Research paper

Effects of Adding Co-ground Talc and Calcium Carbonate on the Retention and Paper Properties of Handsheets

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【Summary】

In this study, 2 methods of preparation of talc and calcium carbonate were employed. The 2 minerals were either ground up together with water or the wet-ground calcium carbonate was mixed with dry-ground talc. Then the preparations were added to a typical fine paper furnish to investigate the effects of replacing a portion of calcium carbonate with talc on the first-pass retention (FPR), ash, sizing degree, bulk, tensile strength, smoothness, roughness, brightness, and opacity of the handsheets (with a basis weight 60 g m^{-2}). Handsheets produced with 100% wet-ground calcium carbonate (GCC) and 100% dry-ground talc served as the control groups. The replacement level of talc was 10%, and the dosages examined were 0, 10, 20, and 30%. The results indicated that replacing a portion of GCC with talc enhanced the FPR, ash retention, bulk, sizing degree, tensile index, and brightness of the handsheets at the cost of decreased smoothness and opacity. Comparing the 2 preparations, grinding together the talc and calcium carbonate appeared to produce a more-uniform particle size distribution and smaller average particle diameters than the separately ground and mixed groups. The edges of the platy filler were smoother for the former group as well. Comparing the 2 groups, talc and GCC ground together produced better handsheet filler retention, sizing degree, tensile index, and brightness.

Key words: talc, co-grinding, calcium carbonate, retention, tensile index.

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研究報告

共濕磨滑石粉與碳酸鈣對於留存率及紙張性質的影響

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摘 要

本研究為應用2種滑石粉/碳酸鈣製備方式：混合共濕磨滑石粉/碳酸鈣及單獨濕磨碳酸鈣與乾磨滑石粉混合，來探討滑石粉取代部份碳酸鈣填料時對於一次留存率、灰分、上膠度、嵩度、抗張強度、平滑度、粗糙度、白度、不透明度等的影響。以100%濕磨碳酸鈣及100%乾磨滑石粉為空白組。滑石粉取代碳酸鈣量為10%，填料(碳酸鈣+滑石粉)添加量為0、10、20、30%。實驗結果顯示，滑石粉取代10%碳酸鈣可以提高一次留存率、填料留存率、嵩度、上膠度、斷裂長度、白度等性質，但會降低平滑度及不透明度。共濕磨滑石粉與碳酸鈣組與濕磨碳酸鈣組及乾磨滑石粉組比較，可以得到粒徑分佈較均勻且平均粒徑較小，同時片狀的外型邊緣亦較平順的填料。共濕磨碳酸鈣/滑石粉組與濕磨碳酸鈣+乾磨滑石粉組比較，可以提高填料留存率、上膠度、斷裂指數及白度等性質。

關鍵詞：滑石粉、共濕磨、碳酸鈣、留存率、斷裂指數。

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INTRODUCTION

The history of using talc powder in papermaking stretches back to an earlier period. At the beginning of the 20th century, there were reports of using talc as wet end filler applications in France, Italy, Spain, Japan etc. Lamar (1958) indicated that ultrafine talc had a particle size distribution appropriate for coating operational use. In 1960, Maurice Warner of the Cyprus Minerals Co. initiated the use of high-purity talc as a pitch or resin control agent (Hagemeyer 1984, Laufmann 1998, Lehtinen 2000, Perng et al. 2008).

Talc powder is a platy-structured mineral. A typical talc plate is composed of a SiO_2-MgOH-SiO_2 tri-layer, with a theoretical thickness of 9.4 nm. van der Waals forces act to hold the plates together. Because of the weak plate-to-plate coalescing forces, they are liable to delaminate during a diminution process and thus possess a slippery nature and a lubricating function when incorporated in preparations of coating color formulations. The surface of the SiO_2 layer is hydrophobic and organophilic; the edge of the plate, however, is hydrophilic. A talc plate has a length of ca. 10 μm, a thickness of 2 μm, and a fairly weak cation exchange capacity of 2.4 meq/100 g. Thus, there should be minimal effects on the pH of a suspension (Lamar 1958, Hagemayer 1984, Cavangh and Bates 1994, Lehtinen 2000, Ciullo and Anderson 2002, Perng et al. 2008).

The shapes and physical properties of commonly used papermaking filler mineral pigments such as talc, clay, and ground calcium carbonate (GCC) are shown in Table 1. Talc is the softest natural mineral, and helps extend the service life of doctor blades and slitting knives in paper machines. Talc powder is platy structured, with an aspect ratio of

Table 1. Typical filler properties (Lasmarias and Sharma 2004, Anon 2005)

Property	Talc	Clay	GCC
Mineralogy	Mg-silicate	Al-silicate	Calcium carbonate
Morphology	Macro-crystalline	Blocky	Scalenohedral
Particle shape	Platy	Platy	Irregular
Refractive index	1.57	1.56	1.66
Surface energy (mJ m^{-2})	35~40	55~60	75~80
Median particle size (μm)	5.0~7.0	1.1~1.3	1.46
Brightness (% ISO)	80~90	80~92	91~95
Oil absorption	25~55	30~45	8~18
Moh's hardness	1~1.5	2	3
Aspect ratio	30	15	1

GCC, ground calcium carbonate.

ca. 30, which is higher than those of the kaolin clay and calcium carbonate. Incorporating the mineral can reduce the surface roughness of paper and give improved printability and better ink and coating layer hold-out. The inert chemical nature of talc precludes it from reacting with wet end chemical additives and affecting the electrical balance of wet end systems. The average particle diameter of talc is ca. 3~5-times those of kaolin clay and calcium carbonate; hence, talc is easier to retain in wet end systems. When fully mixed with calcium carbonate and kaolin clay, it can facilitate the retention of other minerals. The simultaneous hydrophobic and hydrophilic characteristics of the talc surface can also help dewater the paper web (Withiam 1991, Sharma and Bash 1998, Lasmarias and Sharma 2004).

There are few reports dealing with applications of talc powder in papermaking wet end as a filler. Lasmarias and Sharma (2004) investigated using talc to replace a portion of precipitated calcium carbonate (PCC) and clay in base stocks of a supercalender and coating base sheet, and examined its effect on retention, drainage, and paper properties. Their laboratory handsheet study indicated that the retention increased, the drainage became faster, and the tensile strength and rotogravure printability improved as well. As for industrial application cases, the proprietary nature prevented their disclosure. However, it is expected that the performance should be similar to the lab results.

In recent years, a domestic paper filler supplier developed the simultaneous wet-grinding of a calcium carbonate and talc ore mixture and successfully promoted its application in several domestic paper mills. The wet-GCC/talc was reputed to give higher retention, sizing degree, and opacity in the mill trial. However, due to the confidentiality clause between the supplier and mill, there was no further report.

The main purpose of this study was to examine the effects of replacing 10% of the calcium carbonate with talc on the fiber retention, ash retention, sizing degree, paper physical properties, surface properties, and optical properties of handsheets. The filler preparations were either wet talc and calcium carbonate ground together or wet-GCC mixed with dry-ground talc. The 100% wet-GCC and 100% dry-ground talc served as the blank groups.

MATERIALS AND METHODS

Experimental design

Two methods of preparation were employed to produce the talc/calcium carbonate mixture. They were either proportionally mixed and then wet-ground together, or they were formed by mixing wet-GCC and dry-ground talc in a fixed proportion. The effects of replacing part of the calcium carbonate with talc in a fine paper stock on the ensuing first-pass retention (FPR), ash content, sizing degree, bulk, tensile index, smoothness, roughness, brightness and opacity of the resulting handsheets were examined. The 100% wet-GCC and 100% dry-ground talc were used as the blank groups. Filler (GCC + talc) dosages of 10, 20, and 30% were used, and the level of talc replacement was 10% in accordance with the commercial specifications. There were 13 sets of experiments, each set was replicated 10 times for a total of 130 sets. The pooled standard deviations of the experiments were: 1.2% for FPR, 1.3% for ash retention, 2.24 s for sizing degree, 0.03 cm^3 g^{-1} for bulk, 1.37 N·m g^{-1} for tensile index, 0.32 s for smoothness, 0.10 μm for roughness, 0.25% ISO for brightness, and 0.25% for opacity.

Materials

Bleached hardwood kraft pulp consisted of acacia pulp (Arauco, Santiago, Chile) and birch (Al-Pac, Athabasca, Canada) blended 2:3, then beaten on-site to a ca. 400 mL CSF freeness. Wet-GCC had an average particle diameter of 1.46 μm, a brightness of 96.5% ISO, a solids content of 61.0% (MSW 75, Jaw Hwa Minerals, Hualien, Taiwan). The dry-ground talc had an average particle diameter of 8.61 μm, a brightness of 91.5% ISO, a solids content of 99.9% (Red 3A, Jaw Hwa Minerals). The calcium carbonate and talc wet-ground together had a particle diameter of < 2.0 μm, 70%; a brightness of 97.0% ISO, a solids content of 47.7% (MSTW 65, Jaw Hwa Minerals). GCC + dry-ground talc had a solids content of 24.0%, and was self-prepared in the lab. The sizing agent was alkyl ketene dimer (AKD), with a solids content of 15.5% (TD-15, Taiwan Hercules, Taipei, Taiwan). The cationic polymer retention aid was a polyacrylamide-type dry powder, with a solids content of 90.4% (Percol 183, Taiwan Ciba Chemicals, Taipei, Taiwan).

Experimental equipment

A 4-decimal-place electronic balance from Mettler Toledo AB204-S, and accurate to ±0.1 mg was used for weighing pulp and pigments. For making the handsheets, a model 306-3 pulp disintegrator, a model 306-A handsheet machine, a model 306-B handsheet dryer, and a model 306-C press from Lien-Sheng Instruments (Gueishan, Taiwan) were used. A Shin-Kwang G-100S mixer (Taipei, Taiwan) was used for stock preparation which had a range of speeds of 250~3000 rpm. A CDV-452 oven from Shang-Mei Instruments (Changhwa, Taiwan) was used for drying test materials. Instruments used for testing of the handsheets included a model SE 065 autoline compatible tensile strength tester from Lorenten & Wettre (Kista, Sweden); a model ME 90 Parker Print-Surf (PPS) roughness tester from Messmer (Gravesend, Kent, UK); a Labscan XE brightness/opacity tester from the Hunter Lab (Reston, VA, USA); and a Bekk smoothness tester from Kumagai Riki Kogyo (KRK, Tokyo, Japan). For observing the filler pigments, a model S-3000N scanning electron microscope from Hitachi (Tokyo, Japan) was used.

Methods

Suitable amounts of filler suspensions were oven-dried at 105℃ for 1 h, a small amount of the dried filler cake was placed on the specimen stage of the SEM, and the specimen was imaged with an accelerating voltage of 15 kV to observe the filler shapes.

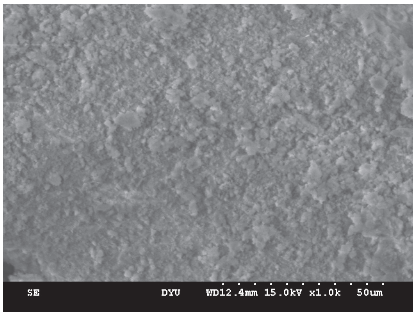
To a 0.3% consistency pulp stock, 4 filler groups comprised of wet-GCC alone, dry-ground talc alone; wet co-GCC/talc; and wet-GCC plus dry-ground talc, each at 0, 10, 20 and 30% dosages to dry pulp were separately added. After thorough mixing, 0.5% of the AKD sizing agent and 300 mg L^{-1} of a cationic retention aid were sequentially added. Then handsheets of 60 g m^{-2} were formed (TAPPI T205 sp-02), and the FPRs were measured.

The resultant handsheets were conditioned overnight under a standard atmosphere of 23℃ and 50% relative humidity in a constant-temperature and -humidity chamber. Then the paper grammage (TAPPI T410 om-02), caliper, bulk (TAPPI T411 om-05), ash content (TAPPI T413 om-02), Stoeckigt sizing degree (TAPPI T433 cm-02), tensile strength (TAPPI T494 om-01), smoothness (TAPPI T479 cm-99), roughness (TAPPI T555 om-14), brightness (TAPPI T452 om-02), and opacity (TAPPI T519 om-02) were determined.

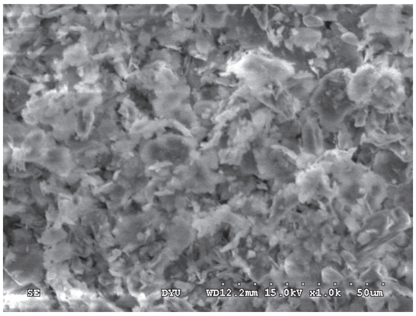
RESULTS AND DISCUSSION

Wet co-GCC/talc effects

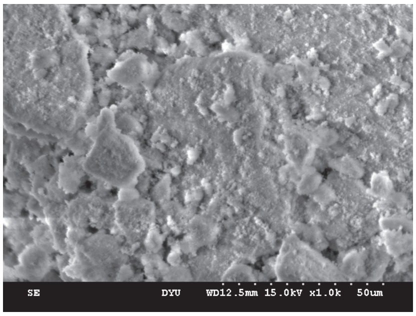
The SEM micrographs of the 4 experimental filler groups delineated above are shown in Fig. 1. The average particle diameter, brightness, and specific surface area of these groups are shown in Table 2. From the micrograph and table, it can be seen that the wet co-GCC/talc appeared to have talc particles with more evenly distributed sizes and smaller average particle diameters of ca. 6.32 μm than the dry-ground talc. In addition, the plates of talc generally had smoother,



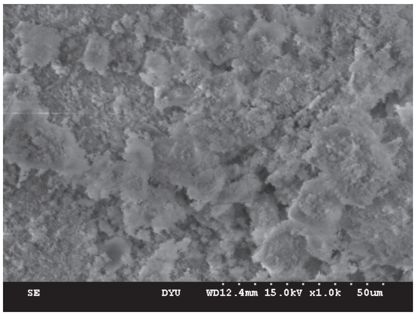
(A) $CaCO_3$ (ground calcium carbonate)



(B) Talc



(C) Wet co-ground $CaCO_3$/talc



(D) GCC + talc

Fig. 1. Scanning electron microscope photomicrographs of the 4 types of filler (×1000).

Table 2. Properties of the experimental filler groups

Group	Median particle size (μm)	Brightness (% ISO)	Surface area (m^2 g^{-1})
Wet-ground $CaCO_3$	1.46	96.5	2.61
Dry-ground talc	8.61	91.5	0.58
Wet co-ground $CaCO_3$/talc	1.84 (1.34/6.32)	97.0	2.45
Wet-ground $CaCO_3$ + dry-ground talc	2.18	96.0	2.41

less-jagged edges. The average particle diameter of the wet co-GCC/talc was also finer, ca. 1.34 μm, than the wet-GCC alone. Among the 4 groups, the ranking for particle size distribution, brightness, and specific surface area were in the order wet-GCC; wet co-GCC/talc; wet-GCC and dry-ground talc, and dry-ground talc.

First-pass and filler retentions

The effects of different filler groups and filler dosages on the FPR of the handsheets are shown in Fig. 2. The pooled experimental standard deviations of the FPR and ash retention were 1.2 and 1.3%, respectively. Adding fillers apparently decreased the FPR and ash retention of the system. Among the 4 filler groups, wet-GCC had the poorest FPR and ash retention, while the dry-ground talc had the best performance. The wet co-ground mixed filler had the second-best FPR and ash retention, followed by post-mixed wet-GCC and dry ground talc. A probable reason for the good performance of co-GCC/talc was the more-uniform and diminutive size distribution which appeared to be particularly helpful for filler retention. Our experimental results are in agreement with those of Lasmarias and Sharma (2004) who noted that the addition of talc to calcium carbonate filler enhanced retention rates.

Paper bulk

The effects of different filler groups and ash contents of handsheets on the bulk of the resulting paper are shown in Fig. 3. The pooled standard deviation of the experiments was 0.03 cm^3 g^{-1}. The figure indicates that the ash content was associated with decreased paper bulk. Among the 4 groups, the bulk of handsheets containing only wet-GCC had the least bulk, while the dry-ground talc only

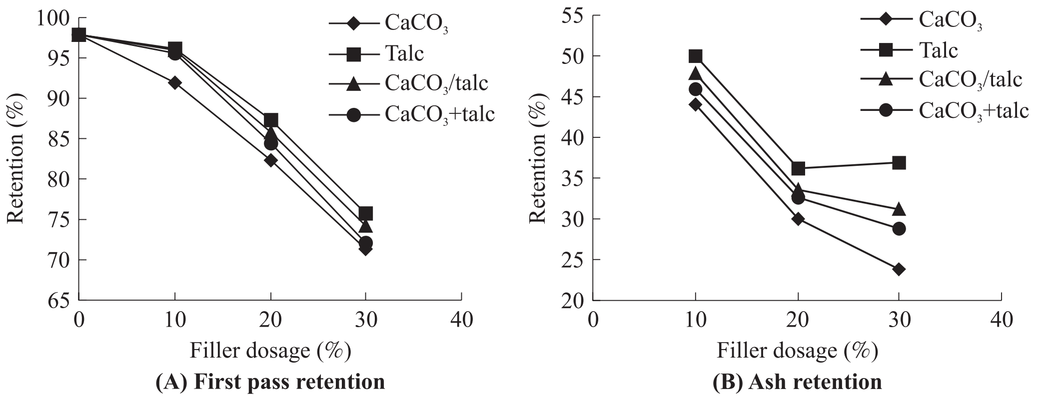


Fig. 2. Effects of filler type and dosage on the first pass retention (A) and ash retention (B).

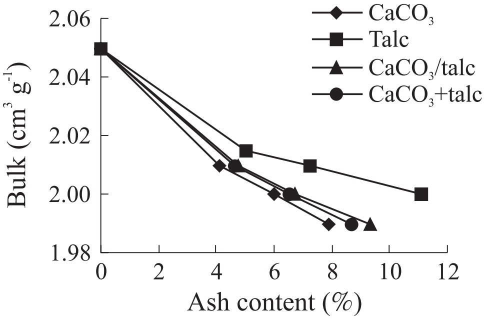


Fig. 3. Effects of filler type and ash content on the bulk of the handsheets.

group had the highest bulk. There was no significant difference in the contributions to paper bulk between the wet co-ground filler group and the post-mixed wet-GCC and talc.

Sizing degree

The effects of different filler groups and ash contents on the sizing degree of the handsheets are shown in Fig. 4. The pooled standard deviation was 2.24 s. The results indicated that talc enhanced the sizing degree. However, sizing degree decreased with an increase in ash content. Among the 4 groups, wet-GCC had the lowest size, and dry-ground talc the highest size. The post-mixed calcium carbonate and talc had moderate performances. Wet co-ground GCC and talc, however, produced handsheets with a higher sizing degree than the post-mixed group. This phenomenon may have been related to the specific surface area of the respective minerals. The larger the specific surface area was, the slower the AKD maturation rate became, leading to degradation of the sizing agent. Thus with a protracted reaction time, the AKD was less able to react with fiber surfaces and in turn react with water molecules to become hydrolyzed, which would consequently result in a reduced sizing degree.

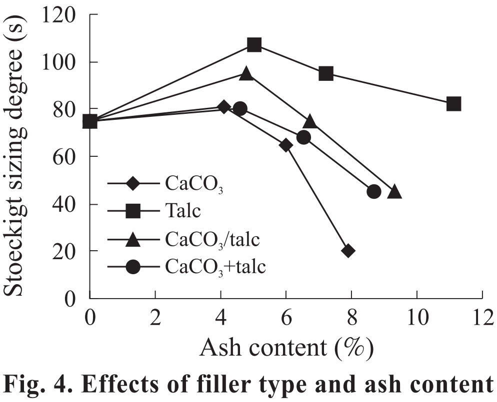


Fig. 4. Effects of filler type and ash content on the sizing degree of the handsheets.

Tensile index

The effects of different filler groups and handsheet ash contents on the tensile index of the resulting papers are shown in Fig. 5. The pooled standard deviation of the experiments was 1.37 N·m g^{-1}. The ash/filler content appeared to decrease the tensile index of paper since filler particles generally interfere with fiber-to-fiber bonding. Among the 4 filler groups, the mixed wet-GCC and talc groups had a higher tensile index than either of the pure filler groups. Wet co-GCC/talc appeared to have the best tensile index, slightly better than the post-mixed GCC/talc group. In the middle was the dry-ground talc-only group, and the wet-GCC-only group performed the poorest in this regard. A more-uniform and diminutive particle size distribution might have been a contributing factor. In addition, the

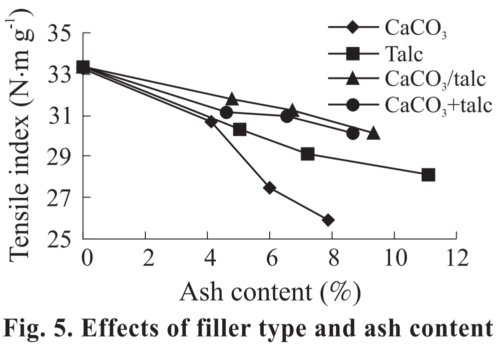


Fig. 5. Effects of filler type and ash content on the tensile index of the handsheets.

10% larger-sized talc particles might have assisted in aligning fibers to form a 3-dimensional bonded structure which increased the tensile index of the paper. These experimental results support the conclusions of Lasmarias and Sharma (2004) that incorporating co-ground talc improves the tensile index of paper.

Smoothness and roughness

Figure 6 shows the effects of different filler groups and ash contents on the smoothness and roughness of the resulting papers. The pooled standard deviation of the smoothness measurements was 0.32 s, and that of roughness was 0.10 μm. Increased ash content appeared to decrease the smoothness and increase the roughness of the paper. The trends, however, were not consistent. Among the 4 groups, dry-ground talc alone had the lowest smoothness, whereas the post-mixed wet-GCC and dry talc had the highest smoothness, followed by wet-GCC. With regard to the roughness, at a relatively low ash content, the mixed filler groups had higher roughness values than groups with either fillers alone. At a high ash content, however, the dry-ground talc alone group had the highest roughness.

Brightness and opacity

The effects of different filler groups and ash contents on the brightness and opacity of the resulting papers are shown in Fig. 7. The pooled standard deviations were 0.25% ISO for brightness and 0.25% for opacity. The results indicated that an increased ash content led to higher brightness and opacity of the handsheets. For paper brightness, the wet co-GCC/talc had the highest value, whereas, the dry-ground talc alone produced paper with the lowest brightness. It appeared that substituting 10% of the calcium carbonate with talc increased the brightness of the paper. Based on the additive principle, a brighter filler pigment should elevate the fiber-filler mixture, in other words, the filled paper. The intrinsic brightness of the pigments thus appeared to dominate the observed effects.

As for the paper opacity, among the 4 filler groups, wet-GCC-only had the highest opacity, and dry-ground talc-only had the poorest. The mixed GCC-talc groups had medium opacities. Substituting 10% of the GCC with talc decreased the opacity of the paper. This phenomenon might have been related to the size distribution of the pigment particles. Wet-GCC had the smallest average particle diameter (1.46 μm), which increased the frequency of light passing through the air-to-filler interfaces and increased light scattering, hence the increased opacity. Adding 10% of the larger-particle talc (averaging 8.61 μm) to wet-GCC caused an increase in the average

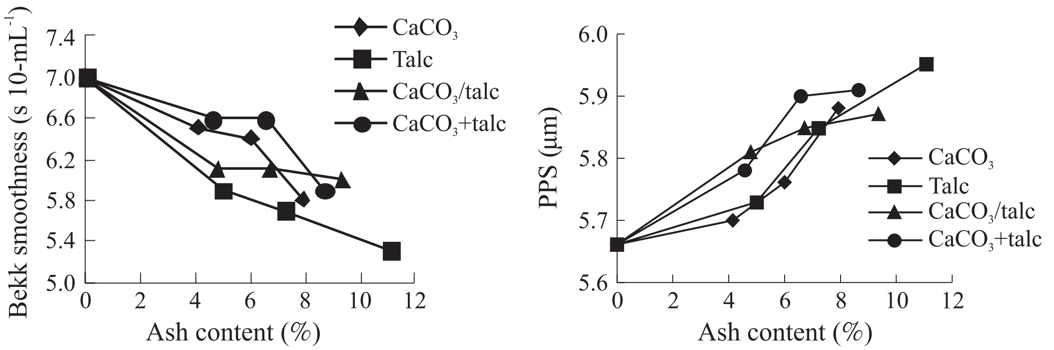


Fig. 6. Effects of filler type and ash content on the smoothness and Parker Print-Surf (PPS) roughness of the handsheets.

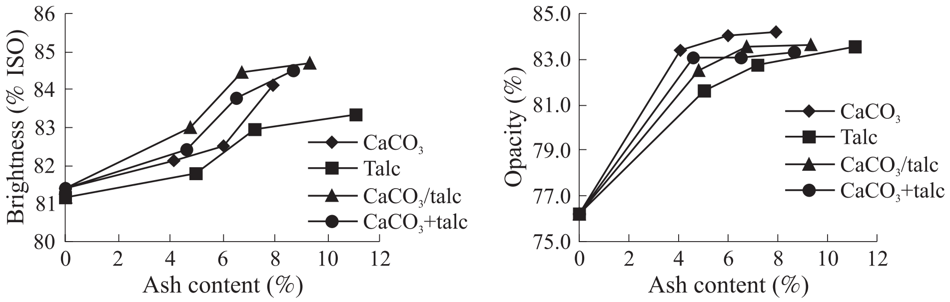


Fig. 7. Effects of filler type and ash content on the brightness and opacity of the handsheets.

particle size, and this reduced the opacity of the paper. There appeared to be comparable effects between the 2 mixed filler groups.

CONCLUSIONS

The experimental results of replacing 10% of the calcium carbonate with talc indicated an increased first pass retention, filler retention, bulk, sizing degree, tensile index, and brightness, however, at the cost of decreased smoothness and opacity of the handsheets. Wet co-ground talc and calcium carbonate produced a more uniform and smaller particle size than the corresponding mixed wet-ground calcium carbonate and dry-ground talc. Furthermore, the outer edges of the filler particles appeared to be smoother in the former group as well. The wet co-ground filler produced paper with better filler retention, sizing degree, tensile index, and brightness than the group with separate filler diminution and then mixed treatment.

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