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Basalt Rock Fiber Reinforcement

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***Abstract*: Basalt is one of the most common igneous rocks on the planet and is the only ingredient needed to make basalt fibers which in turn is converted into basalt rebars. Recent development in fiber production technology allows the making of basalt fibers which are made from basalt rock. Basalt bars commonly known as Basalt Fiber Reinforced Polymer (BFRP) is an innovative component, a new material, which can be used in construction and civil applications as an alternative material to steel rebar. This paper compares the test results of beams designed with steel rebar and basalt rebar using ETABS. As more testing is completed and more design aids become available, it will help engineers to include basalt rebars in projects. Its use will become more widely accepted.**

***Keywords*: Igneous, bondage, innovative, alternative.**

1. Introduction

In our day to day life and in this modern era we always find a good substitute for any material which is new, better and economical than the material which we are using on a daily basis. This material should be beneficial. Basalt rebar is one such material/product which can replace steel and prove beneficial to use. Basalt rebars are made from basalt rock which originates from volcanic magma and flood volcanoes, a very hot fluid or semi-fluid material under the earth crust, solidified in the open air. Basalt is a common term used for a variety of volcanic rock, which are gray and dark in colour. Basalt primarily comprises minerals plagioclase, pyroxene and olivine. When heated at high temperature, basalt is capable of producing a natural nucleating agent, which plays a major role in the thermal stability of the material. This leads to increased volumetric integrity when compared to other materials. Chemical composition of basalt rock is given in the table below.

Table 1

Chemical	%W
SiO_2	52.8
Al_2O_3	17.5
Fe_2O_3	10.3
MgO	4.63
CaO	8.59
Na_2O	3.34
K_2O	1.46
TiO_2	1.38
P_2O_5	0.28
MnO	0.16
Cr_2O_3	0.06

Basalt rebar is made from basalt fiber which is a high performance non-metallic fiber made from basalt rock melted at high temperature. The molten rock is then extruded through small nozzles to produce continuous filaments of basalt fiber. Basalt fibers have the following properties.

A. Properties of basalt fibers

1) Thermal Resistance

Basalt fiber has excellent thermal properties of that of a glass fiber. It can easily withstand the temperature of 1200°C to 1300°C for hours continuously, without any physical change.

Unstressed basalt fibers and fabrics can maintain their integrity even upto 1250°C, which makes them superior to glass and carbon fiber.

2) Mechanical strength

Basalt fiber has a tensile strength of 3000-4840 MPa. It has high stiffness and strength. Basalt fiber has slightly higher specific gravity, 2.6-2.8 g/cc, than other fibers.

3) Chemical Resistance

Basalt fibers have very good resistance against an alkaline environment, with the capability to withstand pH upto 13-14. It also has a good acid and salt resistance.

4) Corrosion and fungi Resistance

Basalt fiber has better corrosion resistance. It does not undergo any toxic reaction with water and air or gases also. Moisture regain and moisture content of basalt fibers exist in the range of less than 1%. Basalt materials have strong resistance against the action of fungi and microorganisms.

5) Abrasion Property

Basalt material is extremely hard and has hardness values between 5 to 9 on Mohr's scale, which results in better abrasion properties. Even continuous abrasion of basalt fiber-woven fabrics over the propeller type abraders does not result in the splitting of fiber by fracture and results only in breaking of individual fibers from woven structure which eliminates the possibility of causing hazards.

6) Ecological Friendliness

Basalt fibers have natural raw material, which is basalt rock; it does not cause any damage to health. Basalt fiber has no biological hazards and solves waste disposal problems. It does not clog the incinerator as glass. Hence, it is incinerator friendly.

Fig. 1. Basalt rock

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Fig. 2. Basalt fibers

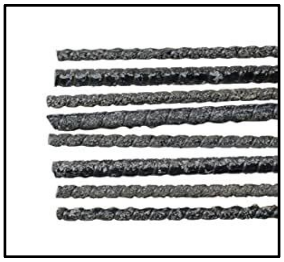

Fig. 3. Basalt bars

The notable characteristics of basalt rebars are mechanical properties, high tensile strength - up to 2.9 Gpa, Young's modulus -upto 90 GPa, Chemically inert, acidic, alkaline states, high thermal stability - effective in insulating, electrical and sound properties, less weight and reduced self-weight characteristics, low elastic-moduli when compared to other FRP composites and conventional steel (Values provided based on various literature studies, exact values are decided only by the manufacturer based on quality of materials involved in manufacturing). Basalt bar is 4 times lighter than steel reinforcement with equal strength characteristics, which significantly reduces transportation costs for shipping, loading and unloading, as well as operating expenses at the construction site.

2. Literature Review

Marek, et. Al., 2013 has done preliminary studies on BFRP rebars by testing its tensile test by unique testing equipment and analyzing the type of failure of BFRP strands and incorporating it to the failure modes in structures. Studies on stress-strain behavior were noted to be linear and completely different from steel reinforced structures which is considered to be a major disadvantage as structures involving large plastic deformations cannot be made by this kind of reinforcement. i) It discusses the Load - deflection, cracking behavior and stress limitation under BFRP Reinforced beams. ii) Different amounts of longitudinal reinforcement at bottom phase by 8 mm BFRP rebars is examined using M30/35 Grade. iii) Modulus of elasticity from the stress - strain curve was determined and was compared with conventional steel reinforced beam samples and showed that the elastic moduli of BFRP was about 5-7% smaller. iv) Along with the nature of crack and failure pattern, the width of crack formed during periodic loading was studied and was found to be of a higher value when compared to the steel reinforced sections. v) Based on loading pattern and failure criteria it was concluded that critical load carrying capacity was about 20-25% higher than conventional steel rebars. Ahmed and Farid, 2016 carried out investigation on concrete beams strengthened by Basalt rebars for their shear behavior by constructing 10 samples of beams (L=2000 mm; c/s = 152 mm × 254 mm) reinforced along longitudinal direction alone without any transverse reinforcement to test variability in terms of different geometry and level of reinforcement. Further the results were checked for acceptance according to standard values as per American standard codes (ACI-440.1R-15) which proved to be conservative. Also it clearly states the validity of design codes for determining the concrete contribution in shear strength of BFRP reinforced concrete beams. Behaviors of these various groups were analyzed in terms of (i) Strain variations during loading in both concrete and rebars. (ii) Detection measurement at mid span during loading (LVDT). (iii) Cracking loads and failure modes arising as a result of all these varied behaviors are thereby calculated. Pouya and Anil, 2015 carried out tests on progressive deformation in concrete due to sustained loading is analyzed along with exposure to alkaline solution at high temperatures and the results were compared with the acceptable standard values as per American Concrete Institute (ACI). It has been analyzed that the creep rupture strength of BFRP rebars are comparatively lesser than their tensile strength, when compared to that of steel bars. The creep nature of BFRP rebars depends on its own properties, resin and their bonding with each other. Ahmed, et al., 2015 studied the factors of bonding strength and behavior of BFRP rebars in concrete. The test was based on a pull out mechanism and the test results were incorporated with that of GFRP rebars. The bonding nature was compared with many parameters like, Embedded length intoconcrete surface; Material of bars and elasticity & Diameter of bars. Although BFRP and GFRP showed almost the same bond-slip curves, BFRP rebars showed an average of 75% increased bonding capacity than GFRP. The bonding behavior of BFRP rebars were studied based on (a) embedded length (b) modulus of elasticity (c) bar diameter, and was concluded by experimental verification that the bonding nature varied inversely in all the three parameters considered.

3. Methodology

1) Preparation of basalt rebars

With the help of the melting and extrusion process the basalt rock is first converted into basalt continuous filaments. Technological process of manufacturing basalt filament consists of melt preparation, fiber drawing (extrusion), fiber formation, application of lubricants and finally winding. Basalt fibers are currently manufactured by heating the basalt and extruding molten liquid through a die in the shape of fibers, as shown in plant layout figure.

Crushed rock material is put into a bath type melting furnace by a dozing charger, which is heated using air gas mixture or electrically. Crushed rocks are converted into melt under temperature 1285°C to 1450°C in the furnace bath. Molten basalt flows from furnace to feeder through feeder channel and feeder window communicating to recuperate. The feeder has a window with a flange connected to slot type bushing and is heated by furnace waste gases or by electrically. The melt flows through platinum-rhodium bushing with 200 holes which is heated electrically. The fibers are drawn from melt under hydrostatic pressure and subsequently cooled to get hardened filaments. A sizing liquid with components to impart strand integrity, lubricity and resin compatibility is applied, and then filaments are collected together to form ‘strand’ and forwarded to take up devices to wound on the forming tube. By varying the drawing speed of the fiber and temperature of the melt, fibers of a wide size range could be produced. For example, a drawing speed of 12m/s and nozzle temperature of 1325°C a fiber of 7 micron were produced while at 4m/s and 1285°C a fiber of 17 micron was produced. Later, the rebar is made using the pultrusion process (a continuous manufacturing process of pulling composite materials with constant cross-section through a die) to wet fibers typically using vinyl-ester or polyester resins. The basalt fibers are wetted with resin and then the bars are shaped and compacted.

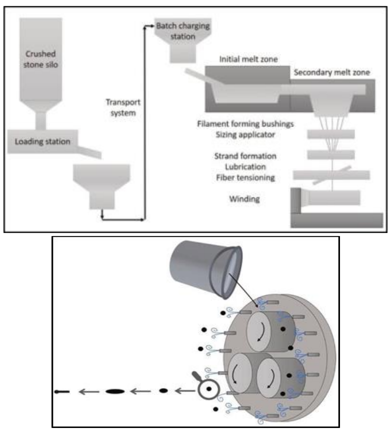

Fig. 4. Plant layout

2) ETABS

A beam is designed in an engineering software program ETABS. First, the material properties and data related to basalt rebar is put into the software. Next, the material properties of concrete are selected for M30 concrete. Beams are constructed and subsequent results are noted down.
Material properties of basalt rebar are:

Table 2
Properties

Properties	Value
Modulus of Elasticity	59.3 GPa
Poisson's ratio	0.22-0.25
Yield strength of 8⌀ bars	1210 MPa
Thermal modulus	Vertical (9-12)-10^-6/°C Lateral (21-22)-10^-6/°C
Density	1.9-2.1 kg/m^3

A beam is designed in ETABS. The simply supported beam has a width of 200mm and depth of 500mm and has a span of 5m. The beam is subjected to point load and udl of 5 KN/m. The beam is revised as a fixed beam and again subjected to point load and udl of same intensity. First the settings of ETABS are set as per Indian Standard code. The IS unit is set to metric and steel design code is selected as IS 800:2007 whereas concrete design code is selected as IS 456:2000. Next the axes were selected and set to the desired value of 2 in X direction and 1 in Y direction. Spacing of grid in X direction was set as 5 whereas in Y direction as 1. The typical storey height was set to 1. The material property is then selected for concrete, steel rebar and basalt rebar. Grade used is M30 for concrete, rebar used is Fe500 and mild steel 250. A new material is defined for basalt rebar in the software where the material properties of basalt are fed into the software. The section properties of the concrete beam are selected as rectangular and the dimensions of 200mm x 500mm are set. Cover at the top and bottom of about 25mm is set up.

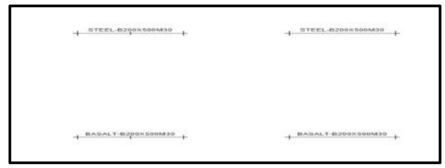

Fig. 5. Section

After allocating all the material and section properties select the line displayed on the screen to convert it into a beam reinforced with steel. Again the steps are repeated for developing beam reinforced with basalt rebar. Joints, hinged and roller support, are then assigned to both the beams. Next, the loadings are assigned to the beams. Uniformly distributed load of 5 KN/m is assigned to the simply supported beams. Consequently, keeping the load intensity the same the udl is later converted to point load for further analysis of simply supported beams. To get clear results the beam was again revised into a fixed beam subjected to udl and point load of same intensity.

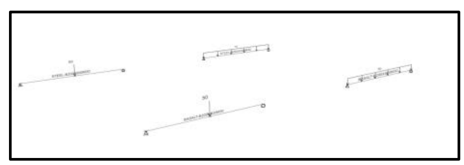

Fig. 6. Loading diagram with simple support

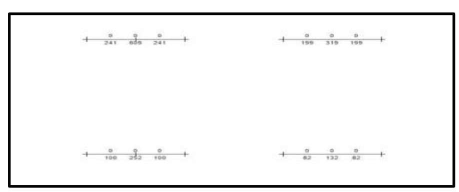

Fig. 7. Bottom reinforcement

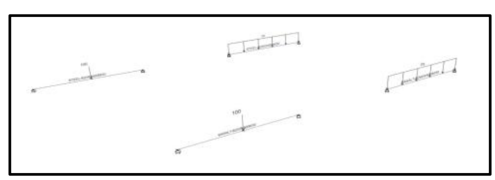

Fig. 8. Loading diagram with ends fixed

Towards the end, for the analysis purpose enable all the joint checks and frame checks. Run the analysis to check for possible errors. The results obtained from all the designed beams are noted and compared to conclude the report.

Table 3
Bars

Beams	Loading (KN/m)	Shear Force (KN)	Bending Moment (KN-m)	Deflections (mm)
SS with udl-basalt bars	10	25	31.25	1.415
SS with udl-steel bars	10	25	31.25	0.539
SS with point load-basalt bars	50	25	62.5	2.348
SS with point load-steel bars	50	25	62.5	0.894
Fixed with udl-basalt bars	20	50	41.667	0.548
Fixed with udl-steel bars	20	50	41.667	0.209
Fixed with point load-basalt bars	100	50	62.5	1.273
Fixed with point load-steel bars	100	50	62.5	0.435

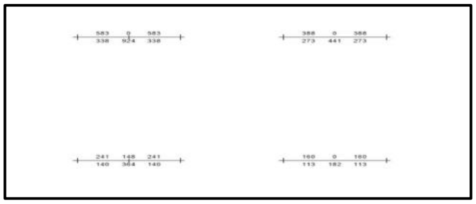

Fig. 9. Top and bottom reinforcement

4. Results and Discussion

Basalt rebar weighs 4 times less than steel rebar and its tensile strength is 3 times higher. Basalt rebars are manufactured from basalt fibers by pultrusion technology. The surface is profiled and sanded. This kind of surface treatment results in a better adhesion in concrete. Basalt rebars are produced in diameters from 4 mm to 16 mm and the length of the bar ranges from 500 m to 800 m. Basalt rebar is resistant to corrosive environments. However, typical corrosion happens to steel materials. Therefore at least 4 cm concrete layers are needed to keep the steel reinforcement safe. In case of basalt rebar concrete, the covering layer is reduced to 1 cm. Basalt rebars reduce tensile stress which is used to prevent sudden break with long term loaded bars.

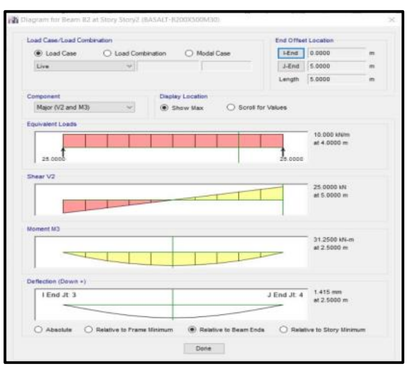

Fig. 11. Analysis of simply supported beam with udl-basalt bars

For this research paper, the beams were designed on ETABS. Four different beams reinforced with basalt rebars with varying loads were tested and results of the same were noted down and compared with the beams reinforced with steel rebars. Shear force, bending moment and deflections occurring in the beam were noted for comparison. The overall performance of the basalt rebar with respect to steel rebars reinforced in M30 concrete beams was good. Although, the results show that the deflections in beams reinforced with steel bars was much less as compared to beams reinforced with basalt rebars. As per IS 13920, clause 5.3.1.b percentage elongation of bars used should be more than 14.5. However, the basalt bars have a lengthening percentage of about 2.7 only. Also, the modulus of elasticity of basalt bars is 59.3 GPa whereas that of steel bars is 200 GPa. The following figure of simply supported beams subjected to udl of 10 KN/m is shown as a part of the result.

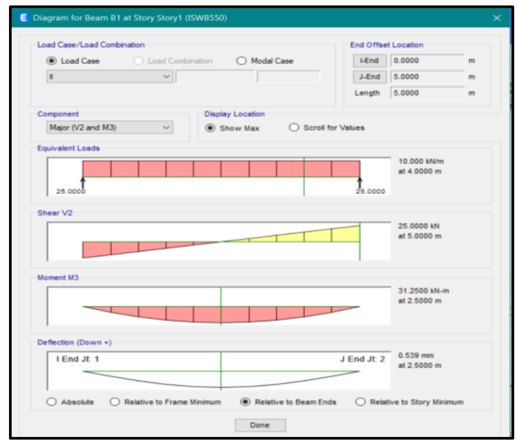

Fig. 12. Analysis of simply supported beam with udl-steel bars

5. Conclusion

The properties of basalt fibre and basalt rebars were studied in which it was observed that basalt fibres are definitely a potential building material having higher thermal stability and higher mechanical properties. Basalt can be used in manufacturing and made into fine, superfine, ultrafine fibers. Basalt is an alternative raw material for fiber forming because of its relatively homogenous chemical structure, its large scale availability throughout the world, its freedom from impurities and of course its ability to form fibers in molten state. The fibers have good thermal resistance, mechanical strength, chemical resistance, corrosion and fungi resistance, abrasion properties, ecological friendliness which in turn imparts all these properties to the basalt bars which are formed from the fibers. The basalt bars are light in weight which results in saving concrete and allows a lightweight construction. With basalt rebars, the concrete reinforcement contains mainly a natural raw material which does not need a separation after the end of the lifecycle of reinforced concrete. It needs no special coating like glass fiber rods. Smaller rods allow for more critical spacing and designs. On average 60% less CO_2 emission in final concrete structures due to production process, logistics and material optimization. It can be used in civil applications like marine, underground water tanks, bridges and chemical factories. This product acts as corrosion resistant in those environments. Basalt is well known as a rock found in every country round the world. Basalt rock is more in India (especially in Maharashtra). The cost of basalt is 10 times lower than that of raw materials for fiberglass. Basalt is more available than any other raw material. Thus, it is possible to install this technology in India (Maharashtra).

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