Experimental Research on Mechanical Properties of Basalt Fiber Reinforced Composites

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Abstract: Basalt Fiber has a good prospect in civil engineering because of its excellent mechanical properties, physical properties and lower prices. Many types of basalt fiber reinforced polymer (BFRP) including sheet, plate and rod, can be made by compounding fiber and epoxy resin. In order to apply BFRP reasonably and scientifically in practical engineering, it is necessary to know its mechanical properties well. The mechanical properties of BFRP sheet and bar are mainly studied in this paper. The influences of various parameters on the mechanical properties of BFRP are discussed in detail. The results may provide a reference for manufacturers, further research and engineering applications.

Keyword：Basalt Fiber; composite fiber; mechanical properties

1 Introduction

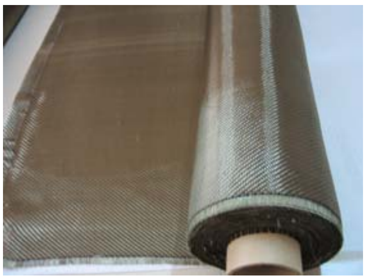
Continuous basalt fiber (CBF or BF) is a kind of inorganic fibers. It is made from basalt rock with glassy state that is formed when volcanic eruption, and then melted in high temperature, rapidly drawn to fibers. It is golden brown. There are outstanding characteristics of basalt fiber: high temperature resistance, ablative resistance, good acid-proof & alkaline-proof, and thermal stability. Especially, in applications of constructional engineering, compared with carbon fiber, basalt fiber has advantage of cost performance. It is a new basic material and high-tech fiber that can satisfy the development requirements in national economy basic industry [1]~[5].

The application researches of basalt fiber in civil engineering domestic and abroad is in preliminary stage. Thus, researches on mechanical performances of basalt fiber reinforced plastics (BFRP) are very important [3]~[5].

2 Basalt fiber composites

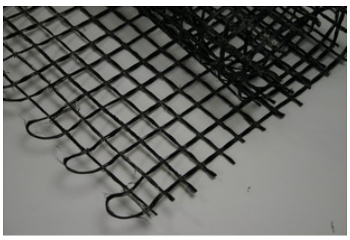
Compared with other fibers, the applied patterns of basalt fiber in civil engineering include chopped strand basalt fiber, sheet, section bar, panel, bar (rod), cable, etc. as picture 1. This paper focuses on experimental research on chemical performances of basalt fiber sheets and bars which are typical, and discusses each parameter impacting the chemical performances.

（a） Basalt fiber chopped strands

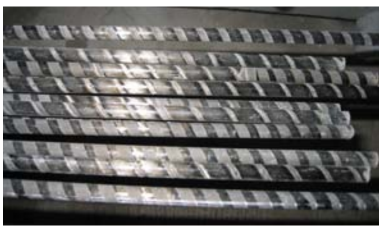


（b）Fiber sheets

（c）Roving



（d）Grids



（e）Bars

（f）Plates

Picture 1 Types of basalt fiber

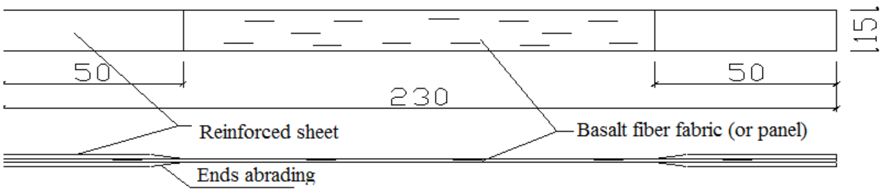
3 Chemical performances of basalt fiber sheet and analysis on influencing parameters

3.1 Introduction of basalt fiber unidirectional fabric

The weaving method of basalt fiber unidirectional fabric is the same as other fiber fabrics'. But the knitting tightness is thicker than other fiber fabrics, e.g. carbon fiber fabric. The calculated thickness t is needed in the property experiment of unidirectional fabric, whose method is to use volume density (ρ_v) to divide unit area weight (ρ). The test method of unit area weight refers to the specification of JG/T 167-2004.

3.2 Tensile experiment of BFRP fabric

The unidirectional tensile specimen of basalt fiber fabric is made according to the standard of GB/T 3354-1999, as picture 2. The length of specimen is 230mm, width is 15mm. The experiment is taken with Reger universal testing machine, the loading speed is controlled as 2mm/min. The displacement meter is fixed in the middle of specimen to test the elongation. The load is continued to add until specimen is broken. Picture 3 is the photo.



Picture 2 Measurement of specimen

Take several typical data to analyze the impact of parameters on BFRP mechanical property, such as types of basalt fiber fabrics and resin, basalt fiber diameters, etc.

（a）Fiber fabric specimen

（b）Tensile of fiber fabric specimen

Picture 3 Specimen photos

3.3 The influence effect of production technology of basalt fiber fabric on BFRP fabric mechanical property

Table 1 shows the productions made by basalt fiber manufacturers during early stage. The calculated thickness is 0.1mm. Total 10 specimens are used in tensile experiment. The max tensile strength is 1207.9MPa, the minimum is 629.4MPa. The difference is 578.5MPa; the calculated average value is 924.3MPa; the mean-square deviation is 153.1MPa; and the coefficient of variation is 0.166. The elastic modulus and ultimate elongation are measured, owning similar regularity. As a whole, these productions don't have so satisfied performances; especially the discreteness is too large, which isn't suitable for using in practical engineering.

Table 1 The experimental data of initial basalt fiber fabrics (impregnated in imported glue)（Group A）

Test No.	Test area （mm²）	Maximum load（N）	Tensile strength （MPa）	Elastic modulus （MPa）	Breaking elongation （%）
1	1.5	1237.7	825.1	59176.9	1.39
2	1.5	1322.4	881.6	55398.0	1.66
3	1.5	1305.3	870.2	63000.2	1.57
4	1.5	944.1	629.4	67157.1	1.05
5	1.5	1811.8	1207.8	60349.6	2.33
6	1.5	1366.7	911.1	67057.0	1.37
7	1.5	1623.4	1082.3	61347.0	3.49
8	1.5	1337.4	891.6	71598.6	1.28
9	1.5	1308.1	872.1	59058.7	1.43
10	1.5	1607.9	1071.9	54475.7	2.30
Average value	1.5	1386.5	924.3	61861.8	1.60
Mean-square deviation	-	-	153.10	5427.00	0.76
Coefficient of variation	-	-	0.166	0.088	0.480

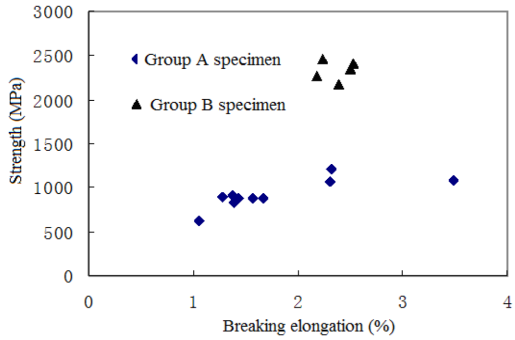
Table 2 The experimental data of basalt fiber fabrics after production technology improved

(impregnated in imported glue)（Group B）

Test No.	Test area （mm²）	Maximum load（N）	Tensile strength （MPa）	Elastic modulus （MPa）	Breaking elongation （%）
1	1.785	4049.0	2268.3	94115.6	2.18
2	1.785	4194.2	2349.7	94159.6	2.50
3	1.785	4305.3	2412.0	100377.5	2.53
4	1.785	3861.0	2163.0	100321.0	2.39
5	1.785	4399.3	2464.6	138917.5	2.23
Average value	1.785	4161.8	2331.5	105578.3	2.37
Mean-square deviation	-	-	118.90	18894.00	0.16
Coefficient of variation	-	-	0.051	0.179	0.066

Table 2 is the result of property experiment for the newest produced basalt fiber fabrics after technology improved. The max tensile strength is 2464.6MPa, the minimum is 2163.0MPa. The difference is 301.6MPa; the calculated average value is 2331.5MPa; the mean-square deviation is 118.9MPa; and the coefficient of variation is 0.051. Strength, elastic modulus and breaking elongation are improved obviously.

The experimental results comparison between group A & B specimens is as picture 4.



Picture 4 Experimental results distribution map of group A & B specimens

From table 1 & 2 and picture 4, the performance of initial products are worse and more discreteness; while the improved products are better strength, elastic modulus and elongation. Shown from pertinent data abroad, the tensile strength of basalt fiber made in Ukraine and Canada can reach 3500MPa～4840MPa. It indicates that along with the improvements of basalt fiber production technology in China and weaving technology of basalt fiber unidirectional fabric, the mechanical performance indexes of BFRP are expected to better.

3.4 The influence of resin types on mechanical performance of basalt fiber fabric

In order to research the influence of resin types on BFRP mechanical performance, two kinds of resin glues are chosen in experiment. One is group B specimen impregnated by TXD-750 impregnate glue made by Mitsubishi Corporation Japan; the other is group C specimen, impregnated by domestic resin; all of whose mechanical property indexes are satisfied with standards and specifications. The mechanical indexes of two kinds of materials are in table 3. The experimental data of group C specimen is in table 4.

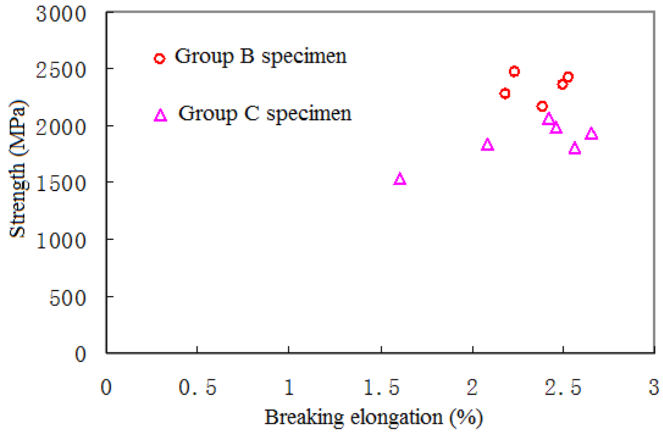
Table 3 The experimental data of basalt fiber fabrics after production technology improved

(impregnated in domestic resin)（Group C）

Test No.	Test area （mm^2）	Maximum load（N）	Tensile strength （MPa）	Elastic modulus （MPa）	Breaking elongation （%）
1	1.785	2728.5	1528.6	95442.7	1.61
2	1.785	2820.1	1579.9	—	—
3	1.785	3294.4	1845.6	89735.2	2.08
4	1.785	3455.9	1936.1	87454.5	2.65
5	1.785	3211.5	1799.1	88380.8	2.57
6	1.785	3698.6	2072.0	90247.2	2.42
7	1.785	3529.4	1977.2	85531.3	2.47
Average value	1.785	3248.3	1819.8	89465.3	2.30
Mean-square deviation	-	-	176.80	3379.5	0.39
Coefficient of variation	-	-	0.097	0.038	0.170

Note: There’s no test data for No. 2 specimen, for the strain meter is something wrong.

The compared results of property experiment between group B & C specimens is in picture 5.



Picture 5 Experimental results distribution map of group B & C specimens

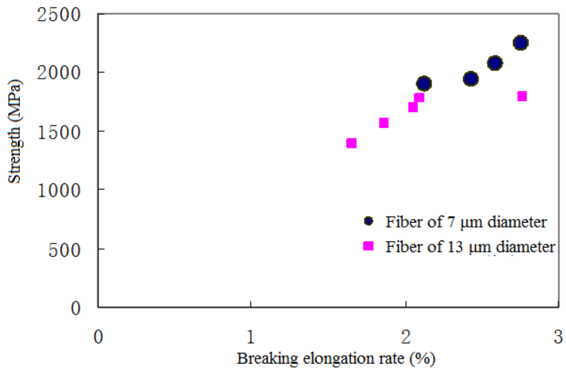
The tensile experimental data of group B & C as BFRP sheets impregnated by imported resin TXD-75 and a domestic resin is shown as table 4 and picture 5. For group B specimen, the average tensile strength is 2331.5MPa, mean-square deviation is 118.90 MPa, and coefficient of variation is 0.051; for group C specimen, the average tensile strength is 1819.8MPa, mean-square deviation is 176.80MPa, and coefficient of variation is 0.097. According to above, the ultimate tensile strength, elastic modulus and ultimate tensile strain of group B specimen impregnated with imported resin are better than group C specimen's. The reasons are: (1) During the production process of continuous basalt fiber, there is sizing with 0.4% ratio around fibers. Matching problem exists between sizing and resin used for BFRP sheet. If resin is well matched with sizing, the adhesion stress after composited is strong, the co-work performance of BFRP composites is outstanding, and the mechanical property index of BFRP is high. Otherwise, the index is low. (2) The internal properties of impregnated resin also affect the performance of BFRP fabric, such as elongation, curing shrinkage rate. Large resin elongation can ensure co-work perfectly before BFRP is broken. If the elongation of resin is small, the resin will be partly broken prematurely, results to reduce mechanical property index of BFRP fabric. Because the ultimate strain of carbon fiber fabric is less than that of basalt fiber fabric, there's lower demand of resin elongation rate for carbon fiber fabric. In this experiment, the elongation rate of TXD-750 is larger than the domestic resin's, so the composited BFRP fabric with former resin has better mechanical performance.

3.5 The influence of fiber diameters on mechanical performance of basalt fiber fabric

There are several diameters for basalt fibers: 7μm, 13μm, 15μm, etc. This experiment uses unidirectional fabrics weaving with 7μm &13μm diameters fibers. The same epoxy resin of TXD-750 is impregnated for two kinds of fiber fabrics, in the same condition, with the same calculated thickness 0.107mm. The tested data is in table 4. In order to easily describe, we call basalt fiber fabric with 13μm diameter fibers as CBF-13, and call fabric with 7μm as CBF-7. The experiment results' comparison is as picture 6.

Table 4 The experimental data of basalt fiber fabrics with different diameters

Specimen	Fiber diameter（μm）	Tensile strength（MPa）	Elastic modulus（GPa）	Breaking elongation rate（%）
CBF-13	13	1392	88470	1.66
		1567	84157	1.87
		1789	78539	2.41
		1698	90523	2.06
		1773	80724	2.10
CBF-7	7	1932	77019	2.43
		2240	86698	2.76
		2077	84255	2.59
		1904	91689	2.13



Picture 6 Experimental results distribution map of fabric with different fiber diameters

Analyzing the experimental data in table 4 and picture 6, we can see that: (1) The tensile strength of basalt fiber fabric with CBF-7 is 2038MPa, and breaking elongation rate is 2.48%; while the tensile strength of fabric with CBF-13 is 1643MPa, and breaking elongation rate is 2.09%. Then tensile strength and ultimate strain of CBF-7 are better than that of CBF-13; (2) The elastic modulus of CBF-7 is 84.9GPa, and CBF-13 is 84.5GPa. There is little difference between both. The possible reasons are: (1) With the same material, larger the fiber filament diameter is, less quantity fibers are distributed in the same size specimen, and smaller the bonding area is when impregnated in resin. Thus, this reduces the whole loading effect to a certain degree, then results to lower strength; (2) In fibers' treating process, impacted by technology, raw material, etc. internal defects of large diameter filament are more than small diameter ones. That is to say the filament strength of 13μm basalt fiber is already less than strength of 7μm basalt fiber. So the corresponding BFRP sheet has the lower strength.

Basically, there's no great difference of damaged type between two kinds of fibers. Mostly, the fractures of fibers are threadlike in the middle of specimen. Small part of fibers are broken and extracted from the clamped terminal ends.

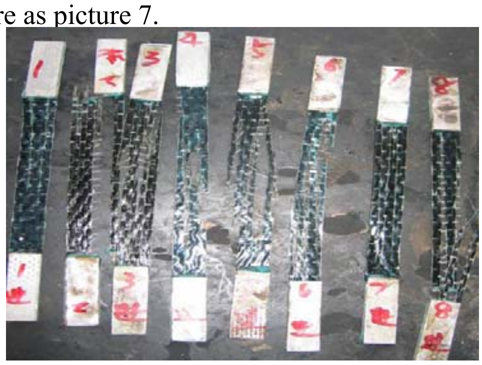
3.6 Other effect factors

From above experiment, besides resin and filament diameter, which influence mechanical performance of basalt fiber unidirectional fabric, there is still an important effect factor that is weaving method. Before unidirectional fabric is impregnated in resin, each basalt fiber tows are straightened and tight. During impregnated process, they are coated by brush. These tows are bended and tilted after rolling, results that solidified tows can't co-work and strength lower. However, for carbon fiber unidirectional fabric, the weaving quality is better, so there're fewer problems like this. After carbon fibers become to finished productions with impregnation, the tows can be still straight, tight and appropriately ranged. Regarding to this, weaving method can also largely affect mechanical performance.

3.7 Damage characteristic

Several damage types appear in experiment. Most of sheets in the middle of specimen are drawn into threadiness. Parts of sheets are broken at the clamped terminal ends because of stress concentration. Small parts are slipped out from ends. Still small parts are fractured one side due to uneven loading, and then the rest of tows continue to fracture. The damaged phenomena are as picture 7.

（a）Damage of sheet specimen



（b）Damage photos of specimens

Picture 7 The damage photos of basalt fiber sheet

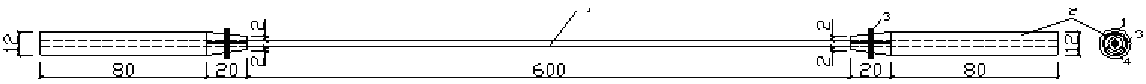
3.8 Proposed standard value

Take the improved basalt fiber unidirectional fabric as example, with 95% guarantee rate, strength standard value of BFRP: $f_k = \mu_f - 1.645\sigma_f$. The average value of group C specimen impregnated with a domestic resin is 1819.8MPa, Mean-square deviation is 176.8. It can be calculated as $f_k = 1529.0MPa$, it could be $f_k = 1500MPa$. For group B specimen with imported resin impregnated, it can be calculated as $f_k = 2135.9MPa$, and could be $f_k = 2100MPa$.

4 Basalt fiber bars

4.1 The mechanical performance of basalt fiber bars

In the tensile experiment for basalt fiber bars, three specimens are made as 3mm bars. The machine is Reger universal testing machine, with 2mm/min as controlling speed. Free length of specimen is 600mm. In order to avoid slip from clamped terminal ends during experiment, both ends of bars are anchored in sleeves with structural adhesive. Small deformation sensor is put in the middle of specimen to test the strain. The tested mechanical property indexes are in table 5. The basalt fiber filaments are the early production from manufacture. The specimen for tension is as picture 8. Experiment schematic and damage photos are as picture 9.

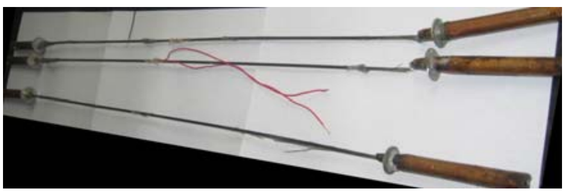


1- Basalt fiber bar φ 3mm
2-Thickness of copper sleeve, external diameter φ 12mm
3- Q235 strengthened sheet thickness 2mm, external diameter φ15mm, inner diameter φ 8*10mm, bonded with copper sleeve using structural adhesive
4- Structural adhesive

Picture 8 Specimen for tension

Table 5 Mechanical performance of 3mm basalt fiber bars

Specimen No. (No)	Area (mm^2)	Maximum load (N)	Tensile strength (MPa)	Elastic modulus (MPa)	Breaking elongation rate (%)
1	7.07	6050.3	853.5	39989.9	2.17
2	7.07	6853.6	968.9	28619.5	2.67
3	7.07	6067.4	854.7	34223.2	2.22
Average	—	—	892.4	34277.5	2.67



（a）Tensile photo （b） Part of destruction photo (c) General failure photo

Picture 9 Experiment and damage schematics of 3mm diameter basalt fiber bars

Two basalt fiber bars of 8mm diameter with nicks are also made. They can be anchored with ordinary clamping pieces. Their maximum loadings are 9500N & 8432N, strength are 189.1MPa & 167.0MPa. The result isn't so perfect. The reason is analyzed that resin in BFRP bars is not matched with sizing using in filaments producing, and the production technology also doesn't reach the standard. But the new material has been improved and the further experiments have been taking.

5 Suggestions and prospect

Comparison of mechanical performances among basalt fiber fabrics and other fiber composites (fabrics) is in table 6. The applications of carbon fibers, aramid fibers and glass fibers are matured in engineering. PBO fibers and Dyneema fibers are developed recently in Japan. Seen from the table, all kinds of fiber fabrics have their own characteristics. Such as, carbon fiber fabric has high strength and elastic modulus; Dyneema fiber fabric has good ductility and energy absorption capacity. The mechanical property of basalt fiber fabric is close to aramid fiber fabric's and glass fiber fabric's, but with better physical properties.

Basalt fiber is a new kind of materials, also a kind of naturally green inorganic material. Our country has rich mineral resources, and masters the core manufacture technology. We should give deep researches, objective publicity, reasonable applications and play its advantages, such as low price, inorganic and ductility. However, the substandard phenomena must be forbidden that parts of illegal construction enterprises use basalt fibers in engineering, for falsely saying as carbon fibers. Along with technology improving in producing basalt fiber and composites, the performances are expected to be better. Standards should be formulated as soon as possible. There should be compared researches with other fibers and hybrid fibers.

Table 6 Comparison of basic mechanical performance among basalt fiber and other fibers

Type of fiber fabric	Thickness （mm）	Designed strength (MPa)	Elastic module (GPa)	Elongation rate (%)
High-strength carbon fiber fabric	0.111	3550	235	1.5
High-elastic module carbon fiber fabric	0.143	2000	550	0.4
Aramid fiber fabric	0.193	2100	120	1.8
Glass fiber fabric	0.118	1500	74	2.0
PBO fiber fabric	0.128	3500	235	1.5
Dyneema fiber fabric	0.258	1800	60	3.0
Basalt fiber fabric	0.119	2100	90	2.3

6 Conclusions

This paper briefly introduces the experimental results of basic mechanical performance of basalt fiber reinforced plastics (BFRP), and analyzes the possible factors influencing basic performances. The research results can be referenced for manufacturers. There are some reference values for further researching continuous basalt fibers. It is good for the application and dissemination of basalt fiber in civil engineering.

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