

# EFFECT OF COATING COMPOSITION IN DOUBLE COATING ON THE PENETRATION OF FINE PARTICLES INTO SUBSTRATE

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## **Abstract**

The influence of the first coating layer on the properties of the second coating layer is reported. For various model coating compositions, ratios of first and second coating weights are used to generate coating layers. The void volume, pore size distribution and light scatter coefficient of the coatings are measured. In some cases, the fine material from the second layer seems to penetrate the first layer to reduce the void fraction of the total system. Rapid setting coating, for example thin layers on porous first layer tends to generate porous coating layers.

## **Introduction**

The main objective of coating in paper industry is to improve printability by surface reconstructing which reduce roughness and increase optical properties of base paper. As part of producing high quality of coated paper, the coating system in some paper mills is changing from single to double coating. However, little is understood as the interaction of the first and second coating layer in terms of the final coating structure.

In paper coating, the pigment size and shape distributions, and the interactions between the coating components play an important role in the evolution of the coating structure [1-3]. Also the surface and structural characteristics of the base paper are known to influence the consolidation of coating structure and the final surface properties of coating layer. Base paper, which is consisted with cellulose, filler and some additives, has a high porosity. It contains different pore size distribution in its surface and interior. Especially in the coating of a porous substrate, the pore space is penetrated by liquid from the coating. This penetration is caused by hydrodynamic pressure that develops in the applicator and metering gaps and by capillary pressure [4]. The results of the effect of substrate on the coating's void fraction indicate that, at the same coat grammage and composition, void fraction increases with increasing porosity of the substrate. These results demonstrate the important role played by the substrate on the consolidation of the coating structure. On a porous substrate, the coating consolidation is faster than on a non-porous substrate because of the porous substrate, dewatering of the coating by drainage through the substrate [5].

The process of double coating consists of two layers. The first coating must provide the necessary fiber coverage and form a satisfactory surface for the application of the second coating. The structure of the first coating also affects the properties of the finished product. Others have found that the open structure of the carbonate first coating contributed to a lowering of the print gloss of the product, and a weakening of the second coating [6, 9]. Comparing single and double coating, at the same coat weight and formulation, indicate that double coating results are better than single. In order to achieve the desired uniform surface and coating hold out with high coating weights, multiple coating is a possible solution [7]. In addition, surface latex concentration increased with increasing coating weight of top coating. When coating weight of double-coated paper was rather heavy, both micron and sub-millimeter scale profiles were improved [8].

The structure of first coating is influenced not only by its component, but by also characteristics of base paper. Moreover pore size and size distribution of first coating are expected to influence the top coating properties, but this is not well understood. The absorbency of the substrate has been shown to influence the properties of the coating. However, a number of issues are not well understood.

This paper uses model coatings to understand how the porosity and structure of one coating layer influences the porosity of the final coating layer. The goal is to understand, in general, how the porosity of one layer, a coating layer or substrate, changes the properties of the top layer.

## Experimental procedure

The coating layers were prepared by using drawdown coater on plastic (Mylar) film. Coating formulations are shown on table 1. Each formulation was used for first and second coating to make double-coated layer. The ratios of second/first were 0.2, 0.5, 1, 2, and 5 to form a 30g/m<sup>2</sup> coating. For the various second/first ratios, formulation 1 was adopted. To confirm the trend of different second/first ratio, formulation 2 and 3 were used for the ratios of 0.5 and 2. Each sample in these experiments was dried at room temperature. A device for measuring first critical concentration (FCC) and second critical concentration (SCC) was used to quantify the consolidation times. The light scattering coefficient and void volume of each sample were characterized by Ultra Violet (UV) and oil absorption test, respectively. Pore size distribution for single and double-coated specimen was measured by mercury porosimeter.

Table 1. Formulation used in experiments

Items	Unit	F1	F2	F3		F4		F5	
				1st	2nd	1st	2nd	1st	2nd
#1 Clay	pph	100							
Coarse Ground Calcium Carbonate 0.1 $\mu$ m	pph							100	
Polystyrene Pigment 0.25 $\mu$ m	pph						100		100
Polystyrene Pigment 0.5 $\mu$ m	pph		100		83.3				
Polystyrene Pigment 1.0 $\mu$ m	pph				16.6				
Polystyrene Pigment	pph			100		100			
S/B Latex	pph	10	20	10	10	10	10	10	10
Solids Content	%	55	50	27.9	35	27.9	35	60	27.9

## Results and Discussions

By using the formulation 1, the consolidation time to reach at FCC and SCC increased with increasing first coating weight from  $5\text{g/m}^2$  to  $25\text{g/m}^2$  as shown in figure 1. This is expected because the thickness of wet coating increases with increasing coating weight. That means the thicker wet film need more consolidation time to form unrecoverable structure. In the result of FCC and SCC of the second coatings, which were coated on the first coating layer, the consolidation time also increased with increasing with second coating weight. However, the increasing rate of the consolidation time was reduced than the case of first coating. In here, we have to think about the base substrate used in first and second coating. The substrate of the first coating was non-porous mylar film but the substrate of the second coating was porous substrate, which was consisted with pigment and latex components. Therefore, due to different porosity of the substrate, the tendency of consolidation time to arrive the FCC and SCC of second coating was faster than that of the first coating. So according this idea, we can imagine that the porosity of the second coating layer is higher than that of the first coating.

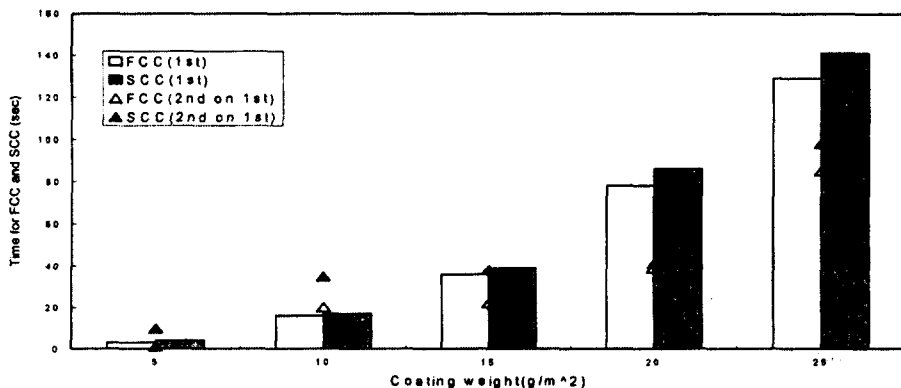


Figure 1. Effect of coating variations of first and second coating on the FCC and SCC.

Figure 2 shows that the void volume of the first coating layer decreased linearly with increasing coating weight over the range tested. The consolidation time of FCC was larger with increasing coating weight. Therefore, the consolidation of coating layer is faster at lower coating weights. The rapid consolidation of thin coat layers may lock in structure that has been recently been sheared. This is similar to results reported by Nisogi et al. [10]

However, in double coating, the tendency of void volume was different from expectation: similar levels of void volume between various second/first ratios are obtained. There is a slight decrease in the void volume as the weight of the second layer increases. This is difficult to understand in that the first layer (5g/m<sup>2</sup>) was the bulkiest layer. When the 25g/m<sup>2</sup> was added on this layer, we see the least bulky. The time for consolidation of this second layer is the largest and we would again expect this condition to be the most bulky. This result may be caused from the effect of heavier coating weight on void volume, which reduced due to first layer's bulky structure.

The decrease in void volume with the increase in the second layer thickness may be a result of fine material being transported into the first coating layer as shown in figure 2. This transport, due to capillary pressures or hydrodynamic pressures during application, causes a decrease in the void fraction of that first layer. Particles from the second layer end up in the first layer voids. The net result is a final coating layer that has a low void volume. This mechanism has not been previously identified in the literature. Therefore, if the pore size of the first layer in double coating composition is large enough to take fine material which include pigment and latex, the final coating layer of double coating has denser structure than that of small pore size in first layer.

The effect of coating weight on the light scattering coefficient (L.S.C) is shown in figure 3. In the first coating, L.S.C. decreased with increasing coating weight. This means that low coat weight produced bulky structure as seen with void volume. However, according to increase the second coating weight on different first coating layers to form same final coating weight, the first layer with lower second coating already formed denser structure. Therefore, the L.S.C. between first and second coating with same coating weight has obtained big difference. This tendency of L.S.C. coincided with result of the void volume shown in figure 2.

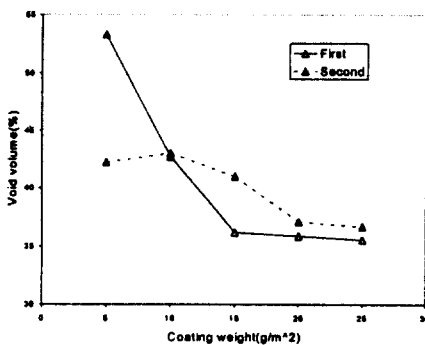


Figure 2. Relationship with coating weight composition and void volume.

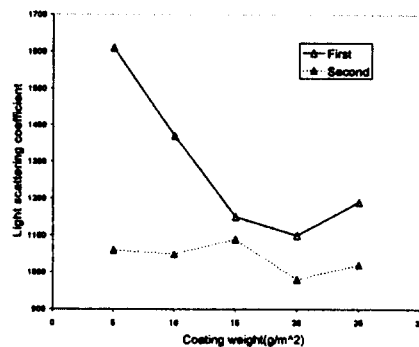


Figure 3. Relationship with coating weight composition and light scattering coefficient.

The result of pore size distribution of first and double coated specimen is shown in figure 4 and 5. In the result of first coating, the intrusion volume increased with increasing coating weight. The pore size was located between 0.03 - 0.07 $\mu$ m. Although second coating was performed on the various first coating thickness, the pore size distribution has not been changed with first coating.

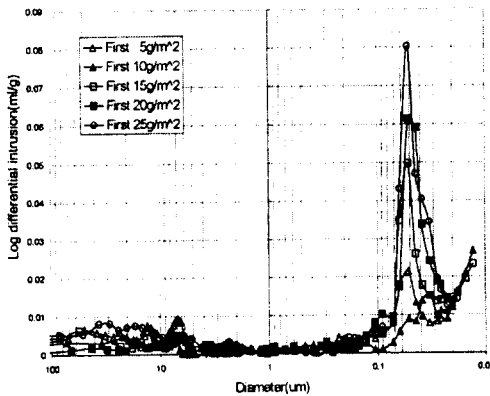


Figure 4. Pore size distribution of first coating. The coating was made from #1 clay and latex.

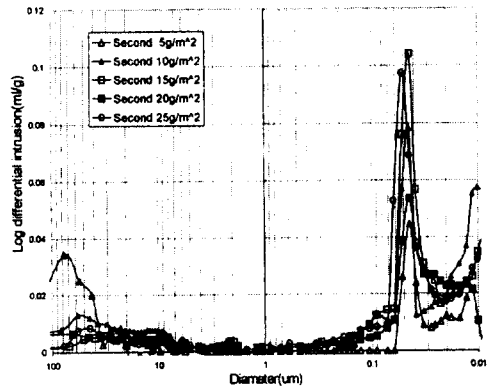


Figure 5. Pore size distribution of double coating. The coating of first and second were made from #1 clay and latex.

To confirm the previous tendency according to change second and first coating ratio, the formulation 2 was composed with polystyrene pigment and styrene-butadiene latex. The ratio of coating composition to compare each other was 10/20 and 20/10 (second/first). The effect of second/first ratio on consolidation time was confirmed that consolidation time to FCC and SCC increased with increasing second coating weight.

Table 2. Results of the FCC, SCC and void volume. The coatings were made from using the coating color which was consisted with 0.25 $\mu$ m P.P 100pph and 20pph latex

Items	Unit	First coating		Second coating on the first	
	g/m'	10	20	10/20	20/10
FCC	sec			40	72
SCC	sec			73	112
Void Volume	%	20.4	22.4	19.9	19.8

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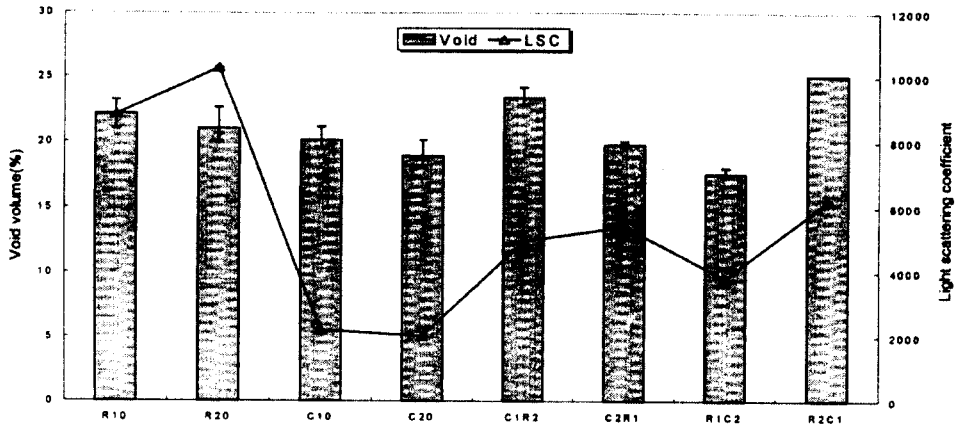


Figure 6. Effect of voids in first coating on the void volume and LSC. R means  $1.0\mu\text{m}$  P.P and C means combination with  $0.25\mu\text{m}$  and  $0.5\mu\text{m}$  P.P. The number 1, 10 in the symbol represent  $10\text{g}/\text{m}^2$  and 2, 20 in the symbol is for  $20\text{g}/\text{m}^2$  coating weight, which was applied on the substrate.

From using the formulation 3, we summarized the results of void volume and L.S.C. as shown in figure 6. Void volume of the first coating decreased with increasing coating weight from 10 to  $20\text{g}/\text{m}^2$ . It means first layer of  $10\text{g}/\text{m}^2$  has more voids in the layer, which was resulted from faster consolidation than that of higher coating. This tendency was not changed in different pigment size. However, total void volume increased with increasing pigment size. Especially it is affected to L.S.C. of the first layer.

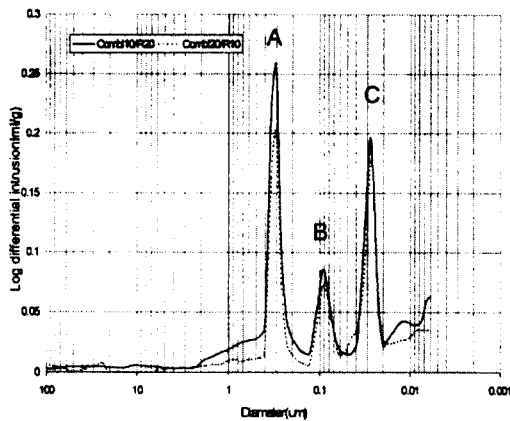


Figure 7. Pore size distribution of C 10/R20 double coating.

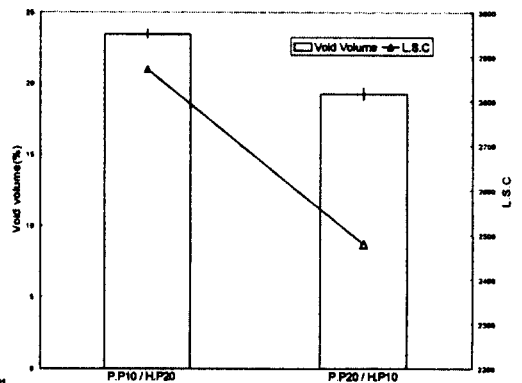


Figure 8. Relationship with void volume and LSC. The pigments for first and second coating were  $1\mu\text{m}$  hollow plastic (H.P) and  $0.1\mu\text{m}$  solid plastic pigment (P.P)

In the same coating weight of double coating, the second coating of hollow pigment has higher void volume than that of the solid pigment. Because second coating of hollow pigment coated on porous substrate of first layer which helps to consolidate the second layer. We can also confirm this result followed result of porosimetry.

In figure 7, three typical peaks were observed. Each peak's range is that peak A is located in 0.15-0.4 $\mu$ m, peak B is located in 0.07-0.15 $\mu$ m and peak C is located in 0.02-0.04 $\mu$ m. We estimated that these peaks were formed from space between hollow polystyrene for peak A, peak B was came out from solids polystyrene and peak C was came out from inner part voids of hollow polystyrene. We could not find any kind of evidence from this result to confirm the changed pore size distribution due to void filling of the solid p.p. into void space between hollow pigments on the first coating.

To induce the void filling effect from the fine pigments into the first layer's pore, 0.1  $\mu$  m polystyrene was adopted as like formulation 4. In the figure 8, the void volume and LSC decreased with decreasing first coating weight of hollow pigment. Because dominant void area is dependant on hollow pigment and the travel void area diminished with lower first coating of hollow polystyrene.

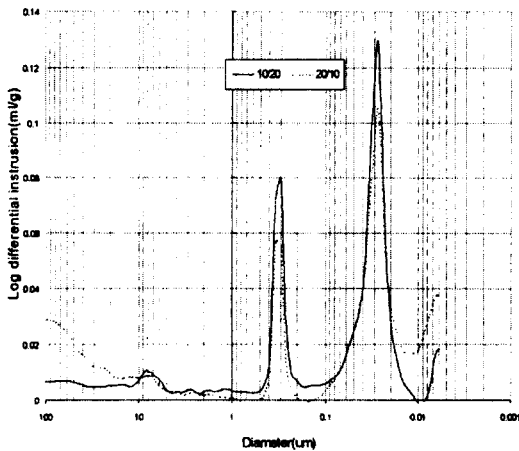


Figure 9. Pore size distribution of double coating. The first coating was made from 1.0 $\mu$ m Hollow P.P and the second coating was 0.1 $\mu$ m P.P

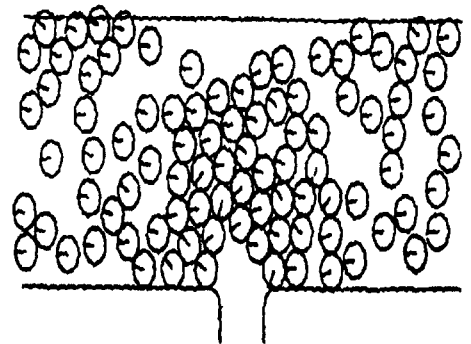


Figure 10. The influence of the pore size on the loss of particles into a pore. (1992, Tappi coating conference, Martti Toivakka)



Figure 9 was shown that one of peak observed in figure 7 was disappeared. The peak of second coating from  $0.1\ \mu\text{m}$  polystyrene was merged into lowest pore diameter peak. Because the total pore volume from  $0.1\ \mu\text{m}$  polystyrene reduced due to its small size. Although the pore size is  $0.1\ \mu\text{m}$ , we couldn't see void filling effect. One of the reasons is bridging effect, which is produced from each particle. This idea was suggested by Toivakka as shown in figure 10. In this figure, although the radius of the pore is twice of the particle, the particle can not penetrate into the substrate pore.

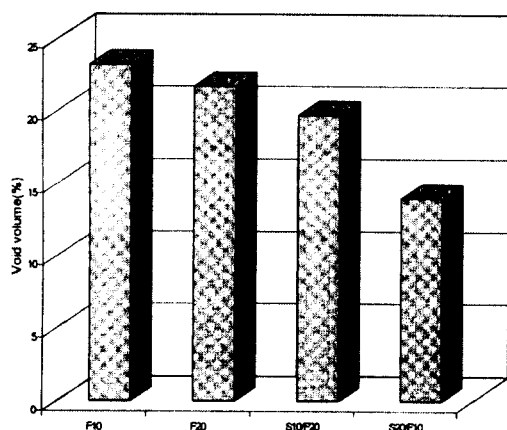


Figure 11. Relationship with coating composition and void volume. The pigments used in first(F) and second coating(S) were coarse calcium carbonate and  $0.1\ \mu\text{m}$  plastic pigment, respectively. 10 and 20 represent coating weight.

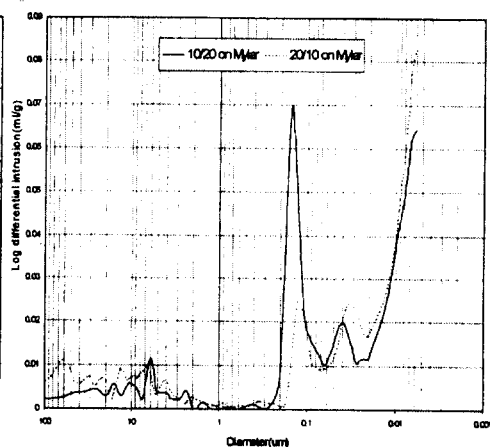


Figure 12. Pore size distribution of double coating on mylar film. The first coating was GCC60 grade and second coating was  $0.1\ \mu\text{m}$  P.P.

Figure 11 contains the result of void volume for coarse calcium carbonate with  $0.1\ \mu\text{m}$  polystyrene as the second layer. As coating weight increased from 10 to 20g/m' in first coating, the void volume decreased as with previous coatings. In addition, this result agreed with two layered coating. The reduction rate of void volume in double-coated layer was bigger than that of the first coating (figure 11). In addition, this tendency could confirm by pore size distribution as shown in figure 12. At high coating weight of second coating, pore size distribution was moved to little bit lower case than low second coating weight of first coating. Because low coating weight of first coating had already bulkier structure than high coating weight of first coating, the penetrated amount of fine particles from first coating increased. Therefore, this is one of the reasons to reduce pore size in high second coating weight of double coating. More over, the other reason is that higher

coating in second coating has produce dense structure by retarding consolidation time by the increased wet coating thickness.

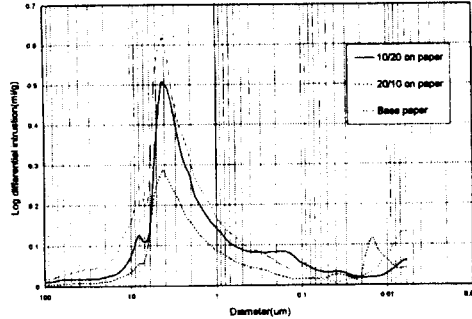


Figure 13. Pore size distribution of double coating on paper.  
The first coating was GCC60 grade and second coating was 0.1µm P.P

Although pore size distribution was moved to lower position by three reasons, It was very difficult to find any evidence of decreased pore size distribution according to different second coating, which was performed on the paper (figure 13). Because the pore size distribution range of paper is too broad to distinguish with that of the double layer coating. However, the intrusion volume decreased with increasing second coating weight. As we confirmed effect of different coating weight composition and particle size on void volume and pore size distribution of double layered structure, this result will be affect not only to coating properties but also to printing properties. Formulator who has responsibility to properties of coated paper should consider complicate factors because the substrate of printing process is single coated paper or multiple coated paper.

## Conclusions

The structure of double coating layer is influenced not only by its components, but by also characteristics of the substrate. Void volume of double coating was determined by coating weight composition of first and second coating. It decreased with increasing second coating weight. In addition to effect of coating weight on the void volume, penetration of fine particles into void of first layer had also diminished total void volume and reduced pore size when first layer is formed bulky structure by using coarse pigment. Therefore, the results indicate that the fine material in the second layer can penetrate into the first layer to reduce the overall void volume and alter the pore size distribution. This kind of penetration will be affect to coating structure and printing properties.

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