Application of Synthetic Fiber in Air Filter Paper

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Synthetic fibers have characteristics that plant fibers do not have, such as water resistance, chemical resistance, heat resistance, and thermal stability. If mixed with plant fibers and applied to make air filter paper, then the required properties of paper could be obtained. Two kinds of synthetic fiber, polypropylene (PP) and polyester (PET), were mixed with softwood pulp to make air filter base paper. The effects of the mixing ratio, the beating degree of softwood pulp, the variety and addition amount of reinforcing agents, and the process of pressing and drying on the properties of base paper were explored. Samples were found to meet the requirements of the physical properties and porosity of the filter paper base paper at the same time when the mixing ratio of synthetic fiber and plant fiber was 20/80, the beating degree of softwood pulp was 22 °SR, and the added amount of cationic polyacrylamide (CPAM) was 0.06%. The PP fiber fell off easily from the page, but PET fiber did not. The addition of PET fiber increased the porosity, tear index, and folding endurance of the paper. In sum, PET fiber was more suitable for making air filter paper than PP fiber.

Keywords: Synthetic fiber; Polypropylene fiber; Polyester fiber; Air filter paper

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INTRODUCTION

Air filter paper has a close relationship with the automotive industry (Wu 2011). Automobile air filter paper is composed of base paper after the resin impregnation process, which is mostly applied to the internal combustion engine of automobiles, ships, and tractors (Tang and Liu 2011). Air filters are located in the intake system of engines, which directly affects their use (Hong *et al*. 2011). Air filter paper can improve the combustion efficiency of engines, prevent engines from premature wearing, and prolong the service life of engines (Chen 2006). A reasonable addition of synthetic fiber can improve both the filtration performance and the physical strength of filter paper.

There is continuous development in papermaking technology, with new types appearing constantly. With the advent of various papermaking additives, the raw material of papermaking is no longer limited to plant fibers, but includes metal, mineral, and synthetic fibers. Compared with other raw material fibers for papermaking, synthetic fibers have the advantage of being low in price and accessible, and they have some desirable characteristics when mixed with plant fibers. Synthetic fibers typically have long fiber length and high freeness. The filtering speed of filter paper made of synthetic fibers is far higher than that of plant fibers. Most synthetic fibers cannot fibrillate, so there is no bonding force between fibers (Zhang 2001).

Using synthetic fiber as a substitute for a portion of plant fiber to make air filter base paper could impact the physical properties of base paper greatly. This work explored the ratio of synthetic fiber and softwood fiber, the beating degree of softwood pulp, the variety and additional amount of reinforcing agents, and the process of pressing and drying effect on the air filter paper. This data will guide the design of air filter paper with ideal properties.

EXPERIMENTAL

Materials

The plant fiber was bleached sulfate softwood pulp imported from Chile, and polypropylene fiber and polyester fiber were purchased from Longfeng Chemical Fiber Products Co., Ltd. (Binzhou, Shandong, China). Cationic starch (CS, for short, AR) was purchased from Kangpu Huiwei Technology Co., Ltd. (Beijing, China). Its substitution degree is 0.025 to 0.035. Cationic polyacrylamide (CPAM, for short, TG), with a molecular mass of 800,000, was purchased from Gongyibang Clean Water Material Co., Ltd. (Zibo, China).

Instruments

A standard sheet forming machine (RK-ZA-KWT, PTI co., Ltd., Traun, Austria), rotary drum dryer (E110, AMC, New York, USA), vacuum dryer (RK3A-KWT, PTI), and Valley beater (1304027, KRK, Osaka, Japan) were used.

Methods

Pulp Preparation

According to GB/T 24325 (2009), 360 g of oven dry bleached sulfate softwood pulp was immersed in water for 4 h, and then processed by the Valley beater to the required beating degree.

Papermaking and Performance Testing

Synthetic fibers were mixed with softwood pulp to make air filter base paper with a density of 110 g/m^2, using a standard sheet forming machine. They were dried by vacuum dryer and rotary drum dryer. The performance of the filter base paper was tested according to GB/T 24323 (2009).

RESULTS AND DISCUSSION

The Effect of the Ratio of Synthetic Fiber on the Properties of Base Paper

Softwood pulp was refined to 38 °SR, then mixed with synthetic fiber to make air filter base paper. The aim was to achieve a basis weight of 110 g/m^2. The proportion of synthetic fibers were 0%, 10%, 20%, 30%, 40%, and 50% (relative to the amount of oven dry base paper). The base paper was pressed for 5 min and dried by vacuum dryer to produce air filter base paper. At last, the physical performance of the base paper was tested according to the GB/T 24323 (2009). As shown in Figs. 1 and 2, the additional amount of synthetic fiber increased the bulk and porosity of the base paper. The bulk and porosity of base paper made by PP fibers were larger than those made by PET fibers. The reasonable explanation is that the surface of the polypropylene fiber is smooth, the binding force formed when mixing with the plant fiber is extremely small, and the polypropylene fiber is straight, thus increasing the aperture of the base paper.

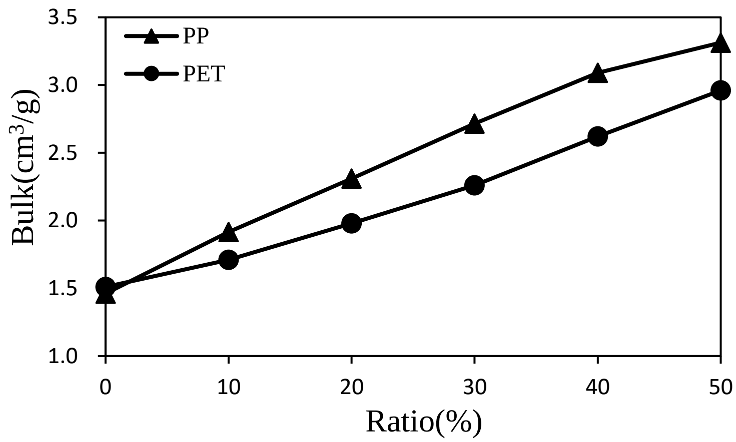

Fig. 1. The effect of the ratio of synthetic fiber on the bulk of base paper

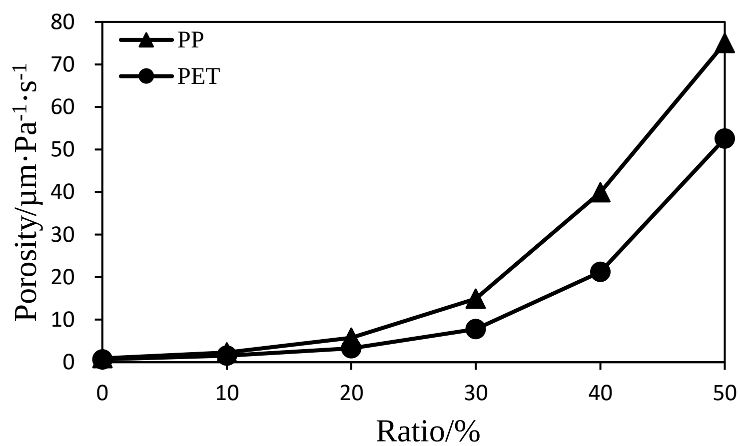

Fig. 2. The effect of the ratio of synthetic fiber on the porosity of base paper

Figures 3 and 4 show that the tensile and burst index of base paper decreased, and the downward trend of the additional of PP fibers was more apparent than PET fibers with the additional amount of synthetic fiber added. The tensile and burst index of base paper made by PET fibers were larger than those made by PP fiber.

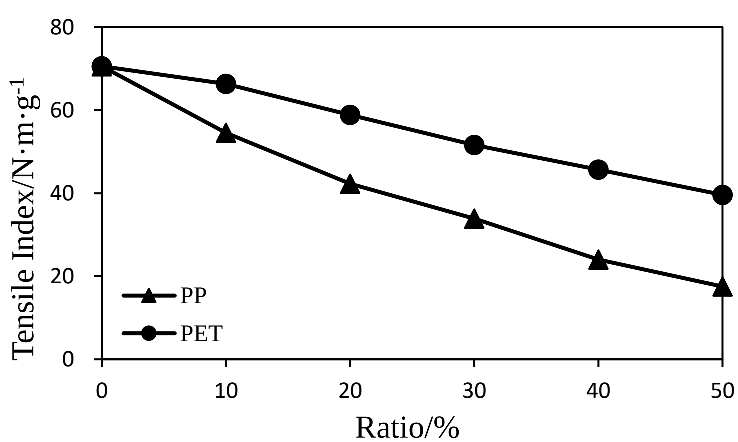

Fig. 3. The effect of the ratio of synthetic fiber on the tensile index of base paper

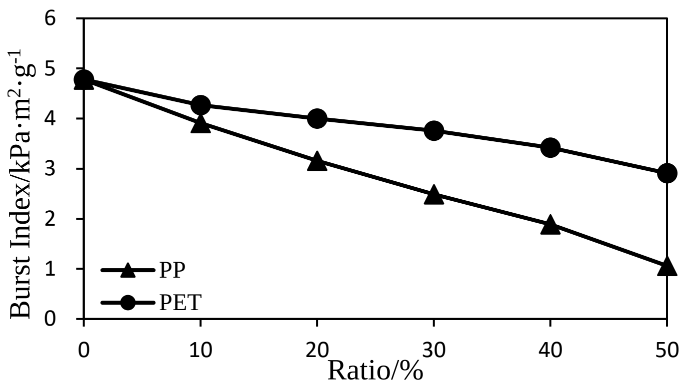

Fig. 4. The effect of the ratio of synthetic fiber on the burst index of base paper

The strength differences were attributed to the fact that the surface of the polyester fiber does not have any hydrogen bonds that can bind with the softwood fibers, so the binding force between the fibers is small, leading to a continuous decrease in the tensile index and the burst resistance index.

Figures 5 and 6 note the effect of replacing some of softwood fibers with synthetic fibers on the tear index and folding strength of base paper. The tear index and folding strength of base paper made by PP fibers decreased slightly with the additional amount of PP added, but the tear index of base paper made by PET fibers increased linearly. The folding strength of base paper made by PET fibers increased first and then decreased, and reached the maximum when the proportion of PET fibers were 20%.

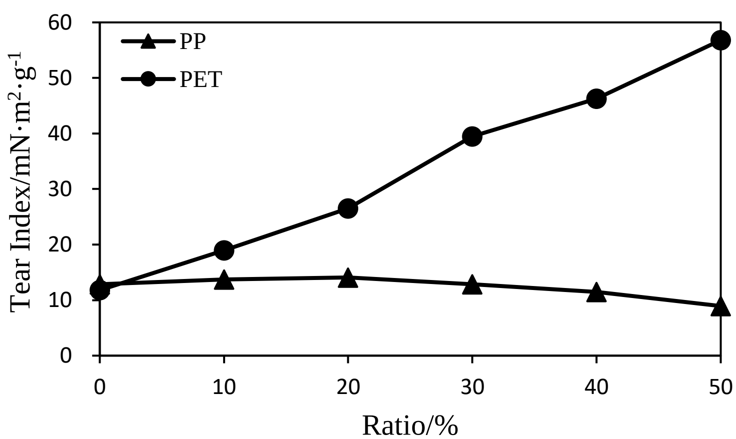

Fig. 5. The effect of the ratio of synthetic fiber on the tear index of base paper

With an increasing amount of polypropylene (PP), the folding resistance gradually decreased, and the tear index increased first and then decreased. With the increasing of its proportion, the number of polypropylene fibers increased, the binding force between fibers gradually decreased, and the bulk of the paper gradually increased, so the binding force between fibers decreased significantly. With the increase of the amount of polyester fiber PET added, the tear index gradually increased, and the folding endurance increased first and then decreased. But as the added amount continued to increase, the binding force between the fibers was drastically reduced, resulting in a significant reduction in the degree of folding resistance.

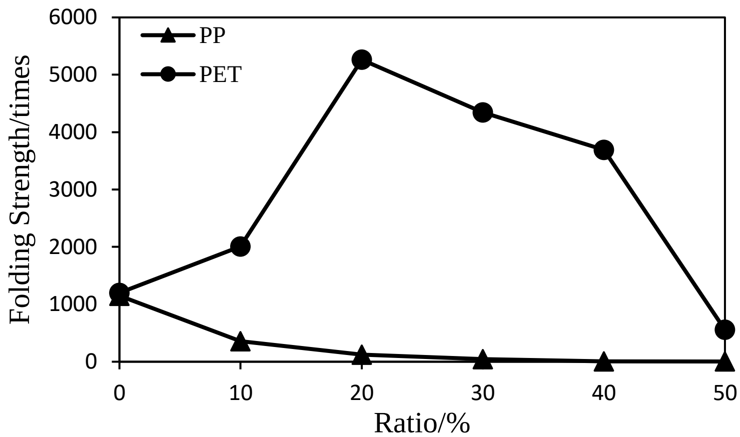

Fig. 6. The effect of the ratio of synthetic fiber on the folding strength of base paper

Because PP fibers are stiff, they are mixed with synthetic fibers to make air filter paper; this increases the looseness and bulk of the filter paper, while improving the porosity of filter paper. PET fibers are flexible, so softwood pulp replaced with PET fibers could increase the bonding strength between fibers, so that the bulk of filter paper made by PET fibers was smaller than that made by PP fibers. Most synthetic fiber cannot fibrillate, so there is no bonding force between fibers (Zhang 2001), causing the physical strength of filter paper made by PP fibers to weaken. As a result, PET fibers are flexible and can form a larger contact area between PET fiber and plant fiber. As a results, the tensile and burst index of filter paper made by PET fibers declined more gently than those made by PP fibers.

After forming, pulling out PET fibers from the page required more energy than made PP fibers, so the tear index and folding strength of filter paper made by PET fiber increased first and then decreased. Although replacement of softwood pulp with PP fibers could improve the folding strength of base paper, the proportion of PP fiber should not exceed 20%.

Given the bulk, porosity, and physical strength of base paper, various properties of base paper made by synthetic fibers could be balanced when the proportion of synthetic fiber was 20%, so the ratio of PET fiber was set to 20%.

The Effect of the Beating Degree of Softwood Pulp on the Properties of Base Paper

In order to improve the physical strength of base paper, the beating degree of softwood pulp was changed to explore its effect on the properties of air filter base papers when they were made. Softwood pulp was refined for 0 min, 10 min, 20 min, 30 min, 40 min, and 50 min to 14 °SR, 16 °SR, 22 °SR, 30 °SR, 34 °SR, and 38 °SR, respectively, then mixed with synthetic fiber to make air filter base paper. Its basis weight was 110 g/m^2, and the ratio of synthetic fiber was 20%, then base paper was pressed for 5 min and dried by vacuum dryer. At last, the physical performance of base paper was tested.

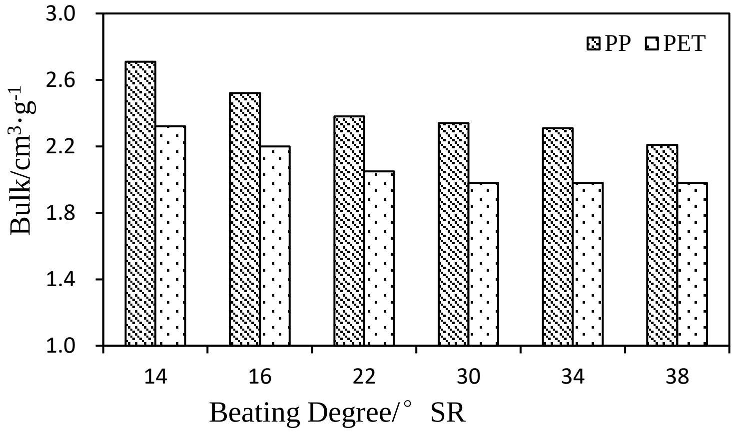

Fig. 7. The effect of the beating degree of softwood pulp on the bulk of base paper

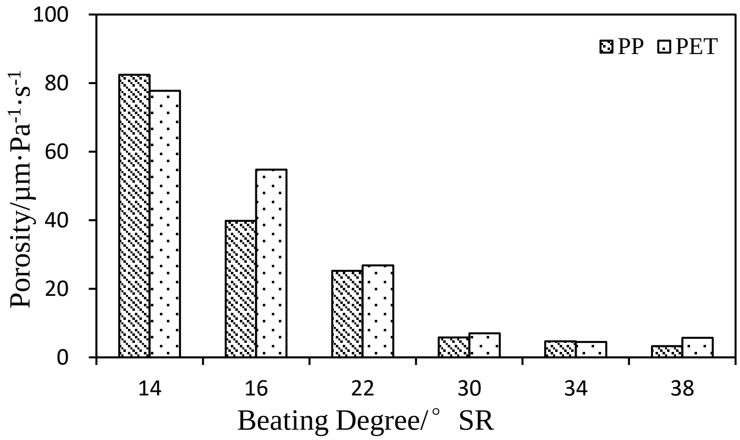

Fig. 8. The effect of the beating degree of softwood pulp on the porosity of base paper

As can be seen in Figs. 7 and 8, as the beating degree increased, the bulk and porosity of base paper decreased, especially the porosity. To ensure the porosity of air filter base paper, the beating degree of softwood pulp should not exceed 30 °SR.

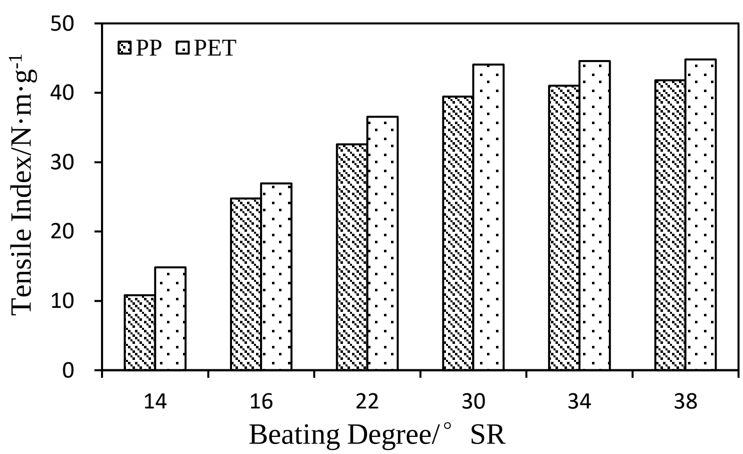

Fig. 9. The effect of the beating degree of softwood pulp on the tensile index of base paper

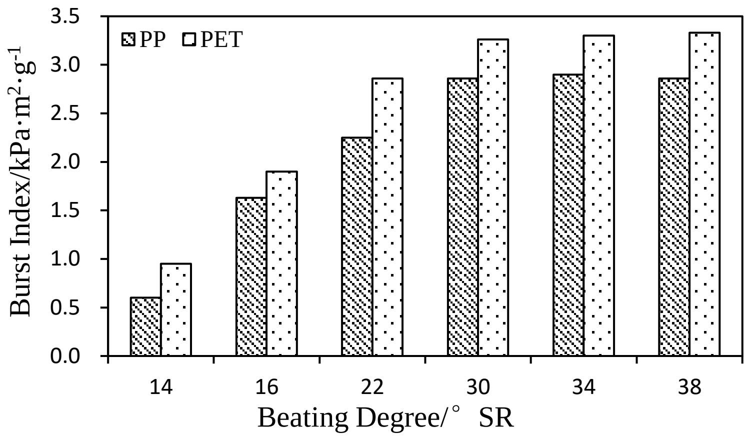

Fig. 10. The effect of the beating degree of softwood pulp on the burst index of base paper

Figures 9 and 10 show the effect of the beating degree of softwood pulp on the tensile and burst index of base paper. With increasing beating degree of softwood pulp, the tensile and burst index of base paper increased rapidly. When the beating degree was higher than 30 °SR, the increasing trend slowed down, and the tensile and burst index of base paper made by PET fibers were higher than made by PP fibers. The increase of the beating degree could improve the properties of base paper obviously.

The tear index of base paper increased first and then decreased as the beating degree increased and reached a maximum when the beating degree was 22 °SR in Fig. 11. From Fig. 12, it can be seen that the increasing of the beating degree had no significant effect on the folding strength of base paper made by PP fiber, but exactly the opposite behavior was observed when made by PET fiber. Thus, increasing the beating degree improved the folding strength of base paper made by PET fiber.

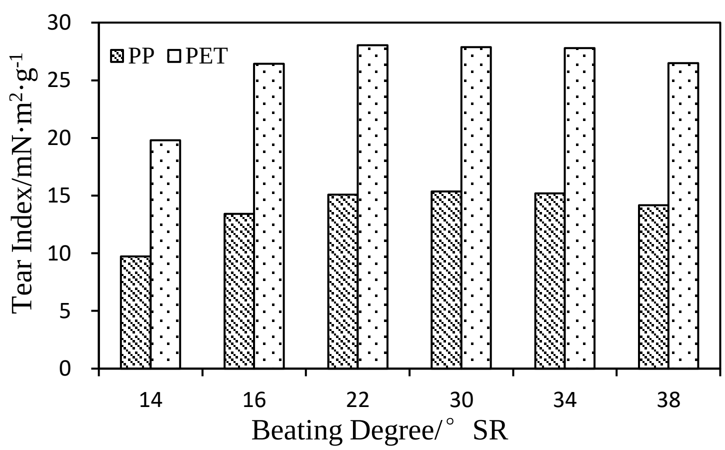

Fig. 11. The effect of the beating degree of softwood pulp on the tear index of base paper

With the increase of the beating degree of softwood pulp, fiber swelling and fibrillation also increased, which enlarged the specific surface area of fiber. More hydroxyl groups became available, which promoted hydrogen bonding and bonding strength between fibers, so the pore diameter and porosity of base paper decreased (Page 1989; He *et al*. 2010).

In consideration of the filtration ability and effectiveness of air filter paper and difficulty of filter processing, the beating degree should not be too low, but on the other hand it should not be too high. Otherwise it would affect the physical strength, filter efficiency, and clogging capacity of filter paper. In conclusion, in order to guarantee both porosity and filtration properties of base paper, and ensure the mechanical properties of base paper, the beating degree of softwood pulp should be 22 °SR.

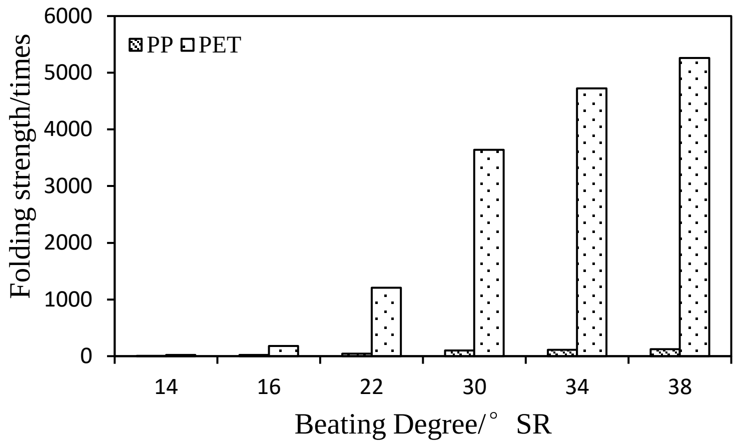

Fig. 12. The effect of the beating degree of softwood pulp on the folding strength

The Effect of the Bonding Agents on the Properties of Base Paper

Although increasing the beating degree could improve tensile strength, it could decrease the porosity and bulk. So in order to guarantee both tensile strength of base paper, without any great influence on the other performance of base paper, reinforcing agents were used (Hu *et al*. 2002). This study used two common bonding agents, cationic polyacrylamide (CPAM) and cationic starch (CS). This is because the cationic reinforcing agents can directly adsorb on the fiber surface, enhance the bonding force between fibers significantly, and will not bring too much anionic trash to the circulation system of white water.

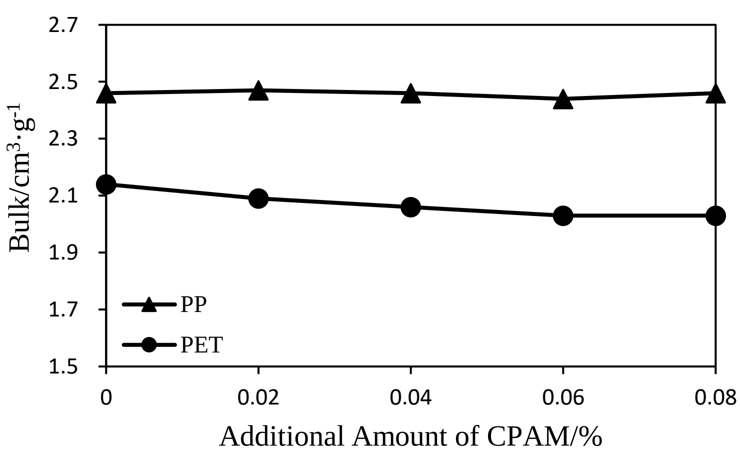

Fig. 13. The effect of the additional amount of CPAM on the bulk of base paper

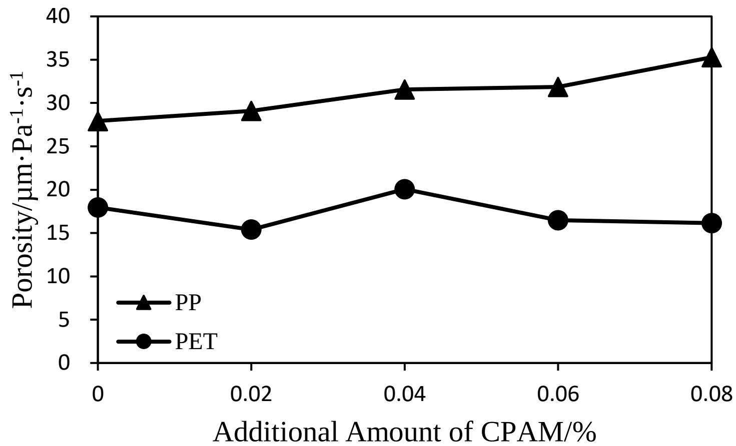

Fig. 14. The effect of the additional amount of CPAM on the porosity of base paper

The effect of cationic polyacrylamide on the properties of base paper

The beating degree of softwood pulp was selected to be 22 °SR, and then the softwood pulp was mixed with synthetic fiber to make base paper for which the basis weight was 110 g/m^2, and the ratio of synthetic fiber was 20%. An additional amount of CPAM was chosen as 0%, 0.02%, 0.04%, 0.06%, or 0.08%. After pressing for 5 min, dried by vacuum dryer, the samples were tested to evaluate physical performance of base paper.

As can be seen in Figs. 13 and 14, the increase of CPAM had no significant effect on the bulk of base paper made by PP fiber, but the porosity of base paper decreased slightly. In contrast, the bulk of base paper made by PET fiber increased slightly, there was no significant effect on the porosity of base paper, and the bulk and porosity of laboratory handsheets made by PP fiber were higher than by PET fiber.

Figures 15 to 17 show that the tensile and burst index of base paper made with PP fiber increased with the increasing of the addition amount of CPAM, but the tear index decreased slightly. The tensile, burst, and tear index of base paper made with PET fiber increased slightly first and then decreased with the increase of CPAM, and were obviously higher than those made by PP fiber, so the increase of CPAM was more advantageous to improve the physical strength of base paper made by PET fiber.

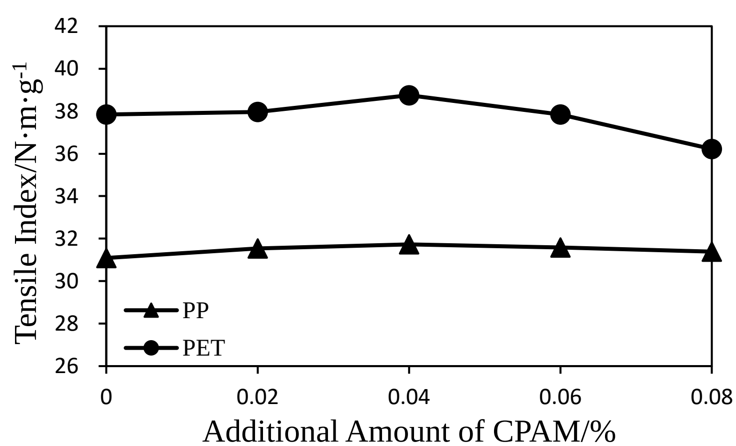

Fig. 15. The effect of the additional amount of CPAM on the tensile index of base paper

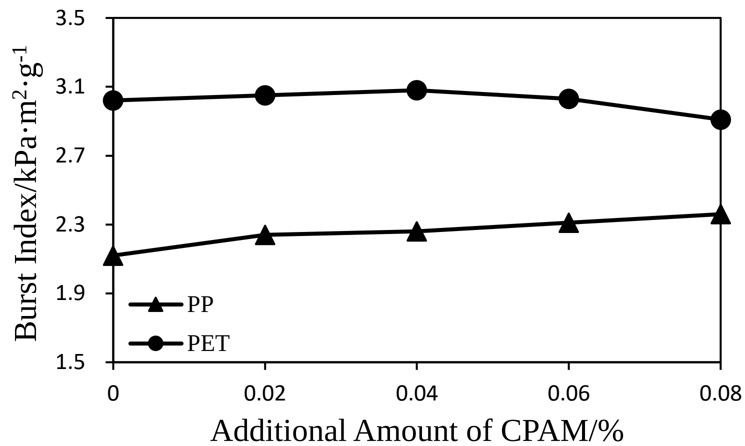

Fig. 16. The effect of the additional amount of CPAM on the burst index of base paper

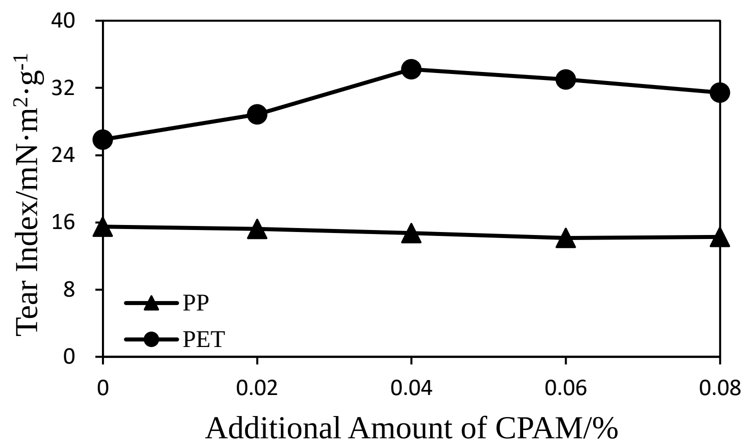

Fig. 17. The effect of the additional amount of CPAM on the tear index of base paper

Because cationic polyacrylamide is cationic, it can adsorb on the surface of fiber and improve the fiber-to-fiber bonding as an intermediate medium, so the mechanical properties of base paper increased with the increase of CPAM. The burst, tear index, and folding strength of base paper made by PET fiber increased when the amount of CPAM was more than 0.04%. The excessive CPAM could accelerate the fiber-to-fiber flocculation, which reduced the formation of base paper and increased the physical properties of base paper. So, the additional amount of CPAM should be 0.04%.

The Effect of cationic starch on the properties of base paper

The beating degree of softwood pulp was set to 22 °SR, and then the softwood pulp was mixed with synthetic fiber to make base paper. Its basis weight was 110 g/m^2, and the ratio of synthetic fiber was 80%. The additional amounts of CS were 0%, 0.2%, 0.4%, 0.6%, and 0.8%. After pressing for 5 min, dried by vacuum dryer, the physical performance of the base paper was tested according to the standard method.

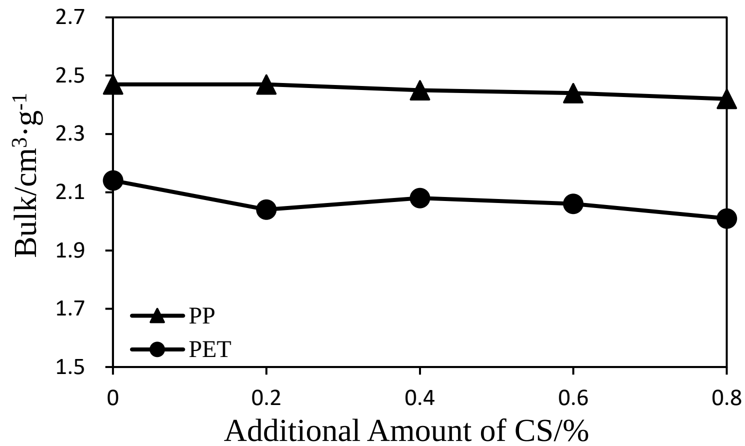

Fig. 18. The effect of the additional amount of CS on the bulk of base paper

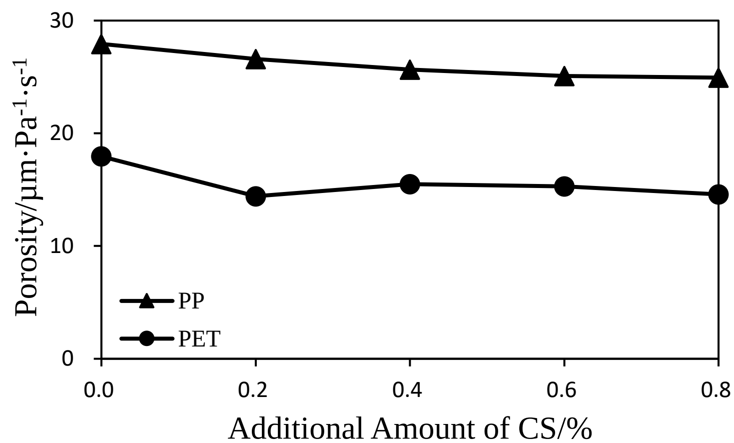

Fig. 19. The effect of the additional amount of CS on the porosity of base paper

As can be seen in Figs. 18 and 19, the bulk and porosity of base paper decreased with an increase in the additional amount of CS, and the bulk and porosity of base paper made with PP fiber were higher than those made with PET fiber. This was due to the addition of CS that increased the fiber-to-fiber bonding strength, leading to the decrease of the bulk and porosity of base paper.

Figures 20 to 22 show that with the increase of CS, the tensile and burst index of base paper made by PP fiber increased, but the tear index decreased slightly. The physical strength of base paper increased first and then decreased and achieved a maximum when the amount of CS at 0.4%. The physical properties of the base paper made by PET fibers were far higher than those made by PP fibers.

Because cationic starch is cationic, it can closely integrate with negative fibers and can improve the fiber-to-fiber bonding strength. However, the fiber-to-fiber flocculation increased obviously, and the impact on formation of base paper with the increase of CS, so the strength properties of base paper decreased. In conclusion, a 0.4% level of CS elect to 0.4% was judged to be most favorable.

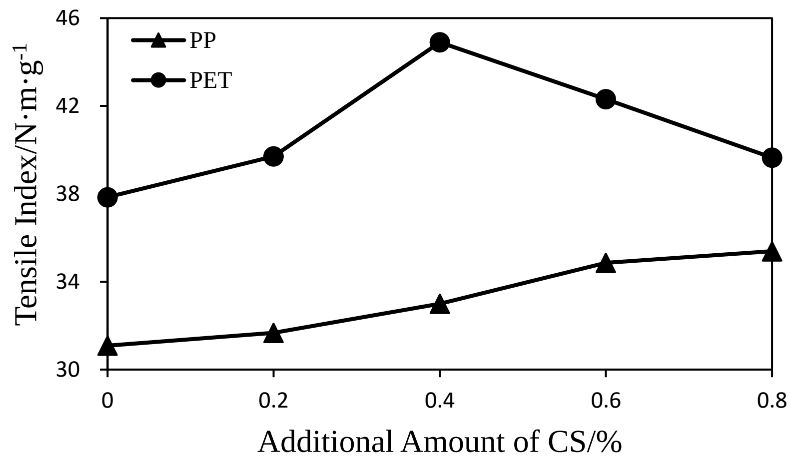

Fig. 20. The effect of the additional amount of CS on the tensile index of base paper

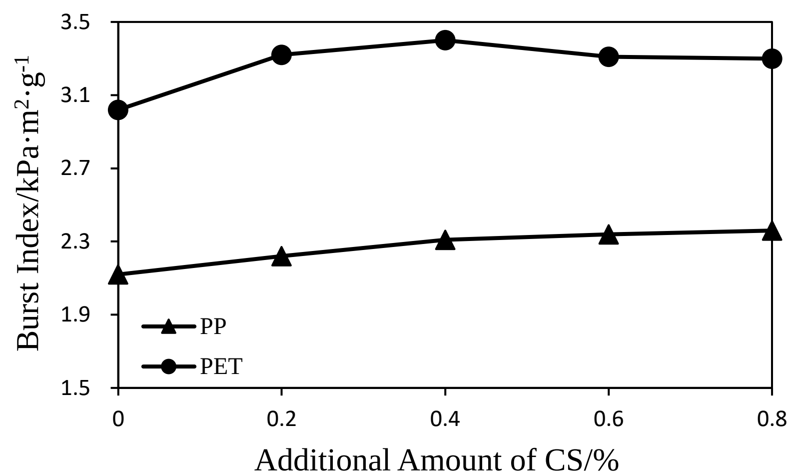

Fig. 21. The effect of the additional amount of CS on the burst index of base paper

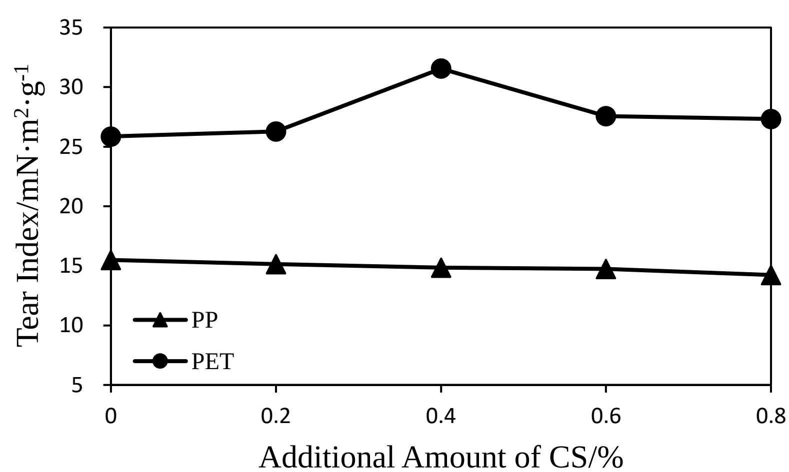

Fig. 22. The effect of the additional amount of CS on the tear index of base paper

Selection of reinforcing agent

CPAM and CS could increase the physical properties of base paper effectively. Table 1 shows the contrast of two kinds of strengthening agents at ideal conditions. The porosity of base paper with CPAM was superior to CS, and the porosity of base paper made by PP fiber was higher than the base paper made by PET fibers, but the physical strength was generally lower than the latter. Considering the porosity and physical strength, choosing CPAM as the strengthening agent was more suitable for making air filter paper.

Table 1. The Contrast of Two Kinds of Strengthening Agents at Ideal Condition

Synthetic Fiber	PP		PET	
Strengthening Agent	CPAM	CS	CPAM	CS
Basis Weight (g•m^2)	110.13	115.56	112.26	107.43
Bulk (cm^3•g)	2.46	2.45	2.06	2.08
Tensile Index (N•m•g^{-1})	31.73	33.00	38.75	44.90
Burst Index (kPa•m^2•g^{-1})	2.26	2.31	3.08	3.40
Tear Index (mN•m^2•g^{-1})	14.73	14.84	34.22	31.55
Porosity (μm•Pa^{-1}•s^{-1})	31.57	25.70	20.06	15.50

The Effect of Pressing and Drying Methods on the Properties of Base Paper

Softwood pulp and PET fibers were mixed to make filter paper until the basis weight was 110 g/m^2, the ratio of PET fiber was 20%, and the beating degree of softwood pulp and mercerized pulp were 22 °SR and 16 °SR, respectively. An additional amount of CPAM was 0.06%. The paper was pressed for 5 min first, then dried by vacuum dryer, pressed for another 5 min, then dried by rotary drum dryer, and then dried by rotary drum dryer without pressing to make air filter paper. Finally it was tested according to GB/T 24323 (2009) to test physical performance of base paper.

As shown in Table 2, the physical properties of base paper made by PET fibers were generally higher than base paper made by PP fiber, but the porosity was generally lower than the latter. Being dried by rotary drum dryer could improve the porosity of base paper, but the physical properties had no obvious change.

Table 2. The Effect of Pressing and Drying Methods on the Properties of Air Filter Base Paper

Synthetic Fiber	PP			PET		
Pressing and Drying Method	P+V	P+R	R	P+V	P+R	R
Basis Weight (g•m^2)	110.13	114.35	114.04	112.26	111.70	105.86
Bulk (cm^3•g)	2.46	2.84	3.74	2.06	2.83	3.63
Tensile Index (N•m•g^{-1})	31.73	29.33	22.54	38.75	29.22	25.01
Burst Index (kPa•m^2•g^{-1})	2.26	2.10	1.76	3.08	2.63	2.16
Tear Index (mN•m^2•g^{-1})	14.73	16.20	15.67	34.22	28.59	23.27
Porosity (μm•Pa^{-1}•s^{-1})	31.6	46.3	>100	20.1	37.2	92.0

PS: P+V means the base paper was pressed for 5 min and dried by Vacuum Dryer; P+R means the base paper was pressed for 5 min and dried by Rotary Drum Dryer; R means the base paper was dried by Rotary Drum Dryer without pressing.

In conclusion, PET fiber can be preferred for better physical properties, and for drying, the Rotary Drum Dryer without pressing is preferred to obtain better permeability.

CONCLUSIONS

1. The specified properties of base paper for air filtration were achieved when mixed synthetic fiber with softwood fiber to make air filter paper had a ratio of synthetic fiber of 20%, the beating degree of softwood pulp was 22 °SR, the additional amount of CPAM was 0.04%, and the paper was dried by rotary drum dryer without pressing.
2. Polypropylene (PP) fiber was observed to fall off easily from the sheet, whereas polyester (PET) fiber did not, and the addition of PET fiber could increase the porosity of paper. Meanwhile the PET could also improve the tear index and folding endurance of the base paper. Namely, PET fiber was more suitable for making air filter paper than PP fiber.

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