# Physical Properties and Printability Characteristics of Mechanical Printing Paper with LWC

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Acrylic styrene latex was used in combination with nanoclay at two different loading levels and calcium carbonate at four loading levels to improve printability characteristics of mechanical printing paper. SEM micrographs indicated filling of the voids and covering of the printing paper surface. Different rheological behavior of the coating that contained two coating pigments, in addition to their different viscosity, was clearly evident. Calcium carbonate was more advantageous due to the reduction in pumping costs. Paper coating improved roughness and air-permeability properties. Water absorption of the coated paper was decreased by at least 50% which significantly affects the dimensional stability of the paper during web offset printing. Specular gloss and print density were significantly increased at a 1% probability level by coating the surface of the paper. Contrary to the control sample, picking of the paper (which is of great importance after printing and for linting on the printing cylinder) did not occur.

*Keywords: Scanning microscope; Precipitated calcium carbonate; Nanoclay; Surface picking; Printability*

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## INTRODUCTION

Coating the surface of paper improves the qualitative characteristics of the printing paper. Coating materials in the paper enhance optical characteristics (brightness, opacity, and light scattering), surface smoothness (*i.e.* reduction of roughness especially after paper calendaring), formation of sheets (*via* filling the voids between the fibers), printability of the paper during different printing processes (due to better uniformity of the surface), dimensional stability of the paper (dimensional changes upon water absorption, as in the heat-set web offset print method), and paper durability. Some conventional materials for coating the paper include calcium carbonate (precipitated and ground), talc, clay, gypsum (calcium sulfate), plastics (polystyrene), and titanium dioxide (Gullichsen and Paulapuro 2000).

When coating the paper, an aqueous suspension called color coating is applied on one or both sides of the paper. After introducing the needed amount of coating (small, medium, or large), the coated paper is dried and finished. By finishing the coated paper, smoothness and specular gloss are created on its surface. The coating will cover the surface peaks (knobs) caused by the fibers in the base paper in addition to filling its voids. Different coating methods usually tend to fill the voids of the fibers by covering the peaks (through thin layers). The objective of some paper-coating methods is to make a uniform thickness of the paper by covering its surface peaks, although the voids may not be filled completely.

The coating has different components, the most important of which is pigment. The type of the pigment used in the coating differs according to the printing method employed. For example, the coating of the paper used for inkjet printing with liquid ink is different from that of heat-set web offset printing with paste ink. The most commonly used mineral pigments are kaolin clay and calcium carbonate. The pigments comprise particles smaller than 10 µm. The most important consequence of coating a paper is improvement of its printability characteristics. The coating layer must bear different pressures applied during the printing. For instance, strength of the paper toward thickness of the paper (Z direction) and/or its pick strength must be sufficiently high due to the sticky behavior of the offset print ink. The blade-coating method is a common practice in the papermaking industry. No special structure is formed in this method because a high pressure would break down the colloidal interactions in the coating process. This method is very important because it not only fills the voids of the paper, but also applies pressure on the peaks of the base paper during coating (Gullichsen and Paulapuro 2000; Paper Standards and Measurements 2007). The potential application of this method for coating paper at high speeds (2000 m/min) has made this technique economically noticeable (Kipphan 2001). No similar research has been done in Iran yet on coating using nanoclay and precipitated calcium carbonate to improve characteristics of print papers. The following addresses some foreign studies on this subject:

The application of calcium silicate nanoparticles for coating the paper in inkjet printing has been found promising in a relevant work. Comparing characteristics of the text printed on the uncoated paper (control sample) and the one treated with this mineral material demonstrated that the coated paper provides improved characteristics with respect to the treatment cost (Wygant *et al.* 1995).

Coating the surface of a carton with precipitated calcium carbonate (PCC) and ground calcium carbonate (GCC) up to 14 g/m$^2$ shows that the best specular gloss is achieved, with the particles showing narrow particle size distribution. Adding a further amount of latex leads to a partial reduction in specular gloss of the carton due to increased roughness. Almost the same results were obtained regarding brightness and whiteness of the carton. Meanwhile, the addition of more latex will decrease porosity and light scattering (Wygant *et al.* 1995).

The increased mass of the paper coating due to the creation of a much smoother layer leads to a smaller percentage of missing dots. This percentage is reduced in the papers that are coated with particles of greater aspect ratio (platy form) due to the better compressibility of the paper (especially during calendaring) (Preston *et al.* 2007).

The aim of this study was to improve the printability characteristics of mechanical printing paper *via* coating the surface with latex and two types of pigments (nanoclay and calcium carbonate).

## MATERIALS AND METHODS

Mechanical printing paper with 70 g/m$^2$ base weight was procured from Mazandaran Wood and Paper Co. This base paper is produced from hardwoods with specification as follows: 7.5% moisture, 69% brightness, 86% opacity, 10% ash, and 1.5 g/m$^2$ starch. The properties of the materials used including nanoclay and precipitated calcium carbonate are summarized in Table 1. The acrylic styrene latex used was of the hard film type (SH-315 from Simab Resin Co.). This latex had a milky appearance with an anionic emulsion system, 50% content solid particles, 300–9000 centipoise viscosity, and a minimum film-forming temperature (MFFT) of 20 °C.

Mixing the pigment and latex with 5 wt% and 10 wt% nanoclay and 20, 30, 40, and 50 wt% PCC was implemented by a dispersing apparatus at a rotation speed of 1500 rpm for 10 min. Lightweight coating was done using a blade coater on the paper surface making a thin film of 4–6 g/m$^2$.

**Table 1.** Specifications of the Mineral Pigment of the Coating

| Component | Trade Name | Manufacturer | Particle Size (µm) | Density (g/cm$^2$) | Weight Percent (%) |
|---|---|---|---|---|---|
| Precipitated Calcium Carbonate | Aragonite | Neka Sang | 5–6.5 | 2.82 | 20-50 |
| Nanoclay | Cloistie-30B | Clay Products | 10%<2<br>50%<6<br>90%<13 | 1.98 | 5,10 |

The study of the microscopic structure of the coated papers was conducted using a scanning electron microscope at Sharif University of Technology. The following standard tests were done to determine the properties of the paper:

- Basis weight: T410-Om88
- Specular gloss: T480-Om05 and T653-Om03
- Thickness: T411-Om89
- Air permeability (Gurley method): T460-Om02
- Roughness: T555-Om04
- Printability and surface picking (IGT): ISO 3783
- Water absorption (Cobb test): T441-Om09
- Density: (IGT)

Variations of viscosity and rheology of the coating material were recorded in a rheometer apparatus made by Anton Paar Co. (MCR 300) at a rotation speed of 30 rpm. Data analysis was done by SPSS statistical software in terms of one-way analysis of variance. The average values were finally compared and classified using the Duncan test at a 99% confidence level.

## RESULTS AND DISCUSSION

### Rheological Behavior of the Coating

Figures 1 and 2 depict variations of viscosity for the latex with 10% nanoclay and 50% calcium carbonate, respectively. It can be seen that the behavior of two types of the coatings used were changed by increasing the mixing time. The viscosity of the coating with 50% calcium carbonate was lower than the one containing 10% nanoclay. The viscosity demonstrated an ascending trend by increasing the mixing time with latex up to about 16 min, and then it became a descending trend through a thixotropic property. Although the coating with nanoclay did not show significant changes before 53 min, it increased significantly after 53 min. A greater amount of solid particles in the coating may alter water-retention capacity and viscosity of the coating, while improving the picking strength and specular gloss, decreasing binder consumption, and making the process cost-efficient (Dahlvik *et al.* 2011; Willenbacher *et al.* 1997). Using the coating that contains calcium carbonate with a great amount of solid particles (even with a large aspect ratio) is likely to reduce the costs of dilution and dewatering for the purpose of solving the problems associated with pumping the coating material (Gullichsen and Paulapuro 2000).

However, there are some problems with using the blade-coating method, for example, inability to control rheological behavior of the coating as a key parameter. It seems that this parameter has complicated correlations with some factors such as formulation of the coating (water retention capacity), parameters of the coating machine (*e.g.*, blade stiffness, blade angle, and speed), and properties of the paper (*e.g.*, porosity, compressibility, roughness, and wettability). Therefore, measurement of the rheological characteristics is necessary to ascertain the computational fluid dynamic (CFD), though it is rather difficult to predict the behavior of various materials in the coating process *via* experimental techniques (Willenbacher *et al.* 1997).

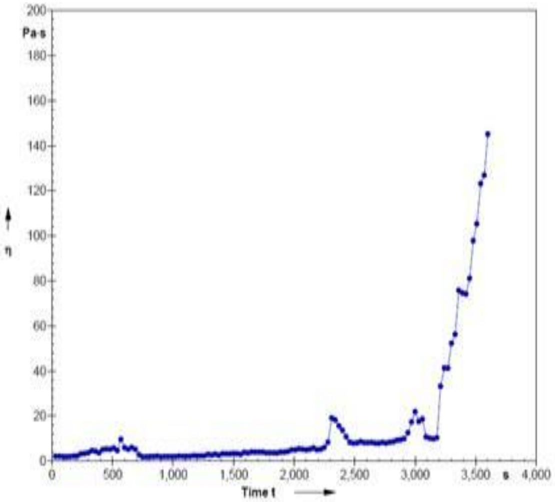

**Fig. 1.** Variations of viscosity for latex and 10 wt% nanoclay

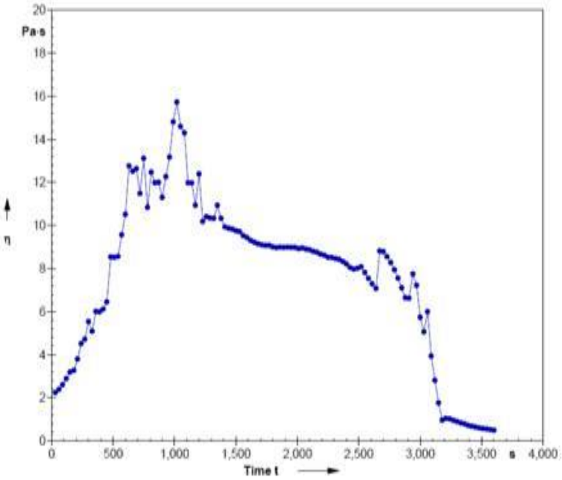

**Fig. 2.** Variations of viscosity for latex and 50 wt% calcium carbonate

## Microscopical Structure of the Coated Paper

Figures 3 and 4 illustrate the surface of the paper coated with materials containing 20 wt% and 40 wt% calcium carbonate, respectively. It is evident from Fig. 4 that introduction of 50 wt% calcium carbonate has coated the surface of the fibers significantly better than the one with 20 wt% calcium carbonate. This coating would make better coverage of the paper surface, which can positively affect the printing quality. Leveling of the surface changes the absorption of ink which will finally improve the quality of the small print components in the versions copied from the original version. After coating color is applied on a base sheet, it consolidates into a porous structure that determines the physical and functional properties of the coated product. The pore size distribution of a coating layer determines its suitability for the intended printing process (Larrondo and Lepoutre 1990).

## Physical Properties and Printability of the Paper

The results of the physical properties and printability of the treatments under study are listed in Table 2 with a statistical comparison. One-way analysis of variance revealed that there was no significant difference between average thicknesses from various treatments. Taking into account the studies conducted on the paper with small amounts of coating, the coating with nanoclay particles offers a greater density than the one containing structural calcium carbonate.

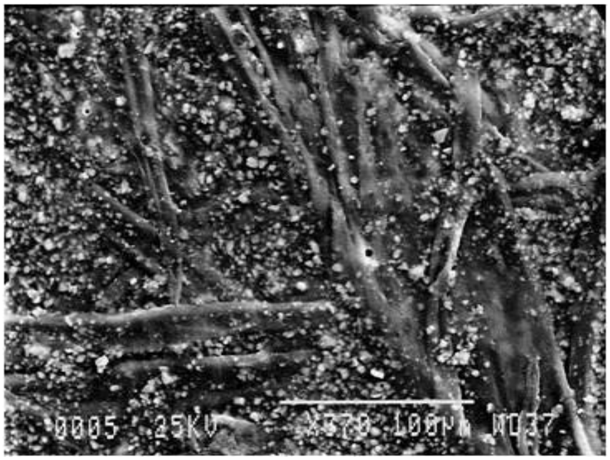

**Fig. 3.** Coating the print paper with latex and 20 wt% calcium carbonate (370× magnification)

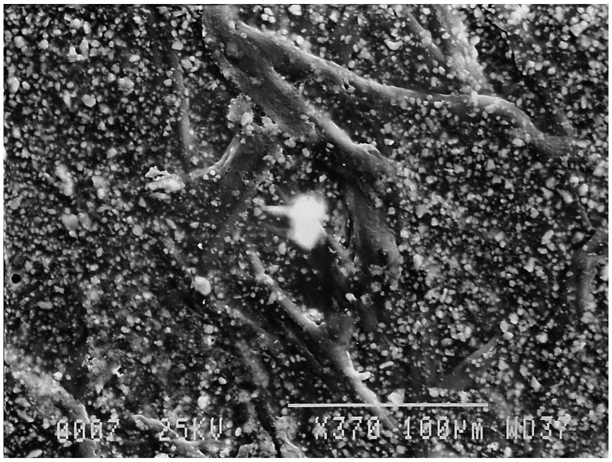

**Fig. 4.** Coating the print paper with latex and 40 wt% calcium carbonate (370× magnification)

Moreover, Figures 5 and 6 shows surfaces of the papers coated with 5 wt% and 10 wt% nanoclay, respectively. It can be observed that using 10 wt% nanoclay provides the a much better surface coating of the fibers as compared to that of 5 wt% nanoclay.

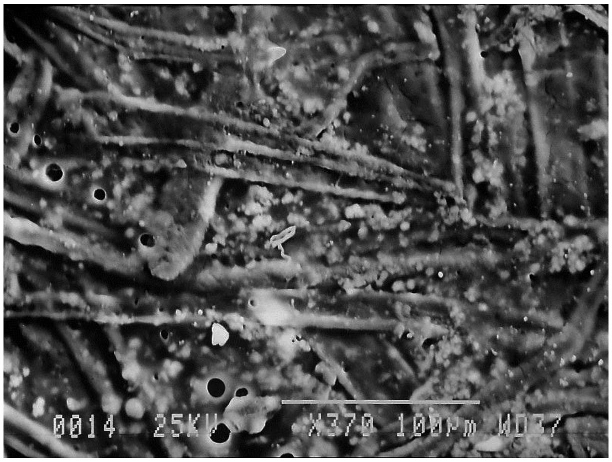

**Fig. 5.** Coating the print paper with latex and 5 wt% nanoclay (370× magnification)

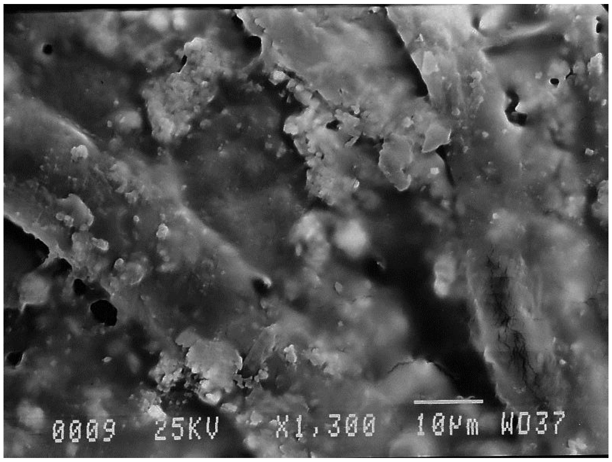

**Fig. 6.** Status of nanoclay particles on the fibers at 10 wt% (1300× magnification)

The porosities of the nanoclay incorporated a greater shape factor and showed a more parallel arrangement on the surface of the paper (Chinga 2002). Considering the lower initial density of the nanoclay (Table 1), the greatest thickness of the paper (before calendaring) belonged to the treatment with the nanoclay, which can enhance the compressibility and reduce the thickness of the layer after calendaring and finishing operations. This may lead to forming some missing dots (Preston *et al.* 2007).

There is a significant difference among the average values of surface roughness from seven different samples of paper under examination at the 1% probability level. The maximum surface roughness was attributed to the control sample, whereas the minimum value belonged to the treatment with 50 wt% calcium carbonate which is categorized under D and A groups by using Duncan's multiple range test, respectively. Parkers' method (PPS) offers the best correlation with the paper printing quality (Preston *et al.* 2007). This observation was properly in accordance with the results of missing dots (Singh 2008). This characteristic was still considerable in the coated papers, and an even smoother surface of the paper would have been obtained if the calendaring process was utilized after the coating. The roughness of the calendared chemical thermo mechanical pulps were found to be about 2 µm in comparison with the samples that were not calendared (Singh 2008).

According to a report of the German Graphic Technology Research Association (FOGRA) in 2006, some 21% of the problems in paper printing are related to ink stability and drying. Thereby, reduction of the surface porosity is expected to have a positive effect on optical properties and printability of the paper as well as on the slow stability of the ink (FOGRA 2006). Examination of the coating material with different pigments demonstrated that the effect of porosity on the surface roughness of the coated paper was negligible (Sood *et al.* 2010).

Air permeability presented some information about the relative porosity of the paper. It should be noted that one may determine total volume and permeability of the paper pores thanks to the low viscosity of air rather than the size of the pores (Wygant *et al.* 1995). The resistance against air permeation in the treated papers was significantly greater than in the control sample. So the apparatus was unable to measure this effect for B, C, and G treatments. One-way variance analysis showed that there is a significant difference between measured average values at the 1% confidence level. The structural differences between coating layers with different components can be the main reason for different values of this characteristic in various treatments. Duncan's multi-range test puts four measurable treatments in four different groups.

It is possible to determine the position of the ink (dispersion and penetration) on the paper by measuring the amount of water. Using this method is of great importance for papers that are printed by the heat-set web offset technique (Paper Standards and Measurements 2007). It can be inferred from Table 2 that the maximum water absorption in the paper (Cobb test) was for the control sample, whereas the minimum water absorption belonged to the nanoclay treatments.

**Table 2.** Statistical Comparison and Classification of Average Physical Properties and Printabilities of the Coated Papers

| Sample Code | Treatment | Thickness (µm) | Surface Roughness (µm) | Air Permeability (S) | Water Absorption (g/cm$^2$) | Specular Gloss | | Print Density | Rate of Surface Picking | Apparent Quality |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 20° | 75° | | | |
| A | Control | 88.5 | 5.1 $^{d*}$ | 43 $^{a}$ | 29.53 $^{b}$ | 4.9 $^{a}$ | 3.8 $^{a}$ | 1.2 $^{a}$ | 72.9 | Poor |
| B | 5% nanoclay | 90.67 | 4.9 $^{d}$ | O.R. | 12.73 $^{a}$ | 7.8 $^{b,c}$ | 7 $^{f}$ | 1.79 $^{b}$ | Not picked | Fair |
| C | 10% nanoclay | 89.33 | 4.43 $^{b,c}$ | O.R. | 13 $^{a}$ | 8.4 $^{d}$ | 6.5 $^{e}$ | 1.78 $^{b}$ | Not picked | Fair |
| D | 20% calcium carbonate | 88.67 | 4.23 $^{b}$ | 416.1 $^{b}$ | 17.67 $^{a}$ | 7.5 $^{b,c}$ | 5.9 $^{c,d}$ | 2.02 $^{d}$ | Not picked | Excellent |
| E | 30% calcium carbonate | 88.57 | 4.47 $^{b,c}$ | 769 $^{c}$ | 13.43 $^{a}$ | 5.7 $^{c,d}$ | 8.9 $^{e}$ | 1.72 $^{b}$ | Not picked | Good |
| F | 40% calcium carbonate | 86.67 | 4.7 $^{c,d}$ | 1847 $^{d}$ | 15.8 $^{a}$ | 5.3 $^{c}$ | 9.5 $^{f}$ | 1.92 $^{c}$ | Not picked | Good |
| G | 50% calcium carbonate | 86.33 | 3.63 $^{a}$ | O.R. | 15.53 $^{a}$ | 7.1 $^{b}$ | 7.1 $^{b}$ | 2 $^{d}$ | Not picked | Excellent |
| | Computational F | 1.315 | 25.12 | 36623 | 17.04 | 37942 | 67071 | 2327 | | |
| | Significance level | 0.31 $^{n.s.}$ | 0.000 ** | 0.000 ** | 0.000 ** | 0.000 ** | 0.000 ** | 0.000 ** | | |

*Small letters show the mean statistical grouping by Duncan's multiple range tests.
O.R. out of measurable range of the apparatus
** The difference between the averages is significant at the 1% level.
n.s. Difference between the averages is not significant.

This characteristic feature was reduced to nearly half in the coated papers, which is important from the dimensional stability point of view in the print machines as well as in improved quality of printing, particularly in the heat-set web offset method. By Duncan’s classification, the papers coated with nanoclay and calcium carbonate were placed in one group (a), while the others were placed in the other group. How the ink is dispersed on the paper depends on the equilibrium between wettability, surface tension, and the porosity of the paper which affects the ink absorption behavior (Preston *et al.* 2007).

The amount of specular gloss is dependent on the surface structure and porosity of the substrate. The roughness at the micrometer scale can be covered to some extent by a film of ink (Ström *et al.* 2003). Two incident angles of 20° and 75° were applied to determine the specular gloss of different treatments. However, investigation on the amount of this characteristic was more important for the coated (not printed) paper at 75° (Ström *et al.* 2003). Table 2 shows variations of the specular gloss and print density of different treatments which are known as determinants for the amount of required ink for the printing operation being economic. It can be observed that specular gloss of the paper has been reduced by increasing the amount of pigments at a 75° angle. As previously mentioned, one reason may be failing to perform the finishing operations (calendaring) on the coated paper. Topography of the coated paper is affected by macro roughness (base paper) and micro roughness of its surface (Chen 2012). The difference between these two characteristics at the two angles may be assigned to topographic variations of the paper at these two angles. The print density is indicative of a greater thickness of the stabilized ink layer, which is itself a result of the wider coating network as well as the stringer bonding between the base paper and the ink. This characteristic has a significant effect on the quality of the printed version. The print density was reported to be 1.5 and 2 for the uncoated and coated papers, respectively (Kipphan 2001; Tripathi *et al.* 2007). Increasing the print density led to a greater specular gloss of the coated paper of the rotogravure and smaller pores of the coated paper, respectively. Meanwhile, the PCC-treated sample demonstrated lower specular gloss and print density in comparison with the sample that was treated with GCC (Preston *et al.* 2007). The maximum print density was related to D and G treatments which introduced the lowest roughness (Table 2). These two treatments are located in the same group based on Duncan’s classification. On the other hand, visual comparison of printability among different samples shows that the best quality of printing was associated with the papers treated with calcium carbonate. The print quality of the paper prepared via blade coating was raised at greater masses (Preston *et al.* 2007). In multicolor printing, the paper must pass through printing cylinder and the offset blanket several times. A good adhesion quality of the ink on the coated paper is necessary in the printing process. Aggregation of the ink particles on the roll blanket, and picking of the printed surface are among the important issues (Wygant *et al.* 1995). A comparison among different pigments for paper coating revealed that calcium carbonate had the best performance in terms of not being picked from the surface of the printed area (Sood *et al.* 2010). Studying the picking ability via two methods (i.e. IGT and Prüfbau) offers promising results for the heat-set web offset method (Paper Standards and Measurements 2007). The picking test was implemented in an IGT apparatus (Model AIC2-5) by oil with high viscosity at different speeds. Comparison of the treated papers with the control sample (Table 2 and Figure 7) indicates that the surface of all the treated papers are not picked, although the control sample had been picked at 72.9 m/s speed. Comparing the coatings of the offset paper with two pigments of GCC and glossy clay implies that the coating with GCC pigment with smaller particles creates a greater surface which can be due to the specific area, capability of the ink to be stabilized, and enhanced hydrophility of the nanoclay (Dahlvik *et al.* 2011).

**Fig. 7.** Results of picking test on the surface of the printed areas: Comparing control samples and treated samples (A = Control; B = 5% nanoclay; C = 10% nanoclay; D = 20% calcium carbonate; E = 30% calcium carbonate; F = 40% calcium carbonate; G = 50% calcium carbonate)

## CONCLUSIONS

1. The SEM images confirm the statements about the objectives of coating. We can see an improvement of paper quality and looks, as coating fills the cavities and covers the surface of base paper. Filling of paper surface pores and irregularities influences ink absorption and, together with covering paper, improves the ability of a printed image to reproduce the smallest details of the original image.
2. It is expected that preparation method and condition would be different due to the different rheological behaviors of nanoclay and calcium carbonate pigments.
3. Surface roughness and resistance against air permeation were improved for the coated papers in comparison with the control sample. This enhancement could be even greater when a further finishing operation (calendaring) is performed.
4. Reduction of the water absorption by at least 50% in the coated papers indicates that no considerable dimensional change of the paper roll will occur in the heat-set web offset system by using dampening solution, which will improve the printing quality itself.
5. Increased specular gloss of the coated papers and their higher print density imply improvement of printability for this kind of the paper.
6. Running the picking test on the papers demonstrated that the coating has reinforced adhesion of the ink to the paper, while avoiding the problem of linting on the rolls (especially an offset blanket roll) and picking of the printed area.
7. To summarize, a light coating (4 to 6 g/m$^2$) on mechanical paper from pulp from Mazandaran Wood and Paper Co. showed that the printability characteristics of this paper will be certainly be improved as compared to the control sample even without running the finishing operations (*e.g.*, calendaring).

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