Test Report of
Basalt Fiber Reinforced Concrete and Polypropylene Fiber Reinforced Concrete, Polyacrylonitrile fiber reinforced concrete

1. Foreword

Concrete is widely used in structural engineering with its high compressive strength, low cost and abundant raw material. But common concrete has some shortcomings, for example, shrinkage and cracking, low tensile and flexural strength, poor toughness, high brittleness, low shock resistance and so on, that restrict its applications. To overcome these deficiencies, additional materials are added to improve the performance of concrete.

Fiber reinforced concrete is a cement-based composite material that has been developed in recent years. It has been successfully used in construction with its excellent flexural-tensile strength, resistance to splitting, impact resistance and excellent permeability, and frost resistance. It is an effective way to increase toughness, shock resistance, and resistance to plastic shrinkage cracking of the mortar.

Fiber reinforced concrete composite properties, such as crack resistance, reinforcement and increase in toughness are dependent on the mechanical properties of the fiber, bonding properties of the fiber and matrix, as well as the quantity and distribution within the matrix of the fibers. In relation to the elastic modulus, fibers are divided into two types, those where the elastic modulus of fibers is less than the elastic modulus of the matrix: ie. cellulose fiber, polypropylene fiber, polyacrylonitrile fiber, etc.; and those where the elastic modulus of fibers is greater than the elastic modulus of the matrix: ie. asbestos fibers, glass fiber, steel fiber, carbon fiber, aramid fiber, etc. Basalt fiber is a new material that has been increasingly used in recent years.

Basalt fiber (BCF) is an inorganic fiber material. It is an all-natural material and originates from volcanic rock. Basalt rock is melted at high-temperature (1450 ° C) and rapidly drawn into a continuous fiber. It then can be chopped into various lengths. Its color can vary between brown, gold, or gray. The basic characteristics of Basalt materials are high-temperature resistance, high corrosion resistance, resistance to acids and alkalis, high strength and thermal stability. Basalt materials can be used as a reinforcing composite material for the construction industry, specifically as a less expensive alternative to carbon fiber.

These tests examine the performance of Basalt Chopped Strands (BCS), reinforced concrete. The tests will also compare and analyze the reinforcement performance with polypropylene and polyacrylonitrile fibers.

2. Brief introduction of Basalt Fiber (BCF)

In addition to high specific strength, high specific modulus, BCF also has excellent temperature resistance (-260~700□), anti-oxidation, anti-radiation, thermal and sound insulation, filtration, anti-compression strength and high shear strength, high availability, and good cost performance. It is found in nature as an inorganic non-metal material, and is a new basic material and high-tech fiber that can satisfy the demand for the development of basic infrastructures.

The technical specifications of basalt fiber are laid out in table 1 and table 2. (1) The naturalness of raw material. Since the raw material of BCF is naturally found in the form of volcanic extrusive rock, it has natural chemical and thermal stability and does not possess any known health risks. (2) Comprehensiveness of performance. Basalt fiber is a “multi-performance” fiber. For example, it is resistant to alkalis and acids; it is thermally, electrically and sound insulated; its tensile strength can be greater than large-tow carbon fiber, its elongation is better than small-tow carbon fiber.

Basalt has a 3-dimentional molecule and when compared with single infiltrating linear polymeric fibers, it has higher anti-compressive strength, shear strength, adaptability in any harsh environment, anti-aging, as well as other excellent characteristics. (3) Cost effectivness. Basalt fiber for cement and concrete is not expensive, it is a competitive alternative product of polypropylene fiber and polyacrylonitrile fiber. (4) Natural compatibility. Basalt fiber is a typical ceramic fiber, it’s easy to disperse when mixed with cement concrete and mortar. Fresh basalt fiber 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 fiber 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. BCF is natural material and will bring revolutionary changes in construction and transportation.

Table 1: main technical indicators of BCF

No	performance	Number
1	Thermo-physical properties	
	working temperature, ℃	-269～700℃
	bond temperature, ℃	1050℃
	Thermal Conductivity, w/m.°K	0.03～0.038
2	physical properties	
	filament diameter(μm)	7～15
	density (kg/m^3)	2650
	elastic modulus(kg/mm^2)	10000～11000
	Tensile strength（MPa）	4150～4800
	Tensile strength under heat treatment, %	
	20 ℃	100
	200℃	95
	400℃	82
3	Chemical stability (weightlessness in 3-hour boiling) , %	
	2N HCl	2.2
	2N NaOH	6.0
	H_2O	0.2

Table 2: comparison of properties among basalt fiber and other fibers

fibers	density (g/cm^3)	Mechanical strength (MPa)	Elastic modulus (GPa)	elongation (%)
Glass fiber				
A-glass	2.46	3310	69	4.8
C-glass	2.46	3310	69	4.8
E-glass	2.60	3450	76	4.76
S2-glass	2.49	4830	97	5.15
silicon fiber	2.16	206~412	——	——
quartz fiber	2.20	3438	——	——
carbon fiber				
large-tow	1.74	3620	228	1.59
middle-tow	1.80	5100	241	2.11
small-tow	1.80	6210	297	2.20
Aromatic polyamide fiber		3620	41.4	3.6
Kevlar 29	1.44	3480		1.5
Kevlar 149	1.47			
polypropylene fiber	0.91	270-650	38	15-18
polyacrylonitrile fiber	1.18	500-910	75	11-20
basalt fiber	2.65	4150~4800	100~110	3.3

3.Experimental Study

3.1 Content

These tests examined the effect of different quantities of fibers mixed in the concrete:

(1).Effect on working concrete (slump) when (BCF) is added;

(2).Effect of basalt fiber on the cubic compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, and static compression of concrete;

(3).Effect of basalt fiber on impact resistance of concrete;

(4).Effect of basalt fiber on impermeability, frost-resistant properties, shrinkage of concrete;

(5).Effect of basalt fiber on early anti-shrinkage cracks of concrete;

(6).Combining the results of previous tests, comparing the properties of basalt fiber reinforced concrete with polypropylene fiber and polyacrylonitrile fiber reinforced concrete.

3.2 Raw material

(1).Cement:

(2).Coarse aggregate: granite stone size: 5~25mm

(3).fine aggregate: sand size modulus: 2.6

(4).water: common water

(5).Additive: superplasticizer

(6).fly ash: grade A ash

(7).Chopped basalt strand: .

2# mixing basalt fiber: diameter - 17μm, length – 12mm, quantity: 1kg/m^3;

3# mixing basalt fiber: diameter - 15μm, length – 18mm, quantity: 3kg/m^3;

(8).Polypropylene fiber, diameter: 31μm, length: 19mm, trefoil shaped, density: 0.91kg/m^3

(9).Polyacrylonitrile fiber, diameter: 1.9dtex, length: 6mm. density: 1.18kg/m^3

Table 3: Main parameters of BCF

Properties	BCF	
Moisture(%)	0.1	
Proportion (relative density)	2.65	
Length of fiber	＞5μm	
elongation(%)	3.3	

Heat reflect and burning situation	no combustion	
acid and alkali resistance	Better	
Tensile Strength (cN/tex) （1cN/tex=11.8MPa）	＞66.3	

3.3 Tests

(1) Fresh concrete slump test.

□ The compressive strength, flexural strength, splitting tensile strength and elastic modulus of static pressure of concrete were tested;

□ Impermeability, frost resistance (slow-freezing method), the shrinkage, and result of concrete were tested. The ordinary concrete's long-term performance and durability were tested;

□ Cement mortar anti-shrinkage and crack performance were tested. Cement mortar crack resistance was tested. Crack resistance index and crack effectiveness were tested. Technical Specification of fiber reinforced concrete structure was tested;

□ Concrete anti-impact performance test and result were assessed according to the American Concrete Institute's ACI一544. Fiber reinforced concrete performance was tested.

Hammer quality: 4.45kg, descent height: 1000mm, the hammer dropped on the steel ball with Φ63.5mm of the specimen, the impact loading transmits to the specimen across the steel ball. The size of the specimen is φ150mm×64mm (cut from a cube specimen with 200mm length, after removal of surface shape 50mm), 3 specimens in a group. Test result: after cracking by dropping hammer, when the cleft width of the specimen is more than 3mm, record the crack times, test result is the average of 3 data.

3.4 System of mixing

Concrete: fine aggregate + cement + fiber + water + additive + coarse aggregate, mix for 3 minutes. Concrete was vibration formed by using a shaking table.

3.5 Test mix is in table 4 and table 5

Table 4: test mix (kg/m^3)

Fibres Unlimited B.V. ● Oude Apeldoornseweg 69 ● 8171 LV Vaassen ● The Netherlands
Telephone: +31 (0)578 569950 ● Fax: +31 (0)578 569955
Bank (Euros): ABN AMRO 48.40.75.004 ● Bank (US Dollars): ABN AMRO 41.99.26.925 ● BIC: ABNANL2A
VAT: NL8169.01.144.BO1 ● Chamber of Commerce: 08148636

No.		cement	Fly ash	sand	stone	water	JC-2	fiber
1	Blank concrete	420	60	656	1069	175	7.2	/
2	Basalt fiber concrete	420	60	656	1069	175	7.2	1.0
3	Basalt fiber concrete	420	60	656	1069	175	7.2	3.0
4	Polypropylene fiber oncrete	420	60	656	1069	175	7.2	0.9

Table 5: test mix (kg/m^3)

No.		cement	sand	stone	water	Additive	fiber
5	Blank concrete	450	666	1184	150	4.5	/
6	Polyacrylonitrile fiber	450	666	1184	150	4.5	1.0

4.Test result

4.1 Test result of concrete slump containing different fibers, different mixing quantities and no fiber is in table 6.

Table 6: influence of mixing fiber on fresh concrete slump

No.	slump（mm）
1.Blank concrete	190
2.Basalt fiber concrete	180
3.Basalt fiber concrete	175
4.Polypropylene fiber oncrete	180
5.Blank concrete	185
6.Polyacrylonitrile fiber	165

4.2 Test result on the influence of the concrete slump with different fibers, different mixing quantities and without fibers on compression strength ratio, flexural strength ratio, splitting tensile strength ratio, frost resistance, antifreeze performance, impermeability, shrinkage, shock resistance and shrinkage/cracking properties of cement mortar is found in table 7.

Table 7: the influence of mixed fibers on compression strength, flexural strength, splitting tensile strength, impermeability, shrinkage, antifreeze performance, shock resistance and shrinkage cracking properties of cement mortar

No	compression strength ratio	flexural strength ratio	splitting tensile strength ratio	Improved coefficient of impermeability	Shrinkage ratio	antifreeze performance	anti-shock resistance	shrinkage cracking properties of cement mortar	
						Strength loss rate ratio		Crack lower coefficient	Limited effectiveness of split grades
2	92.8	93.8	98.3	35	97	90	133	47	3rd class
3	99.4	101.9	101.2	50	100	54	210	61	2nd class
4	99.8	100.9	100.2	40	97	48	193	58	2nd class
6	99.0	100.0	102.6	56	86	11	162	73	1st class

Remarks: ①Compression strength ratio – percentage of compression strength of concrete with basalt and concrete without fiber of the same class;

 Flexural strength ratio - percentage of flexural strength of concrete with basalt and concrete without fiber;

 Splitting tensile strength ratio - percentage of splitting tensile of concrete with basalt and concrete without fiber;

 Improved coefficient of impermeability caculated by type (1):

$$\lambda = \frac{D_{m0} - D_{m1}}{D_{m0}} \times 100 \quad \text{(1)}$$

λ——Improved coefficient of impermeability, %

D_{m1} ——seepage height of tested concrete, mm;

D_{m0} ——seepage height of benchmark concrete, mm.

 Anti-shock resistance caulculated by type (2)

$$C_j = \frac{N_1}{N_0} \times 100 \quad (2)$$

C_j ——anti-shock resistance of concrete, %

N_1 ——devastating impact times of tested concrete, time

N_0 ——devastating impact times of benchmark concrete, time

 Shrinkage ratio – shrinkage of concrete with basalt and concrete without fiber;

 Strength loss rate ratio in antifreeze performance - strength loss rate ratio of concrete with basalt and concrete without fiber;

 Crack lower coefficient was tested;

 Limited effectiveness of split grades was tested.

5. Analysis of test results

5.1 After putting fibers into concrete, as the fibers evenly distribute in concrete, they effectively prevent the disintegration of concrete and greatly improve the cohesive properties and impermeability, slightly lower the slump of concrete, but reducing degree is poor. In this respect, Basalt fiber and polypropylene fiber are basically the same, while polyacrylonitrile fiber has a greater rate of decline.

5.2 In the case of similar volumes, the addition of fibers slightly lowers the compression strength of concrete, reducing degree of the 3 fibers is basically same. In the case of lower volumes (1.0kg/m^2), reducing degree of compression strength is greater.

5.3 In the case of similar volumes, addition of the 3 fibers caused nearly no change of flexural strength, splitting tensile. In the case of lower volumes (1.0kg/m^2), the flexural strength and splitting tensile is lower. Adding fibers can make up for the concrete brittleness.

5.4 Putting fibers into concrete improves the shock resistance. After adding fibers into concrete, the fiber is thin and the specific surface area is large, the quantity of fibers in unit volume is big, they compose the 3D chaos distribution construction. This well mixed chaos network system helps to improve absorbed the kinetics of impact. When concrete receives an impact load, the fibers can mitigate the concentration of stress within inner crack tip and effectively impede the

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rapid development of breaks, absorb kinetics of impact, thereby improving the impact performance. In the case of similar volumes, improving the impact performance of basalt fiber reinforced concrete is higher.

5.5 After 25 freeze-thaw cycles, the compressive strength loss of concrete with fiber is less than concrete without fiber. Putting fibers into concrete can ease the effect of inner stress caused by the change of temperature, avoid temperature break to expend. At the same time air is put in during the process of mix, it increases the air content increasing and improves the anti-freeze performance. Within the 3 fibers, the freeze performance of polyacrylonitrile fiber is best. In the case of similar volumes of mixed fibers and after 25 freeze-thaw cycles, the compressive strength loss of concrete with basalt fiber and polypropylene fiber is the same.

5.6 Impermeability of fiber reinforced concrete is improved. Fibers, 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. This greatly reduces the microporosity content. Fiber reduces the initial original cracks in concrete. The obvious crack resistance effect improves the impermeability capacity of fiber reinforced concrete. In the case of similar volumes, basalt fiber has a better impermeability capacity than polypropylene fiber.

5.7 The 28-day shrinkage of fiber reinforced concrete has no obvious change as compared with benchmark concrete. After mixing fiber with chaos distribution, the plastic shrinkage of concrete is effectively restrained, and the energy of shrinkage is separated to the fibers. The result is high tensile strength, low elastic modulus, increased toughness, and control of the production and development of micro-fractures within the concrete. The drying shrinkage of concrete is caused by water loss. When fiber is mixed, as fiber 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. Bonding and mechanical meshing strength between the fiber and cement can increase anti-shrinkage and cracking, as well as reduce shrinkage and deformation. In the case of similar volumes, shrinkage and deformation resistance of polyacrylonitrile fiber is best, whereas basalt fiber and polypropylene fiber is equal.

5.8 The shrinkage cracking properties of fiber mixed, cement mortar is improved. Mixed fiber in concrete is distributed in a state of chaos. It reduces the shrinkage stress of concrete, increases its cohesive property, effectively avoids its segregation, makes water hard to move, and reduces the possibility of break caused by plastic shrinkage of cement mortar. By increasing the volume of fiber, plastic break of the mortar is reduced. Basalt fiber has small diameter and length. With equal quality, more quantity of fiber results in an increased surface area. As the cohesive surface between the fiber and cement increases, the cohesive force improves with it. As the fiber receives more plastic crack stress, its plastic crack performance resistance increases. In the case of similar volumes, the shrinkage cracking properties of basalt fiber and polypropylene fiber is equal, but due to the fact that the size of the polyacrylonitrile fiber is small and the length is short, then the quantity of fiber in unit volume will be high. Therefore, the early shrinkage cracking property is improved.

5.9 From the test result, the properties test result of basalt fiber, polypropylene fiber, and polyacrylonitrile fiber is same. The performance of concrete does not noticeably change when the volume does not reach a certain quantity. Certain properties of basalt fiber, such as impact resistance, are better than both polypropylene fiber and polyacrylonitrile fiber. The preferred volume of basalt fiber is 3.0kg/m^3.

6 Conclusion

From the test data:

（1） From the test situation, basalt fiber can totally replace polypropylene fiber and polyacrylonitrile fiber. Currently, environmental protection and conservation of resources are more critical, therefore, basalt fiber reinforced concrete will have a growing presence in the construction field;

（2） With its excellent properties, such as crack resistance, impact resistance, impermeability and freeze resistance, basalt fiber is helpful for improving durability and increasing the working life of concrete. Although using fiber will increase the cost of one cubic meter of concrete, when considering the improved properties of concrete with fiber, the extended working life, then its total cost is reduced;

（3） The application field of high performance concrete is growing, but the brittle and crack performance of common concrete is more serious. Fiber can hinder early plastic cracking and shrinkage cracking, and effectively improve properties of High Strength Concrete. Therefore, it has broad application prospects;

（4） Basalt fiber has no adverse effects when mixing, pouring and shaping. It can also improve the cohesion and stability of concrete;

（5） Fiber 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;

（6） Basalt fiber can improve impermeability, freeze-thaw cycles and anti contractility of concrete. As compared with organic polypropylene fiber and polyacrylonitrile fiber, inorganic basalt fiber 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 deepwater pier, bridge and cold regions.

7 Description

(1) Since the sample sizes in this test were small , the advantages of fiber, such as splitting resistance, are preliminary. Additional testing should be performed.

(2) Because of the various sizes of the different fibers, and the fact that size will directly influence the test results, then the effects of different fiber sizes should be compared.