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Investigation of the properties of a filter material made of composite basalt fiber

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In this paper, the ecological degradation filter material was prepared by mixing natural coniferous wood fiber and basalt fiber, and the relationship between material structure, filtration rate, pore size and fiber content was studied. The results show that when the spunlace pressure is too high, the vertical and horizontal strength drops faster. The basalt fiber composite needle-punched filter material has excellent acid resistance. The basalt coated filter media has high filtration efficiency, good air permeability, high breaking strength and good filtration performance.
Keywords: basalt fiber, filter, performance.

Випробування властивостей фільтруючого матеріалу із композитного базальтового волокна. *Fuyong Tang, Hua Li*

У цій статті екологічний матеріал, що фільтрує, був приготовлений шляхом змішування натурального хвойного деревного волокна і базальтового волокна, і був вивчений взаємозв'язок між структурою матеріалу, швидкістю фільтрації, розміром пор і вмістом волокна. Результати показують, що коли тиск спанлейсу занадто великий, вертикальна та горизонтальна міцність падає швидше. Композитний голкопробивний фільтруючий матеріал з базальтового волокна має відмінну кислотостійкість. Фільтруючий матеріал з базальтовим покриттям має високу ефективність фільтрації, хорошу повітропроникність, високу міцність на розрив і хороші характеристики фільтрації.

1. Introduction

In recent years, people pay more and more attention to high temperature resistant basalt fiber in the field of filter materials.

In this paper, natural coniferous wood fiber and basalt fiber are compounded to prepare ecological degradation filter materials; the relationship between material structure, filtration rate, pore size and fiber content is studied, which provides some experimental basis for basic theoretical research and industrialization research of composite fiber filter materials.

2. Experimental

2.1. Basic characteristics and properties of basalt fiber

Basalt fiber is an engineering material with excellent properties such as flame retardant, corrosion resistance, high temperature resistance, low hygroscopicity, small elongation, etc. [1]; it is applied to sound absorption materials, friction materials instead of asbestos, and reinforcement of highway pavement [2]. It can prevent swelling of materials caused by water ingress, and can be used for filling and reinforcing dams, fiber cement products, etc. However, there is little research on the surface characteristics and chemical stability of basalt fiber in acid-base medium [15]; moreover, no study of its structure has yet been reported.

2.2. Composition characteristics of basalt fiber and function of oxide

In crystalline minerals, isomorphic substitution of elements is widespread, which is the main factor causing a change in the chemical composition of minerals. Isomorphism means that in the process of mineral crystal formation, the position of a certain particle (ion, atom, complex anion or molecule) of the crystal is occupied by a particle which lattice constant is slightly different without changing the crystal structure type [3]. In mineral crystals, the isomorphic substitution is common, but the substitution of particles is not arbitrary. Some particles can be substituted for each other, while others can't. The number of substitutions between some particles is not limited, and others are limited to a certain range.

Under different external conditions, substances with the same chemical composition can generate minerals with different internal structures, shapes and physical properties. This phenomenon is called homogeneous polymorphism [4, 5]. In the homogeneous polymorph, each mineral is called a homogeneous polymorph variant, and each of them is an independent mineral species. For example, under various temperature conditions, many homogeneous polymorphs can be formed, while all the chemical components of homogeneous polymorphs are silicon dioxide.

2.3. Testing materials and instruments

Filter materials were four kinds of needle-punched filter materials, namely, polyester needle-punched felt, glass fiber needle-punched double-sided felt, basalt fiber composite needle-punched felt and Fumeisi high-temperature resistant composite needle-punched felt.

The Acid-base treatment solution consisted of nitric acid (2 mol/L), hydrochloric acid (2 mol/L), sulfuric acid (1 mol/L) and sodium hydroxide solution (2 mol/L).

Instruments: a BPG-9100BH high temperature drying oven; a dynamic filter material performance tester; a JSM-5610LV scanning electron microscope with a high vacuum mode resolution of 3.0 nm, magnification of 18X~300000X, accelerating voltage of 0.5 kV ~ 30 kV. The filter performance test method and sample preparation are in accordance with the relevant requirements of GB/T 6719-2009.

Sample pretreatment

The surface of the basalt fiber filter material was modified by finishing agent technology. Steps are as follows:

(1) Firstly, the test filter material sample is pretreated at high temperature to remove the interference of chemical substances on the surface of the original filter material fiber; (2) Various modified raw materials are converted into sizing agent according to a certain proportion, and then the sizing agent is evenly coated on the surface of the sample of the test filter material after high-temperature pretreatment; then it is subjected to high-temperature heat treatment again and cooled to normal temperature.

(3) After surface modification, the sample of test filter material is put in an oven at a constant temperature of 400°C for 24 h, then taken out and cooled to normal temperature.

2.4. Manufacture of filter test piece

The beating method provides pulp without long fibers. The steps are as follows:

(1) Firstly, the required weight of the dry pulp board is calculated according to the water content in the dry pulp board (generally between 6–8 %), the required mass ratio of plant fibers, the pulp concentration and beating degree; then the pulp board is soaked in a certain amount of clear water for more than 6 hours.

(2) The soaked pulp board is torn into small pieces of 25 mm×25 mm and slowly added into the beater. It takes about 3 ~ 5 min to dissolve them.

(3) During the beating process, at certain intervals, it is determined whether the beating degree of the pulp reaches the expected pulp degree. The beating is continued until the required beating degree.

Web quality, such as mass deviation per unit area, unevenness, fiber ratio, color matching and fiber arrangement direction, directly affects the appearance and performance of nonwoven materials. Fiber defects cannot be repaired in post-processing, but sometimes they are enlarged and exposed. There are two ways of netting in nonwoven production system: dry netting and wet netting. Among them, dry-laid web can be divided into mechanical carding web and air-laid web.

According to the characteristics of the fiber and the final use of the product, mechanical carding and air-laid were chosen in this experiment, and through the comparison between them, the air-laid method was finally chosen. In order to improve the utilization rate of basalt fiber, the mixture ratio of basalt fiber/Nomex is 50/50 by air-laying, and the phenomenon of low cohesion of air-laid fiber can be compensated by the following reinforcement process.

2.5. Test method

2.5.1. Mechanical property test of basalt fiber

Basalt fiber is a high-strength and high-modulus rigid fiber, which is characterized by small deformation, high strength and easy brittle fracture. Therefore, its strength and elongation test method differs from that for ordinary flexible fiber, mainly in sample preparation and error correction. In particular, basalt fiber is relatively thin, although its fracture stress is relatively high, but its tensile fracture strength is relatively small. During the operation process, especially during the clamping process, the introduced compression, bending, torsion or non-axial tensile force may damage or destroy the fiber, resulting in test errors.

In order to accurately and reliably test the strength of basalt fiber, this experiment adopted a method for measuring the tensile strength and modulus testing of high modulus monofilament. The process is as follows:

(1) Cutting paper cards with windows;
(2) Preparing glue;
(3) Sticking basalt fiber;
(4) Curing the binder;
(5) Preparation of a tensile specimen.

2.5.2. Acid and alkali resistance test

Samples of four kinds of filter materials in vertical and horizontal directions were placed into acid solutions with different concentrations, kept at 30°C for 72 hours, taken out, washed and dried to assess the change of tensile properties. The used acid solutions were: nitric acid (2 mol/L), hydrochloric acid (2 mol/L) and sulfuric acid (1 mol/L).

Then the samples of four kinds of filter materials in vertical and horizontal directions were placed into three beakers containing the 2 mol/L sodium hydroxide solution; and after 24 hours, 48 hours and 72 hours respectively, they were taken out, rinsed and dried to evaluate the change of tensile properties with the treatment time.

2.5.3. Filtration velocity measurement

Using the device for testing the filtering ability of the filter material, ambient air enters the pipeline from the inlet of the test pipeline, passes through the tested filter material and flowmeter, and is sucked off by the suction pump. The resistance of the filter material is directly read by the digital micro-pressure meter connected to the measuring points before and after the filter material. The filtration classification efficiency is calculated by the mass concentrations of particles with different sizes on the front and back sides of the filter material, which are read by two Grimm portable dust particle monitors arranged in front of and behind the filter material [6].

The biggest feature of this experiment is that the mass concentration and number of dust particles from 0.23 μm to 20 μm in dusty gas can be directly measured by instruments. The single-factor experiment on this subject is to measure the filtration efficiency in a pure state.

Test method for the dust holding capacity of the filter material: generate dust evenly every two minutes at an air speed of 1 m/min and a dust amount of 0.59/min. Under conditions of stationary filtration, the air speed is low, and the structure of the dust layer does not change, which can be roughly considered as the natural state of the pile, and there is a linear relationship between the time and the thickness of the dust layer. The main parameter tested in this experiment is the efficiency of filtering and classification, which is shown as follows:

$$\eta_i = \left(\frac{C_1 - C_2}{C_1}\right) \cdot 100\%, \qquad (1)$$

where C_1, C_2 are, respectively, the mass concentrations of particulate material with a certain particle size in the pipeline before and after the measured filter material, kG/m^3.

In this experiment, four particle sizes of 0.5 μm, 1 μm, 2 μm and 5 μm were selected to analyze the filtration efficiency of the product.

2.5.4. Air permeability

Moisture permeability, water permeability and water resistance are collectively referred to as permeability. Nonwovens for different uses have different requirements for permeability. In this topic, according to the application of high-temperature resistant filter materials, we mainly study the air permeability of materials, mainly by measuring their air permeability, porosity and pore size distribution [7].

The principle of the test on air permeability is as follows: a pressure difference of 128 Pa is added on both sides of the test material, and when the flow is steady, the air flow through the sample of unit area per unit time is measured in mm/s, and the test is repeated at least 10Ntimes at different parts of the same sample.

Porosity is defined as the percentage of pore volume in the total volume of materials. Typically, porosity is defined as:

$$\Phi = 1 - \frac{V_s}{V_b} = 1 - \frac{\rho_b}{\rho_s} = [1 - m/(\rho \cdot \delta)]. \qquad (2)$$

Among them: V_s is the solid volume of sample (m^3); ρ_s is the solid density of sample (g/m^2); V_b is the apparent volume of sample (m^3); ρ_b is the apparent density of sample (g/m^2); m is the mass area ratio (g/m^2); ρ is the raw material density (g/m^3); δ is the material thickness (m).

The directly measurable data of basalt fiber nonwovens are areal density, thickness and void ratio formula:

$$\varphi = 100[1 - m/\rho \cdot \delta]. \qquad (3)$$

Among them: m is the mass area ratio (g/m^2); ρ is the raw material density (g/m^3); δ is the material thickness (m).

In this experiment, a multi-function pore size meter is used to test the pore size: the maximum pore size can be obtained by measuring the pressure at the beginning of the gas flow; this is generally determined by the size of the first bubble when testing the material, i.e. the size of the pores at the point of the bubble.

The method of average fluid pore size means that under the action of pressure gradient, the gas flow increases rapidly with an increase in the pressure difference from the first bubble on the surface of the sample. When the pressure difference reaches a certain value, and the ratio of the flow through the wet sample to that of the dry sample of the same area is equal to 1/2, this pressure difference is called the average flow pressure difference; and the calculated equivalent capillary diameter is called the mean flow pore size or the mean fluid pore size [8, 9].

3. Results and discusion

3.1. Analysis of breaking strength and elongation test results

The materials studied in this paper are mainly used in the filtration of flue gas and dust, and the service life of the filter materials is limited due to the constant physical and chemical exposure during operation. The breaking strength and elongation of the material is an important index to measure the life of the high-temperature resistant filter material. Generally speaking, high temperature resistant filter materials should have higher strength and lower elongation.

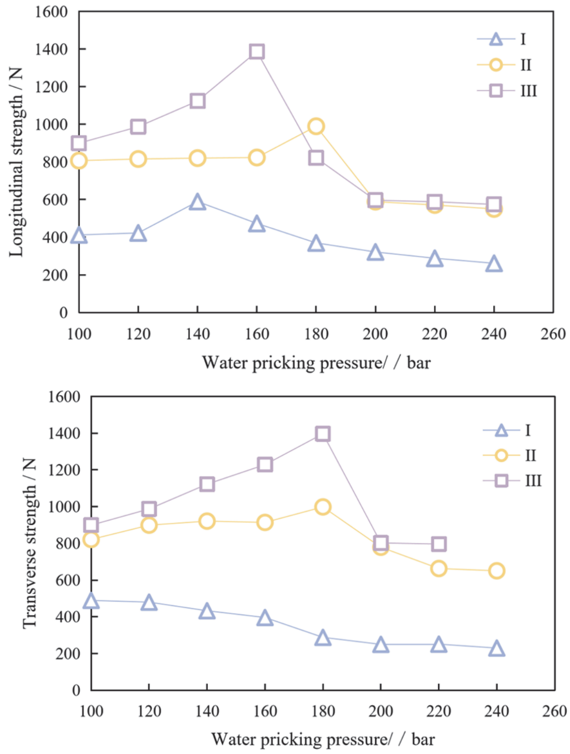

Fig. 1. Influence of spunlace pressure and areal density on longitudinal and transverse strength of products.

In this paper, the tensile properties of high temperature resistant filter materials are studied by changing the parameters of the spunlace process. The specific test results and analysis are as follows.

It can be seen from Fig. 1 that the longitudinal breaking strength curves of samples I, II and III are similar, each with a maximum breaking strength peak. The spunlace pressure of sample I is 162 bar, that of material II is 200 bar, and that of material III is 183 bar. At the same time, it can be seen that the breaking strength of the material increases with an increase in the spunlace pressure before the critical point, and decreases with an increase in the spunlace pressure after the critical point.

The transverse strength curves of the three samples are slightly different. With an increase in the spunlace pressure, the strength of the material I does not increase, but somewhat decreases, while that of material II and III increases first and then decreases.

As can be seen from Fig. 2, as the speed of the net curtain increases, the vertical

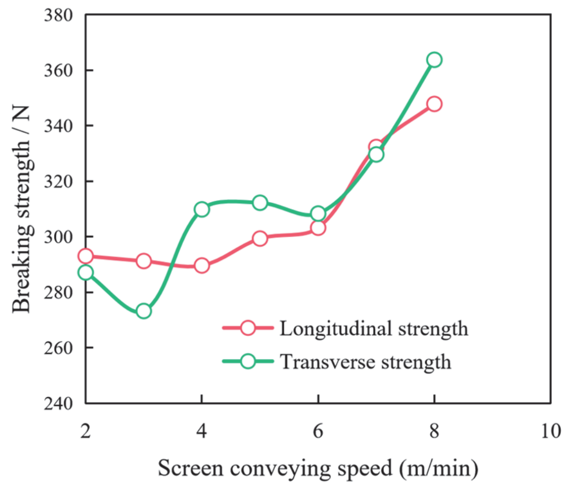

Fig. 2. Influence of conveying speed of net curtain on longitudinal and transverse strength of products.

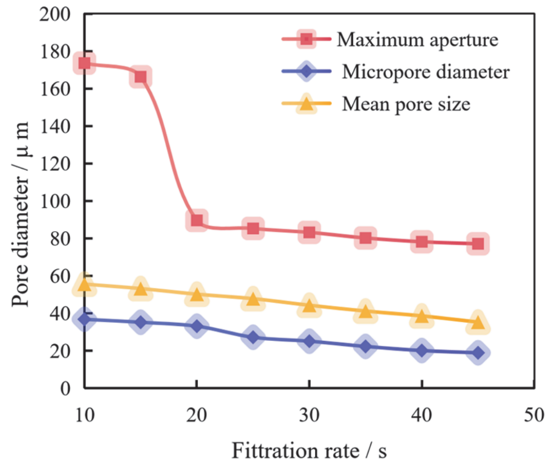

Fig. 3. Relationship between the pore size and filtration speed at different beating degrees.

and horizontal strength of the product increases.

The main reasons for the analysis are as follows: according to the analysis of the longitudinal and transverse strength of the product by the spunlace pressure and spunlace number, it can be seen that the longitudinal and transverse strength of the fiber web with the areal density of 460 g/m^2 is higher, when the spunlace pressure is 150 bar and the spunlace number is less than 4.

In this experiment, the pressure reached 210 bar, and the number of spunlace channels exceeded 4 channels. In this case, instead of improving the entanglement between fibers in the material and between fibers and base cloth, basalt fibers would be damaged, and the surface of the web would be wrinkled and stagnant.

When the speed of the conveying curtain is increased, the time for the web to be impacted by spunlace is shorter, and the damage of high-pressure water to the web is reduced.

3.2. Influence of different beating degree and basalt fiber content on the filtration rate

The relationship between filtration speed and pore size is shown in Figs. 3, 4.

When other conditions are constant, different beating degrees directly affect the sizes of various pore sizes of filter materials, and then affect the filtration rate. It can be seen from Fig. 3 that the trend of change in the relationship between the maximum pore diameter and the average pore diameter and the filtration rate is basically the same, that is, it decreases with a decrease in the pore diameter, and the filtration rate obviously slows down after a decrease in the pore diameter to a certain extent.

When other conditions are constant, different basalt fiber content affects the pore size of the filter material, and then affects the filtration rate of the filter material. It can be seen from Fig. 4 that the effect of the basalt fiber content on the filtration rate of the filter media is basically the same as that of beating degree, but the trend of change is obviously different from that for different beating degrees; this shows that the degree of beating and the content of basalt fiber affect the filtration rate differently. Even with the same pore size, the filtration rates are different, which shows that the increase in the beating degree has an important effect on the filtration rate.

From this point of view, for basalt fiber composite filter media, adding a small amount of basalt fiber can increase the filtration rate, but increasing the content of basalt fiber has no obvious effect on the filtration rate, so we should consider reducing the beating degree to improve the filtration rate.

The experimental results and the analysis of the above data show that the filter media filtration method provides traditional deep filtration, and the filtration efficiency should be affected by the filter media fibers and fine particles in depth. In the primary stage of filtering, particle separation occurs inside the fiber layer, and then particle separation on the surface takes place. With an increase in the filtration time, the dust grows into dendrites, and bridges are

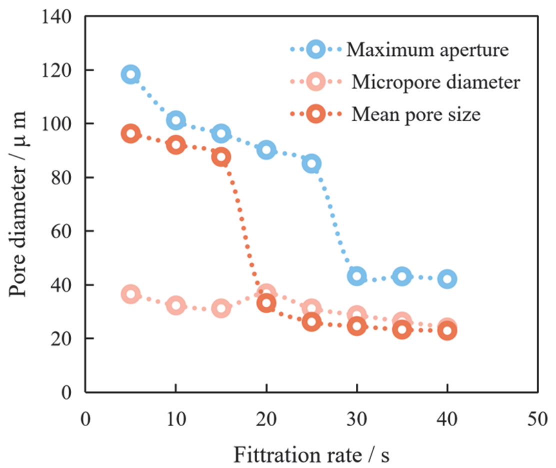

Fig. 4. Relationship between the pore size and filtration rate at different basalt fiber content.

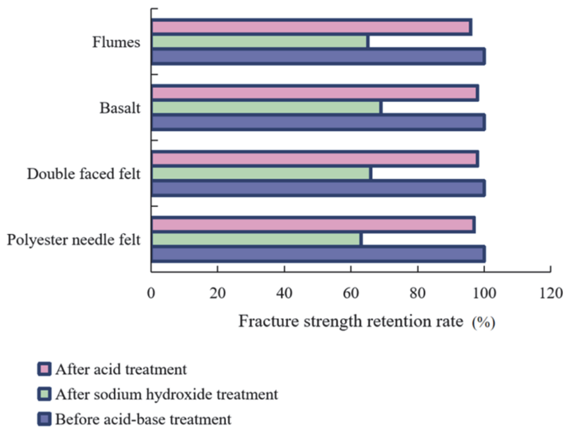

Fig. 5. Comparison of longitudinal breaking strength retention rate of needle-punched materials after acid-alkali treatment.

formed between fiber meshes. The dust layer deposited on the surface of the filter material is used to realize filtration, which is a filtration method integrating adsorption, inertial collision, interception, and diffusion effects [10].

3.3. Acid-alkali contrast

In order to compare the acidity and alkalinity of the filter materials, inorganic acids were chosen with the same concentration of hydrogen ions of 2 mol/L. The breaking strength retention rates of needle-punched filter materials after three kinds of acid treatment can be averaged, and the comparison charts of breaking strength retention rates of four kinds of filter bags after acid-alkali treatment for 72 h were obtained, as shown in Fig. 5 and Fig. 6 respectively.

As can be seen from Figs. 5 and 6, the strength retention rate of four kinds of filter materials after acid solution treatment is more than 96 %. However, the strength retention rates after alkaline solution treatment are all less than 77 %, so the acid resistance of the four filter materials is obviously greater than the alkali resistance.

In addition, it can be seen that in the longitudinal and transverse directions, the strength retention rate of the basalt fiber composite needle-punched filter material treated with NaOH is slightly higher than that of other three filter materials, so its alkali resistance is slightly better than that of other three filter materials.

3.4. Air permeability of coated filter media

The measurement of porosity is an indirect measurement. Non-woven filter materials make it possible to evaluate the efficiency of filtration by porosity. The larger the porosity, the smaller the resistance of the filter material to the fluid flow. Porosity is directly related to the structural characteristics of the filter material, that is, the density, areal density and thickness of the material.

The air permeability directly affects the fluid resistance of the fiber filter material, the difficulty of dust removal and the amount of energy consumption. If the air permeability is good, the fluid resistance is small, and the lower the energy consumption, the better the dust removal effect. The test results of air permeability of coated filter media are shown in Fig. 7.

It can be seen from Fig. 7 that 10 coated filter materials have the highest air permeability with and without a film; the air permeability with and without a film is over 220 mm/s, and the air permeability with a film is almost twice that without film, followed by 7 and 4 coated filter materials with better air permeability, 1 and 2 coated filter materials with the worst air permeability, and the air permeability of front and back surfaces is within 75 mm/s.

Ten kinds of the coated filter media adopted the same coating process, so the influence of a film on air permeability can be neglected. The difference of air permeability is mainly caused by the difference in the porosity of basalt woven fabric due to the difference in the base fabric organization and the change of gas flow resistance when passing through the woven fabric, which leads to the difference in the air permeability between different coated filter materials.

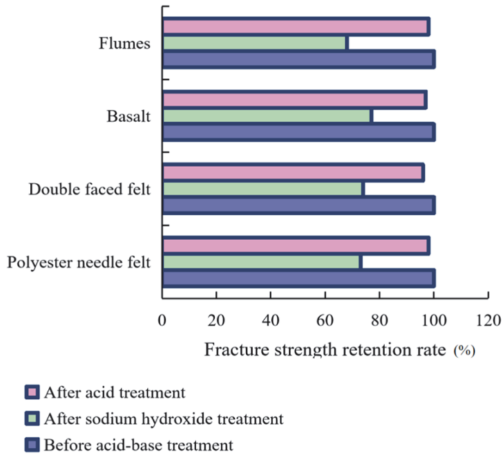

Fig. 6 Comparison of transverse breaking strength retention rate of needle-punched materials after acid-alkali treatment.

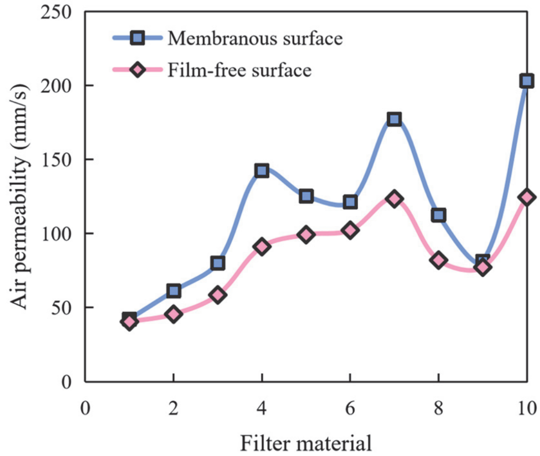

Fig. 7. Air permeability of coated filter media.

4. Conclusion

In this paper, natural coniferous wood fiber and basalt fiber were compounded to prepare an ecological degradation filter material; and the relationship between the material structure, filtration rate, pore size and fiber content was studied. Based on a large number of experiments and studies, the following conclusions are drawn:

(1) The strength and elongation of the studied filter material are comprehensively influenced by the base cloth and the upper and lower layers of webs. With an increase in the spunlace pressure, the vertical and horizontal breaking strength of samples with three different areal densities first increased and then decreased. The higher areal density, the higher the breaking strength of samples. At the same time, it was found that the lower areal density of samples, the faster the vertical and horizontal breaking strength decreased when the spunlace pressure was too high.

(2) The acid resistance of the basalt composite needle-punched filter material is obviously better than the alkali resistance, and it is suitable for use under high temperature and acid conditions.

(3) The relationship between the pore size and filtration rate shows that the trend of change in the pore size and filtration rate is basically the same under different beating degree, and this trend of change is basically the same under different basalt fiber content. However, when the basalt fiber content reaches the percolation threshold, the influence on the filtration rate will decrease, so the beating degree can be reduced to improve the filtration rate.

(4) The fabric structure has a great influence on the air permeability of the coated filter material. Under the same compounding process, the air permeability of 10 coated filter materials is the best, exceeding 220 mm/s.

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