Effect of Papermaking Conditions on the Ink Absorption and Overprint Accuracy of Paper

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The ink-absorption capacity is an important factor for evaluating the printing quality of paper. In this study, the effects of different parameters of papermaking on the ink-absorption capacity of paper were investigated. The results showed that hardwood pulp exhibited better performance in increasing the absorptivity of paper compared with softwood pulp. When the content of hardwood pulp in paper was increased from 0% to 100%, the ink mark length decreased from 5.1 cm to 4.3 cm. Furthermore, a basis weight change from 100 g/m^2 to 60 g/m^2 increased the ink-absorption capacity, as revealed by a decrease of the ink mark length from 4.8 cm to 4.4 cm. Both sizing agent and beating degree affected the ink-absorption performance of the paper. For example, a shorter ink mark length of 5.1 cm was obtained at a low beating degree of 5000 r compared with that of 5.1 cm at 15000 r.

Keywords: Ink absorption; Pulp; Sizing; Beating

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INTRODUCTION

Printing technology continues evolving with the development of society (Kwon and Kim 2007; Kim *et al*. 2012). Paper is one of the most important printing substrates and has played an important role in the improvement of printing speed and quality, especially paper with high ink-absorption capacity (Havlínová *et al*. 1999). The strength of the ink absorption significantly affects the printing hue of the printed matter and the glossiness. If the adsorption of paper to ink is too fast, then the vehicles in ink will penetrate into paper too much, resulting in a printing product that looks dull. Otherwise, the bad adsorption of paper to ink will reduce the drying rate of printing product, which will further result in a dirty product (Jiang *et al*. 2011; Pjanic and Hersch 2015).

Paper is a porous material, unlike other substrates such as plastic film or tinplate. It has a layered structure similar to soil and sedimentary rock, and is accompanied by many capillary structures (Reme and Helle 2002; Chinga-Carrasco 2009). Because the voids formed by the fiber network are the basis for the ink absorption of paper, the absorption capacity of the ink is an important quality index of printing papers. In recent decades, various advanced tools and techniques have been used to study the penetration of ink into papers; microscopy has received much attention due to its accurate and efficient capture of the infiltration details of ink in papers. Ngo *et al*. (2017) used scanning electron microscopy (SEM) to investigate the ink penetration of different coated paper cross-sections. Heard *et* *al*. (2004) and Sodhi *et al*. (2008) studied the distributions of ink components in printed coated paper by combining focused ion beam (FIB) techniques with a transmission electron microscope (TEM). Yan and Li (2008) and Ozaki (2011) researched the penetration of the ink vehicle by staining it with a fluorescent dye and obtained a 3-D characterization using confocal laser scanning microscopy (CLSM). Li and He (2011) employed ultraviolet-curing fluorescent rose ink as a substitute and investigated the penetration and distribution of ink pigments by CLSM. Combining the microstructure of paper and transforming the properties of the osmotic liquid to achieve lateral diffusion leads to penetration and solidification on the papers (Enomae *et al*. 2012). For printing products, the ink absorption of the paper is only one aspect affecting the quality, and the overprinting accuracy of printed patterns is another factor. It is mainly manifested in the surface compressibility of the paper.

This study explored the absorption properties of papers by changing the basis weight, pulp, beating, and sizing of papers. The IGT system was used to simulate the actual printing environment and perform the ink absorption experiment, exploring the effects of basis weight, pulp, beating, and sizing on the absorption of papers. Moreover, using digital printers to compare the overprinting precisions of papers with different basis weights and different fiber compositions, it was shown that the overprinting precision of hardwood paper was significantly greater than that of softwood paper, and as the paper basis weight increased, the overprinting accuracy decreased.

EXPERIMENTAL

Materials

The bleached kraft pulp of polar and pine was procured from Asia Symbol (Shandong) Pulp and Paper Co., Ltd. (Rizhao, Shandong, China). Alkyl ketene dimer (AKD) was provided by Shandong Chemicals Company. It was prepared into solution with a consistency of 10±0.5% and viscosity of 15 mPa•S at 25 °C. Di-n-butyl phthalate solution with 0.1% pigment (Sudan Red) was used to act as printing ink.

Methods

Beating of pulp

Pulp samples were beaten in a PFI mill (A-8, Norway) at 10% stock consistency. The interspaces between the beating roll and beating chamber were 0.18 mm, and the load applied during refining was 3.4 N/mm. The beating degree was measured by the drainage of pulp.

Analysis of fiber morphology

Analysis of fiber morphology was performed using an OpTest Fiber Quality Analyzer (FS-5, OpTest Equipment Inc., Hawkesbury, ON, Canada).

Observation of fiber morphology and paper surface aperture by polarized light microscope

The surface topography of the papers was observed (10×10) using an NP-800M polarized light microscope (PLM, Nanjing Jiangnan Novel Optics Co., Ltd, Nanjing, China).

Preparation of handsheets

To test the effect of sizing treatment on ink absorption, handsheets of 70 g/m^2 were prepared by putting the required softwood pulp (1%), AKD (0.1%) and water into the disintegrator and using the Rapid Kothen Sheet Former machine (RK-3A, Austria). The paper was vacuum-heated and dried at 95 °C for 10 min. Without special explanation, sizing agent was not present in other samples. Before testing, all the samples were treated at 23 °C and 65% relative humidity for 24 h.

Determination of ink absorption

The ink droplets between the printing plate and the paper strip in the sector of the IGT printing applicator (GST-1, IGT Testing Systems, Almere, Netherlands) were 5.8 mg ± 0.3 mg and spread out. The ink mark length was measured as an indicator of absorption capacity; the ink mark length increases as the absorbability of the paper decreases.

Determination of overprint accuracy

The handsheets were affixed on A4 paper, and adjacent color patches were printed twice on the handsheets using a Bizhub PRESS C6000 electrostatic printer (Konica Minolta, Tokyo, Japan). The whitening, or overprinting, distance between the colors patches was measured, which was the overprint accuracy.

RESULTS AND DISCUSSION

Effect of Beating on the Ink Absorption

Beating is an important step in papermaking. Beating resulted in swelling, fibrillation, removal of primary layer and outer secondary layer. Correspondingly, the adsorption ability to ink was facilitated. On the other hand, beating could promote the binding of cellulose and further hinder the osmosis of ink.

Table 1 shows the size distributions of pulp fibers, as measured by the fiber quality analyzer (FQA). The fiber length decreased from 1.221 mm to 1.116 mm when the beating degree was increased from 15 °SR to 40 °SR. Moreover, the width correspondingly decreased from 28.2 μm to 26.9 μm. During the beating process, the raw fibers were separated into several fibrillated fibers, which increased the surface area of the fibers and the number of hydroxyl groups. The hydrogen bonding among hydroxyl groups enhanced the bonding forces among the fibers.

Table 1. Effect of Beating Degree on Fiber Morphology

Beating Revolutions (r)	Beating Degree (°SR)	Fiber Mean Length (mm)			Width (μm)	Fines Content (%)	
		Arithmetic Length	Length-weighted Length	Weight-weighted Length		Arithmetic Length	Length-weighted
5000	15	1.221	2.085	2.665	28.2	41.3	10.4
10000	26	1.165	1.894	2.624	27.6	43.2	9.7
12500	33	1.313	1.875	2.609	27.3	43.8	9.4
15000	40	1.116	1.846	2.589	26.9	44.5	9.1

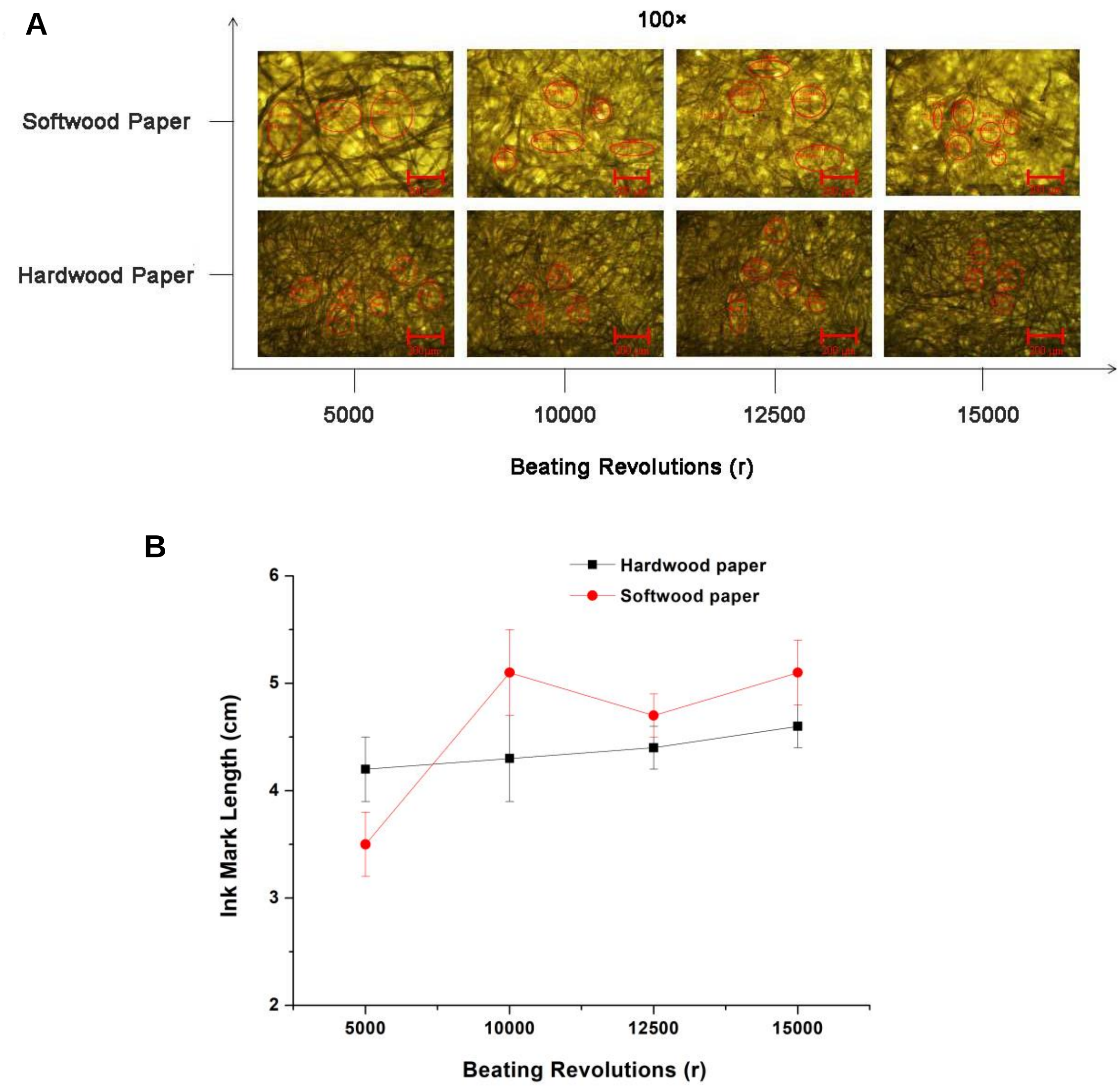

Fig. 1. (A) The capillary structure sizes of the paper surfaces; (B) the ink mark lengths of different papers

A two-step process was employed in printing, involving pressing the ink into the voids on the surface of the paper and the subsequent penetration of the ink into the voids by capillary absorption. As shown in Fig. 1B, beating remarkably reduced the ink absorption of both softwood paper and hardwood paper. The ink absorption performance of the hardwood paper was better than that of the softwood paper, which was mainly attributed to the short and narrow fibers of hardwood pulp. Many capillary structures and high surface smoothness resulted from the paper preparation to improve the spreading, adhesion, and penetration of ink. Furthermore, the ink absorption of the paper was closely related to the gap size between fibers. The gap sizes of papers with different beating speeds were measured with a polarizing microscope, as shown in Fig. 1A. The prepared paper with a beating revolution value of 5000 revs showed a void distribution of 120 µm to 165 µm between fibers. These large voids allowed the ink to penetrate into the papers and caused a short ink mark length of 3.5 cm, indicating excellent ink absorption. With increased beating speed, the space between the fibers decreased to a range from 50 µm to

85 µm. The ink mark length increased to 5.1 cm due to decreased ink penetration. In contrast, beating displayed a limited effect on the ink absorbability of hardwood paper, revealed by a slight decrease of void size from 70 µm to 90 um to 55 µm to 70 um when the beating revolutions increased from 5000 to 15000 revs. One possible explanation for this result was that the fiber distribution, with small surface voids, was relatively uniform for the shorter hardwood fibers.

Effect of Different Pulps on the Ink Absorption

The types and sizes of the fibers affected the ink absorption of the paper. The effect of different pulps, softwood pulp and hardwood pulp, on the ink absorption of the prepared papers is shown in Fig. 2.

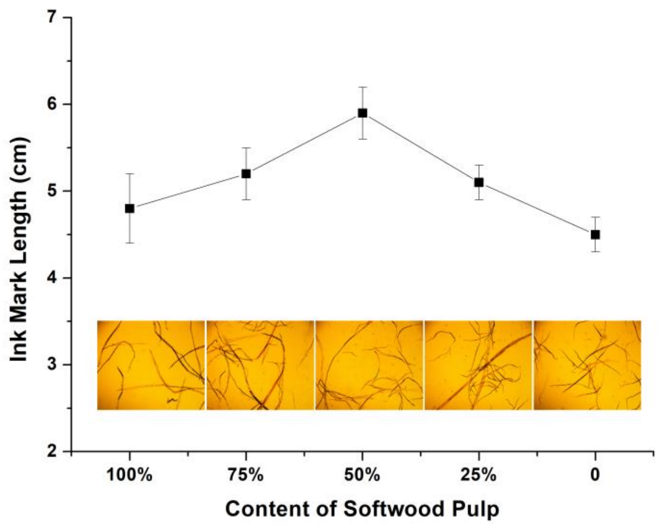

Fig. 2. The ink marks of different pulp papers

Figure 2 shows the changes of ink mark length for different papers prepared with various softwood pulp contents. The ink mark length first increased rapidly from 4.8 cm to 5.9 cm with the increase in softwood pulp content, and then it plateaued at 50% softwood pulp content (reaching a maximum length of 5.9 cm), and subsequently decreased to 4.3 cm. Generally, the fibers in softwood pulp are longer than those in hardwood pulp. Meanwhile, the high crystallinity index of softwood fibers hindered ink penetration and absorption into the paper. In contrast, the fibers in hardwood pulp are generally shorter and weak, which resulted in good ink absorbability. When the softwood pulp and the hardwood pulp were mixed together, particularly with each at 50% content, the prepared papers had longer ink mark lengths (*i.e.*, low ink absorption). A possible reason for this result was that the fine fibers filled the network structure from long fibers stacking of softwood pulp to form a smooth and compact surface. Therefore, the ink penetration into the paper was hindered, resulting in low ink absorption. As the softwood pulp content was decreased to 0% (pure hardwood pulp), the smooth surface with large specific surface area and excellent liquid absorption for the obtained papers facilitated the adhesion and spreading of the ink. This led to high ink absorption (with a short ink mark length of 4.3 cm).

Effect of Sizing on the Ink Absorption

The purpose of paper sizing is to increase its hydrophobic performance, so the softwood paper can resist liquid. The effects of sizing with an AKD dosage of 0.1% on the ink absorption were also investigated.

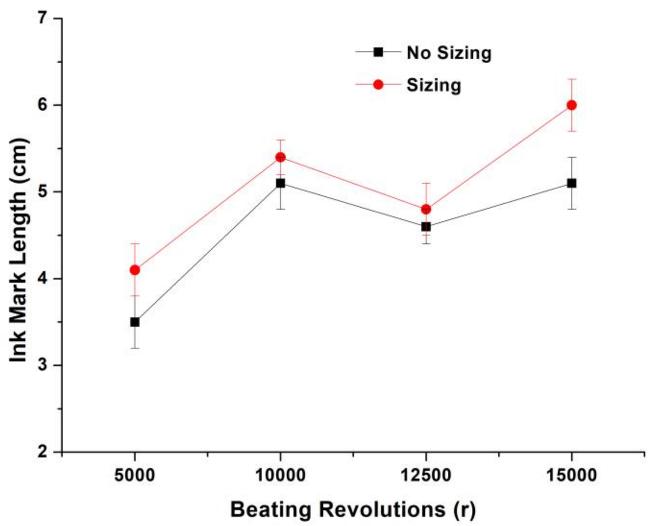

Fig. 3. Comparison of ink mark lengths on softwood paper for sizing

As shown in Fig. 3, the sizing decreased the ink absorption of the paper (the short ink mark length). For the paper with a beating number of 5000 revs, an ink mark length of 4.15 cm was observed after sizing, which was 0.65 cm longer than that without sizing. Under the weak beating, the sizing agent was evenly distributed and firmly adhered on the rough surfaces of long fibers. Its filling effects efficiently hindered the ink's entrance into the voids on the paper surface, thus reducing the ink absorption of the paper. When the beating number increased to 15000 revs, the sizing exhibited a more effect on reducing ink absorption. The ink mark length of 5.1 cm before sizing was markedly lengthened to 6 cm after sizing, which was mainly attributed to the micro-fibrillation of fibers under high beating speed and adequate filling of voids by sizing agents. The results indicated that the sizing can inhibit ink absorption of paper, especially for that with a high beating speed.

Effect of Basis Weight on the Ink Absorption

Basis weight has important effects on the printing adaptabilities of paper, such as tensile strength, folding strength, and tearing strength. Increasing the basis weight will increase the opacity and color contrast of paper, thus improving the quality of printed matter. Figure 4 displays the effect of the basis weight on the ink absorption of the paper.

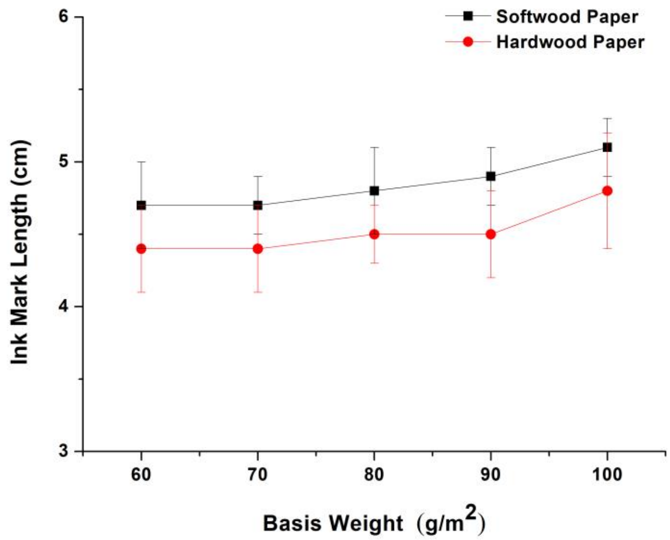

Fig. 4. The effect of basis weight on the ink mark length

As shown in Fig. 4, the ink absorptions of the softwood and hardwood papers slightly decreased with increasing basis weight, as revealed by the increasing ink marks length. When the basis weight varied from 60 g/m^2 to 100 g/m^2, the corresponding ink mark lengths for the softwood and hardwood papers changed, respectively, from 4.7 cm and 4.4 cm to 5.1 cm and 4.8 cm. Because the increased basis weight only facilitated the deposition of pulp fibers in the Z-direction of the paper, which has no effect on the fibers and internal structure of the paper, only a slight increase in ink mark length was detected. Meanwhile, the longer fibers tend to sink first and crosslink to form the lower layer of paper on the molded net during paper formation and dewatering. The fine fibers fall into the gaps on the surface of the wet web of paper due to their minimal size. The size of the void structure was effectively reduced, which thus resulted in the low ink absorption of the paper.

Effect of Different Basis Weights on the Accuracy of Overprinting

The surface compressibility of paper, one of the important factors affecting the clarity of the printing patterns and the accuracy of overprinting, determines the contact degree between the paper surface and the inking rubber at the moment of embossing. The basis weight significantly affects its surface compressibility, which in turn determines the accuracy of overprinting and finally reflects the quality of printing products.

The basis weight of a paper can directly reflect its compressibility, which is responsible for the printing smoothness of a paper under the action of printing pressure. Especially during the first printing, the thickness of the paper was compressed by the printing pressure and partially rebounded after the cessation of the pressure. Therefore, the registration deviation always appeared during the subsequent overprinting because of the contact difference between two printings. When the basis weight of the paper was relatively low, the printing pressure caused a low compression deformation of the paper, due to the strong resilience of thin paper. As a result, the overprint had a relatively small error.

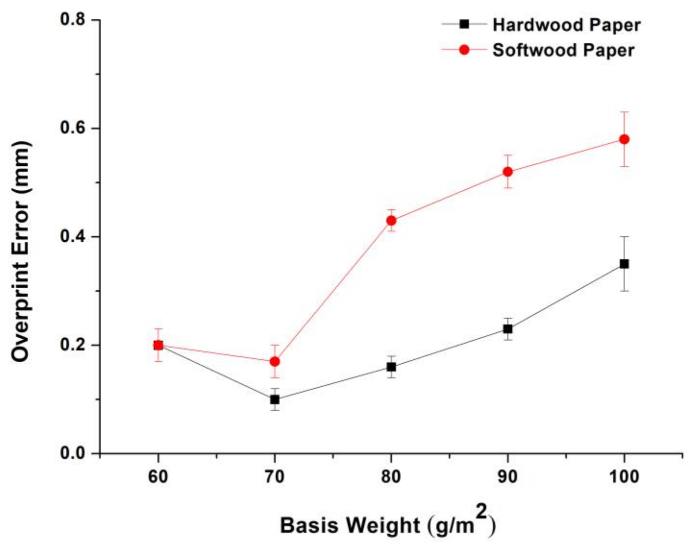

Fig. 5. Influence on overprint precision of different basis weights

As shown in Fig. 5, a negligible overprinting error of 0.1 mm to 0.2 mm was observed for the paper with a basis weight of 60 g/m^2 to 70 g/m^2, which resulted in greater precision and accuracy of overprint. As the basis weight increased to 90 g/m^2, the overprinting error also increased, reaching to 0.72 mm. The increase was mainly attributed to the remarkable compression deformation and poor resilience during the overprinting process with the thickness increase of the paper in Z-direction. When the thickness could not be restored to the initial size under the action of rebound, a larger overprinting error occurred. Moreover, the overprinting error was related to the papermaking materials. The papers from hardwood exhibited superior performance in the overprinting (low overprint deviation), compared with that of softwood. The main reason for this result was that the hardwood contained more long and narrow micro-fibers. Therefore, the paper from hardwood had better printing performance and greater overprint accuracy.

CONCLUSIONS

1. Compare to paper made from softwood, paper made from hardwood exhibited superior properties for the ink absorption capacity and overprinting precision, which was attributed to a greater content of fine fibers.
2. After beating, the void structure of the obtained paper became denser, resulting in decreased ink absorption capacity.
3. The increase of basis weight had a negligible effect on the ink absorption capacity.

ACKNOWLEDGMENTS

The authors are grateful for financial support from the Natural Science Foundation of Shandong Province (ZR2017MC007), R&D Focus of Shandong Province (2017GGX80102), International Cooperation Funding of Qilu University of Technology (QLUTGJHZ2018030; QLUTGJHZ2018027), and Jiangsu Provincial Key Laboratory of Pulp and Paper Science and Technology(KL201906; KL201905).

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Article submitted: September 8, 2019; Peer review completed: November 23, 2019; Revised version received: November 21, 2019; Accepted: November 22, 2019; Published: January 8, 2020.
DOI: 10.15376/biores.15.1.1397-1406