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CHAPTER THIRTEEN
Manufacture of Coated Paper Grades

CRITERIA FOR COATING FORMULATIONS

Concepts for formulating aqueous coatings to be applied to paper or paperboard are analogous to the painting of a fine piece of wood. The properties of the finished product will closely equate to those of the substrate. One cannot expect a finished piece of furniture to exhibit a smooth, glossy surface if the raw wood was rough, scratched, and porous. Following this line of reasoning with paper, one would not expect that a surface application to poor raw stock would yield a fine quality, highly finished grade of paper. The best results are obtained by utilizing the flattest, smoothest surface possible, sizing the paper web, precoating it, and then applying a thin topcoat of high quality.

General Requirements

Depending on the desired end product, consideration must be given to the proper choice of coating material. The objective is to arrive at the target surface finish with a minimum of coating application under the best economic conditions. This is the stage where most manufacturing companies depart from generalities to obtain their goal. Commercial products are generated under different conditions for the same end use, according to plant location, equipment and processes in place, and materials available. Other restrictions will result from the grade structure into which the coated product will be marketed, grade competition, the anticipated method of printing, and the cost that can be afforded.

Basestock for coated paper and paperboard grades can consist of groundwood, bleached groundwood, thermo-mechanical pulp (TMP), various similar treated wood grades, bleached fiber, or recycled fiber. Sometimes blends are utilized. The coated grades are classified according to basis weight, brightness, opacity, and gloss. A further differentiation results from the printing processes for which they are intended. Major grades of coated paper are:

- Sheet offset (wood-free)
- Quality web offset; premium No. 1 through No. 3 (wood-free)
- Publication grades; Nos. 4 and 5 for offset or rotogravure (wood-containing or wood-free)
- Film (wash) coated grades; FCO, MFC, MFP
- Label grades; C1S (wood-free)
- Solid bleached sulfate; SBS (wood-free paperboard)
- Coated natural kraft; CNK (wood-containing paperboard)
- Recycled paperboard.

End-use requirements and method of application dictate the levels and types of ingredients that are employed in formulating a coating color. For example, the quantity of total binder required for coatings to be printed follows the order: sheet-fed offset > web offset > web letterpress > rotogravure. The choice and level of specialty starches and synthetic binder will determine sheet gloss (before and after calendering), ink gloss, varnish holdout, wet pick resistance, coating flexibility, and other quality factors of coated paper.

An important consideration is the availability of the raw materials. If a new plant is constructed, raw material availability becomes an economic issue. For example, if clays are needed, the project manager must consider dry or slurried forms. Freight rates must be taken into account. Pigment slurries will be shipped with approximately 30% water. Bulk systems for any raw material, particularly starch, must be looked at carefully. Cornstarch has a water content of about 12%, and this must be factored in when a coating is prepared. Latex dispersions contain about 50% water. Starch suspensions cannot be prepared at a solids content higher than about 3.5 lb/gal. Starch dispersions have a maximum in solids content of about 35-40%, dextrins 40-45%, while latex dispersions may reach 50-55%. These limitations affect the use of water in the preparation of high solids coatings, especially with starch as major binder.

Coating Materials

Coating formulations are often like Topsy - they just grew that way. Sometimes the reason for adding an ingredient is lost with the passage of time. Some formulations are like sacred animals that cannot be touched in any way. Of course, at times when things are running well and costs are within reason, one may be justified in taking that kind of stand. However, if one assumes that the paper industry is dynamic, as it most certainly is, then the only thing that is constant is change. Internally, there can be changes in fiber use, methods of manufacture, coating, and finishing. Externally, there can be changes in printing presses, inks, market demand, supplier products, etc. Because of these changes, coating formulations should be reviewed periodically to ensure optimum performance at minimum cost. A previous edition of this monograph *(1)* listed various coating formulations that resulted from a mill review conducted by a TAPPI committee in the early 1970s. Due to the rapid change in the coated paper industry, a reference to specific past recipes could now be misleading. At the present stage, a better guide for a formulator will be familiarity with the current trade and scientific literature, awareness of trends in formulating coating colors, and a good knowledge of the properties of coating materials and their mutual interactions *(2-4)*.

Coating Binders

A variety of adhesives are available to the coating formulator to use as coating binder. Natural adhesives are starch derivatives, soy protein, and casein. Synthetic binders are emulsions of homopolymers or copolymers in water (styrene-butadiene, styrene acrylate, polyvinyl acetate, and acrylics) or water-soluble materials (polyvinyl alcohol and water swellable emulsions).

Since starch is usually the most economical binder for pigmented coatings and is readily available, formulators try to incorporate as much of it as possible into the formulation. The addition of synthetic binders *(5)* is often necessary to meet specific rheological requirements for the color as well as targets in surface strength, calendered gloss, sheet flexibility, ink gloss, and varnish holdout for the coated product. Usually, the latex portion of the coating binder will increase and the starch portion will decrease as the grade structure scale is ascended. Thus, starch content in the binder portion may vary from 100% in the lower quality grades to 25% or less in the highest quality grades, with one or more of the synthetic binders making up the difference. Frequently, carboxymethyl cellulose (CMC), polyvinyl alcohol, or sodium alginate is added to adjust rheology and water-holding characteristics.

Although coating color viscosity is primarily a function of its solids content and the interaction between coating ingredients, the viscosity grade of starch and the choice and quantity of binder use, i.e., the starch-to-latex ratio, are also major contributors. The trend toward higher-quality (value-added) products in the paper industry has increased the use of hydroxy-ethylated starches and dextrins and replaced, to some extent, chemical-thermal starch conversion. A grafted starch has been developed to combine the properties of natural and synthetic binders, but its application has thus far been limited to use on size presses *(6)*.

There are certain limits on the use of a binder in a coating, depending on pigment particle size and surface. Generally, the quantity of added binder has to stay well below the critical pigment void volume in order to generate opacity through light scattering. Although high binder concentration improves surface strength, it will do so at the expense of brightness, opacity, and gloss.

Coating Pigments

Pigments in the formulation *(7, 8)* are the principal contributors to brightness and opacity of a coating. They provide the material volume to fill in irregularities in the surface and render the paper smooth. Since they are the major constituents of a coating, they will also affect viscosity, gloss development, and print performance.

In the past, one or more of the kaolin clays were the major pigments used for paper coating. Kaolin clays are platey and have a large hydrodynamic diameter, which restricts the workable solids content. An increase of solids content can be achieved by mixing clays of different particle size. The solids of a clay-based coating are generally limited to 60-62%. Use of kaolin in the coating provides smoothness, ink receptivity, density, and gloss. New kaolin pigments have been developed for improvements in coating holdout, ink receptivity, and high levels of surface and printed gloss.

In current practice, calcium carbonate has become an alternative. A strong trend toward neutral or alkaline papermaking has made it possible to utilize large quantities of fine ground or precipitated calcium carbonate as coating pigment. An important benefit is the lifting of coating color solids to the concentration range of 70%. A disadvantage derives from the lower power of calcium carbonate pigment to generate surface gloss. In many cases, a limited amount of clay addition is required for high-carbonate coating formulations in order to achieve the desired levels of paper and ink gloss and to control ink receptivity.

Fine ground calcium carbonate has near spherical particles. A solids content up to 70% in the color is possible. Precipitated calcium carbonate has a rhombic (rice grain-like) crystalline structure, which lowers the attainable solids content. Calcium carbonate pigment facilitates the production of paper products with matte or dull finish, but low scuff resistance can be a quality problem. Precipitated calcium carbonate is used to enhance brightness and as a means for raising ink absorbency.

Coarse grade calcium carbonate often serves a multifunctional purpose. It tends to increase the "toothiness" of the coating because of its large particle size. When used in the base coat, it improves adhesion to the top coating. When coated papers are heavily supercalendered for high smoothness, it will retard gloss development. In addition, it can improve blade runnability by providing a certain blade cleaning action.

Ground calcium carbonate with narrow particle size distribution is a new development, especially for high-quality coated paper grades. The pigment combines high brightness with high opacity. Good holdout on the sheet facilitates improvements in smoothness and gloss. However, the narrow particle size distribution increases the color viscosity at high shear, requiring higher blade pressure. Coatings with this pigment have a fast rate of dewatering and immobilization, which increases even more when the color is diluted for runnability. Formulating coatings with narrow particle size distribution poses a special challenge to the papermaker and requires special binder selection.

Titanium dioxide pigment is used in coatings to increase opacity. The addition of plastic pigments (polystyrene, urea-formaldehyde) will improve gloss and ink receptivity. A recent trend toward high-gloss grades and hot soft roll calendering has led to an increasing use of polystyrene pigment as a component of coating formulations. Special benefits can be derived from the use of hollow sphere pigments. Industrial gypsum has been tried as coating pigment, but the accompanying high level of dissolved calcium ions can affect coating dispersion and viscosity *(9)*.

The flow properties of high solids suspensions can be improved by blending pigments of different size *(10)* and the use of special "engineered" pigments.

Coating Adjuncts

Polymeric phosphate and/or acrylates are required adjuncts for the dispersion of pigments and rheology control. Dyes, color pigments, and optical brighteners are added to achieve the correct shade of white that pleases the customer. Starch, polyvinyl alcohol, and carboxymethyl cellulose act as enhancers for fluorescent brightness development. Some optical brighteners can affect starch viscosity. Excessive use will induce color and decrease brightness again. Most coating formulations contain antifoams or defoamers *(11, 12)*.

The pH can have a great effect on coating color viscosity, especially if alkali-sensitive latex is used as cobinder with starch. Adjustments of pH are frequently made with ammonium hydroxide since its volatility allows a drop in coating pH during drying, which can result in some gain in water resistance. However, volatilization and pH drop may already occur during coating application to paper, especially if the color is circulated hot. In this case, it is advisable to add periodically ammonium hydroxide to maintain the pH at target. If residual alkalinity in the coating is desired to help ink drying, sodium hydroxide can be used, either alone or in combination with ammonium hydroxide. In many cases, ammonium hydroxide and sodium hydroxide are interchangeable. OSHA regulations on exposure to ammonium vapor by the coating operators have led to the preferential use of sodium hydroxide for pH control.

Insolubilizing agents, such as melamine formaldehyde resins, glyoxal, glyoxal-based resins, or AZC, are incorporated in starch-latex coatings to crosslink the starch and improve wet-rub resistance. Some latexes contain functional groups or stabilizing systems, which will also react with insolubilizing agents to even further improve wet-rub resistance. By utilizing latex and insolubilizing agent together, starch coatings with excellent multicolor offset printability can be obtained.

Cellulose derivatives (CMC, HEC), alginates, and polyvinyl alcohol are used as water retention aid, thickener, and rheology modifier *(13)*. Starch grafts with latex, or grafts of protein with latex, have been developed. Such binders could provide a single-component system that combines the film forming and wetting control properties of latex with the water-holding properties of a natural binder. The use of a graft product as a sole coating binder could be useful to eliminate differential binder migration as a cause for print mottle.

Coating Preparation

The selected coating materials must be efficiently blended into the coating formulation. Various methods are available to guide the formulator in the appropriate choice of ingredients *(14-16)*. Modern coating plants utilize a continuous blending operation, drawing from bulk supplies of pigments, binders, and functional additives *(17-19)*. Special attention is required to select the appropriate agitators *(20, 21)* and screens *(22-24)*. Jet cooking is used to disperse starch. The viscosity of a coating color can be affected by the mixing order of components. Various interactions may occur, when dispersed pig-

TABLE 1. Major printing processes

Printing Method	Gravure	Letterpress	Offset Lithography	Flexography	Screen
Principle	Small holes or recessed areas carry ink to the printing area. The surface is the nonprinting area.	Printing area is raised above the surface of the supporting material (metal).	The printed image is developed on a "plate." Plates are made of many materials and sensitized in several ways to produce the printing image.	Printing area is raised above the surface of the supporting material (rubber).	Printing accomplished by a mesh-type element where open areas print and unprinted areas are blocked.
Substrate	Printing stock consists of coated and uncoated paper, paperboard, metallic foils, films, etc., used primarily in publication printing and packaging.	Utilizes coated and uncoated papers and board. Used extensively for newspaper printing.	Prints coated and uncoated papers, paperboard, cloth, plastic foils, etc. Used extensively in commercial printing, magazine publications, label manufacture, etc.	Utilizes coated and uncoated papers, paper-board, films, metal foils, etc. Used extensively in packaging industry.	Can use almost any substrate. Coated and uncoated paper, paperboard, films, metal foils, glass, wood, etc.
Ink	Electrostatic assist systems being used.	Inks dry by oxidation and polymerization. High-speed heat-set inks dry by evaporation on high-speed presses.	Inks dry by oxidation and polymerization. Web presses use heat-set inks.	Inks dry by evaporation and are the low-viscosity solvent type.	Inks vary widely depending on end product desired.
Sheet run	Predominantly roll fed.	Predominantly roll fed but some sheet-fed.	Utilizes roll and sheetfed process — roll fed experiencing greatest growth.	Predominantly roll fed.	Predominantly sheet-fed. Used in advertising and decorative printing.

ment, latex, and starch are blended (25-27). Some of these interactions may be unexpected, such as destabilizing effects by certain defoamers, lubricants, and salts (28). Under certain conditions, there can be rheological shock when starch, polyvinyl alcohol, optical brighteners, and cellulosic thickeners are combined (29). High-speed pilot coaters are often utilized to evaluate the runnability of coating colors and their effect on coated paper properties before using them in commercial practice (30, 31).

DESIGN REQUIREMENTS FOR COATED PAPER GRADES

In formulating a coating for paper or paperboard, the end use for which the product is intended and the equipment available for surface treatment must be considered. The raw materials that can be obtained and the converting equipment that follows coating application will impose certain constraints. When designing the finished product, the anticipated printing methods will be foremost in the coating engineer's mind. By applying a coating to paper, the surface has to become level and uniform to be capable of receiving a detailed printed image that is free of defects. The surface may be matte, dull, or glossy.

Tables 1 and 2 list the basic printing processes and their specific requirements for paper properties. **Table 3** illustrates the quality and value spectrum of coated paper grades. TAPPI's TIP 0108-01 provides a glossary of printing terms and printing defects.

Sheet Offset (Lithography) Printing

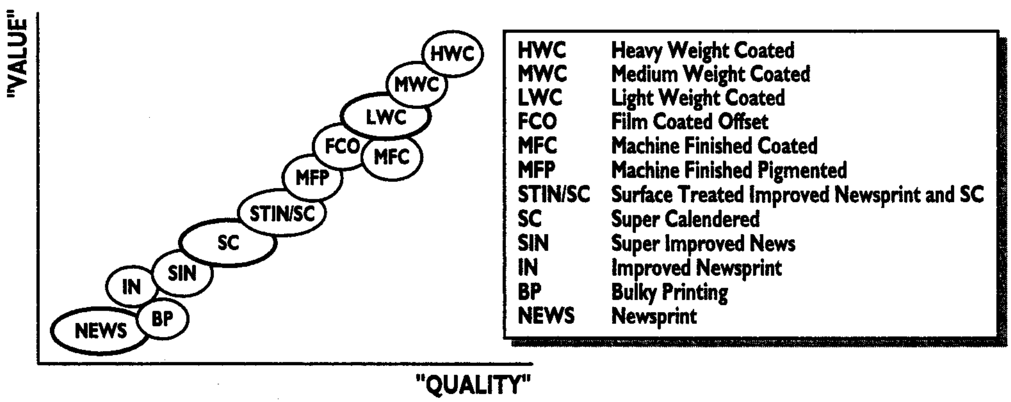
This process uses a metal or synthetic printing plate, a rubber blanket, heavy-bodied inks, and a water fountain. No drying is applied after ink application. The ink dries slowly by oxidation. A coated sheet for this process must exhibit water resistance (surface wet rub strength), internal strength or bond, pick resistance (surface strength), and uniform moisture content. The surface must be capable of accepting fast-setting inks and controlling ink setting without generating a mottled print. Another requirement is

TABLE 2. Paper requirements for printing

Properties	Gravure	Letterpress	Offset Lithography	Flexography
Surface smoothness	V	M	L	M
Surface levelness	V	M	L	L
Surface absorptivity	V	M	M	M
Surface strength	L	M	V	L
Wet rub	O	L	V	L
Sheet resiliency	V	M	O	V
Moisture*	L	M	V	L
Surface abrasiveness	M	M	M	I

* Best results when in balance with press room condition - web offset grades will run lower to reduce blistering tendency.
Importance: V = Very. M = Moderate. L = Little. O = Unimportant.

TABLE 3. Quality and value spectrum of coated paper grades (wood-containing and wood-free)



fast absorption of non-alcohol fountain solution while maintaining the required wet and dry pick resistance.

Web-fed Offset Printing

This printing process utilizes paper in roll form, and both sides are generally printed simultaneously (perfecting press). Web presses run at high speed and utilize a drying oven, which involves flame impingement or drying by medium-to-high velocity air. This printing process requires high internal paper strength, blister resistance, and good folding ability *(32)*. Except for somewhat lower print strength, the same paper product requirements exist as for the sheet-fed offset grades.

Rotogravure Printing

Coated paper is generally supplied in roll form for rotogravure printing. The printing press uses engraved metal rolls to which fluid ink in a solvent vehicle is applied. Excess ink is doctored off, so that only ink in the cups is transferred to the surface of paper during printing. A sheet for this process must exhibit surface smoothness (Sheffield 25-30 maximum), resiliency or cushion effect, and good surface absorbency. Every effort should be made to produce a smooth sheet, even if resiliency must be sacrificed. If the sheet surface is not flat, resiliency must be maintained. Electrostatic assistance on new printing presses is helpful in reducing missing dots in the printed image. Rotogravure is the process of choice for long run, high-quality printing.

Letterpress Printing

Because this process utilizes metal plates with raised letters, it requires relatively low- to medium-tack inks. Paper may be printed as rolls or sheets. General requirements are a smooth flat surface, good ink receptivity, and a cushion effect or resiliency, as well as good sheet and roll mechanical conditions.

Flexographic Printing

Flexography is another process in which the printing image stands up in relief. The inking system consists of an ink trough, a rubber-covered fountain roller, and a screened (Anilox) inking roller into which cells of uniform size and depth are engraved. The ink in the cells is transferred to the surface of the printing cylinder, which carries a soft rubber or photopolymer plate. The image is transferred under light pres-

TABLE 4. Major paper coating systems

Coating Equipment	Speed, ft/min	Coating solids, %	Coat Weight lb/side/ ream (3300 ft²)	Coat Weight g/m² per side	Viscosity, cP
Air knife	150-1500	35-50	4-20	6-30	100-500
Blade coaters[a]					
Puddle	500-4000	50-65	2-8	3-12	500-3000
Inverted blade	500-4000	50-70	2-14	3-21	500-5000
Short dwell	500-4000	50-70	2-14	3-21	500-5000
Rod coaters					
Champflex	150-1500	45-60	2-8	3-12	100-10000
Magnetic	...	45-55	...	...	...
Reverse roll coater	500-2000	45-60	2-20	3-30	1000-12000
Gravure coater	300-1500	50-60	3-15	4-22	500-5000
Transfer roll coater	500-3000[b]	45-60	3-15	4-22	2500-10000
Size press					
Conventional (2 roll)	200-2500[b]	8-15	1-3	2-4	100-500
Gate roll	200-3000	10-50	2-6	4-9	100-5000
Blade or rod metered	(New technology)				

[a] Best operation above 1000 ft/min.
[b] Related to machine speed.

sure. Very fluid inks are used that are mostly solvent-based and dry mainly by evaporation. These are increasingly replaced by water-based inks. This "rubber stamp" printing process is applicable to a wide range of paper and paperboard grades, especially for packaging applications. Paper requirements are similar to those for letterpress printing. Sizing and surface resistance are needed when water-based inks are used.

Non-impact Printing

The most important processes are inkjet printing and electrophotographic printing. In inkjet printing, the image is generated by directing a stream of small droplets or particles in rapid succession to the paper surface. Paper for inkjet printing must be well sized to prevent ink spreading and to maintain dimensional stability, especially when water-based inks are used. Cationic charge in the coating will aid in "freezing" the ink drops on the paper surface. In electrophotography, images are generated by the effect of light on the charge distribution on a photoconductor drum or belt. The charge pattern attracts toner, which is then transferred to paper and fixed by fusion. Paper for electrostatic printing must have controlled conductivity (resistivity) for quality image transfer. Non-impact printing is increasingly used on both uncoated and coated paper grades.

Varnish Application

Coated papers are frequently varnished. Many publishers have installed varnishing units on printing presses to generate improved protection of magazine covers and enhanced aesthetic appeal. Therefore, when considering a coating formulation, the sheet must also varnish satisfactorily after printing and other converting operations.

Barrier Coating Application

The demand for barrier coatings and improved holdout has increased in recent years. In general, a barrier coating is applied to hold a special coating on the surface of the sheet, and, in many cases, must also serve as a "tie-coat." For example, in hot-melt, pressure-sensitive label production, barriers improve the finished product's performance and shelf life. Special barriers are required for solvent holdout of photosensitive papers. The most significant factors are barrier efficiency and economics.

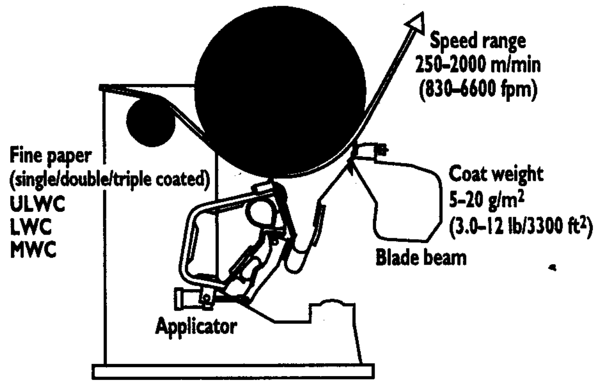
Folding Carton Manufacture

Consumers are looking for products that will have high aesthetic values, reproduce well in the printing process, accept bronze or varnish application, die-cut, and fold into cartons. The products must exhibit good gluing characteristics so that the carton will hold the consumer's product well and remain intact during long periods of shelf life.

COATING APPLICATION METHODS

Major coating application methods in current use are size presses, roll coaters, blade coaters, and airknife coaters. Comprehensive process control is an essential condition for successful coating application *(33, 34)*. In certain cases, temperature control of the coating color or of the entire coating process may be

FIGURE 1. Commercial jet coater with metering blade



required *(35)*. **Table 4** lists the major coating systems and the corresponding coating color requirements. In recent years, the blade coater with jet applicator has been introduced and widely accepted (**Fig. 1**). The coating color requirements are similar to those for the short dwell coater. Successful operation depends on effective removal of entrained air from the color.

TABLE 5. Size press coating formulations

Ingredients	Parts Solids By Weight	Range
Clay, No. 2 or delaminated	100	90-100
Starch, hydroxyethylated	25	0-40
Latex, styrene-butadiene	15	0-35
Curing agent	0	0-1.5
Calcium carbonate, ppt	0	0-5
Titanium dioxide, analase	0	0-10
Sodium alginate	0.2	0-0.5
Calcium stearate/ polyethylene-type lubricant	0.5	0-1.0
Solids, %	33	18-45
pH (NaOH)	8.5	7.5-9.5
Coating weight, g/m²	9-12	4.4-17.8
Viscosity, Brookfield, Model RVT, Spindle No. 3, 100 rpm (60.0°C), cps	250	...

Flooded Size Press Coating

The size press is primarily used for surface sizing of paper with a clear dispersion of starch. Most applications are for offset printing or the new methods of non-impact printing. Depending on the manufacturer, surface size concentrations may range from 2% to 8%. Pearl starch (after enzymatic conversion, pressure cooking, or chemical-thermal conversion), oxidized starch, or hydroxyethylated starch are used as binders. In mills that use southern hardwood fiber, which contains vessel segments, the application of clear surface size serves to prevent picking on the offset press. If the majority of fiber in the substrate consists of northern woods and minimal amount of hardwood with vessel segments, pigmented formulations can be used.

Clear surface sizing is used for the production of printing and writing papers, Xerox® and laser copy papers, envelope grades, wrapping papers, coating basestock, and other commodities. A precoat with starch is used to improve the silicone holdout of release papers. Clear starch applications will range from 1 lb to 3 lb/ream total. A ream defines a paper surface of 3300 ft² (3000 ft² for paperboard) corresponding to 500 sheets, 25 × 38 inches in size.

The flooded size press can also serve as a simple roll coater. Size-press coating colors must have significantly higher binder content than coatings applied by other methods. This increase is necessary because of drainage into the basestock due to low viscosity of the formulation, color dewatering, and the impregnating effect of the size-press nip.

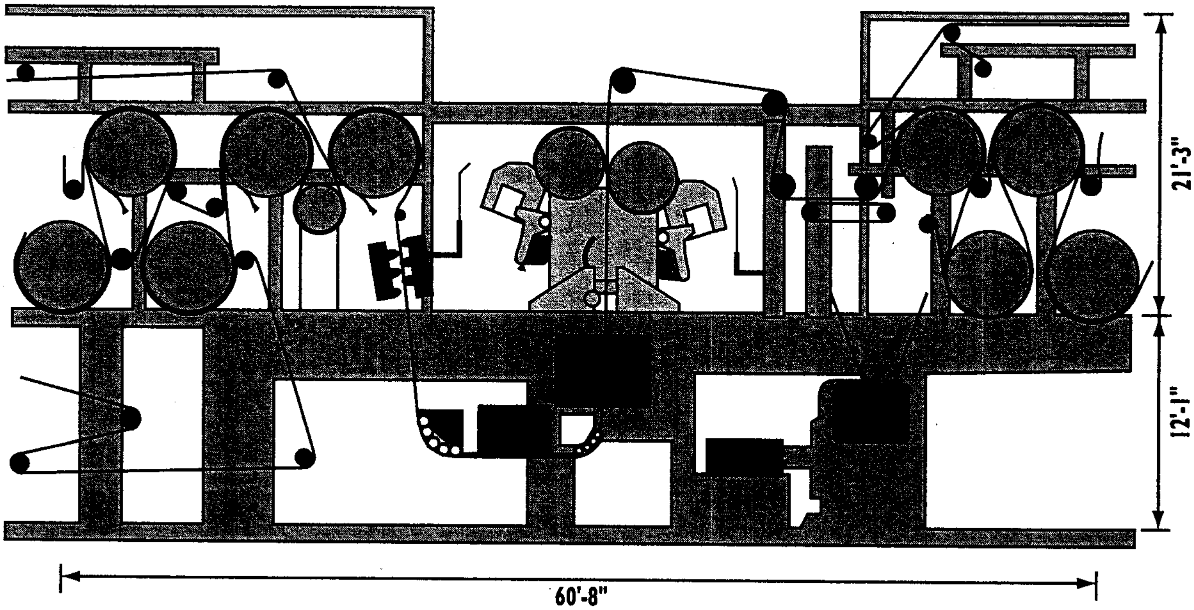
Pigmented sizing is used for the production of higher quality uncoated grades, book papers, inkjet papers, and commodity grades just below the coated level. Size-press coating serves often as a precoat for subsequent on-machine or off-machine coating. In cases such as letterpress, rotogravure, or flexographic printing when the end use of the paper does not require high surface and internal strength, many paper manufacturers will use pigmented surface size.

In general, binder and pigment will be used at pigment to binder ratios from 1:1 to 4:1. Coating color viscosity is usually between 150 cP and 450 cP Brookfield, measured at 60 rpm and at the size-press application temperature of 52-71°C (126-160°F). In many cases, a synthetic binder replaces part of the starch in the formulation. Pigmented applications vary in solids content from 10 to 50%, and the coat weight will range from 2 lb to 6 lb/ream per side. **Table 5** summarizes the formulation range of coatings for use on the flooded size press.

Gate Roll Coating and Metered Size Press Coating

By the addition of gate rolls or short dwell coater heads to the size press, production problems due to

FIGURE 2. Installation of a metered size press in a paper machine



pond splashing and web breaks can be eliminated and runnability improved. The operation principle of the gate roll size press was depicted with Figure 4 in chapter 11. **Figure 2** illustrates the installation of a metered size press in a paper machine.

Both coaters are operated with clear or pigmented colors. Higher solids formulations (up to 55% for gate roll coaters, up to 60% or more for the metered size press) can be applied. Less water needs to be evaporated, which facilitates a substantial increase in production speed. Starch and latexes are used as coating binder *(36)*. Shear stress is higher than on the regular size press; hence, changes in the formulation will be required, especially when synthetic binders are part of the coating formulation. **Table 6** lists pigmented formulations for gate roll coating. There is much activity underway to develop optimal coating formulations for metered size press coaters. New developments are periodically reviewed at TAPPI's biennial metered size press forum and at the PTS coating symposia in Munich, Germany.

TABLE 6. Gate roll coating formulations

Ingredients	Parts Solids Weight
Clay. No. 1 or 2	100-95
Titanium dioxide, anatase	0-5
Starch, hydroxyethylated	75-0
Latex, acetate, styrene-butadiene, regular or alkali sensitive	25-30
Calcium stearate/polyethylene-type lubricant	1
Solids, %	30-55
pH	8.5-9.0
Viscosity, Brookfield, 100 rpm, cps, 48.9°C	400-700
Coating weight, g/m²/side	5.9-6.7
Method of printing	Offset

The new coaters are used as precoaters *(37, 38)* and for the production of a broad spectrum of coated and uncoated grades *(39, 40)*. Starch is frequently used as surface size or coating binder. Some current and future applications are listed below:

- Wood-free paper grades:

  Production of pigmented and standard coated grades (U.S. No. 3)

  Precoating for the production of art coated grades (precoat for double and triple coating)

  Lightly pigmented and surface energy modified papers for high definition digital printing

  Office papers surface sized with hydrophobic additives to improve inkjet printing

  Office papers surface sized with binding agents to improve laser printing and xerography.

- Wood containing paper grades:

  Production of LWC grades for rotogravure printing

  Production of FCO grades for offset printing (MSP, followed by soft nip calender)

  Upgrading of old paper machines for the production of wood-free specialty grades such as carbon-

TABLE 7. Massey roll coating formulations

	Parts Solids By Weight		
Ingredients	**Letterpress**	**Web Offset**	**Sheet Offset**
Clay, No. 1	...	85-100	...
Clay, No. 2	100	...	90-95
Titanium dioxide, anatase	...	0-15	5-10
Starch, enzyme converted	20-25	20-25	20-25
Calcium stearate	...	...	1.0
Ammonium stearate	1.0	1.0	...
Solids, %	34-50	34-50	45-50
PH	8-9	8-9	6-7
Viscosity, Brookfield, Spindle No. 5, 20 rpm, 37.8°C, cps	3500-5000	500-5000	3000-4000
Coating weight g/m²/side	4.4-7.4	4.4-7.4	7.4-14.8

less copy papers (CF-reactive clay or phenolic resin, backside starch)

Base for CB coating (pigmented coating, backside starch)

Label paper (precoat for double coated paper, backside starch)

Gift wrap (precoat for double coated paper, backside starch)

Base for thermal paper (pigmented coating, backside starch)

Release paper (silicon-chromium stearate application, backside starch)

Surface pigmented newsprint to improve heat offset printing for catalogs, inserts, coupons, Sunday magazines, etc.

Packaging papers with barrier coatings to resist penetration by moisture, vapors, oil, or grease

Pigmentation of white top or mottled white linerboard to improve appearance and multicolor flexo printing and to control friction

Linerboard and corrugating medium treated to improve crush resistance and to allow increased use of secondary furnish.

Gate roll coaters are widely utilized in Japan for the production of the lightly coated Bitokishi papers *(41)*.

Recent developments in metered size press technology, and its combination with soft calendering, has made it possible to produce coated paper grades by metered size press coating on modern wide and high-speed paper machines *(42)*. Metered size presses are used on paper machines that are up to 8.5 meters wide and are operated at up to 1800 m/minute. C2S applications require web guidance and drying by contactless means *(43)*.

A special metered size press design utilizes a large metering roll covered by a wound wire (HSM roll). The coating is applied as a puddle in the nip between metering roll and transfer roll (**Fig. 3**). The size of the wire determines the quantity of applied coat weight. The coater is utilized on rebuilt paper machines to produce matte and gloss grades by simultaneous coating application to both sides of the sheet. Coat weights of up to 12 g/m² are obtained with coating colors of 58-62% solids.

Smooth Roll Coating

Numerous varieties of smooth roll coaters exist; examples are the Massey coater, the K-C-Mead coater, and the Champion roll coater. These units consist of a series of contacting hard and soft rolls with the applicator roll generally being soft. Smooth roll coaters will give good fiber coverage and contour coating, but, if coating rheology is not carefully controlled, a pattern can result that will interfere with printing of the product *(44)*. The units are used for the on-machine application of pigmented precoats for subsequent blade coating. Another application is the production of enamel grades with heavy coat weight.

Coating binders may be natural (starch) or synthetic (latex) in varying proportions, and the pigment may be clays, calcium carbonate, titanium dioxide, aluminum hydrate, and various combinations thereof. Total coating solids will range from 45% to 60%, depending on coat weight and the product being manufactured. Precoat must be compatible with the topcoat. Base coating for offset printing has to contain binder in the range of 18% to 20% to assure good surface strength. Precoats for letterpress and rotogravure printing are kept in the 10-14% range.

FIGURE 3. Size press with attached metering rolls

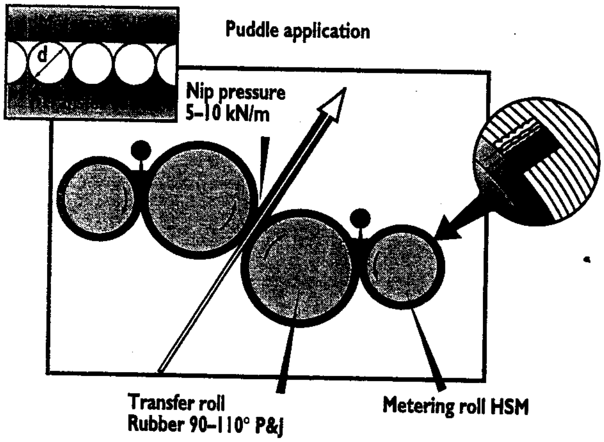


TABLE 8. Billblade coating formulations

Ingredients	Parts Solids By Weight
Clay, No. 1 or 2	60-100
Calcium carbonate, ppt or fine ground	0-40
Starch, hydroxyethylated	6-12
Latex, styrene-butadiene or acetate	6-13
Calcium stearate or polyethylene-type lubricant	1
Curing agent, melamine-formaldehyde or glyoxal	3% on total binder
pH (NH_4OH)	8.5
Solids, %	25-60
Viscosity, Brookfield, cps, 100 rpm, 120°F (49°C)	250-1500 (500-1000)
Coating weight, g/m²/side, maximum	9-12

Waterproofing agents (insolubilizers) are added to the coating if the product is printed by offset. When the roll coat is the final coat, consideration must be given to pigment and binders that will produce a good printing surface (minimize pattern), develop reasonable levels of gloss, and provide appropriate absorbency for the printing process. Coat weights will range from 3 to 15 lb/ream/side (**Table 7**).

Rotogravure Coating

In the rotogravure process, a metal roll with engraved small cups is used as part of a roll coater. This unit can apply a precise coat weight if coating solids, viscosity, and basestock conditions are kept constant. Rotogravure coaters are used for the production of paper grades with high coat weight and good fiber coverage. The cost of the gravure roll and frequent refinishing after abrasion are drawbacks from an economic standpoint. Gravure coaters are used as precoater or as a topcoat applicator at speed ranges from 100 m/min to 500 m/min. Synthetic and natural binders, and combinations thereof, are used in conjunction with conventional pigment systems. Coating solids range from 50% to 65%, and coat weights may vary from 3 to 15 lb/side/ream, depending on the selection of the knurls or lines/inch etched in the gravure roll and the coating solids.

Billblade Coating

By replacing one roll of the size press with a blade, the hybrid Billblade coater is formed. The operating principle of the Billblade coater was depicted with Figure 1 in chapter 12. The basestock passes through a flooded nip between a roll surface and a blade surface. The unit was designed to allow product upgrading and increased coating speed at lower drying demand. Billblade coaters are primarily used for the production of NCR grades. Coating solids and viscosity generally range higher than for a size press. Starch and latex are used as binder. Different colors can be applied simultaneously to the two sides of the web if the appropriate baffling is installed to minimize intermixing. Viscosity can be higher if only the blade side of the coater is used, such as in label manufacture, while the roll side applies a lower viscosity surface size. The lower end of the viscosity range is more desirable when both sides of the coater are to be used with the same formulation; otherwise, an orange peel pattern can develop. **Table 8** shows a range of coating formulations for the Bill-blade coater.

Blade Coating

Blade coaters apply an excess of coating to paper and remove a major part of the color with a scraping blade. In contrast to roll coaters, blade coaters fill in the surface and level it, but at the expense of uniform fiber coverage. They provide a smooth surface for the development of high gloss by supercalendering or hot/soft calendering.

Blade coaters, either on- or off-machine, can be classified as four major types:

- Puddle or trailing blade coaters
- Flooded nip or inverted blade coaters
- Short-dwell coaters
- Fountain or jet coaters.

Principal formulation differences between these classes depend on the viscosity levels at which the coaters operate. In general, the puddle coaters can handle higher viscosity formulations, i.e., up to 15,000 cP (Brookfield, 20 rpm). High viscosity minimizes turbulence and splashing in the pond.

TABLE 9. Generic coating formulations for high-speed blade coating

Components	Publication Web Offset		Publication Roto	Freesheet Web Offset
No. 1 clay	50	...	...	70-75
No. 2 clay	...	75	20	...
Delaminated clay	50	25	80	...
Calcium carbonate (fine ground)	...	...	...	20
Titanium dioxide	...	0-5	...	0-5
Plastic pigment	...	...	...	5-8
Latex	10	8	5-6	12
Starch	8	8	3	3-4
Insolubilizer	0.5	0.5	...	0.5
Lubricant	1	1	1	1
Dispersant	0.2	0.2	0.2	0.2
PH	8.5	8.5	8.5	8.5
Percent solids	58	58-60	58-60	63-68

Inverted-blade units are run at a maximum of about 6000 cP. Short-dwell coaters are operated with lower viscosity colors and sometimes lower solids. Jet coaters also benefit from lower viscosity but allow higher solids levels.

The appropriate coating color viscosity can be obtained for each coater by the choice of ingredients, especially the right starch viscosity. In high-speed blade coating, certain adjustments to the coating recipe are required in order to prevent weeping or whiskering at the blade *(45, 46)*. A frequent cause for paper rejects is scratching at the blade due to entrapment of small particles or excessive dewatering of the coating color.

Contact time between coating application and metering-off the excess can be short (short-dwell coater, low pressure), variable (distance between applicator and blade), or extended (roll applicator, high pressure). Metering blades can be set in the stiff mode (high angle) or the sliding mode (low angle). Alternative metering units are smooth or profiled rods. Blade coating is generally used as topcoat or final coating application. Many paper manufacturing companies use blade coaters for both precoat and topcoat *(47)*. Bitokoshi is a lightly coated paper grade produced in Japan with the short dwell coater *(48)* or the gate roll coater. Recently, triple coating has been commercialized with the use of metered size presses for precoating.

In some cases, metering rods are utilized instead of blades for precoat and/or topcoat applications, especially in the manufacture of paperboard grades. Small rods operate relatively free of scratches, when compared to blade coaters. The pigments and binder systems in the precoat and topcoat must be compatible. If the topcoat uses a solvent vehicle (pressure sensitive labels, etc.), barrier properties to solvent absorption can be obtained while good binding properties are maintained.

Table 9 lists generic coating formulations from the late 1980s for high-speed paper coating. Current trends are a substantial increase in the use of calcium carbonate (fine ground and precipitated) in the pigment fraction in order to increase coating solids, and the utilization of fine pigment blends with specific particle size distributions for high paper gloss. As a consequence, the use of starch in the binder fraction is decreasing to maintain fold strength of the coated product.

Airknife Coating

Airknife coaters are versatile, but they have certain limitations. Coating by airknife has found broad application in the manufacture of coated board, where it is used as a topcoat over a blade precoat, but the reverse is also practiced *(49)*. The online airknife is a contour-type coater that applies coating uniformly as a layer on the paper surface. It does not provide leveling as the blade coater, but it does assure excellent fiber coverage. Operating speeds of on-line airknife coaters range from 50 m/min to 500 m/min. Many of them are utilized in an off-machine position at speeds of about 1200 ft/min. They are operated in a solids range of 35% to 50%, applying coat weights from around 4 lb to 20 lb/side/3300 ft^2. Both synthetic and natural binders are used in the coating formulations, and all coating pigments may be utilized, depending on the end product being manufactured. Due to the low shear stress at the line of application, it is possible to run airknife coaters also with a 100% synthetic binder system

Specialty Coatings

Laminators, waxing units, hot-melt, and pressure-sensitive adhesive applicators, folding and gluing machines, and varnish applicators are used to apply special coatings to paper. Starch is widely utilized on laminators, corrugators, and gluing machines. The special requirements of the applicators have to be considered in the recipes for coating colors.

FINISHING METHODS

After surface sizing or coating, the product has to pass various conversion operations before it can be shipped as a finished product to the customer.

Drying

Careful adjustments of intensity and rate of drying are required in order to obtain a quality product free of mottle defects *(50)*. Various airfoil and infrared heaters are used, and appropriate staging of the drying process is essential *(51-54)*. When starch is used as part or total binder in the coating formulation, nonuniform migration of the starch in conjunction with water evaporation can lead to severe interference with ink receptivity and fountain water dissipation in offset printing *(55)*.

Supercalendering

In order to facilitate surface smoothness and gloss by supercalendering without sticking to the calender rolls, the coatings must contain lubricants and plasticizers as well as the correct quantity of binder. The effects of the number of nips in the calender, nip pressure, temperature, speed (nip residence time), and the material on the soft rolls such as plastic, fiber, or filling material have to be considered in formulating the coating. Latex binders with a low glass transition temperature will be most prone to sticking. The use of starch as co-binder in the coating formulation will reduce sticking.

Hot/Soft Calendering

A new development is the use of high-temperature calenders on the paper machine. Since the sheet enters the calender nips hot, special attention needs to be paid to the thermal sensitivity of the coatings. Although latex binders are preferred for achieving high levels of gloss, starch remains an additive of choice in order to decrease tackiness of the coating in a hot nip. An alkaline pH in the coating color might induce starch discoloration. A careful analysis of the temperature sensitivity of coating colors is required before they are used in high-temperature calendering.

Winding and Trimming

The finished product must be capable of being rewound or trimmed from speeds of 50 m/minute to more than 2000 m/minute. Care should be taken to maintain as low a coat weight as possible to reduce flouring, dusting, or linting on finishing equipment. Special care is required for the conversion of multiple coated sheets with high coat weight, which might have low friction.

COATING FORMULATIONS FOR PAPER

The most important aspect in coating formulation design is to secure attainment of the appropriate rheological characteristics of the color at high rates of shear and elongation. Both synthetic and natural binders are commonly used, and the pigment system may be all clay, all calcium carbonate, or mixtures of the two. Small particle size pigments are utilized to raise paper gloss. Calcined clays, TiO_2, and polystyrene (both hard and soft-shell) are frequently employed as additive pigments. Sometimes pigments and binders will interact, which will affect rheology, dewatering, and performance.

The binder level should be maintained as low as possible, compatible with the end-product requirements, but it also has to produce the desired pick resistance (surface strength). Excessive binder content in the color can have adverse effects on the optical and print properties of the finished product. Synthetic binders are utilized to improve supercalendering. In the production of paperboard (>0.3 mm caliper), different formulations are required for high- and low-speed operations.

Coat weight will range from 2 lb to 10 lb/ream (3.300 ft^2)/side. On absorbent lightweight sheets and board grades without surface sizing or precoating, coat weights up to 14 lb/ream are not uncommon. The speed of commercial blade coaters has steadily increased. For lightweight, coated-two-side (C2S) paper (32 lb-50 lb), blade coater speed may approach 2000 m/min. This development requires adjusting the coating formulations to more severe demands for high shear stability, uniformity of coating holdout, and uniformity of coating drying at fast rate. Formulations for high-speed blade coating are based primarily on latex as the major binder. Starch has maintained a strong position in precoating and as a co-binder in top coating, particularly in the production of publication web offset (LWC) grades. Viscosity and water-holding power are controlled by the addition of cellulose derivatives, alginates, polyacrylates, or polyvinyl alcohol. Various attempts have been made to formulate and apply a cationic coating *(56)*.

Sheet Offset Grades

Formulations for sheet offset grades tend to contain hydroxyethylated starch and to have higher latex levels, higher total binder content, and higher curing agent levels than for web offset grades due to the

TABLE 10. Coating formulations range for sheet offset grades

Coating Ingredients (Parts)	High Starch	Low Starch
Clay, Hi-Brite No. 1 or Fine No. 1	75	20
Calcium carbonate, fine ground or precipitated	25	80
Titanium dioxide	0	10
Synthetic pigment (polystyrene)	0	10
Binder level	12	16
% Starch	25	0
% Latex, primarily SBR	75	100
Thickener, optical brightener	As needed	
Cross-linker (% on binder)	2.5	10
Lubricant	0	1
% solids	58	>58
Coat weight (3300 ft²/side)	7	15

TABLE 11. Coating formulations for enamel and matte grades (from the 1980s)

Ingredient or Grade	Parts Solids By Weight Enamel	Matte
Formulation		
Clay, high brightness	...	90
Clay, No. 1	80	...
Calcium carbonate, ppt or fine ground	15	...
Calcium carbonate, coarse ground	...	5
Titanium dioxide, anatase	5	5
Starch, hydroxyethylated, med. Viscosity	...	9-12
Starch, enzyme conv. or oxidized	4	...
Latex, styrene - butadiene	12	9-12
Calcium stearate	1	...
Glyoxal or	2	3
Mel-formaldehyde	1	2
Solids, %	60-61	60
pH (NH_4OH)	8.5	7-7.5
Properties		
Coating weight g/m²/side	11.8	5.9-7.4
Basis weight, g/m²	118	88.9
Smoothness, Sheffield, 3-in. orifice	30	...
Gloss, 75°	65	10-12
Wax pick no.	>9	...
Brightness	83-84	82
Opacity	94	...
Sizing, internal	Yes	None
Sizing, surface or precoated	Yes	Yes
Grade no.	2	2
Viscosity, Brookfield cps (20 rpm)	15,000-18,000	6000-8000
(100 rpm)	4000-5000	...
Temperature, °C	37.8	26.7

more stringent demands of sheet-fed presses. The basestock is increasingly alkaline sized and filled with calcium carbonate. Current trends toward heavier coat weights and multiple application strive to meet market demands for optical properties, high ink gloss, and good runnability on modern printing presses. The coatings are formulated with high bright, fine pigments, and contain a large quantity of synthetic binder, but must be suitable for high-temperature soft calendering. The formulation has to be designed for runnability at high solids, attainment of high smoothness and gloss targets, and retention of coated paper stiffness. In multicolor offset printing, the coated paper surface has to print without back trap mottle due to uneven ink receptivity. Back trap mottle can be caused when the coated sheet is not dried at an optimal rate, and when the coating is not sufficiently balanced in porosity, surface free energy, and ink trapping. The matte and dull grades achieve their low levels of gloss through choice of pigmentation, machine finishing, or single-nip supercalendering. Matte grades are often not calendered, while the dull grades are lightly supercalendered.

Table 10 illustrates the current range of coating ingredients used in the production of sheet offset grades *(57)*. **Table 11** shows examples of coating formulations for enamel and matte grades from the 1980s.

Quality Web Offset Grades

Web offset coating formulations command the broadest range in coating composition. The grades are classified depending on their brightness and opacity. The average binder level in the coating has been 16 parts on 100 parts pigment with a range of 15 to 20, but is being decreased to 12-16%, due to the increased use of synthetic binders. Hydroxy-ethylated and oxidized starch, as well as enzyme and ammonium persulfate converted cornstarch, is

TABLE 12. Coating formulations range for quality web offset grades

Coating Ingredients (Parts)	High Starch	Low Starch
Clay, No. 1	100	60
Calcium carbonate, fine ground or precipitated	0	25
Titanium dioxide	0	5
Synthetic pigment (polystyrene)	0	10
Binder level	12	16
% starch	50	25
% latex, primarily SBR	50	75
Cross-linker (on binder)	2.5%	10%
Lubricant	0	1
% solids	58	>58
coat weight (lb/3300 ft²/side)	5	10

TABLE 13. Coating formulations range for publication web offset grades (LWC)

Coating Ingredients (Parts)	High Starch	Low Starch
Clay (delaminated)	20	100
Clay, No. 2	80	0
Clay (calcined, structured)	0	10
Titanium dioxide	0	5
Synthetic pigment	0	10
Binder level	10	15
% starch	75	25
% latex (SBR or PVAc)	25	75
Cross-linker (% on binder)	2.5	10
Lubricant	0	2
% solids	up to 57	>57
Coat weight (lb/3300 ft²/side)	4	8

applied. For the higher-quality grades, hydroxyethylated starches are used in combination with synthetic binders. Major synthetic binders are styrene-butadiene or acrylics (75-80%) and polyvinyl acetate (20-25%). Curing (cross-linking) agents are often added to the formulations. Most recipes also contain stearates or polyethylene-type lubricants for coating leveling, which also will act as lubricants and anti-sticking agents during calendering.

Current trends in the manufacturing of web offset grades are governed by an increased consumption of calcium carbonate to provide an alkaline basestock, which also facilitates the increased use of calcium carbonate as a coating pigment. The current market requires more surface smoothness and higher levels of brightness, opacity, and ink gloss. In addition, the formulator has to meet an increasing demand for surface strength, due to the introduction of fast printing presses with more inking stations and the use of non-alcohol fountain solutions.

A wide range of gloss grades is produced, depending on pigmentation and degree of finishing. A new trend is the use of small particle size pigments and pigment blends. The coatings of matte and dull grades contain some coarse pigment, such as ground calcium carbonate, or the grades are just machine finished or single-nip supercalendered to improve levelness without glossing. Some mills are using engraved or etched supercalender rolls to achieve low-gloss finishes, i.e., 25-35% gloss for the dull grades and up to 15% gloss for matte grades.

Table 12 illustrates the range of coating ingredients currently used for the production of quality web offset grades (Nos. 1 through 3) *(57)*.

Publication Web Offset Grades

These commodity grades (Nos. 4 through 6) are produced on fast, wide paper machines, primarily with short dwell coaters. The basestock may contain treated wood or be wood-free. The coating contains increasingly more synthetic binder with thickening agents (at the expense of starch) in order to overcome surface roughness induced by the short dwell coater. In a recent trend, film presses are used to apply the coating, followed by on-machine hot/soft calendering. The current market trend calls for lighter sheets (less fiber, less coat weight), while still maintaining good print opacity and high brightness. The formulator utilizes delaminated clay in order to achieve good surface holdout at low coat weight, calcined or structured clay for opacity, and synthetic pigments to facilitate the development of gloss during calendering. **Table 13** illustrates the range of coating ingredients in currently used formulations for LWC Offset grades *(57)*.

For some coated products, immobilization formulas that are partially destabilized have been developed to affect the rate of dewatering *(58)*. A decrease in the immobilization solids content will lead to improved coating holdout and affect structure and bulk. The rate of coating dewatering on paper can be controlled by adjustments in the quantity of pigment dispersant, the addition of cationically charged polymers such as cationic starch or polyamines, or the use of large and anisometric (platey) pigments. The effect of immobilizing additives can be characterized by dewatering the coating color on unglazed ceramic plates (monitoring for a sudden decrease of gloss or determining the remaining solids by scraping and weighing), by determining the solids content when the viscosity increases rapidly, or by pressure filtra-

TABLE 14. Coating formulations for rotogravure grades (from the 1980s)

Coater	1	2	3	4	5	6	7
				Formulation			
Clay, No. 2	100	50	100	100	...	50	100
Clay, delaminated	...	47-45	...	...	80	50-47	...
Calcium carbonate, ppt	...	...	...	...	20	...	...
Titanium dioxide, anatase	...	3-5	...	...	...	0-3	...
Starch, hydroxyethylated	...	...	...	...	2	13-15	...
Starch, oxidized	14-18	18-24	...	...	...	...	...
Starch, enzyme conv.	...	...	15-16	16-17	...	...	15
Latex, styrene-butadiene or acetate	...	...	...	...	8	2	...
Calcium stearate, PE type	1	1	...	...	0.5	1	1
Solids, %	54-57	50-54	54-56	55-57	60	50-55	...
PH	7.3	7.3	8.0	8.0	...	7.3	8.8-9.2
				Properties			
Coating weight, g/m²/side	7.4-8.9	5.9-6.7	5.9	8.9	11.8	5.9-8.9	7.4-8.9
Basis weight, g/m²	56-66.6	53.3	50-53	56-64	103.6	53-59	53
Smoothness, Sheffield	24-28	<30	...	...	20	<30	...
Gloss, 75°	53-55	50-52	46	48	70	49-53	...
IGT, ink no. to pick	>3	...	3	3	...	...	4
Wax pick no.	...	...	...	...	...	...	7-8
Brightness	70	68	68	69	80	68-70	68
Opacity	90-93	88-89	...	...	93	89-91	...
Porosity, Sheffield	27-34	30-35	...	...	...	27-35	...
Pulp, chemical	...	...	45	45	100	...	...
Pulp, groundwood	~100	~100	55	55	...	~100	...
Grade no.	5.6	5.6	...	...	...	5	...
Method of printing	LP	LP	LP	LP	RG	RG	RG

LP = Web letterpress. RG = rotogravure.

tion *(59)*. Setting a coating on paper by fast immobilization improves fiber coverage and increases coating bulk and porosity but decreases coating strength. Coating immobilization is primarily utilized for the production of LWC offset and gravure printing paper grades.

Rotogravure, Flexo, and Web Letterpress Grades

These primarily wood-containing grades are manufactured for the printing of magazines, inserts, supplements, mail order catalogs, flexible packaging, gift-wrap, etc., and are at the low end of the coated paper grades spectrum (No. 5 and 6). Except for the use of less binder and low or no starch, recent manufacturing trends, marketing trends, and coating formulations for rotogravure grades are similar to those for publication offset grades. In previous practice, predominately enzyme or ammonium persulfate converted cornstarch had been used. Current practice utilizes oxidized starch, hydroxyethylated starch, or dextrins. Cross-linkers are generally not needed. The coating has to be soft and compressive in order to generate the required high level of smoothness for rotogravure or letterpress printing. Delaminated clays are utilized to improve smoothness for rotogravure printability, to improve opacity, and to reduce ink show-through, especially with lightweight magazine papers. The use of thin and mostly solvent-based inks puts little stress on the coating surface. Roto and flexo grades are increasingly printed with water-based inks.

Table 14 illustrates the wide range of commercial coating formulations that have been used in the 1980s for these grades. **Table 15** lists coating ingredients currently used for the production of LWC Roto with short dwell coaters *(57)*. LWC grades are also increasingly produced with metered size presses. **Table 16** displays a representative coating formulation *(60)*.

There has been interest in using cationic starch or other cationic polymers in the recipe of coatings for rotogravure papers *(61)*. Strong ionic interaction will affect pigment dispersion and provides for fast coating immobilization at low solids. An improved structure with increased bulk for fiber coverage and gains in the optical properties can be achieved, albeit

TABLE 15. Coating formulations range for publication gravure grades (LWC)

Coating Ingredients (Parts)	High Starch	Low Starch
Clay delaminated)	20	100
Clay, No. 2	80	0
Clay (calcined, structured)	0	10
Titanium dioxide	0	5
Synthetic pigment	0	10
Binder level	4	8*
% starch	50	0
% latex (SBR or PVAc)	50	100
Cross-linker (% on binder)	None needed	None needed
Lubricant	0	1.5
% solids	Up to 57	>57
Coat weight (lb/3300 ft^2/side)	4	8

TABLE 16. LWC coating formulation for use on the metered size press

Coating Ingredients	Parts
Clay	50
Calcium carbonate	50
Latex	8
Starch (dextrin)	5
% solids	63-64
Coat weight (on 30 lb sheet)	7.5 lb/ream

at a certain loss in coating strength. Producers of LWC paper grades are interested in utilizing this concept.

Label Paper Grades

Label grades of coated paper are generally coated on only one side (C1S). Formulations can vary quite broadly, depending upon the quality required and the method of printing. These grades are often heavily supercalendered and tend to require specialty starches, such as hydroxyethylated grades, and latex in the binder portion to develop a high degree of varnish and gloss ink holdout as well as good water resistance and strength for offset printing. **Table 17** lists representative coating formulations for label grades.

TABLE 17. Coating formulations for label paper grades (from the 1980s)

Ingredients	Parts Solids By Weight Coater 1	Coater 2
Clay, high brightness	...	95
Clay, No. 1 (or high glossing)	100	...
Titanium dioxide, anatase	...	5
Starch, hydroxyethylated	4	2
Latex, styrene-butadiene	14	15
Sodium alginate	...	0.15
Calcium stearate or polyethylene type	1	1
Melamine-formaldehyde	0.5	0.17
Solids, %	62-63	63-64
pH (NH_4OH)	8.0	7.5
Viscosity, Brookfield, cps, 100 rpm	1600-1800	4200-5400
Properties		
Coating weight, g/m^2	10	16
Gloss, 75°	62	68
Brightness	79	84
K&N, % drop	16	23
Method of coating	Blade	Blade
Method of printing	Offset	Offset

COATING FORMULATIONS FOR PAPERBOARD

Coating formulations for paperboard are often different from paper coatings, since they have to cover a more open (porous) substrate. Paperboard may also require a different drying strategy *(62)*.

Foudrinier Board Coating

The coating of paperboard requires a stable basestock surface that does not roughen after coating application due to sheet relaxation and fiber rising. The desired stability is usually obtained by surface sizing the raw stock with starch, followed by water box calendering. The coating colors are formulated with natural and synthetic binders, pigments, and additives. The appropriate viscosity grades of starch are chosen to achieve good coater runnability. Hydroxyethylated starch, protein, and latex binders (PVAc) are used to achieve good fiber coverage, easy finishing, good gloss ink, varnish holdout, glueability, and coating flexibility for carton fabrication (**Table 18**).

Cylinder Board Coating

Binders for cylinder board coating usually consist of specialty starches, such as hydroxyethylated grades, and latex for good gloss development with machine calendering *(63)*. These binders contribute also to ink holdout, good varnishability, and glueability. **Table 19** shows coating formulations. Finishing is usually accomplished by dry methods.

SPECIALTY COATINGS

The advent of non-impact printing has led to the development of new coatings. For inkjet printing, the coating requires pigments with large surface

TABLE 18. Coating formulations for fourdrinier board coating (high and low density)

Raw stock	Parts Solids By Weight Bleached		Unbleached
Formulation			
Clay, No. 1	...	100	...
Clay, No. 2	90	...	70
Titanium dioxide, rutile	...	...	30
Calcium carbonate, coarse ground	10	...	...
Starch, hydroxyethylated	6	8	5
Latex, styrene-butadiene	12	...	15
Latex, acetate	...	...	12
Melamine-formaldehyde or glyoxal	0.8	0.8	0.8
Solids, %	63	61	45
Viscosity, Brookfield, cps	3000	2500	100-300
Spindle	4	4	1
Rpm	20	20	20
pH	7-8	7-8	7.0
Properties			
Coating weight, g/m²	5	10	14-17
Gloss*, 75°	55	...	20
Gloss, varnished, 75°	92	...	...
Brightness	80	...	...
K&N ink, % drop	19	...	...
IGT, ink no. to pick	>5	...	>6
Sizing, internal	Yes	...	...
Sizing, surface, starch	Yes	...	Yes
Method of application	Blade	Blade	Airknife
Comments:	Basecoat	Topcoat	Topcoat
Method of printing	RG and LG		

Gloss calendered, 160°C, 7 N/m.
RG = rotogravure. LG = lithography.

area, which allow fast setting of aqueous ink. Cationic charge aids in dye fixation. Fine silicates, precipitated calcium carbonates, aluminum oxide, and fine clays are used as coating pigments. Starch, frequently cationic grades, polyvinyl alcohol, and certain latexes are used as binders. The small size and high surface area of the pigments are often a restriction to reaching high solids levels in the formulation. The coatings are applied with a flooded size press, the metered size press, or various forms of coaters. The basestock must be sufficiently sized in order to maintain dimensional stability after application of water-based ink.

Coatings for electro-photographic printing require control of surface conductivity in order to accept charge for toner adhesion. The treated paper should have excellent dimensional stability, stiffness, absence of curl, and controlled surface friction. For laser printing, the application of starch-based, clear or pigmented surface size may be sufficient, provided conductivity does not exceed a specific level. For high-quality color printing, general coating formulations may be applied, provided the other conditions, stated above, are also met.

Special starch-based coating formulations are utilized to produce conductive base paper for subsequent solvent-applied zinc oxide or dielectric resin coatings. The conductive coating must serve three principal functions: provide good solvent holdout for the topcoat application, provide the necessary conductive properties to assure good performance during imaging, and provide solvent holdout to prevent unwanted toner deposition on the backside if liquid toners are used. Since various conductive resins are cationic, they have to be added slowly and with good agitation to premixed starch-clay slurry to prevent agglomeration. The mix will initially undergo a rapid viscosity rise and then thin out again as more resin is added. Once the maximum in viscosity is passed, the conductive resin can be added at a more rapid rate. **Table 20** shows coating formulations for conductive paper grades. The base paper for the conductive coating is usually precoated on the size press to achieve sufficient smoothness and

TABLE 19. Coating formulations for cylinder board coating

Ingredients	Parts Solids By Weight	Range
Clay, No. 1	80	...
Titanium dioxide, rutile	20	...
Starch, hydroxyethylated, Medium-low viscosity	4	2-4
Latex, styrene-butadiene or acetate	12	12-18
Polyvinyl alcohol, 125 cps	1	0-1
Melamine-formaldehyde	0.8	...
Solids, %	45-46	...
pH	6-7	...
Viscosity, Brookfield, spindle no. 3, 20 rpm, R.T., cps	400-500	...
Properties		
Coating weight, g/m^2	18.0-19.5	...
Top liner brightness	40	...
Caliper, pts	16-30	...
Brightness	80-81	...
K&N ink, % drop	18-27	...
Wax pick no.	>9	...
IGT, ink no. to pick	>7	...
Glueability, s	25-30	...
Method of coating	Airknife	...
Precoating	None	...
Method of printing	RG or LG	...

RG = rotogravure. LG = lithography.

density in order to provide good holdout for the conductive coating.

TESTING METHODS FOR COATED PAPER

The quality of the final printed product depends greatly on the surface properties of the coated paper or board. TAPPI PRESS has published standardized test methods and TIPS for coated paper analysis.

Coated Paper Testing

At the time of this printing, the following test methods had been approved and published by TAPPI PRESS:

- T 421 om-97 "Qualitative (Including Optical Microscopy) Analysis of Mineral Filler and Mineral Coating of Paper"
- T 460 om-96 "Air Resistance of Paper (Gurley Method)"
- T 523 om-97 "Dynamic Measurement of Water Vapor Transfer Through Sheet Materials"
- T 529 om-88 "Surface pH Measurement of Paper"

TABLE 20. Coating formulations for conductive paper grades

Ingredients	Parts Solids by Weight
Clay, No. 1	40-50
Starch, hydroxyethylated	25-40
Conductive resin	25
Solids, %	40
pH	7-8
Coating weight, g/m^2/side	2.2
Basestock weight, precoated, g/m^2	65.2
Surface electrical resistivity, 10% RH, ohms	8×10^9

- T 458 cm-94 "Surface Wettability of Paper (Angle Of Contact Method)"
- T 558 om-97 "Surface Wettability and Absorbency of Sheeted Materials Using an Automated Contact Angle Tester."

Print Testing

There are different testing requirements for the various printing methods: sheet offset, web offset, rotogravure, letterpress, flexographic, and others. In offset printing, high tack inks are used which stress the paper surface. Fountain water solutions on the printing plate and blanket may soften or weaken the surface. A water-sensitive binder can lead to quality defects such as wet picking of the surface or fouling of the blanket and printing plate (piling). Standard procedures for dry pick and wet pick resistance are based on use of the IGT (or similar testers) and the Prüfbau press. Offset printing can be simulated on various proof presses.

Ideally, the test method has to approximate the printing process as closely as possible and, preferably, slightly exaggerate the severity of the process. Short of a full pressroom trial, it is often preferable to employ a series of test methods in which each approximates a different aspect of the printing process. Both wet and dry procedures are used, since the sensitivity of starch toward water can often affect both wet and dry properties. An important test evaluates the uniformity of ink receptivity or "mottle" *(64)*. Variance is evaluated by image analysis *(65)*. Protocols have been developed to assess the relation between variance in surface receptivity, ink holdout, and print mottle *(66, 67)*.

At the time of this printing, the following test methods had been approved and published by TAPPI PRESS:

- TIP 0108-01 "Definition of Graphic Arts Terms"
- T 526 cm-85 "Blister Resistance of Coated Paper in Heatset Printing"
- T 459 om-93 "Surface Strength of Paper (Wax Pick Test)"
- T 514 cm-92 "Surface Strength of Coated Paperboard."

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