinforced Concrete (Ramakrishnan et al 1998). Based on this study they concluded that it is feasible to make concrete beams reinforced with basalt composite rebars. However, they recommended that the bond between the bar and the concrete should be increased in order to increase the load carrying capacity of the beams. They also found that though the basalt bars possess a very high tensile strength, they do not have defined yield point and thus fail in a brittle manner. A typical stress-strain curve is shown in Fig.5. The failure of the rods is very sudden and explosive. However, the failure observed in the beams was a ductile, due to a gradual slip of the bars, thus preventing a brittle failure. In a subsequent project they studied the bond behaviour of BCRs with corrugations, barriers and anchors. From the test of seven beams, they concluded that BCRs are suitable for use in reinforced concrete structures, as the experimental ultimate moments were much higher than the first crack moment and adequate ductility was observed in the tests (Brik, 2003). The design of reinforced concrete elements using BCR could be done as is done using steel bars.

Another research carried out at the university of Akran on plain, 4-slot, and 8-slot basalt fiber rebars, as well as single-, double-, and triple-twisted cables using ASTM C-234 procedure showed improved bond and no slippage between concrete and rebars with slots. Similar results were obtained for twisted cables. The concrete failure was not caused by bond failure or slippage (Sudeep, 2009).

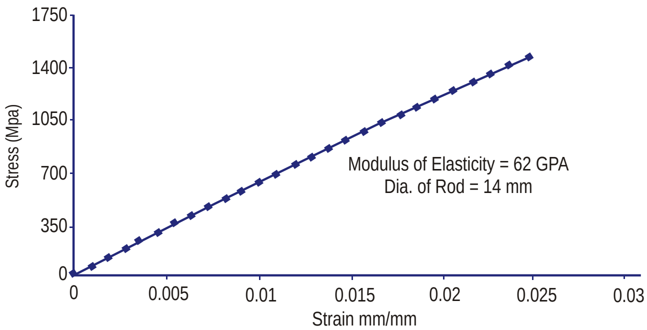

Fig. 5 Typical stress-strain curve for 14mm diameter BCR bar (Ramakrishnan et al, 1998)

Summary and Conclusions

Basalt composite rebars (BCR) have been introduced recently into the market as an alternative to steel bars. They offer a number of advantages over the conventional steel bars as well as FRP bars. Their light weight combined with non-corrosive nature will result in economic and sustainable reinforced concrete structures. BCR is an ideal choice for applications such as marine structures, off-shore structures, parking structures, bridge decks, highway under extreme environments, and structures highly susceptible to corrosion (paper and chemical industries) and for pervious concrete pavements.

References

Garboczi E.J., Bentz, D.P., Snyder, K.A., Martys, N.S., Stutzman, P.E., FeBCRaris, C.F., and Bullard, J.W., An electronic monograph: Modeling and measuring the structure and properties of cement based materials, Materials and Construction Research Division, Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, MD, Jan. 2010, 4189pp. http://ciks.cbt.nist.gov/garbocz/monograph/tablecontents.html. Retrieved 21st July 2010

Kosmatka, S.H., Kerkoff, B., and Panarese, W.C., Design and control of concrete mixtures, 14th ed., Portland Cement Association, Skokie, IL, 2002, 358 p.

Koch, G.H., Brongers, M.P.H., Thompson, N.G., Virmani, Y.P., and Payer, J.H. Corrosion costs and preventive strategies in the United states, Report no FHWA-RD-01-156,U.S. Department of Transportation, Federal Highway Administration, Washington D.C.,2002

Subramanian, N., Corrosion protection of steel structures, The Master Builder, Vol.2, No.1, Jan-Feb 2000, pp.63-66 and No.2, April-May 2000, pp.14-17.

www.basaltfm.com (Basalt Fiber & Composite Materials Technology Development Co. Ltd., Hong Kong)

www.withconcrete.com (RockRebarTM)

Subramanian, N., Pervious Concrete-A green Material that helps reduce water run-off and Pollution, The Indian Concrete Journal, Vol.82, No.12, Dec 2008, pp.16-34.

ACI 440.6-08: Specification for Carbon and Glass Fiber-Reinforced Polymer (FRP) Bar Materials for Concrete Reinforcement, 2008, 6pp., ACI 440.1 R-06, Guide for the design of concrete reinforced with FRP bars, 2006, 44pp., and ACI 440R-07, Report on FRP reinforcement for concrete structures, 2007, 100pp., American Concrete Institute, Farmington Hills, MI,

V. Ramakrishnan, Tolmare, N.S. and Brik, V.B.,, Performance Evaluation of 3-D Basalt Fiber Reinforced Concrete & Basalt Rod Reinforced Concrete, Final Report for Highway IDEA Project 45, Transportation Research Board of the National Academies, Washington D.C. Nov. 1998, 97pp. (http://onlinepubs.trb.org/ onlinepubs/archive/studies/idea/finalreports/highway/NCHRP045_Final_Report.pdf)

Brik, V.B., Advanced Concept Concrete using Basalt Fiber/BF composite Rebar reinforcement, Final Report for Highway IDEA Project 86, Transportation Research Board of the National Academies, Washington D.C., Feb 2003, 71pp.(http://onlinepubs.trb.org/onlinepubs/archive/studies/idea/finalreports/highway/NCHRP86_Final_Report.pdf)

Sudeep, A., Mechanical properties and flexural applications of Basalt fibre reinforced polymer (BFRP) bars, M.S. Thesis, University of Akron, Dec. 2009, 385pp.