ISSN 1027-5495. Functional Materials, 29, No.3 (2022), p. 393-400.
doi:https://doi.org/10.15407/fm29.02.393

Study on properties of basalt fiber composite filter material

Li Guo, Xinwen Wang

School of Civil Engineering, Luoyang Institute of Science and Technology, Luoyang, 471023 Henan, China

Received June 25, 2022

The composite filter material of basalt is studied and analyzed in this paper. In this paper, the advantages of basalt are studied. According to the research, the overall performance of basalt filter is better than that of other materials, reaching about 64.74 %. The research in this paper lays a foundation for the future research of basalt composite filter materials.

Keywords: basalt fiberm, composite filter material, material performance research.

Дослідження властивостей фільтрувального матеріалу з композиційного базальтового волокна. *Li Guo, Xinwen Wang*

В роботі досліджено і проаналізовано композиційний фільтраційний матеріал з базальту. Визначено переваги базальту. Згідно результатам досліджень, основні характеристики базальтових фільтрів є кращими в порівнянні з іншими матеріалами, з ефективністю близько 64,74 %. Дослідження цієї роботи закладають основу подальших розробок базальтокомпозитних фільтрувальних матеріалів.

1. Introduction

The development of natural degradable green composite materials has become a new growth point of composite materials research. The raw materials for producing basalt fiber are basalt, diabase and amphibole, which are widely distributed and abundant in China. The chemical composition of basalt fiber is characterized by high content of alumina, ferric oxide, titanium dioxide and sodium oxide [1–2]. It has porous structure and irregular arrangement. Pores in basalt fibers can be divided into closed pores and open pores, which are spherical and tubular respectively. It has the characteristics of small specific gravity, high porosity, large specific surface area, especially strong acid and alkali corrosion resistance, non-toxicity, incombustibility and excellent mechanical properties. After degradation, it becomes a parent material of soil, so it is environmentally friendly [3–4].

This paper uses a variety of research methods to study and analyze it. In the research of basalt material, the corresponding model diagram and algorithm formula are established for research and analysis.

Basalt is a dense or foamy rock formed by the cooling and solidification of magma from volcanic eruption. Because of its dense texture, its density is heavier than ordinary granite, limestone, sandstone and shale [5–6]. Continuous basalt fiber is an inorganic fiber [7–8]. It is a kind of continuous fiber made from volcanic eruption rocks (including basalt and andesite) formed by volcanic eruption and condensation, which is quickly pulled out after melting at high temperature without any additives [9–10]. As no boron and other alkali metal oxides are discharged during the melting process of basalt, the manufacturing process of basalt continuous fiber is harmless to the environment, with no industrial waste and no harmful gas discharged into the atmosphere [11–12]. Basalt fiber is another new type of environmental protection fiber in the 21st century [13]. The relationship between pore structure of filter media and beating degree, basalt fiber content and filtration

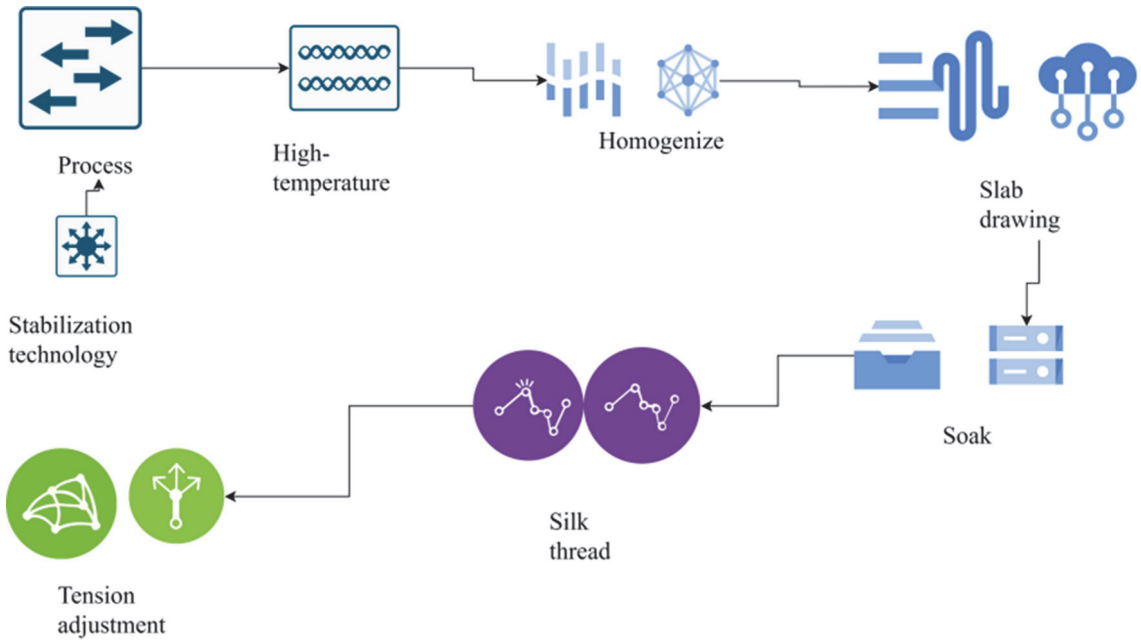

Fig. 1. Xuanwu research fiber technology process.

speed was discussed in detail, and the relationship between maximum pore size, minimum pore size and average pore size and filter material performance was obtained. Some parameters of the pore structure of this kind of fiber composite filter material can be conveniently calculated by using the fitted relation, which provides a certain theoretical basis for production practice. Yunfu, Hang, Zhu think that the main components of basalt fiber, silicon and aluminum oxides, are connected by oxygen atoms to form a continuous linear lattice, so the fiber has high longitudinal strength. Because there are other oxides between crystal chains, the fiber has a porous structure and an irregular arrangement, in which the pores can be divided into closed pores and open pores, which are spherical and tubular respectively, so the basalt fiber is smooth and soft externally and has good spinnability [14]. Zhang H, Sfarra S, Sarasini F put forward the layered random network structure model of basalt fiber composite filter material, and gave the possible bonding mechanism of the interface action of composite filter material [15]. Through the measurement of the maximum pore size, the minimum pore size and the average pore size, the correlation between the macro-filtration performance was studied, and the relationship between the average pore size and basalt fiber content and filtration rate was obtained.

2. Research and analysis of basalt composites

2.1 Research on basalt fiber materials

Man-made fibers mainly refer to fibers made of inorganic raw materials. They include metal fibers, oxide fibers, carbide fibers, boride fibers and carbon fibers. Continuous basalt fibers are made of volcanic rocks (diabase, basalt, etc.).) erupts in nature, continuously melts at the ultra-high temperature of 1,440°C ~ 1,500°C, and then is drawn into wire by a sleeve made of high-temperature resistant platinum-rhodium alloy material [16–17]. Moreover, it is harmless to the surrounding environment during production, does not emit toxic gases into the air, and can be degraded into soil after use, so it is called a new high-tech environmental protection material-21st century. Therefore, the corresponding model diagrams are established, as shown in Fig. 1 and 2.

Continuous basalt fiber is a continuous fiber made of pure natural basalt ore, which is made by high-temperature melting and high-speed drawing of Pt–Rh alloy drawing bushing. GBF for short. Together with carbon fiber, aramid fiber and high-strength polyethylene fiber, it constitutes four kinds of high-tech fibers [16–17]. There are many kinds of fibers, such as carbon fiber, aramid fiber and high-strength polyethylene fiber. Basalt is a refractory ore, with melting temperature above 1500°C and sintering temperature up to 1060°C. The effective service

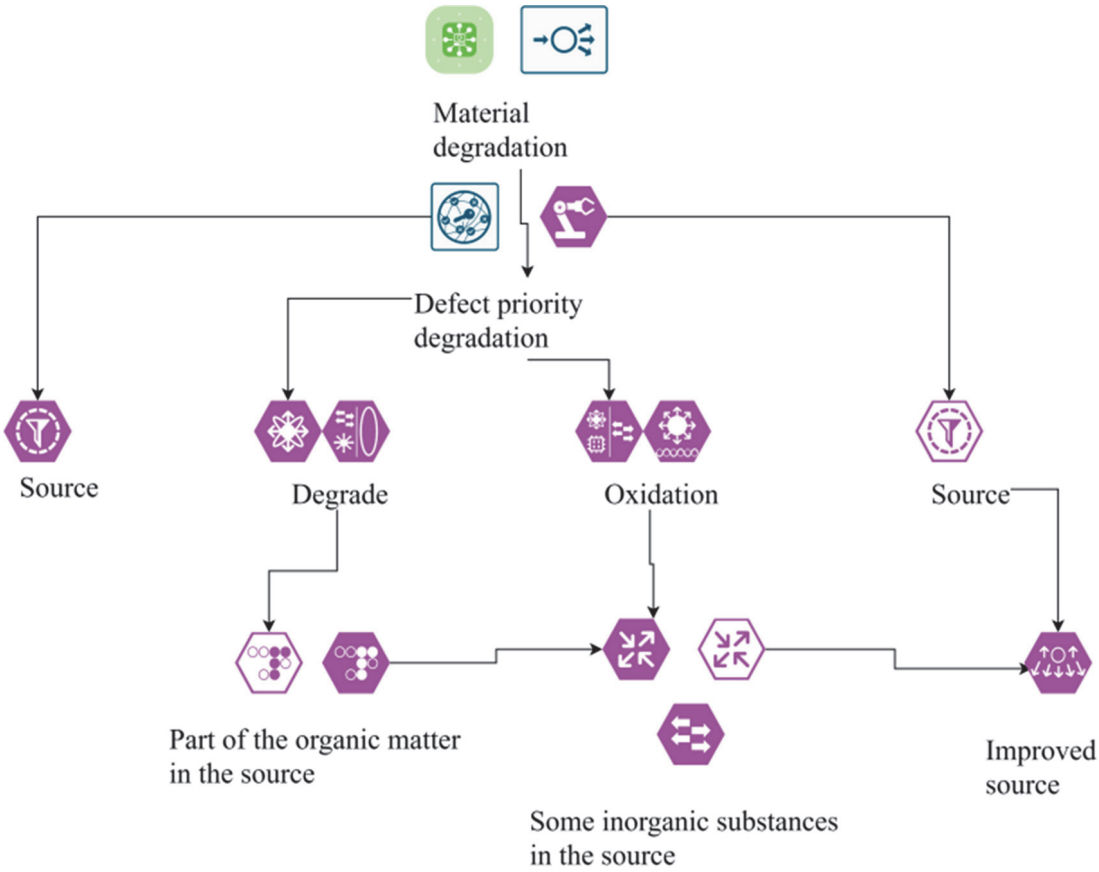

Fig. 2. Schematic diagram of composite mechanism.

temperature range of ordinary basalt fiber is 260 ~ 700°C, while that of special basalt fiber is as high as 982°C. It shows that basalt fiber has excellent high-temperature and low-temperature resistance, and its application temperature range greatly exceeds that of other types of fibers. Basalt fiber contains components such as K_2O, MgO and TiO_2, which play an important role in improving the chemical corrosion resistance and waterproof performance of the fiber. The thermal conductivity of basalt fiber is lower than that of other fibers. Therefore, it has excellent thermal insulation performance. The sound absorption coefficient of basalt fiber is higher than that of other fibers such as glass fiber, so it is an ideal sound insulation material.

The development of its production and preparation technology is mainly a modification of the wire drawing process, which can be divided into three stages, which involve, respectively, platinum crucibles, a combined wire drawing machine with more than two bushing plates, and the drawing process in the pool kiln.

2.2 Research and analysis of basalt fiber materials

In the process of research, it is found that basalt fibers materials are related to the corresponding textile materials. Air and other gas filtration methods are used to draw basalt fiber well, so that it can achieve a certain effect. At present, there are two main types of textile materials used for air and gas filtration. The fibers in nonwoven filter materials have a three-dimensional random arrangement structure, which can not only improve the filtration efficiency, but also improve the flow rate of carrier phase and increase the filtration speed [19–20]. The randomly distributed fibers in nonwoven strengthen the dispersion, interception, screening and trapping of suspended particles in carrier fluid, thus improving the filtration efficiency and effect of the material. Therefore, it is one of the most widely used filtration materials at present. In recent years, non-woven fabrics have made great progress in the application of air filtration, and have better filtration performance than woven fabrics. Study the composition and microstructure of fiber.

Iron is the most important element in the composition of the fiber, so in this paper, the catalytic photometric analysis method is used to determine the iron content in basalt fiber. The structure of basalt fiber was further refined by infrared spectroscopy, infrared microscopy, Raman spectroscopy and other analysis methods, which laid a certain foundation for explaining its properties and interface bonding mechanism of composites.

$$Z_l + \frac{P_1}{\rho g} + \frac{V_1^2}{2g} = Z_2 + \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + h_l, \quad (1)$$

$$h_l = \xi \frac{V^2}{2g}. \quad (2)$$

The above formula is based on catalytic spectrophotometry to study and analyze the iron content in basalt fiber. In the formula, Z_l indicates the type and indicator of acid and the amount of ascorbic acid $\frac{P_1}{\rho g} + \frac{V_1^2}{2g}$ represents the sum of its absorbance. $Z_2 + \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + h_l$ represents its opposite experimental group. $h_l = \xi \frac{V^2}{2g}$ indicates the relative content of iron in this study. In the research, it is found that the distance between two points at the orifice in the fiber structure is very short as shown in formulas (3), (4), (5), (6), (7) and (8).

$$dE = \frac{1}{2} dm v^2, \quad (3)$$

$$dm = \rho \varepsilon A v dt = \rho \varepsilon \frac{\pi d^2}{4} C_v \sqrt{\frac{2P}{\rho}} dt, \quad (4)$$

$$E = \int dE = \frac{1}{2} v^2 \int dm = C_v^2 P C_q \frac{\pi d^2}{4} \sqrt{\frac{2P}{\rho}} \int dt, \quad (5)$$

$$K = \frac{\pi}{4} C_v^2 C_q \sqrt{\frac{2}{\rho}}, \quad (6)$$

$$E_S = K \cdot \frac{d^{2P^3/2} \cdot N}{W \cdot S}, \quad (7)$$

$$E_S = K \sum_{i=1}^{n} \frac{d_i P_i^{3/2} \cdot N}{W \cdot S} \quad (8)$$

dE represents the total number of atoms in its structure, and $\frac{1}{2} dm v^2$ represents the number of atoms whose fiber structure is composed of amorphous crystals. dm represents the atomic number of the reference atom. $\rho \varepsilon A v dt$ represents the atomic density per unit volume. $\rho \varepsilon \frac{\pi d^2}{4} \sqrt{\frac{2P}{\rho}} dt$ represents the measured and separated coherent scattering intensity. E indicates its scattering angle, and a indicates its ray wavelength. $\int dE = \frac{1}{2} v^2 \int dm$ represents the coherent scattering intensity. $\int C_v^2 P C_q \frac{\pi d^2}{4} \sqrt{\frac{2P}{\rho}} \int dt$ represents the atomic fraction, and $\frac{\pi}{4} C_v^2 C_q \sqrt{\frac{2}{\rho}}$ represents the atomic number. E_S represents the average atom spacing, then $K \cdot \frac{d^{2P^3/2} \cdot N}{W \cdot S}$ represents its ray wavelength, and then K sum from i=1 to n { d sub i P sub i sup 3/2 ^cdot^ N } over {W ^cdot^ S } represents the corresponding atom spacing.

Generally, basalt fibers have different lengths and thicknesses, and they are composed of some bent fibers. Basalt fiber has a smooth cylindrical appearance, and its cross section is a complete oblate, which indicates that the glass rod is broken. This is because in the fiber forming process, the melt shrinks into a circle with the smallest surface area under the action of surface tension before being stretched and cooled into solid fiber. The morphology of basalt fiber is different from that of organic fiber. Due to deep wrinkles, the surface of organic fiber is not round. The surface of organic fiber is non-round due to deep wrinkles. Because of the smooth surface of basalt fiber, the cohesion between fibers is very small, which affects the composite effect with the matrix. Basalt fiber content has the greatest influence on the permeability of composites. It can be seen from the research that when the basalt fiber content is close to 40 %, the permeability will suddenly change. The percolation model can be used to explain the sudden change of permeability. In the composite filter material, the pores are connected with each other to form a meandering seepage channel. If the gap is occupied and cannot be connected, the air permeability will be very low, and its filtration performance will not be brought into play. Therefore, in the research, the corresponding data tables are established for research and analysis, as shown in Table 1 and Table 2.

Table 1. Comparative study of various fibers at different temperatures (1)

Relative humidity	Sheep's wool	Gonorrhea	Cotton
63 %	13.4	12.1	7.3
75 %	18.4	14.2	9.9
86 %	23.6	16.2	14.2

Table 2. Comparative study of various fibers at different temperatures (2)

Relative humidity	Glass	Artificial silk	Caplong
63 %	0.24	12.9	
75 %	0.29	16.9	4.8
86 %	1.64	20.7	5.5

3. Study on basaltic composite filter material

3.1 Characteristics and microstructure of basalt

From the above research, it can be seen that basalt fiber is made from natural basalt ore, which is crushed, added into a melting furnace, melted at high temperature, and then drawn by wire. At present, the production methods of basalt fiber mainly include vertical jet of superheated steam or compressed air, centrifugal jet and flame jet. Or the vapor-compressed air vertical injection method is to vertically impact the melt flow from the nozzle by using the high-speed airflow from the nozzle below the nozzle. Under the action of high-speed air flow, the melt flow is dispersed and stretched into many fine fibers. When the fiber air falls on the cotton collecting net belt in the settling chamber, loose cotton is formed. If the adhesive is sprayed at the entrance of the settling chamber, the fibers will be assembled into a cotton layer with a certain thickness, which can be made into fiber products after pressing and drying. In the surface layer of fiber, the shape of ions is different from that of the whole. On the surface of fiber, weak bonds and strong bonds break, and free valence force extends to space. Can not meet the coordination requirements of surface cations, resulting in high surface free energy. To fall; Low free energy, forming a stable surface, one way is to absorb water in the atmosphere. Very close to the fiber surface, positively charged hydrogen ions in water molecules will strongly bond to the surface, causing the water to be polarized, with the positive end facing the fiber surface and the negative end facing outward, further adsorbing water, forming multi-layer adsorption of water. Basalt fiber SMC roving reinforcement fiber is a special reinforcement fiber of SMC. SMC is the abbreviation of SMC, which is a kind of molding compound made of unsaturated polyester resin as binder. SMC has the advantages of superior electrical performance, corrosion resistance, light weight, simple and flexible engineering design, etc. Its mechanical properties are comparable to some metal materials, so it is widely used in transportation, construction, electronics and other industries. According to the research, the corresponding data charts are established, as shown in Fig. 3, 4 and 5.

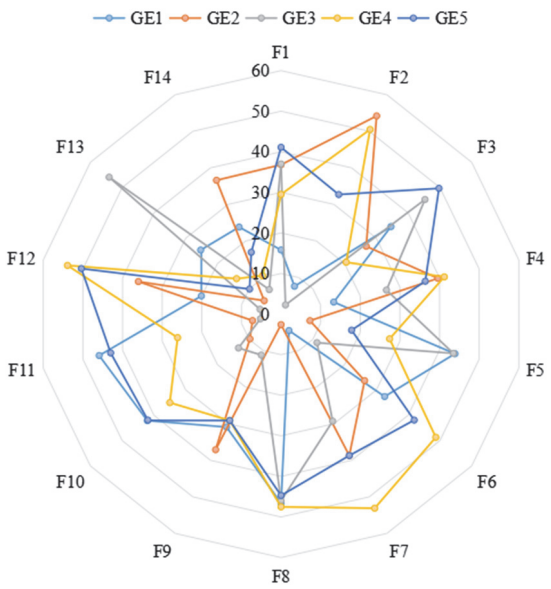

Fig. 3. Basalt analysis data map.

It can be seen from Fig. 5 that the characteristic structure of basalt fiber is related to its internal content elements and its basalt, and its influence is as high as 75.45 %. The characteristics and properties of basalt fiber are closely related to its essential basalt, and the rock mass structure is formed by structural transformation and superficial transformation on the basis of original structure. The primary structure of rock mass depends on its lithofacies, and the structural transformation and superficial transformation are controlled by the primary structure and its geological environment.The island structure means that the silicon-oxygen tetrahedron in the structure exists in an isolated state, and there is no shared oxygen among the silicon-oxygen

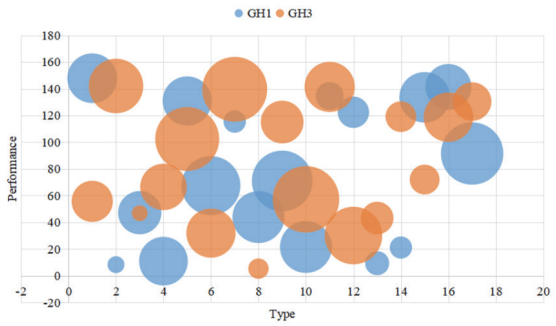

Fig. 4. Data map of basalt material performance analysis.

tetrahedrons. Oxygen ions in silicon tetrahedron will connect with other metal cations besides silicon ions. Layered structure means that the silicon-oxygen tetrahedron extends into a silicon-oxygen tetrahedron layer in a two-dimensional plane through three common oxygen. In the silicon oxide layer, all three oxygen ions in the same plane are shared by silicon ions, forming an infinitely extended six-segment ring layer. These three oxygen ions are bridge oxygen, and their charges have reached equilibrium. The oxygen and negative charge in the other corner are not yet balanced, which is called free oxygen. It will be connected with cations outside the silicon oxide layer. This kind of free oxygen also forms a hexagonal network in spatial arrangement. The structure refers to the four corners of each silicon-oxygen tetrahedron, which are crowned with the adjacent silicon-oxygen tetrahedron. Silicon tetrahedrons are arranged into a "frame" of three-dimensional space. According to many experimental studies, the key point of the microcrystal hypothesis is that silicate amorphous is composed of numerous microcrystals, which are highly deformed crystals in structure and separated by amorphous interlayers. In these intermediate layers, the farther away from microcrystals, the higher the degree of irreversibility. The chemical properties of microcrystals depend on the chemical composition of amorphous substances. Specifically, the so-called "microcrystals" are different from ordinary microcrystals, but are ordered regions with lattice deformation. The particles in the center of "microcrystal" are arranged regularly, and the farther away from the center, the greater the deformation degree. "Microcrystalline" is dispersed in amorphous medium, and the transition from "microcrystalline" part to amorphous part is gradually completed. There is no obvious boundary between them.

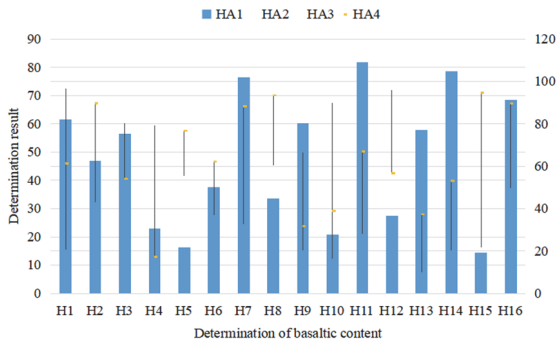

Fig. 5. Study on the content of basalt composites.

3.2 Research on composite filter materials

The strength of continuous basalt fiber far exceeds that of natural fiber and synthetic fiber, and it is an ideal reinforcing material. Continuous basalt fiber has a smooth cylindrical appearance and a complete circular cross section. This is because in the process of fiber formation, molten basalt shrinks into a circle with the smallest surface area under the action of surface tension, and then is stretched and cooled into solid fiber. This manufacturing process is very similar to that of glass fiber, so it is found that basalt fiber and glass fiber have many similarities, and their composition and performance characteristics are consistent to some extent. However, the production process and technology of basalt fiber is different from that of glass fiber. Its main feature is that the former uses single-component pure natural basalt ore for production, and basically no auxiliary materials are added in the melting process. Except for the need to produce special basalt fiber for preferred orientation, the latter is artificial batching. The tensile strength of basalt fiber increases with the decrease of basalt fiber monofilament diameter, but with the decrease of basalt fiber monofilament diameter, the production cost of basalt fiber increases sharply, and the production process becomes more difficult. Therefore, in the research, the corresponding data graphs are established for research and analysis, as shown in Fig. 6 and 7.

As can be seen from Fig. 7, the overall performance of basalt is superior to other materials, up to about 64.74 %. The tensile load of basalt fiber does not increase proportionally with the increase of the number of basalt fiber, which indicates that the large bushing tensile technology can im-

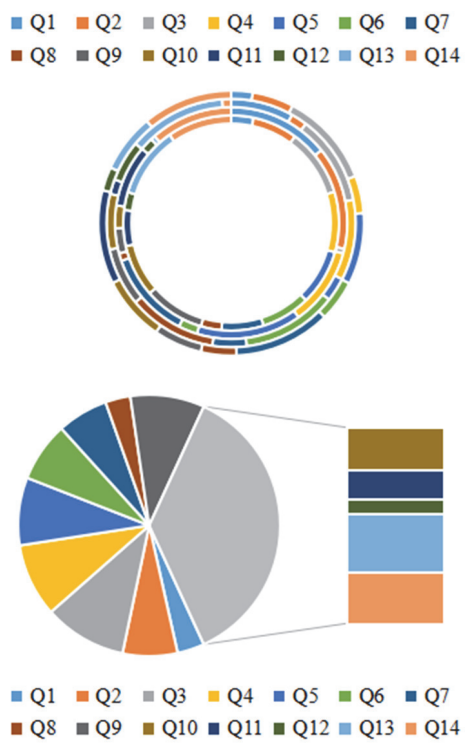

Fig. 6. Study on element content of basalt composites.

prove the overall performance of basalt fiber to a certain extent. Continuous basalt fiber is a new type of reinforcing material, and the properties of basalt composites will be an important basis for our future application materials selection. The composite material is mainly composed of matrix resin and reinforced fiber materials, and the fibers form a whole through the resin matrix. The reinforcing material plays the main bearing role, and the resin plays the role of transferring and balancing the load. The mechanical properties of composites depend to a great extent on the properties, content and layup method of fibers. The technological properties, compressive strength, interlaminar shear strength and other physical or chemical properties of the composite mainly depend on the resin matrix and wetting agent.

4. Conclusions

In this paper, the high-performance composite fiber material of basalt is studied and analyzed. Through this research, it can be known that continuous basalt fiber is a continuous fiber made of pure natural basalt ore, and it is made by high-temperature melting and high-speed drawing of platinum-rhodium alloy drawing bushing. GBF

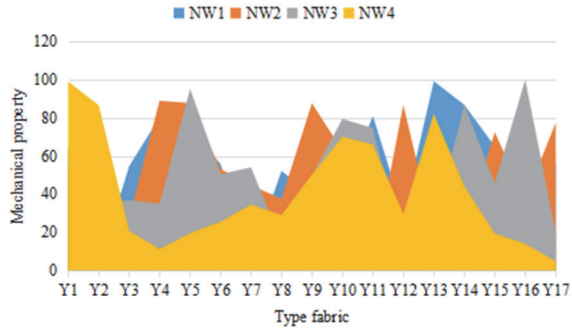

Fig. 7. Study on mechanical properties of different composites.

for short. The thermal conductivity of basalt fiber is lower than that of other fibers. Therefore, it has excellent thermal insulation performance. The sound absorption coefficient of basalt fiber is higher than that of other fibers such as glass fiber, so it is an ideal sound insulation material. In the research, it is found that basalt fiber materials have a certain connection with its textile materials. Air and other gas filtration methods are used in basalt fiber to draw basalt fiber well, so that it can achieve a certain effect better. However, the randomly distributed fibers in nonwoven strengthen the dispersion, interception, screening and trapping of suspended particles in carrier fluid, thus improving the filtration efficiency and effect of the material. Therefore, it is one of the most widely used filtration materials at present. Basalt fiber SMC roving reinforcement fiber is a special reinforcement fiber of SMC. SMC is the abbreviation of SMC, which is a kind of molding compound made of unsaturated polyester resin as binder. SMC has the advantages of superior electrical performance, corrosion resistance, light weight, simple and flexible engineering design, etc. Its mechanical properties are comparable to some metal materials, so it is widely used in transportation, construction, electronics and other industries. Although basalt fiber and its products have a broad application prospect and are being developed to the maximum extent, the production technology of basalt fiber is more complex than that of glass fiber, so the technical level needs to be improved.

Acknowledgments. This work is supported by HenanKey Scientific Research Project of Colleges and Universities(Grant No. 18A560016).

References

1. W.Li, J.Xu, *Materials Science & Engineering: A*, **505**, 178 (2009).
2. Z.Bullent, F.Arslan, Z.Sultan, *Tribology International*, **1**, 40 (2007).
3. J.Shi, H.Zhu, Z.Wu et al., *J. Composites for Construction*, **17**, 4(2013).
4. W.Li, J.Xu, *J. Chinese Ceramic Society*, **36**, 4 (2008).
5. L.Jie, *J. Industrial Construction*, **3**, 6 (2007).
6. J.Ma, X.Qiu, L.Cheng, *Advances in Frp Composites in Civil Engineering*, **53**, 73 (2011).
7. Scalici, T.Pitarresi, *Composites: Part B. Engineering*, **6**, 73 (2016).
8. T.Deak, T.Czigany, *Materials Science Forum*, **589**, 52 (2008).
9. G.C.Zhou, J.Han, Y.U.Bin, *J.Zhejiang Sci-Tech University*, **42**, 62 (2014).
10. R.Li, Y.Gu, Z.Yang, *J.Nuclear Materials*, **466**, 52 (2015).
11. Lee, Myeong-Hoon, Park., *Modern Physics Letters B Condensed Matter Physics Statistical Physics Applied Physics*, **42**, 52 (2015).
12. K.N.Bolshev, V.A.Ivanov, A.V.Malyshev, *Izvestia Vyssih Ucebnyh Zavedenij Priborostroenie*, **54**, 62 (2016).
13. M.Azhar, *Universiti Teknologi Petronas*, **42**, 52 (2014).
14. Yunfu, Hang, Zhu, *J. Materials in Civil Engineering*, **28**, 10 (2016).
15. H.Zhang, S.Sfarra, F.Sarasini, *IEEE Transactions on Industrial Informatics*, **42**, 52 (2017).
16. U.Song-Hak, Y.I.So, W.M.So, *International Journal of Structural Stability and Dynamics*, **42**, 84 (2022).
17. Y.Luo, X.Luo, *Hi-Tech Fiber and Application*, **63**, 76 (2018).
18. L.I.Huifang, W.Chen, W.Sui, *Advanced Textile Technology*, **54**, 22 (2013).
19. L.Hairong, C.Yang, *Technical Textiles*, **21**, 52 (2010).
20. P.Wang, W.U.Hai-Bo, X.Y.Jin, *Nonwovens*, **54**, 52 (2010).