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# Characterization of Base Paper Properties on Coating Penetration

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## ABSTRACT

The influence of base paper properties and fiber type on coating penetration was studied in terms of characterization of coating holdout using two types of handsheets as the base paper which were prepared from thermomechanical pulp (TMP) and hardwood bleached kraft pulp(KP) sized internally with alkyl ketene dimmer (AKD). Laboratory rod draw down coater was used for surface sizing and coating application. Characterization of coating penetration was done by measuring the roughness of the backside of coating layer. The backside of the coating was exposed by dissolving the fibers in a solution of cupriethylenedimine (CED). Data show that internal sizing of base paper is effective and surface sizing is more effective to prevent coating penetration. Comparing between the two types of base papers, backside roughness of coating layer of TMP sheet is much larger and sizing is more effective to reduce coating penetration than those of KP sheet. From the result of water absorption and sizing degree after surface sizing, it seems that internal sizing slows down molecular diffusion much more than capillary penetration, but surface sizing reduces the capillary penetration. Furthermore, predominant mechanism of water into paper of TMP sheet seems to be capillary penetration, but it is molecular diffusion in the case of KP sheet.


***Keywords** : Coating penetration, Roughness, Sizing, Pore size, Water absorption*

## 1. Introduction

The interaction between water and base paper in various coating process is important. The water absorption behavior may determine the initial coating consolidation and the penetration of coating into paper. However, quantitative studies on this topics especially, the influence of sizing and fiber type on coating penetration have not been reported in literature.

In the paper coating process, a water based pigmented coating is applied to the base paper to improve the optical and printing properties. The coating slurry can be absorbed as a continuum into the bulk of base sheet during coating. Therefore, the water uptake behavior of fibers, especially those at the surface of base sheet subjected to coating, is important for coating holdout

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and other coating properties. The term of holdout is often used to indicate the resistance of base paper to coating penetration. Coating penetration is the difference between the application solids and the immobilization solids, since this difference determines the amount of water that must be removed before all motion stops. Lack of coating holdout is primarily caused by excessive and/or rapid penetration. The conditions and properties have increased the demand for improved coating holdout. For improving coating holdout, several studied, for example, addition of water retention agent (1), modification of coating color (2), or pigmented precoating (3) have been studied. However, base paper treatments are also an important factor for improving coating holdout. It was reported (4) that in unsized paper, the liquid phase of the coating readily wets the fibers because of capillary action and penetrates rapidly into the sheet. In sized paper, the penetration was considerably reduced because the walls of the pores resisted wetting. The effect of size press treatment was studied (5).The size press treats the paper and paperboard base stocks with conventional and reactive sizes. On absorbent of unsized papers, rapid initial wetting of the fibers are the primary cause of poor coating holdout. Only treatment with the reactive size reduced coating penetration time. It also showed that the greatest increase in the apparent contact angle between the surface and water. On sized paperboard, where hydrophobicity is already provided by internal sizing and capillary pore size appears to be the controlling factor. The optimum treatment must involve barrier formation or some other mechanism to cover or fill the pores. Recently, the study of precalendering, surface wetting and hydrophobicity treatment was examined (6). It was found that after water coating of the uncalendered base paper, no change in roughness was observed. When using precalendered newsprint type base paper, wetting of the paper surface raised the roughness significantly, but a considerable part of the smoothening achieved by the precalendering was retained after water treatment. Water-induced roughening of the precalendered base paper was reduced by increasing the hydrophobicity of the base paper, but the reduction is small compared to the overall moisture-induced roughening. The mechanism for water absorption by paper have been examined (7,8) and concluded that penetration under capillary pressure (interfiber penetration) and molecular diffusion (intrafiber penetration) are the two predominant processes. Penetration into the base sheet capillaries is often described using the Lucas-Washburn (L-W) equation (9). In the L-W analysis, contact angle, pore radius and sheet void fraction are controlling parameters The L-W equation strictly applies to non-polar liquids in cylindrical capillaries and dose not always apply to penetration of aqueous inks into paper. Fiber swelling and effects due to pore size distribution in paper are not accounted for by this equation. Since cellulose and especially hemicelluoses are water-sorbing natural polymers, water molecules diffuse into the cell wall when a concentration gradient is established. Diffusion of water into cellulose can be very fast. A 10mm film of water can be absorbed by cellulose film in less than one second (10). The diffusion of water into cellulosic materials increased sharply with increasing water content and is slowed down by barriers. The fiber absorption is definitely a property of a particular paper and not simply related to capillary penetration ability.

## 2. Experimental

This study has four experimental steps: (1)

make handsheets with different degrees of sizing and with different fibers, (2) test of sheet properties, (3) apply surface sizing and coatings and (4) characterization of coating penetration. Unbeaten hardwood bleached kraft pulp(KP) and unbleached thermomechanical pulp(TMP) were used for handsheet making. For internal sizing, known amounts of the alkyl ketene dimer(AKD) emulsion was added to a pulp suspension with continuous stirring for sizing. After stirring for 30 sec., the pulp suspension was made into 70 $g/m^2$ handsheets in accordance with TAPPI Test Method 205. TMP handsheets were treated by heat in the oven at 100 ℃ to adjust sizing degree. In the case of surface sizing, hydroxyethylated starch was cooked and this starch as 5 % consistency was applied to base papers using a laboratory rod draw down coater.

The measured sheet properties are sizing degree, contact angle, water absorption, Gurley porosity, pore size and roughness. Hercules size test was adopted to measure sizing level of the handsheet. The water absorption of sheet was tested by immersion in room temperature of water and the contact angle was measured by drop test method. The roughness of the sheets was measured using the Stylus Profilometer and the pore size was obtained by mercury porosimetry. The coating ingredients are pigment(kaolin clay No. (2), styrene butadiene latex binder and dispersing agent. The binder level is 7 parts per hundred and solid content is 63-64 %. Laboratory rod draw down coater was used for coating application. Characterization of coating penetration was done by measuring the roughness of the backside of coating layer. The backside of the coating was exposed by dissolving the fibers in a solution of cupriethylenediamine(CED) according to the method described by Dickson and Lepoutre (11). Before dissolution, a piece of backing tape is placed on the coated side of the sample to provide strength to the separated coating. The sample is soaked in CED and then shaken gently for 30-40 minutes after which the gel-like fibers are removed by washing with water. The separated coating is then ready for measuring the backside roughness after drying.

## 3. Results and Discussion

### 3.1 Base sheet characteristics

A number of base sheet properties were measured to evaluate their effects to coating penetration into paper. Table 1 presents basic properties of the base papers used in this work for coating. From Table 1, it can be seen that the thickness and the void fraction of TMP base paper are significantly higher than those of KP base paper. Especially, the thickness of TMP sheet is almost two times larger than the KP. The higher value of void fraction for TMP sheet may be explained by the weak hydrogen bonding power of TMP fibers due to stiff and undelignified properties. These properties of TMP would lead to be more bulky sheet with much more total pore area compared to the other base paper. Therefore, TMP handsheet has higher thickness and lower apparent density. In case of

**Table 1. Properties of base paper**

| 1 Tem | KP Sheet | TMP Sheet |
|---|---|---|
| Basis weight ($g.m^2$) | 70.0 | 70.0 |
| Thickness (mm) | 0.140 | 0.250 |
| Void fraction | 0.67 | 0.77 |
| Apparent density ($g/cm^3$) | 0.50 | 0.34 |
| Porosity (sec) | 3.0 | 67.0 |
| Surface roughness (㎛) | 3.2 | 3.8 |
| Contact angle | 0 (unsized) | 98 (unsized) |
| Drop disappear time (sec) | 1 (unsized) | 11 (unsized) |

**Table 2. Pore size of KP, TMP base paper**

| 1 Tem | KP Sheet | TMP Sheet |
|---|---|---|
| Pore size peak (㎛) | 9.2 | 3.0 |
| Total intrusion pore volvme (mℓ/g) | 0.82 | 1.06 |
| Total pore area ($m^2$/g) | 7.07 | 12.69 |
| Average pore diameter (㎛, 4V/A) | 0.46 | 0.34 |
| Median pore diameter (㎛, volume) | 9.13 | 3.08 |
| Median pore diameter (㎛, Area) | 0.0075 | 0.0081 |

surface roughness, two kinds of base sheets have similar values, but TMP sheet has a little high roughness value than the other sheet. Table 1 also shows TMP sheet has the highest Gurley porosity followed by KP sheet. The lowest porosity of KP sheet is unexpected. It may be relative to the pore structure, i.e. the pore size and total pore area. This result may be mainly caused by the bigger average pore size of KP sheet than that of TMP sheet. The result in Table 1 indicates that the contact angle and drop disappear time which were measured to determine the wettability of base sheets. Initial contact angle, water drop disappear time of unsized TMP sheet are much higher than that of kraft pulp sheet. These characteristics may be due to the hydrophobic property of TMP fibers which has lignin rich coated surface. The pore size and total pore volume of the handsheets are shown in Table 2, Figure 1 and Figure 2. The pore structure of the base paper is an important parameter for water absorption, base sheet and coated paper properties. TMP base paper has higher pore volume and pore area than that of KP sheet, but in case of pore diameter and pore size peak, the KP sheet is much higher than TMP sheet. This means that total pore volume and the numbers of pore of KP sheet are smaller, but the pore size is bigger than those of TMP sheet. This is mainly due to larger non-bonded area and uncollapsed fiber characteristics of TMP.

## 3.2 Base sheet absorption and surface roughness with internal sizing

The water absorption rate and contact angle were measured to determine the wettability of base papers with the change of sizing degree and fiber type. Both properties were determined by averaging values obtained with five times. Figure 3 shows water absorption rate of sheet by changing of immersion time. Initial stage of immersion time, i.e. until 10 second, both unsized KP and TMP sheets have almost the same water absorption rate, but after 10 second of immersion, KP sheet shows a little higher absorption than that of TMP sheet. With regard to sized paper water absorption, both TMP and KP sheets have similar absorption value in initial time, after that TMP sheet has

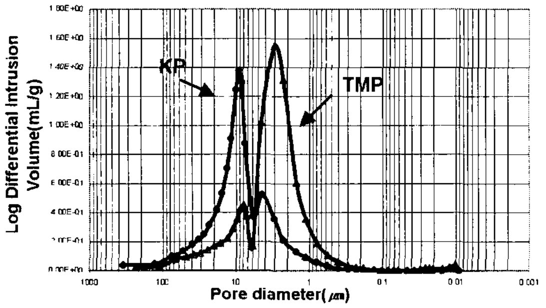


**Fig. 1. pore size distribution.**

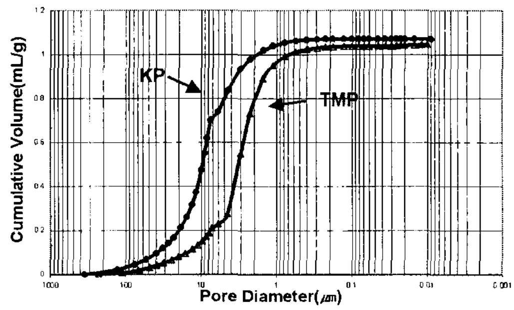


**Fig. 2. Cumulative pore volume curves.**

more higher absorption rate than KP sheet. It seems to be very interesting and important result. Previous researchers examined the mechanisms for water absorption by paper and concluded that penetration under capillary pressure(interfiber penetration) and molecular diffusion(intrafiber penetration) are the two predominant processes (7,10). One possible explanation for above mentioned result is that capillary penetration, not molecular diffusion, of water into the fibers is the predominant mechanism for TMP handsheet which has much more pore volume and hydrophobic properties than KP sheet, but it may be molecular diffusion in the case of KP sheet and internal sizing slowed down molecular diffusion much more than capillary penetration. Figure 4 presents the changing of contact angle measurement for water on KP and TMP sheet and Figure 5 gives the result of time for complete absorption of water drop. From the Figure 4, it can be seen that the initial contact angle of sized KP, TMP sheet and unsized TMP sheet has very similar value of approximately 100 degree, but that of unsized KP sheet is small as about 10 degree. The data of very high initial contact angle of unsized TMP sheet, almost the same of strongly sized KP and TMP sheet, is interesting. It also shows the contact angle of all kinds of papers are decreased gradually with the time. On the other hand, the complete absorption time of water drop for unsized TMP sheet, 11 second, is a little high than 1 second of unsized KP sheet and in case of sized sheet, complete absorption time is over 300 second for both TMP and KP sheet as seen in Figure 5. However, a higher contact angle indicates higher hydrophobicity or lower absorbency. The time required for complete absorption of water drop to disappear on the paper is also used as an indication of sheet absorbency.

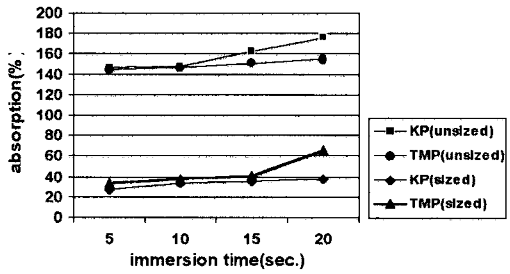


**Fig. 3. Water absorption rate of base sheet.**

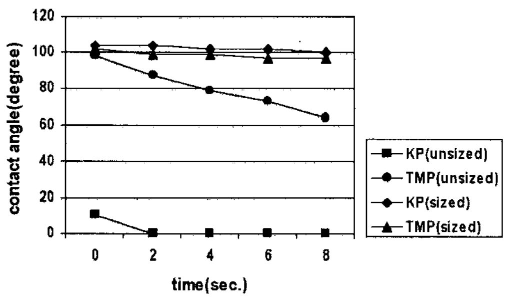


**Fig. 4. Contact angle of base sheet.**

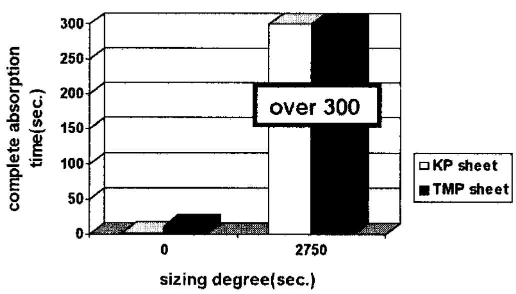


**Fig. 5. Time for complete absorption of 5 *ul* water drop**

### 3.3 Characterization of coating penetration with internal sized base sheet

The dissolution method (11) of fibers for the exposure of the backside of coating layer was used to examine the degree of mechanical adhesion between the coating and the paper. But this new method has been used to measure the backside roughness of the coating layer and characterize coating penetration into base paper by Akinli-Kocak (12) and concluded that fiber swelling by water absorption reduces absorption rate and decreases coating penetration into paper due to closing of sheet surface pores by swelling of the fibers. It also can be seen that the larger the coating penetration, the worse is the backside roughness of coating layer from this literature. It seems to have a good relationship between the coating penetration and the backside roughness of coating layer. Therefore, this method was used to evaluate influence of sizing and fiber type on coating penetration in this study. Figure 6 shows the surface and backside roughness of coating layer for the sized commercial base paper with increasing of sizing degree by heat treatment. It can be seen that both surface and backside roughness of coating layer, especially the roughness of backside, are gradually decreased by increasing of sizing degree of base sheet. These results indicate that sizing of base paper is absolutely necessary to get somewhat the higher smoothness of coating surface and to get the lower coating penetration into paper. It is well known in sized paper that the penetration is considerably reduced because the walls of the pores resist wetting. Clark et al (13) have suggested that the water migrates faster than the binder during capillary migration, but both migrate together during the pressure migration stage. They demonstrated that addition of a reactive size reduced the capillary migration although the pressure migration was almost constant. These explanations from literature support the sizing effect on coating penetration. Figures 6 and 7 show that the roughness of coating layer with change of AKD addition level on KP and TMP handsheets, respectively. Figure 8 shows the comparison of roughness between KP and TMP handsheets. In Figures 6 and 7, it can be seen that the roughness of coating layer is decreased by increasing of sizing level. Especially, in case of TMP paper, the decreasing rate of backside roughness is much larger than that of KP paper. From these figures, it seems obvious that internal sizing of base paper prevents the penetration of coating into base paper. Comparing of roughness between KP and TMP handsheets in Figure 8, backside roughness of TMP sheet is much affected by coating than that of KP base paper. These results imply that coating penetration of

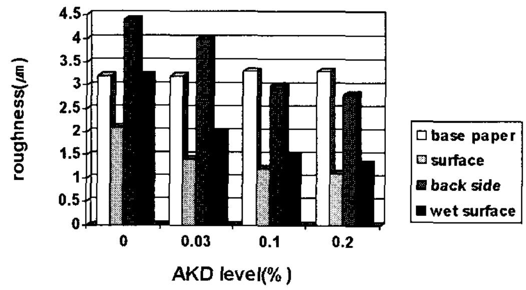


**Fig. 6. Roughness of coating layer of KP sheet**

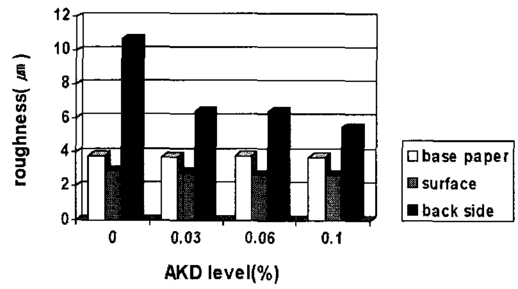


**Fig. 7. Roughness of coating layer of TMP sheet**

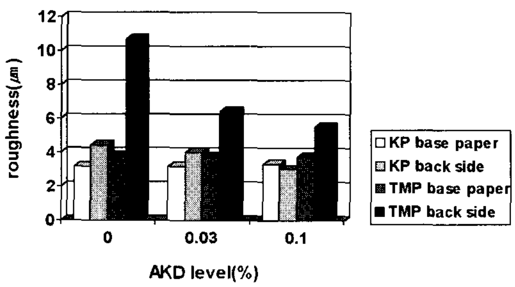


**Fig. 8. Roughness comparison of coating layer of KP, TMP sheet**

TMP sheet is much larger and the sizing is more effective for preventing coating hold-out than those of KP sheet. There are several factors (9) that affect the penetration rate of a liquid into paper, among them, pore radius and contact angle, i.e. wetting of the fiber surface are the factors that are close related to base paper properties. Sizing mainly changes the contact angle. Pore size and wetting of the fiber surface are affected by fiber type. As seen in Table 1, 2, initial contact angle of TMP sheet is much higher and complete water absorption time is longer than KP sheet. This result indicates that TMP fibers could be more easily wetted than KP fibers. In case of pore size, average pore diameter of TMP sheet is smaller, but the total pore volume is much larger than those of KP sheet. This means that the pore number of TMP sheet is the large, but the pore size is smaller than that of KP sheet. However, it is evident that internal sizing is very effective to reduce the coating penetration, but it is difficult to explain the clear reason of rougher coating backside observed on the TMP sheet than on the KP sheet. This result may be related to greater fiber rising character of TMP sheet than KP sheet in contacting water.

## 3.4 Coating penetration of surface sized base sheet

Most of the commercial base papers are sized internally. Surface sizing is also carried out in some case. However, there is not much experimental data available in the literature about surface sizing effects on the coating holdout. This work also attempted to clarify the separate influence of two sizing methods on coating penetration. Figure 9 shows the sizing degree of base papers, i.e. KP sheet and TMP sheet.

KP and TMP sheets were treated by sur-

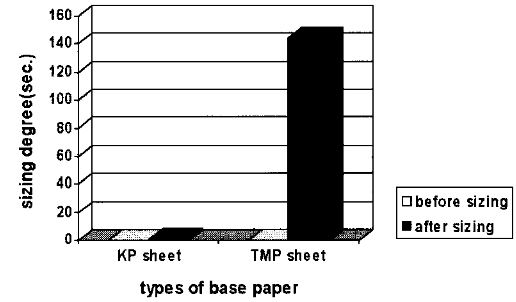


**Fig. 9. Sizing degree of Surface sized base sheet**

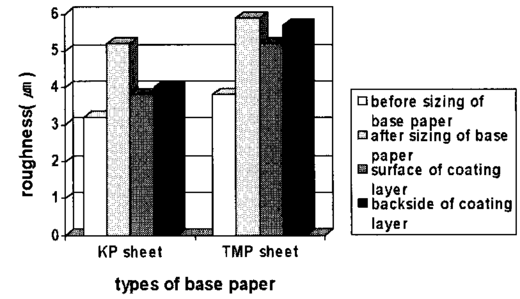


**Fig. 10. Roughness of coating layer of surface sized base sheet**

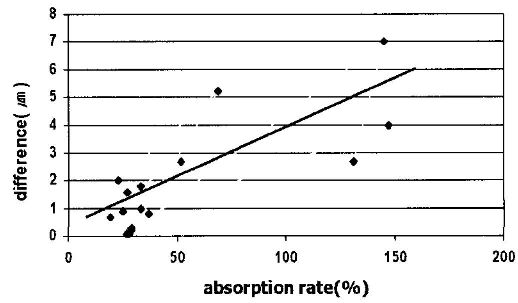


**Fig. 11. Roughness difference between Coating backside and base paper on internal sizing**

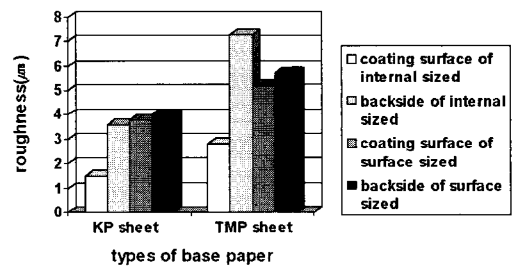


**Fig. 12. Roughness comparison of coating layer between internal and surface sized paper**

face size without internal sizing. As shown in Figure 9, the sizing degree of KP sheet was almost the same before and after surface sizing as 0 second. But, the sizing degree of TMP sheet was greatly increased by surface sizing from 0 to 145 second. These results indicate that sizing degree of KP sheet can not be increased by only surface sizing without internal sizing, but, TMP is possible to give sizing feature with only surface sizing. In previous discussion on base sheet absorption, it was mentioned that capillary penetration and molecular diffusion are the two predominant mechanisms of water absorption. It seems that TMP sheet absorption is mainly caused by capillary penetration, but KP sheet absorption occurs by molecular diffusion and internal sizing slow down this molecular diffusion. The results shown in Figure 9 strongly support above mentioned theory. From the fact that surface sizing is effective for TMP, but not effective for KP in increasing sizing degree, it may be assumed that surface sizing fills up the pore volume of sheet and slows down the capillary penetration. Therefore, it seems that TMP sheets, which is predominantly absorbed by capillary penetration, are more effective than KP sheets to prevent water absorption. Figure 10 shows the roughness of coating layer, Figure 11 shows the roughness difference between base paper and backside of coating layer with change of base paper absorption rate on internal sizing and Figure 12 shows the roughness comparison of coating layer between internal and surface sizing, respectively. It was used the difference of roughness between base paper and backside of coating layer for evaluating of coating penetration between two sizing methods. As shown in Figure 11, the roughness differences between base paper and backside are somewhat proportional to the absorption rate of base paper. The results in Figure 12 also shows all the differences between coating surface and backside roughness in case of surface sizing. The backside roughness of surface sizing is smaller than that of internal sizing. Especially, on internal sizing of TMP sheet, the difference between coating surface and backside roughness is much more bigger than that of surface sizing. These results imply that surface sizing is more effective than internal sizing for reduction of coating penetration. It appears that pore filling and good coverage by surface sizing give the better effect for coating penetration than the internal sizing.

## 4. Conclusions

It is important to find out the critical conditions that prevent the coating penetration into the paper to improve and stabilize the quality of coated paper in coating process. In this study, the influence of base paper properties and fiber type on the coating penetration were investigated and the following conclusions were obtained.

1) Internal sizing is effective, but surface sizing is more effective to prevent coating penetration, therefore, surface sizing is necessary with internal sizing for the better coating holdout.
2) Coating penetration of TMP sheet is much larger and the sizing for TMP is more effective to reduce coating penetration than those of KP sheet.
3) Predominant mechanism of water into paper of TMP sheet seems to be capillary penetration, but it is molecular diffusion in case of KP sheet.
4) It seems that the internal sizing slows down molecular diffusion much more than capillary penetration, but surface sizing slows down capillary penetration.

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