Basalt Fibre Reinforced Concrete an Alternative to the Synthetic Fiber Reinforced Concrete

Puneet Kumar Shrivastav[1] Kshitij Tare[2]
[1]Resident Engineer [2]M.E Scholar
[1,2]Department of Civil Engineering
[1]AECOM- Rodic Consultant Pvt. Ltd (JV) [2]UIT-RGPV, Bhopal

Abstract— The cost of tensile member of concrete has always attracted attention of civil engineers to be supplemented by some cheaper material. This paper focuses the advantages of using naturally available material namely basalt as fibre reinforcement to enhance the strength as well as reinforcement akin properties in the concrete. Basalt an igneous origin rock has excellent load bearing properties can be a choice for massive concrete works in the construction industry. In the paper the engineering properties of basalt fibres are worked out experimentally and were discussed as a comparable choice of already in use synthetic fiber materials. Basalt being cheap and easily available fibre may be used for the construction of structural units with cement-paste or cement mortar / concrete composites have great potential, especially for developing countries.

Key words: Cement, Composites, Compression, Mechanical Properties, Basalt and Natural Fibre, Tensile-Strength, Shrinkage, Slump

I. INTRODUCTION

Concrete is a brittle material having high compressive strength but a low tensile / flexural strength and strain capacity resulting in shrinkage and cracking. Concrete in service may exhibit failure through cracks which are developed due to brittleness i.e. the mechanical behavior of the concrete is critically influenced by crack development and their sub-sequential propagation. To improve stress – strain related properties of concrete fibre reinforced concrete (FRC) have been developed. Fibre reinforced concretes are defined as concrete containing dispersed randomly oriented fibres. Fibres in cement or in concrete serve as crack arrestor which can create a stage of slow crack propagation and gradual failure.

Fibre reinforced concrete is a cement-based composite material that has been developed in recent years. The major advantage of fibre reinforcement is to impart additional energy absorbing capability and to transform a brittle material into a pseudo-ductile material. FRC has been successfully used in construction with its excellent performance towards flexural-tensile strength, resistance to splitting, impact resistance, excellent permeability and frost resistance. It is an effective way to increase toughness, shock resistance, and resistance to plastic shrinkage cracking of the mortar.

Strength and behavior of the FRCs are highly dependent on the characteristics of the fibre reinforced. The properties of concrete matrix and of the fibres greatly influence the character and performance of FRC. The behavioral efficiency of such compact mass is much different to that of plain concrete and many other construction materials of similar nature. Peculiar properties of FRC contributes its increased application during the past few decades and its current field of application includes: airport and highway pavements, earthquake-resistant structures and explosive-resistant structures, mine strengthening and tunnel linings, bridge deck overlays, hydraulic structures and slope stabilization. Extensive research work on FRC has established that addition of various types of fibre such as steel, glass, synthetic, carbon etc., in plain concrete alters and in most of the cases improves strength, toughness, ductility, post-cracking resistance, etc.

II. HISTORY TIME LINE

The use of fibres for strengthening of brittle materials as reinforcement is evident from B.C. Historically. 3000 BC: Egyptians Used mud mixed with straw to bind dried bricks. They also used gypsum mortars and mortars of lime in the pyramids. Chinese Used cementitious materials to hold bamboo together in their boats and in the Great Wall. During 300 BC Babylonians & As Syrians used reed in asphalt to bind stones and bricks. In 476 AD Romans Used pozzolana cement from Pozzuoli, Italy to build the Appian Way, Roman baths, the Coliseum and Pantheon. During the Middle Ages 1000 - 1500: the quality of cementing materials deteriorated resulting in the scare use of burning lime and pozzolan (admixture). Application of masonry mortar and plaster reinforced using horsehair are quite common. 1678: Joseph Moxon wrote about a hidden fire in heated lime that appears upon the addition of water. In early 19 century Louis Vicat of France prepared artificial hydraulic lime by calcining synthetic mixtures of limestone and clay. In the year 1824: Joseph Aspdin of England invented Portland cement by burning finely ground chalk with finely divided clay in a lime kiln until carbon dioxide was driven off. Later few decades were to develop the quality of concrete. In 1836 test procedure for the tensile and compressive strength of concrete were developed in Germany and in 1867: Joseph Monier of France reinforced flower pots with wire ushering in the idea of iron reinforcing bars (re-bar). In 1880 J. Grant of England has chemically analyzed the key ingredients of concrete to show the importance of the hardest and densest portions of the clinker. Later in 1887 Henri Le Chatelier of France established oxide ratios to decide the proper amount of lime for portland cement. During 20 century air entraining agents were introduced to improve concrete's resistance to freeze/thaw damage.

In the early 1900s, asbestos fibres were used in concrete, and in the 1950s the concept of composite materials came into being and fibre reinforced concrete was one of the topics of interest. There was a need to find a replacement for the asbestos used in concrete and other building materials once the occupational health risks (asbestosis) associated with the substance were discovered. By the 1960s, steel, glass and synthetic fibres such as polypropylene fibres were used in concrete. Following the research trends later in 1970 first time Fibre reinforcement in concrete was introduced. This leads to the development of Super plasticizers as admixtures in 1980. In 1985 Silica fume was introduced as a pozzolanic additive. The "highest strength" concrete was used in building the Union Plaza constructed in Seattle, Washington. 1992 The tallest reinforced concrete building in the world was constructed at Chicago and research into new fibre reinforced concretes continues today.

III. Effects of Fibre in Concrete

Fibre reinforced concrete composite properties such as crack resistance, reinforcement and increase in toughness are dependent upon the Physical and chemical properties of reinforcement material, mechanical and bonding properties of the fibre and matrix, as well as the quantity, distribution and Strength of bond within the matrix of the fibres.

Fibres are usually used in concrete to control plastic and drying shrinkage cracking. They also lower the permeability of concrete and thus reduce bleeding of water. Some types of fibres produce greater impact, abrasion and shatter resistance in concrete. Some fibres reduce the strength of concrete. The actual amount of fibres needed to add into a concrete mass is determined by actual characteristic test in the laboratory. The quantity of fibre added is measured as a percentage of the total volume of the composite (concrete and fibres) termed volume fraction (I_f). V_f typically ranges from 0.1 to 3%. Aspect ratio (l/d) is calculated by dividing fibre length (l) by its diameter (d). Fibres with a non-circular cross section are described using an equivalent diameter for the calculation of aspect ratio. If the modulus of elasticity of the fibre is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material. Increase in the aspect ratio of the fibre usually segments the flexural strength and toughness of the matrix.

For a good quality FRC mass the fibres should be homogeneously distributed throughout the given cross sections area or most specifically in control volume containing the reinforcement bars placed where they are required. The fibres should be short and closely packed whereas the reinforcing bars continuous. fibres are divided into two types, one with the EM of fibres less than the EM of the matrix: i.e. cellulose fibre, polypropylene fibre, polyacrylonitrile fibre, etc.; and second with the EM of fibres is greater than the EM of the matrix: i.e. asbestos fibres, glass fibre, steel fibre, carbon fibre, aramid fibre, etc. It has been pointed out that low modulus fibres such as naturally occurring and synthetic organic fibres, when added to cement paste and concrete, do not produce composites with tensile or compressive strength significantly greater than that of the matrix as do high modulus fibres such as steel and glass.

IV. Basalt Concrete Fibre

Basalt concrete fibre (BCF) is an all-natural inorganic fibre material that originates from volcanic rock. Being naturally available, BCF has natural chemical and thermal stability and does not possess any known health risks. Basalt rock is melted at high-temperature (1450 °C) and rapidly drawn into a continuous fibre and chopped into various desirable lengths. Its color can vary between brown, gold, or gray. Basalt has a 3-dimentional molecule and when compared with single infiltrating linear Polymeric fibres, it has higher anti-compressive strength, shear strength, adaptability in any harsh environment, anti-aging, as well as other excellent characteristics. The basic characteristics of Basalt materials are high-temperature (up to 700ºC) corrosion resistance, resistance to acids and alkalis, high strength and thermal stability anti-oxidation, anti-radiation, it is thermal, electrical and sound insulated, anti-compression strength and high shear strength, sufficient availability, and good cost performance enabling it suitable for construction industry.

V. Analysis of Test Results

The raw material used for molding the cubes consist of Cement, Coarse aggregate: granite stone size: 5~25mm, sand with fineness modulus - 2.6, Water, Additive (super-plasticizer), Grade A fly ash and Chopped basalt fibres respectively (table-1). Concrete mixing is done in two separate batches with above ingredients for 3 minutes followed by 1 minute vibration. A total of 28 moulds at the rate of 7 moulds per test mix with 28 days curing were prepared for testing the following engineering properties of basalt fibre mixed concrete.

1) Slump test to find out workability
2) Compressive strength ratio (Cubical mould)
3) Flexural strength ratio
4) Splitting Tensile strength ratio
5) Coefficient of impermeability
6) Shrinkage ratio
7) Anti-shock resistance

VI. Result and Discussion

Sample	Properties						
	1	2	3	4	5	6	7
A*	195	88.0	76.0	65.2	28	82	89
B	179	90.7	91.2	92.4	34	83	110
C	175	93.1	93.4	97.6	39	85	143
D	167	94.8	97.3	99.5	44	87	178

Table 1: Engineering Properties of Sample

*The properties of blank sample are treated as reference

The test results of specimen of basalt fiber reinforced concrete are tabulated in table -2. The following points are worth discussion with reference to the outcomes:

Sample Concrete Mix		Cement	Fly Ash	Sand	Stone	Water	Additive	Basalt Fiber	
								Quantity	Size, µm
A	Blank Concrete	350	50	546	890	140	6	0	
B	Basalt Fiber concrete	350	50	546	890	140	6	1.0	12-15

C	Basalt Fiber concrete	350	50	546	890	140	6	2.0	15-18
D	Basalt Fiber Concrete	350	50	546	890	140	6	3.0	18-21

Table 2: Test Mix Design (kg/m^3)

1) The result analysis shows that the increasing amount of basalt fibres eventually prevents the disintegration of concrete and greatly improves the cohesive properties and Impermeability, slightly lower the slump of concrete, but the rate of changes are not linear.
2) In the case of similar volumes, the addition of fibres slightly increases the compression strength of concrete, flexural strength and splitting tensile. However, some times the relative increase is proportionate.
3) The compressive strength of concrete with fibre is higher than concrete without fibre. Putting fibres into concrete can ease the effect of inner stress caused by the change of temperature.
4) Adding fibres can make up for the concrete brittleness and improves the shock resistance since the fibres are thin and thereby their specific surface area is large.
5) When concrete receives an impact load, the fibres can mitigate the concentration of stress within inner crack tip and effectively impede the rapid development of breaks, absorb kinetics of impact, thereby improving the impact performance.
6) Fibres, which are well mixed and distributed throughout the concrete, can have a “support” effect, and reduces the water separating out, as well as the aggregate segregation. Thus the impermeability of basalt fibre reinforced concrete is improved.
7) Fibre reduces the initial original cracks in concrete. The obvious crack resistance effect improves the impermeability capacity of fibre reinforced concrete. In the case of similar volumes, basalt fibre has a better impermeability capacity than polypropylene fibre.
8) The 28-day shrinkage of fibre reinforced concrete has no obvious change as compared with benchmark concrete. After mixing fibre with chaos distribution, the plastic shrinkage of concrete is effectively restrained, and the energy of shrinkage is separated to the fibres. The result is high tensile strength, low elastic modulus, increased toughness, and control of the production and development of micro-fractures within the concrete.
9) The drying shrinkage of concrete is caused by water loss. When fibre is mixed, as fibre exists in surface material, water loss area is reduced, moisture difficultly moves, therefore capillary tension, produced by the traction of the capillary’s water loss.
10) Bonding and mechanical meshing strength between the fibre and cement can increase anti-shrinkage and cracking, as well as reduce shrinkage and deformation.
11) Basalt fibre has small diameter and length. With equal quality, more quantity of fibre results in an increased surface area. As the cohesive surface between the fibre and cement increases, the cohesive force improves with it. As the fibre receives more plastic crack stress; its plastic crack performance resistance increases.
12) From the test result, the properties of basalt fibre noticeably change as its quantity increased. However, in this experiment the optimum quantity of basalt fibre is not worked out. However, the volume of basalt fibre as 3.0 kg/m^3 has shown good workability and can be adopted.
13) Basalt fibre for cement and concrete is a competitive alternative product of polypropylene fibre and polyacrylonitrile fibre. Being a typical ceramic fibre (with length of fibre less than 5 µm, elongation 3.3 %, relative density 2.65 and moisture content about 0.1%) it’s easy to disperse when mixed with cement concrete and mortar. Fresh basalt fibre reinforced concrete has good characteristics, such as volume stability, good workability, good stability, excellent thermal resistance, anti-seepage, crack resistance and impact resistance. Therefore, basalt fibre reinforced concrete serves the functions of reinforcement, crack resistance, and can extend the life of construction in the fields of housing, bridges, highways, railways, urban elevated roads, runways, ports, subway tunnels, the coastal protection works, plant facilities.

VII. Conclusion

From the test situation, basalt fibre can be a good alternate for polypropylene fibre and polyacrylonitrile fibre. Currently, environmental protection and conservation of resources are more critical; therefore, naturally originating basalt fibre reinforced concrete will have a growing importance in the construction field.

1) With its excellent properties, such as crack resistance, impact resistance, impermeability and shrinkage resistance, basalt fibre is helpful for improving durability and increasing the working life of concrete. Although using fibre will increase the cost of one cubic meter of concrete, when considering the improved properties of concrete with fibre, the extended working life, then its total cost is reduced. Removal of additives can also be worked out based on experimental study to lower the working cost of BCF.
2) The application field of high performance concrete is growing, but the brittle and crack performance of common concrete is more serious. Fibre can hinder early plastic cracking and shrinkage cracking and effectively improves properties of High Strength Concrete. Therefore, it has broad application prospects.
3) Basalt fibre has no adverse effects when mixing, pouring and shaping. It can also improve the cohesion and stability of concrete.
4) Fibre increases the impact resistance of concrete, lowers its brittleness, so it can be used in road and

bridge surface engineering in order to improve the mechanical property of concrete.

5) Basalt fibre can improve impermeability and anti-contractility of concrete as compared with organic fibres.
6) Inorganic basalt fibre has better anti-aging properties. Therefore, basalt reinforced concrete is a kind of representative High Performance Concrete. As a result of its improved durability and long-term performance, it can be used in the field of port deep water pier, bridge and cold regions.

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