A NOVEL TECHNOLOGY TO PRODUCE ULTRA HIGH GLOSS COATED PAPER

Chizuru Wakai*, Hirokazu Morii and Hideki Fujiwara
Central Research Laboratory, Research and Development Division
Nippon Paper Industries Co., Ltd.
21-1 Oji 5-chome, Kita-ku, Tokyo 114-0002, Japan

*Phone +81-3-3911-5170
FAX +81-3-3914-3350
E-mail 0870137@fr.nipponpaper.co.jp

ABSTRACT

A novel process for production of coated paper was developed. The technology can be used on conventional double coating facilities. The precoating is usual pigment coating and the material used for the top coating is a newly developed synthetic polymer pigment. Emulsion of the polymer pigment is applied without binders and then metered. Although the coat weight of the top coating was less than 1 g/m^2 per side, the sheet gloss of uncalendered coated paper was around 70% and after supercalendering it was around 90%. Coated paper obtained by this technology can be printed on web offset presses because of its good blistering resistance caused by relatively low total coat weights. SEM (Scanning Electron Microscope) and AFM (Atomic Force Microscope) show existence of an even layer composed by the spherical polymer particles.

INTRODUCTION

Pigment coating is the technology to increase sheet properties and printing properties of printing paper such as sheet gloss, print gloss, pick strength and smoothness. To increase sheet gloss, calendering (supercalendering or hot soft-nip calendering) is usually used. With calendering, coated paper looses its bulk caused by the pressure under calendering. Cast coating is an alternative method to produce high gloss and high bulk paper. In this process, wet coating layer composed of pigments and binders contacts the mirror finished cast drum. One of the disadvantages of cast coating is its slow production speed. And it means high production cost. Several ideas have been suggested to produce high gloss paper using heated calender instead of cast drums [1-3]. Those technologies are based on coating of pigment / polymeric latex mixture or water-soluble polymer followed by calendering with heated calender. However, gloss development was not sufficient and the technologies do not seem to be commercially available.

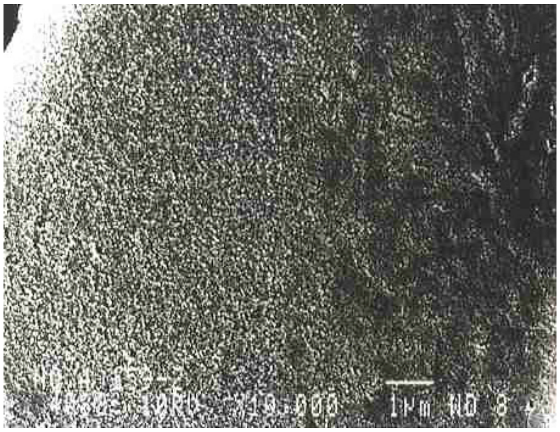
To produce high gloss paper only by conventional pigment coating, high coat weights must be necessary. In case of high basis weight coated paper, some cases 30 g/m^2 per side (or more) of coating color is applied by double or triple coating. Sheet gloss of such coated papers (usually basis weight is high) is high, and many cases over 80%. Density and air resistances for such papers are also high because of high coat weights and calendering. If such paper is printed on a heat set web offset press, blistering is a big problem because of high air resistance. Consequently, it has been difficult to produce web offset grade with high sheet gloss and high basis weight through conventional pigment coating technology even if the productivity is good and production cost is reasonable. Therefore, development of a new technology has been required which we can produce high gloss, high bulk and low air resistance paper with.

We found that a combination of conventional pigment coating and following synthetic pigment emulsion coating showed an extremely high potentiality to produce very high gloss paper. Conventional double coating system can be used for this technology. After supercalendering, sheet gloss of the paper obtained by this technology is over than 85%, and many cases around 90%, although the coat weight of the top emulsion coating is less than 1 g/m^2 per side. It means that the total coat weights are almost the same level as single coating. Because of relatively low coat weights, density of the coated paper is low and air resistance is low. One of the biggest advantages of the coated paper obtained by this technology is that ultra high gloss, high bulk, web offset grade can be produced.

EXPERIMENTAL

Materials (Synthetic pigment)

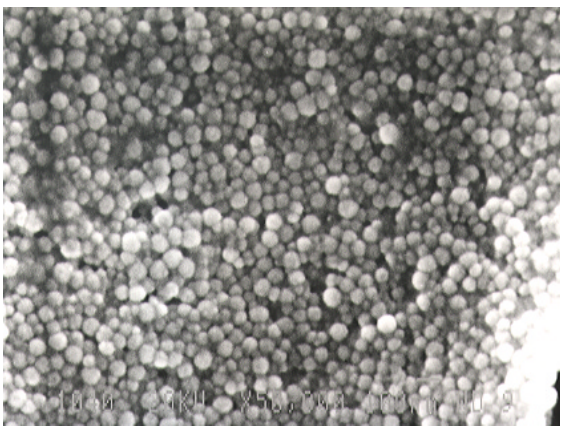
The synthetic pigment that is used for top coating is a styrene-acrylic copolymer. The glass transition temperature is 102°C and the average particle size is 80 nm. Plastic pigment is defined that polymers which is non film-forming and remain discrete under the conditions of application, drying, and finishing [4]. According to the definition above, the synthetic pigment used in this study is a kind of plastic pigment as SEM photos show in **Figure 1, 2** and **3**. The SEM photos show surface of the supercalendered coated paper (precoating is pigment coating and top coating is synthetic pigment coating). Magnification of photos in Figure 1, 2 and 3 are 10,000, 50,000 and 100,000, respectively. As seen in Figure 2 and 3, spherical shape of the synthetic pigment still remains after drying and supercalendering. In order to obtain an image of such small particles, a high accelerating voltage was used with low amount of Au vacuum evaporation. It caused charge up and some shadows as seen in Figure 1.



X 10,000

1000 nm (1 µm)

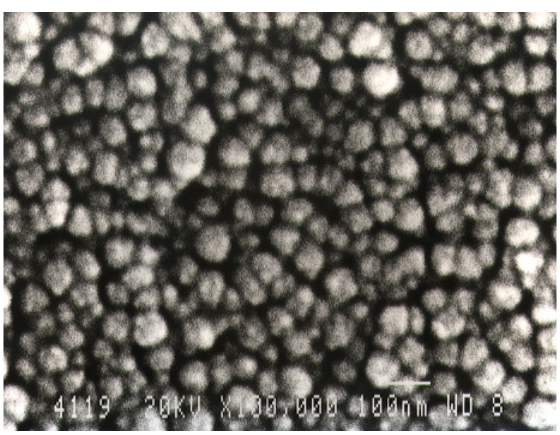
Figure 1. ***SEM- Synthetic Pigment Coated Paper (Supercalendered).***



X 50,000

200 nm

Figure 2. ***SEM- Synthetic Pigment Coated Paper (Supercalendered).***



X 100,000

100 nm

Figure 3. ***SEM- Synthetic Pigment Coated Paper (Supercalendered).***

One of the unique aspects of this technology to be noted is that no binders is necessary for synthetic pigment top coating. In other words, top coating is essentially sole coating of the synthetic pigment. Sufficient binding power and / or pick strength of top coating can be obtained without additional binders. A hypothesis regarding the self-binding power is discussed in the Results and Discussion section.

Pilot coater trials

Pilot coating trials were performed on a pilot coater at the research center of Nippon Paper Industries Co., Ltd. In this study, the flooded nip applicator and airfoil dryers were used. An 87 g/m^2 wood free base stock was used. Precoating and top coating were applied at a speed of 500 m/min. We did not see any coating runnability problems at high coating speed. Top coating trial has been done at a speed of 1700 m/min. There was no problems regarding the coater runnability. The coat weights of 500 m/min and 1700 m/min run samples were almost the same (around 0.5 g/m^2). The top coat weight is usually controlled by the total solids. And the total solids are 20 to 30%. Precoating pigment formulations are shown in **Table 1** and coat weights are shown in **Table 2**, respectively. Coated papers were calendered using a pilot supercalender. Besides the flooded nip applicator, a short dwell coater and a jet fountain applicator were used for the top coating. There were no runability problems in those pilot trials. We have not had any experience of using a metering size press (MSP) for the top coating. The reology of the top color is like Newtonian. Then, we suppose that the coat weight is low and a film split pattern will occur in the case of a MSP for the top coating. A potential using MSP may be a potential coating method, if reology is modified.

	Average Particle Size (μm)	Coating A	Coating B
Fine Regular Kaolin	0.48	60	35
Fine GCC	0.55	40	65

***Average Particle Size was measured with the laser diffraction method.**

Table 1. Precoating pigment formulations.

	Coating A	Coating B
Precoating	13	13
Top Coating	0.5	0.5

Table 2. Coat weights (per side, g/m^2).

Mill trials

To check runnability of this technology, we had mill trials for several times. The coater used for the trials was an off-machine coater equipped with four blade coating stations. All of the application system is jet fountain type. Usually, blade on blade pigment double coated papers are produced with the coater. For the mill trials, first two coating stations were used for the application of conventional pigment precoating. Coating A in Table 1 was used for the precoating and following two stations were used for application of the synthetic pigment emulsion. For gloss development, supercalenders installed in the same production line were used. The heat rolls were 65°C and the mill trial samples were treated under the maximum line pressure. There was no calender stack picking trouble.

Printing trials

We had commercial scale printing trials using coated paper rolls and sheets from mill trials. Toshiba OA-4B2T-600 four color web offset press and Man Roland 304 four color sheet-fed offset press were used to evaluate the printability. Color sequence was Black, Cyan, Magenta, and Yellow (KCMY) for both presses. The types of inks used were shown in **Table 3**. In the case of sheet-fed offset printing, the same types of inks were used for both cast coated paper and mill trial paper, as is popular in Japan. Other printing conditions were the same as used for conventional coated papers.

	Tack Value	Flow Value (mm)
Web offset printing	5.6 - 6.6	19.0 - 20.0
Sheet-fed offset printing	7.5 - 9.5	18.3 - 19.0

Table 3. Types of inks.

Microscopic Analyses

SEM (Scanning Electron Microscopy), JEOL 840A, was used. AFM (Atomic Force Microscope), SII SPI3800, was used to analyze surface of coated paper samples. To get images the contact mode was used.

Ink Surface Interaction Test

To measure ink setting of samples, Ink Surface Interaction Test was done using SeGan Ink Surface Interaction Tester.

RESULTS AND DISCUSSION

Sheet Gloss Development

As seen in **Table 4** and **Figure 4**, uncalendered top coated sample showed almost the same sheet gloss as supercalendered precoated sample. It means that 0.5 g/m^2 of synthetic pigment coating showed the same effect as supercalendering. It can be seen that pigment precoating formulations effected the final sheet gloss. Coating A showed higher sheet gloss than coating B for every stage of the treatment. To understand the mechanism of gloss development, further studies must be needed. However, some factors other than smoothness seem to affect a lot. As seen in **Figure 5**, PPS roughness of a supercalendered precoated (Coating A) sample was 1.25 µm, while that of the uncalendered top coated sample was 2.44 µm although the sheet gloss of those samples were in the same level (75.7% and 72.5%, respectively). Papers with coating B also showed the same tendency.

			Precoated Paper		Top Coated Paper	
			Coating A	Coating B	Coating A	Coating B
	Basis Weight	g/m^2	116.8	115.1	116.8	115.1
Uncalendered	Density	g/cm^3	0.95	0.95	0.98	0.97
	PPS Roughness	µm	3.02	3.23	2.44	2.54
	Sheet Gloss, 75 degree	%	42.7	32.6	72.5	62.9
	Opacity	%	95.0	94.0	95.0	94.4
Super-calendered	Density	g/cm^3	1.10	1.10	1.15	1.14
	PPS Roughness	µm	1.25	1.41	1.04	1.08
	Sheet Gloss, 75 degree	%	75.7	65.8	87.9	84
	Opacity	%	94.3	93.1	94.1	94.1

Table 4. Pilot trial.

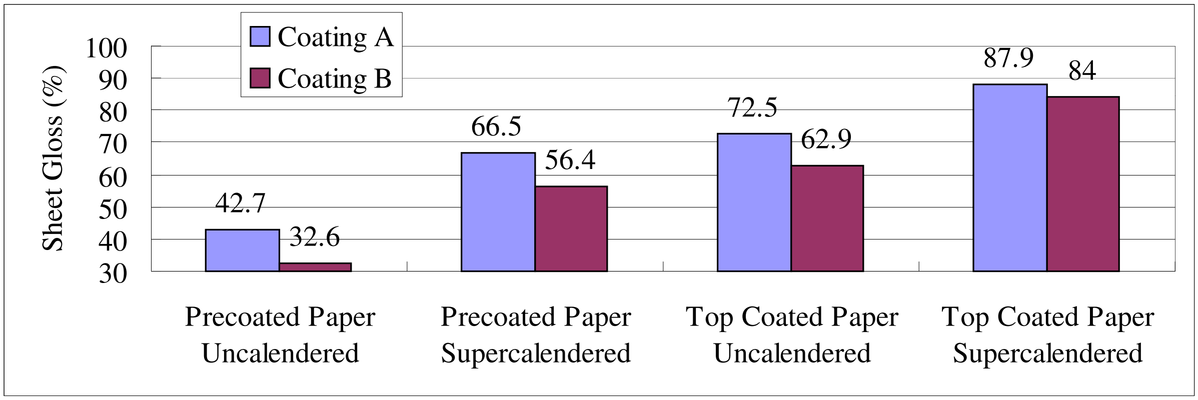


Figure 4. Sheet gloss (pilot trial).

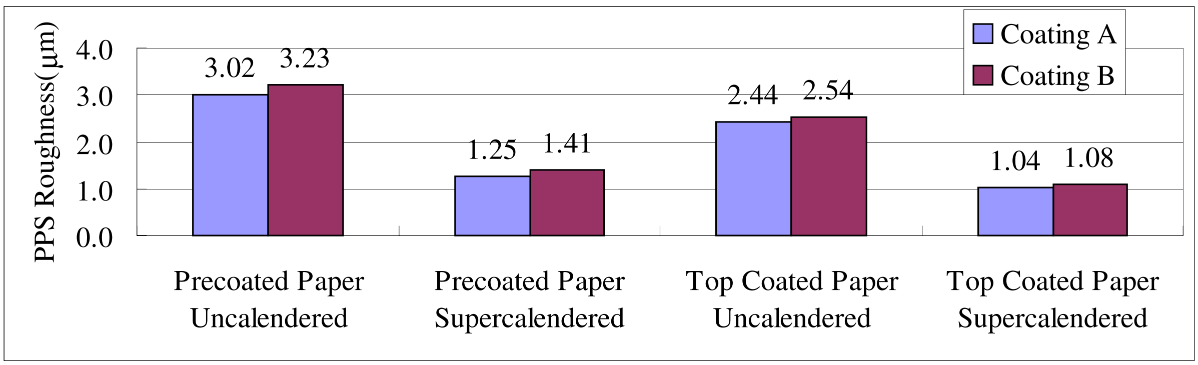


Figure 5. PPS roughness (pilot trial).

Although it is still a hypothesis, however, this phenomenon can be explained as follows. There are several wavelengths in roughness such as micro and macro roughness for uncalendered pigment precoated paper. The synthetic pigment fills void between inorganic pigments of precoating layer and levels micro scale (mostly less than 2 µm) unevenness as seen in **Figure 6**. **Figure 7** shows a Z direction image in which small particles of the synthetic pigment overcoat surface of inorganic pigment and fill void. On the other hand, "longer" wavelength roughness still remains because physical smoothening process by supercalendering has not been taken place.

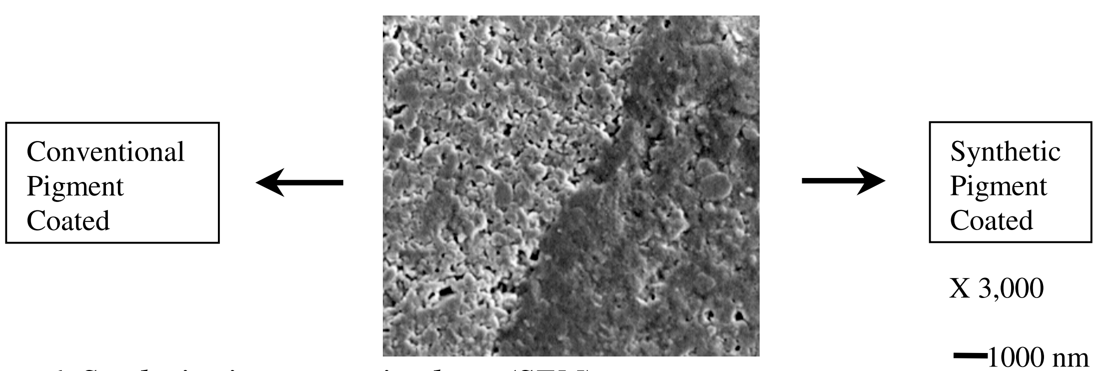


Figure 6. Synthetic pigment coating layer (SEM).

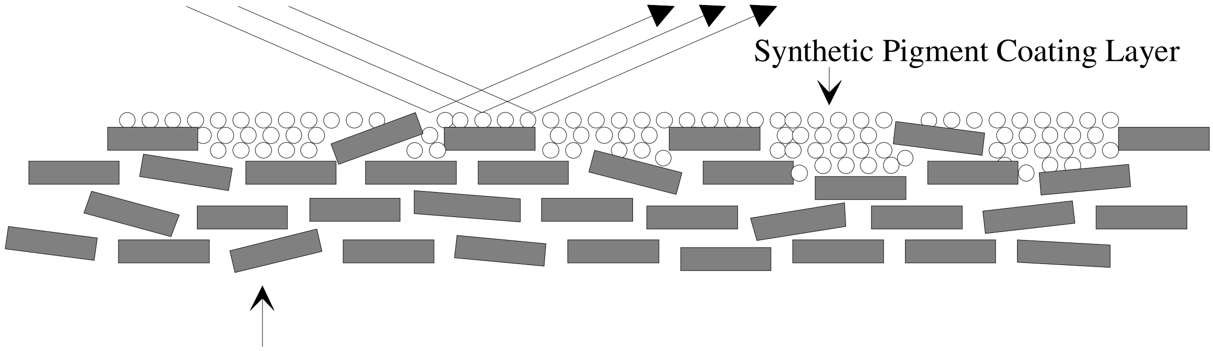


Figure 7. Model of synthetic pigment coating layer.

Figure 8, 9 and **10** show AFM images of a supercalendered top coated sample. Figure 8 shows three-dimensional image of a 1000 x 1000 nm (1 μm x 1 μm) area. In this image, we can see that the surface of the pigment precoating layer is covered by synthetic pigment particles. Figure 10 shows a cross sectional image cut along a line shown in Figure 9. Small "mountains" of synthetic pigment particles were detected and the distance between the top of the mountain and the bottom of the valley was less than 40 nm. It means that surface of the supercalendered top coated sample is very smooth. It is the mechanism of the very high gloss development. As shown in **Table 5** and **Figure 12**, a sample from a mill trial showed very good sheet properties such as sheet gloss of 91.1%(75 degree gloss), 70.1% (60 degree gloss) and PPS roughness was 0.71 μm. Those data are very close to cast coated paper.

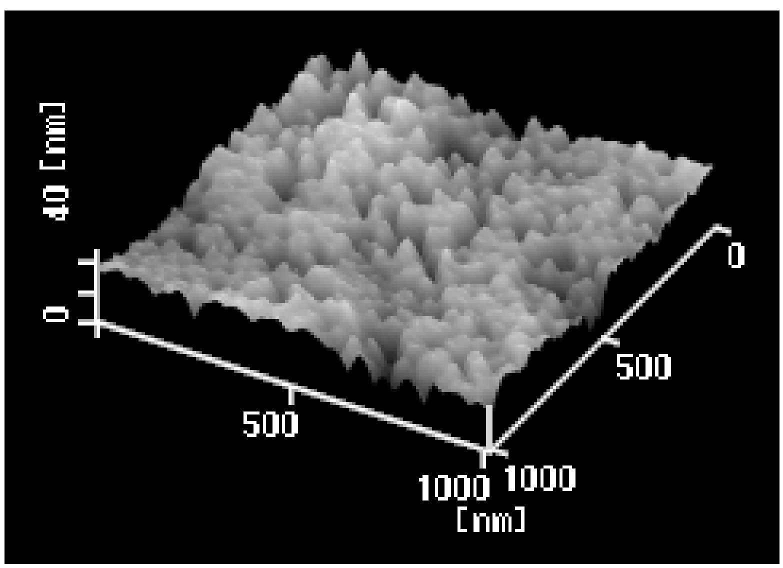


Figure 8. AFM- bird's-eye view.

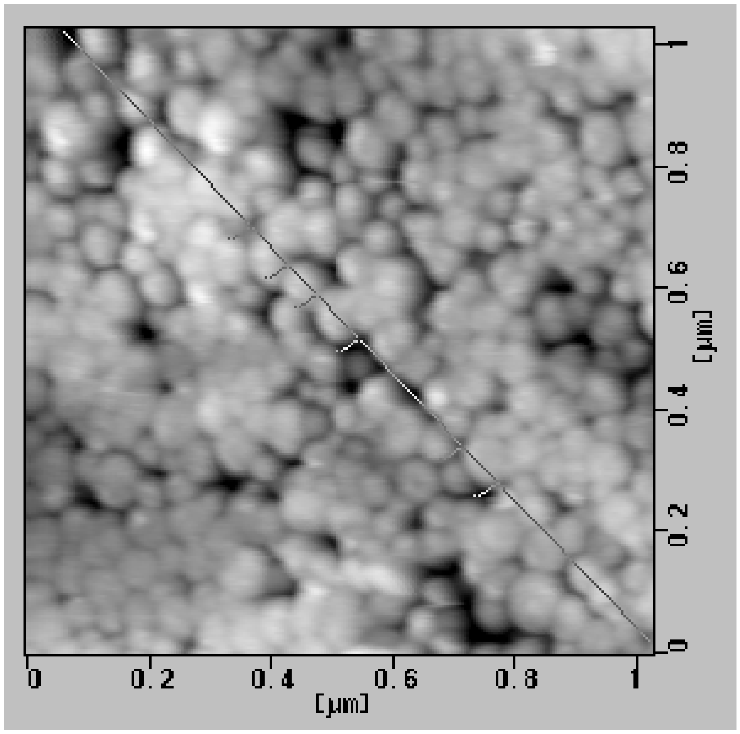


Figure 9. AFM- X-Y plane.

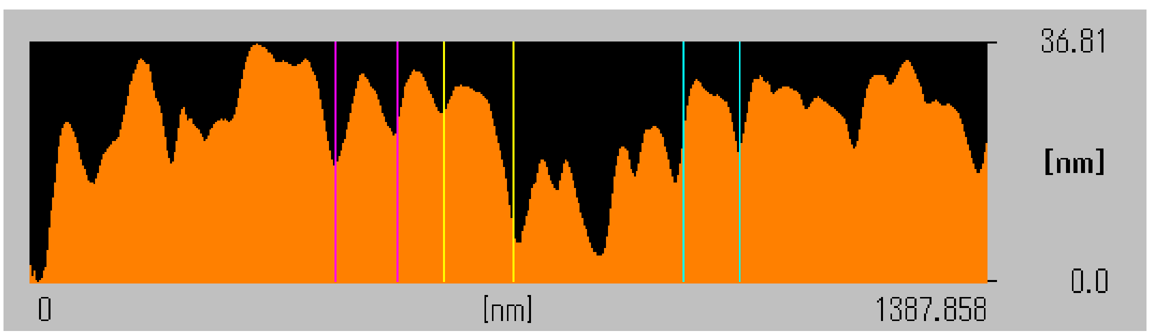


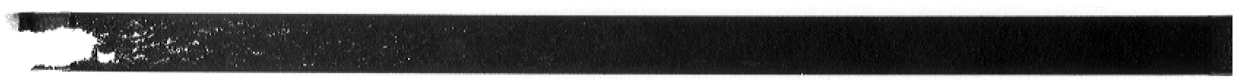
Figure 10. AFM- cross section analysis.

		Cast Coated Paper	Mill trial Paper	Conventional Double Coated Paper	
				Web	Sheet-fed
Basis Weight	g/m^2	129.5	129.4	127.7	132.0
Density	g/cm^3	1.12	1.18	1.12	1.28
Opacity	%	96.5	96.1	95.8	95.3
PPS Roughness	µm	0.74	0.71	1.31	0.82
Sheet Gloss, 75 degree	%	93.0	91.1	66.7	68.4
Sheet Gloss, 60 degree	%	80.5	70.1	30.4	32.3
IGT Pick Testing	m/min		3.6	1.9	2.5
Print Gloss (Web offset printing), 75 degree	%		97.1	88.9	
Print Gloss (Web offset printing), 60 degree	%		84.0	59.8	
Print Gloss (Sheet-fed offset printing), 75 degree	%	92.0	90.6		93.8
Print Gloss (Sheet-fed offset printing), 60 degree	%	71.8	70.6		75.1

Table 5. Mill trial.

Opacity
Opacity was relatively high because the basis weight was more than 115 g/m^2. Accordingly, effect of top coating on opacity was negligible. We think that the synthetic pigment has essentially no effect on opacity, because the particle size is 80 nm that is smaller than the half of visible light. It means that the top coating layer is transparent in visible light.

Self-binding power
One of the unique features for this technology is that top emulsion coating has a self-binding power. The reason for the sufficient strength is unknown, however, the mechanism must be complicated. As is well known, plastic pigment is used for sheet gloss development and /or for opacity. Generally, it is mixed with inorganic pigments such as kaolin clay, calcium carbonate, titanium dioxide and binders such as latex and starch [5, 6 and 7]. The usual plastic pigments (many cases polystyrene) that are widely used for conventional pigment coating do not have substantial binding power by themselves. This synthetic pigment also does not have sufficient binding power in coatings of inorganic pigments. However, it shows the self-binding power in the case of sole coating. As seen in **Figure 11** and Table 5, results from IGT pick testing showed that surface strength of the mill trial paper was very high. With blade coating, coat weights can be controlled from 0.1 to 1.5 g/m^2. Surface strength is sufficient in this coat weight range. It must be noted that picking occurs between the pigment coating and the base sheet.



Mill Trial

Conventional Double Coated Paper (Web)

Conventional Double Coated Paper (Sheet-fed)

Figure 11. IGT picking test.

Printability
As mentioned before, coated paper obtained by this novel technology can be printed in web offset printing process because blistering resistance is sufficient. **Figure 13** shows print gloss for mill trial paper and conventional coated paper. As indicated from the sheet gloss, the print gloss for mill trial paper was extremely high. Print gloss measured by 75 degree gloss was 97.1% and the value by 60 degree gloss was 84.0%. It is easy to see big difference between mill trial paper and conventional web-fed grade double coated paper. On the other hand, print gloss obtained by the sheet-fed offset print trial was not satisfactory as shown in **Figure 14**. The mill trial paper showed a little bit lower print gloss comparing to conventional sheet-fed offset grade coated paper. It is possible to modify the coating formulation to increase the print gloss. The simplest way to change print gloss is to control ink set, as Donigian et al has published [8]. Usually, print gloss increases with decreasing ink set speed. We measured ink set speed with an ink surface

interaction tester [9]. In a process of ink setting, the ink tack increases at first, and then decreases. When inks are set, the ink tacks are 0. As seen in **Figure 15**, results from the ink surface interaction test showed that ink setting of mill trial paper sample was slower than that of conventional double coated paper. Accordingly, further studies are necessary to understand the mechanism of less gloss development in the case of sheet-fed offset printing.

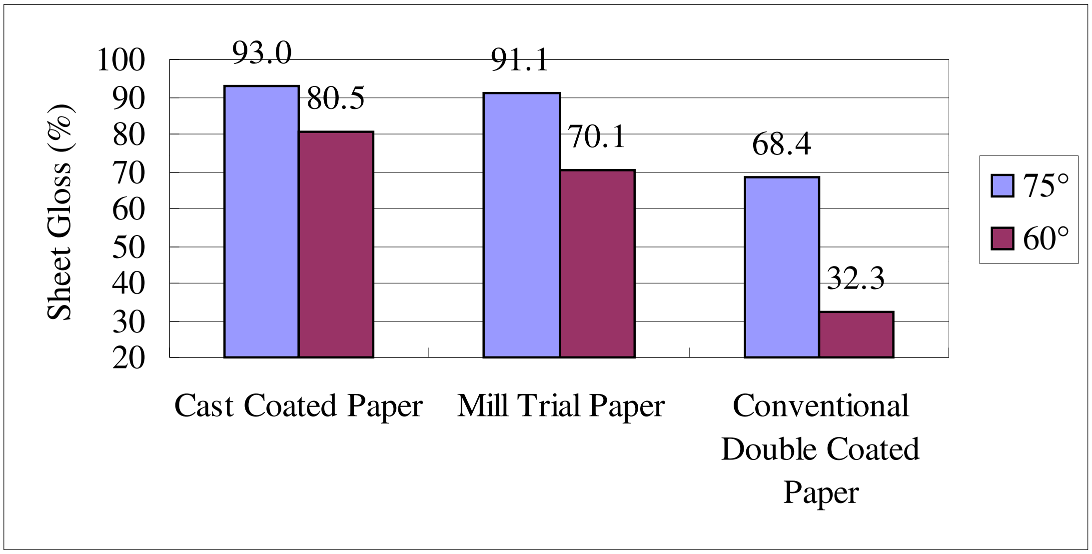


Figure 12. Sheet gloss (mill trial).

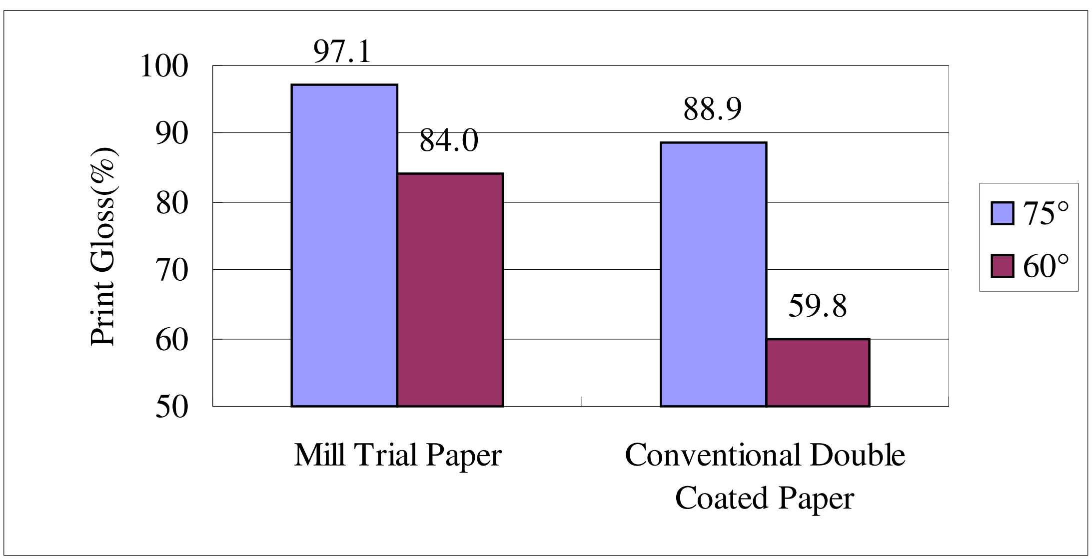


Figure 13. Print gloss of web offset printing (mill trial).

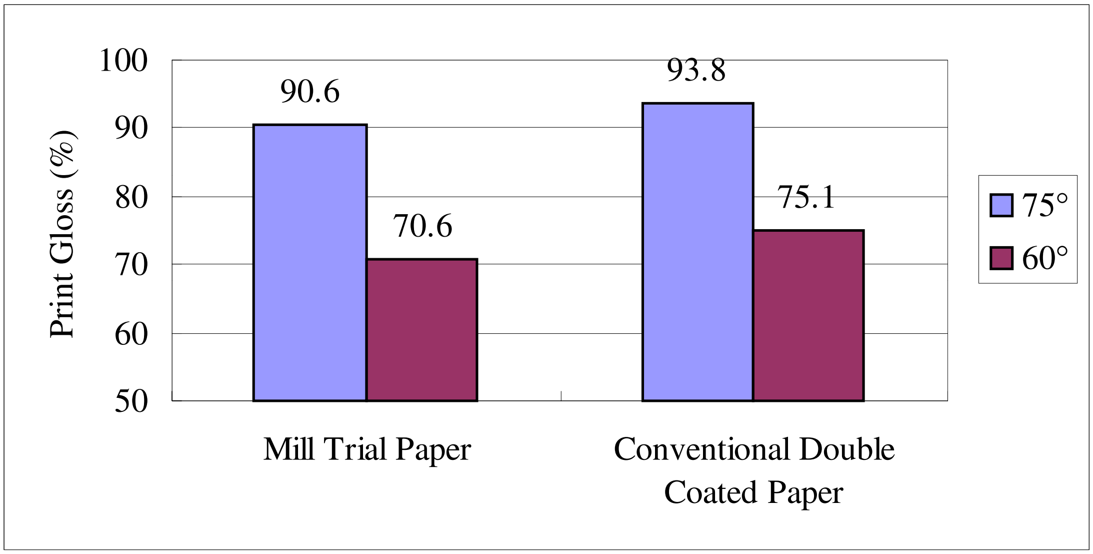


Figure 14. Print gloss of sheet-fed offset printing (mill trial).

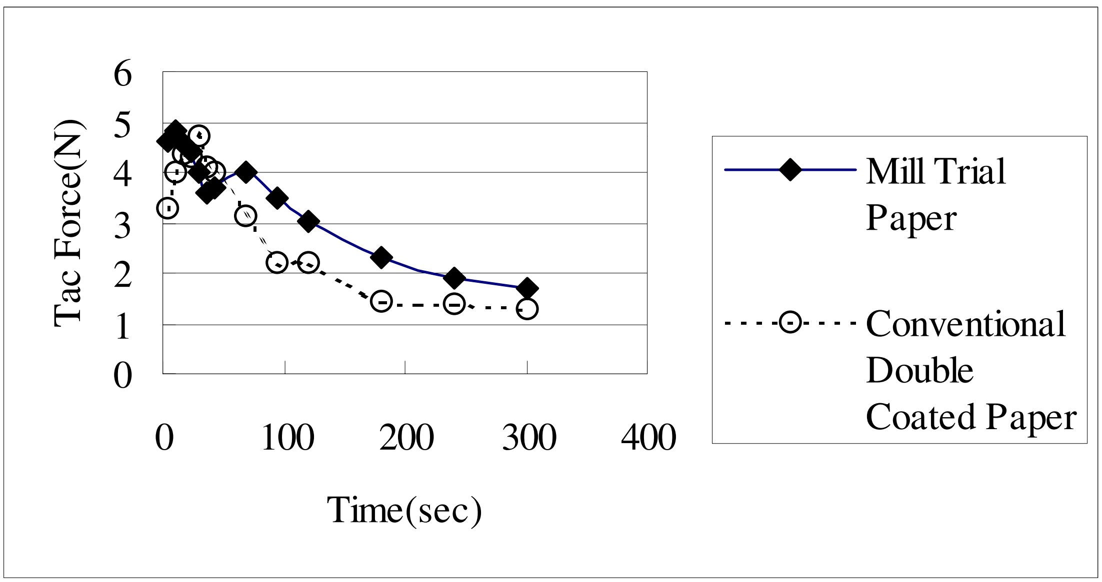


Figure 15. Ink surface interaction test.

CONCLUSIONS

A novel technology to produce very high gloss paper was developed. The process consists of conventional pigment precoating and top coating of a newly developed synthetic polymer pigment. The technology has several properties and advantages as follows.

1. Sheet gloss of the paper is around 90% even if the coat weights are relatively low.
2. Conventional double coating facilities can be used for this technology.
3. Cast coated like web offset grade can be produced because of good blistering resistance caused by relatively low coat weights.

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Received: May 3, 1999
Accepted: January 11, 2001

This paper was accepted for abstracting and publication in the May 2001 issue of *TAPPI JOURNAL.*

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