Characterization of structure and properties of glass fiber filter materials with different dispersant concentrations

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Abstract. In wet papermaking process, the dispersant concentration has great influence on the structure and properties of paper. In this work, dilute H₂SO₄ with a mass fraction of 20% was used as the dispersant, and the glass fiber filter materials were made under the five dispersant concentrations of 0%, 0.06%, 0.11%, 0.17% and 0.22%, respectively, and then the related structures and properties of filter materials were measured and analysed. The results showed that the filtration loss rate and drainage speed during the preparation progress increased with the increase of dispersant concentration. When the pH value of the slurry decreased from 7.78 to 2.59, the uniformity of the filter material became better and the defects reduced. With the increase of acid addition, the pore size of filter material increased gradually, but the thickness, grammage and porosity decreased. In addition, all the prepared filter materials were hydrophilic and oleophilic. In general, the glass fiber filter materials prepared with the acid amount of 0.17% had the highest mechanical strength, and the glass fiber filter materials had the best performance when the pH value of the slurry was maintained in the range of 2.95–3.20.

1. Introduction
Glass fiber, as a kind of raw material with high efficiency and applicability, is made into filter material with its performance advantages and applied in the filtration industry. The preparation process of glass fiber filter material is similar to that of traditional paper, including dry and wet methods. At present, the main steps of papermaking and filter preparation are wet process. Dai et al.¹ summarized the performance characteristics of glass fiber and the application of glass fiber paper in filtration industry.

When glass fiber is in water, its surface is negatively charged. In the process of dispersion, acid solution with positive charge (H⁺) is often added as dispersant to eliminate the electrostatic effect between glass fibers and maintain a certain repulsive force, so as to avoid fiber flocculation and promote its uniform dispersion, and ensure that the prepared glass fiber filter material has good performance. At present, the research on the influence of dispersant on the preparation process and basic physical properties of glass fiber filter materials mainly focuses on the dispersion effect and paper strength, and there is little research on the water filtration process and paper structure and appearance during sheet making. Moreover, due to the influence of environmental and human factors, there is often no unified law. Liu² found that due to the thermal movement, the positron in the slurry suspension presented a certain concentration distribution in a small range from close to far away from the fiber, resulting in a potential difference (i.e. zeta potential) between the solid and liquid, and the absolute value of zeta potential affected the dispersion uniformity of glass fiber. The greater the
absolute value of zeta potential, the greater the repulsion between fibers, and the better the dispersion effect. On the contrary, it would lead to fiber flocculation and affected the paper properties[3,4]. He et al. [5] pointed out that for the same pulp, the more fine fiber content, the greater the absolute value of zeta potential, that is, the better the dispersion effect. Bhardwaj et al.[6] pointed out that in the process of pulping and papermaking, the processing operation of fiber would affect zeta potential. Zheng et al.[7] found that with the decrease of slurry pH value, the zeta potential of glass wool suspension first increased and then decreased, and the pH value of the best dispersion effect was 2.5. Zhang et al.[8] found that when the pH value was 3.0, the tensile index and bursting index of glass fiber paper were the largest. Chen et al. [9] believed that when the pH value was higher than 4.5, the glass fiber began to floccule and could not be evenly dispersed, and the greater the slurry concentration was, the more unfavorable it was to the dispersion. Therefore, the selection of appropriate dispersant concentration is very important for the fabrication of high-performance glass fiber filter materials.

Based on the wet sheet making technology, glass fiber filter materials were prepared and characterized at different dispersant concentrations, including the appearance, structure, strength and surface wettability of the filter materials, and finally the best dispersant concentration was obtained. Among them, the influence of dispersant concentration on the filtration process during sheet making was characterized by drainage speed and filtration loss rate, and the uniformity of glass fiber filter material was judged by observing the appearance of paper.

2. Experimental setup and methods
On the premise of consistent sheet making operation and different dosage of dispersant, the paper was prepared, and then its structure and properties were analysed and characterized.

2.1. Experimental materials
The materials included main and auxiliary materials. Among them, the average diameter of the main material was glass fiber with average diameter of 1.4 μm. Dilute sulfuric acid with a mass fraction of 20% was selected as the dispersion additive, which was prepared in the laboratory. In addition, the liquids used for measuring the contact angle were distilled water and dioctyl sebacate (DOS).

2.2. Experimental setup and procedure
During the preparation of glass fiber filter material, the fiber target quantity was uniformly set as 128 g/m², and the papermaking process operation was carried out according to the settings in Table 1. Under the condition of consistent control of papermaking operation, 5 pieces of glass fiber filter materials with different dispersant concentrations were obtained respectively, and 25 pieces of filter materials were divided into 5 groups and numbered as DC0, DC1, DC2, DC3 and DC4, respectively.

| Table 1. Papermaking operation conditions. |
|-------------------------------------------|
| Set item                                | Methods and parameters                        |
| Material                                | Fiber type                                     |
| Ease dispersion                         | Ease dispersion                                |
| Dispersant                              | Dilute sulfuric acid with mass fraction of 20% |
| Dispersion mixing time                  | 6 min                                          |
| Stirring speed                          | Medium speed                                   |
| Amount of water added                   | 1250 mL                                       |
| Copy film                               | Fiber quantification                           |
|                                         | 0.06%                                          |
|                                         | Water volume                                   |
|                                         | 13500 mL                                      |
|                                         | Opening of drain valve                         |
|                                         | 100%                                           |
According to the amount of water added to the slurry (13500 mL), the concentration of dispersant was set to 0%, 0.06%, 0.11%, 0.17% and 0.22%, respectively, and the concentration of dispersant in the process of dispersion was consistent with that of the whole slurry. The corresponding values of acid addition and dispersant concentration are shown in Table 2.

Table 2. Dispersant concentration and acid addition for different filter materials.

| Filter material | DC0 | DC1 | DC2 | DC3 | DC4 |
|-----------------|-----|-----|-----|-----|-----|
| Dispersant concentration/% | 0.00 | 0.06 | 0.11 | 0.17 | 0.22 |
| Acid addition/mL | 0 | 7.5 | 15 | 22.5 | 30 |

The paper preparation device used was a square sheet making machine, with a maximum pulp capacity of 20 L and a paper size of 250 mm × 250 mm. The process included several main parts, such as material selection, pulping, water filtration, sheet making, and additive treatment, in which the additive treatment also included drying treatment, reinforcement treatment, modification treatment, etc.

Firstly, put the prepared fiber into the dispersion device, and added dilute sulfuric acid of corresponding concentration for dispersion, then strictly controlled the stirring and dispersion time at 6 min. Secondly, added all the evenly dispersed pulp suspension into the pulp cylinder, and slowly stirred with a stirring pestle for 4~5 min to make the suspension uniform. After mixing, opened the drain valve under the slurry drum when the slurry was stable, and a wet paper web on the papermaking net was formed after the white water in the slurry drum was removed. The wet paper web was hygroscopic treated first, then placed on the absorbent paper and in the blast drying oven with constant temperature for 20~50 min.

The above paper making process was repeated under five different dispersant concentrations, and at least five glass fiber filter materials were prepared under each concentration setting. Then the thickness gauge (precision 0.001 mm), electronic balance (precision 0.01 g), aperture test analyser, surface contact angle measuring instrument and push-pull testing machine (precision 0.1 N) were used to measure relevant parameters.

2.3. Evaluation parameters
The making process, appearance, structure and performance parameters of filter materials were analysed and evaluated. The influence of dispersant concentration on the sheet making process was evaluated by water drainage speed and filtration loss rate. The structure parameters of filter material, including thickness, gram weight, porosity and pore diameter, were analysed with the help of instruments. The appearance was observed by filling light photography, and then the uniformity and defects of the filter material prepared under different dispersant concentrations were compared and analysed. Properties included material strength (tear strength and puncture strength) and surface wettability, which were measured and analysed by instruments; In the case of evaluating whether it was wet or not, the degree of intimacy was further evaluated by the contact angle at the initial time.

3. Results and discussion
For each glass fiber filter material, four pieces with fewer defects were selected as the measuring objects from five samples, and then cut into the same size and measured at least 3 times respectively, and finally the average value of each parameter was used. The pH values of slurry corresponding to five dispersant concentrations were 7.78, 6.54, 5.50, 3.08 and 2.59, respectively.

3.1. Drainage speed and filtration loss rate in the process of sheet making
The drainage speed and filtration loss rate of slurry were recorded and calculated by stopwatch timing and electronic balance weighing, as shown in Figure 1. With the increase of acid content from 0.00% to 0.22%, the water drainage speed became faster, and the overall filtration loss rate also increased, indicating that the filtration loss was less affected by the concentration of dispersant.
3.2. Appearance morphology

Figure 2 shows the physical views of different filter materials obtained by fill light photography, including front and back surfaces. It can be inferred that with the increase of dilute sulfuric acid concentration, the filter material defects reduced and the uniformity was improved. According to the actual filter material, there was more fiber aggregation in the dark stripe area and less fiber aggregation in the bright area. It can be seen from the back surface images that with the increase of acid content, the surface morphology of the paper gradually changed from rough to flat, and the amount of dark streaks decreased, indicating that the fiber dispersion was more uniform, and the comparison between front and back was obvious. As can be seen from the front view, the bright colour area gradually changed from stripe to dot like, which also indicates that the uniformity of the filter material was improved and the defects decreased. Therefore, a higher amount of acid was helpful to improve the quality of the prepared filter materials.

3.3. Effect of dispersant concentration on structure parameters of filter material

Figure 3 shows the thickness and gram weight of filter materials prepared under different dispersant concentrations. It can be seen that the structure of the filter material was greatly affected by the dispersant concentration. Without acid, the thickness and gram weight of filter material were the
largest. When the acid content increased from 0.06% to 0.22%, the thickness and gram weight of filter material decreased slightly. Figure 4 shows the porosity and pore diameter of filter materials prepared under different dispersant concentrations. It can be seen that the porosity of the filter material was basically maintained at about 94%–95%, and showed a weak decreasing trend as a whole. The pore size of filter materials increased gradually with the increase of acid content, increasing from 2.29 μm to 3.20 μm.

3.4. Effect of dispersant concentration on performance of filter material
The tensile properties of filter materials involved in this work included strength properties and surface wettability. Figure 5 shows the tear strength and puncture strength of different filter materials. After adding acid, the mechanical strength of the filter material was obviously enhanced, indicating that the entanglement between fibers was enhanced, and the filter material with acid concentration of 0.17% performed best. It should be noted that the glass fiber filter material DC4 with the best uniformity and
the least defects did not have the highest strength, but the filter material DC3 with slightly poorer uniformity had the highest strength.

![Figure 5. Tear strength and puncture strength of different filter materials.](image)

In terms of wettability of filter materials, it was found that the amount of acid hardly affected the surface wettability of filter materials. However, it should be noted that the measured results of DOS droplets on the material surface showed that the contact angle was relatively large when the acid content was 0.17%, and the contact angle at the initial time was less than 90° (between 60° and 80°). Moreover, when the liquid settled on the surface of the filter material, it quickly penetrated into the material, and it was difficult for the instrument to capture the image of droplets.

Based on the above results, when the pH value of the slurry was 2.95~3.20, the paper had the highest mechanical strength, good uniformity, few defects, and moderate thickness, gram weight, porosity and pore diameter.

4. Conclusions
In this work, the filter materials with different dispersant concentrations were prepared by wet sheet making technology. The influence of dispersant concentration on the structure and performance of filter materials was analysed, and the following conclusions were obtained:

(1) The concentration of dispersant in the pulping process had an effect on the water filtration process, filter structure and properties of the pulp. When the dispersant concentration changed, the slurry filtration process also changed, but the range was small, and the filtration loss rate and drainage speed increased with the increase of dispersant concentration.

(2) In terms of appearance and structure, with the increase of acid addition, the defects of glass fiber filter material reduced and the uniformity became better, and the thickness, gram weight and porosity of filter material decreased, but the pore size increased.

(3) In terms of performance, the strength of the prepared filter material was the highest when the amount of acid was 0.17%, and the corresponding pH value was in the range of 2.95~3.20.

(4) The prepared five kinds of glass fiber filter materials were wettable to both water and oil, and the degree of wettability for water was higher than that for oil.

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