Latex binders and binding techniques for disposable nonwovens

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Latex binders can be tailored for a wide range of end uses by varying the binder formulation or the binder application method.

Disposable nonwoven products are items whose utility is expended after one or a limited number of uses. Disposable nonwoven fabrics became a major factor in the marketplace with the early acceptance of the disposable diaper in the 1960s. Since 1970, the volume of shipments of disposable nonwovens has at least tripled. The growth over the past 15 years is due mostly to the rapid penetration of disposable baby diapers, feminine hygiene products, and medical/surgical products. Though these three categories are large and maturing markets, there are many other established and emerging growth opportunities for disposable nonwovens. These growth areas are fabric softener sheets, premoistened towelettes, incontinence products, industrial and household towels, and AIDS/viral containment products. These and dozens of other emerging applications will undoubtedly increase the production and sale of disposable nonwovens.

Latex binders have been in existence at least as long as modern nonwovens themselves. Some products developed before 1950 are still being used in today's nonwovens. There are those who say that latex binders are an "old" technology, with little application in new nonwoven developments. On the contrary, latex technology has evolved over the years and, in many cases, has provided nonwoven products with a range of performance not previously attainable.

The greatest benefit of latex binders is their overall versatility and utility. By experimenting with latex composition, formulation, binder additives, processing techniques, and binder application methods, the possibilities in end use are unlimited.

Latex binders

The properties of a latex binder are determined by a variety of elements. The most important of these are the composition of the backbone polymer, the glass transition temperature, functionality, reactivity, binder formulation, additives, and the addition of special features for specific applications.

Composition

The first factor used to differentiate among the wide choice of binders available for use in the manufacture of nonwovens is backbone composition. Backbone composition deals with the chemistry of the polymer chain itself. Choice of backbone influences glass transition temperature, which in turn influences the hardness or softness of a given binder, dry tensile strength, hydrophobicity or hydrophilicity, elasticity, and in certain instances, long-term aging characteristics. Some of the more important backbone compositions used in the disposable nonwoven industry are styrene butadiene rubbers, vinyl acetate homopolymers and copolymers, and acrylics.

Styrene butadiene rubber (SBR) is formed when a styrene monomer is polymerized with butadiene. As a nonwoven binder, the styrene promotes hydrophobicity and tensile strength, while butadiene contributes elasticity, resiliency, and toughness. The presence of a residual double bond renders SBR susceptible to oxidation during exposure to heat and light, which often results in yellowing and embrittlement. For this reason, SBR must be protected by an antioxidant. In applications where resistance to discoloration and embrittlement are not critical, the performance of an SBR is often acceptable.

Vinyl acetate is another important monomer used in nonwoven binders. Polyvinyl acetate homopolymer is limited as a binder in disposables because of its stiffness. However, copolymers with ethylene and acrylate monomers are widely used. Both of these monomers serve as internal plasticizers. Vinyl acetate homopolymers and copolymers are best known for their low cost, which is critical in most disposable nonwoven applications.

Polyvinyl chloride is a hard, rigid polymer that must be plasticized or softened before it can be used in a nonwoven. This can be done through copolymerization with ethylene or acrylates or through the use of external plasticizers. The main benefit of chlorine in the polymer is low flame response.

Acrylic binders are the most versatile binders because their properties can be most widely altered. Acrylics range

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from very soft to stiff polymers. This range in softness is a result of compositional variation through monomer selection, and not through modification with an external plasticizer. Acrylates are often copolymerized with nonacrylate monomers for various reasons. For example, acrylates can be copolymerized with styrene for hardness and hydrophobicity, acrylonitrile for solvent resistance and durability, vinylidene chloride for flame retardation, and vinyl acetate for lower cost.

Glass transition temperature

A binder's glass transition temperature, T_g, is the temperature at which a film of the binder ceases to exhibit glassy characteristics and begins to take on rubbery characteristics. The T_g correlates directly with backbone composition. Above the T_g, the polymer is expanded to the extent that molecular motion is possible. This mobility causes the polymer to act as a rubber. Below the T_g, the material acts as a rigid glass. This is illustrated in **Fig. 1**. The point at which the log stiffness begins to decrease correlates to the T_g.

It is generally true that the higher the T_g, the stiffer the hand of the binder. Stiffer binders also tend to have higher dry tensile strength. Manufacturers of disposable nonwovens are constantly trying to develop softer, stronger nonwovens.

Functionality

Functionality refers to the chemistry of the polymer side chain. These side-chain groups give the binder the special features for a given nonwoven end use. Functional groups are added to a polymer by copolymerizing small amounts of special purpose monomers. The primary reason for incorporating functional groups in a nonwoven binder is to resist hostile environments.

Hostile environments include exposure to mechanical stress, heat, and solvents. Carboxyl and amide functionality are incorporated into a polymer to provide sites for crosslinking. In many cases, it is the crosslinking that provides the strength and toughness required in a binder. Carboxyl functionality is typically incorporated by copolymerization with acrylic acid or methacrylic acid. Amide functionality is obtained through copolymerization with acrylamide. The functionality of *n*-methylol amide provides a polymer with self-crosslinking properties. Acrylamide is reacted with formaldehyde to form *n*-methylol acrylamide, which is copolymerized with a suitable acrylic ester to form the final crosslinking latex.

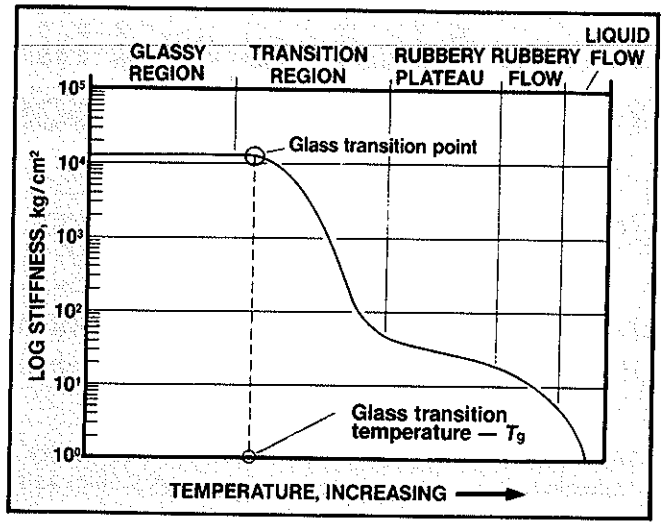
While backbone composition influences dry properties, functionality influences wet and solvent properties.

Reactivity

Latex polymers can also be classified by their reactivity. Reactivity refers to the crosslinkability of the latex. There are four general types: noncrosslinkable polymers, crosslinkable polymers, self-crosslinking polymers, and thermosetting polymers.

Noncrosslinkable polymers are those that do not contain any of the functional groups described previously. Thus, they cannot crosslink with themselves or with added external curing resins. Crosslinkable polymers contain functional groups that will react with an added curing resin but will crosslink to a limited degree with itself. Self-crosslinking polymers, on the other hand, react with themselves and an external curing resin to provide a significant increase in crosslink density. Finally, a thermosetting binder is one with a curing resin already added. Thermosetting binders are capable of generating a high crosslink density on curing.

1. Glass transition temperature exerts a great deal of influence on the stiffness of a resin film. The film is stiff and glass-like when it is at a temperature below its T_g. The film becomes rubbery at temperatures above its T_g.



The most common curing resin used with latex binders is melamine formaldehyde condensate. This chemistry involves reaction of *n*-methylol groups, just as with the conventional self-crosslinking latex polymer. The aim of the curing resin is to increase crosslink density, which improves durability and resistance to deformation.

Formulation

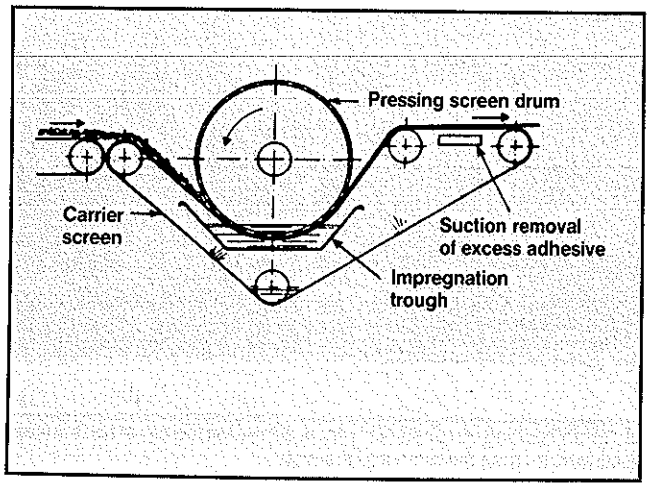
For the most part, binders are not used directly from the drum. Formulating a latex binder involves the use of various ingredients to fine-tune a binder for a particular end use. The most common elements found in a typical latex formulation are, in order of addition to the mix: water, defoamer, wetting agent, crosslinker, latex binder, thickener, and catalyst.

The order in which the formulation ingredients are added is extremely important. Generally, most ingredients are added to the dilution water before introducing the latex. This facilitates visual confirmation that the ingredients have been added correctly. If the latex binder were added first, its opacity would obscure potential incompatibilities. After the binder is added, thickeners are introduced to adjust viscosity. Finally, the catalyst is added just before application to assure stability, and water is added to adjust solids to the desired level.

A small amount of defoamer is normally required, unless the froth-bonding process is to be used. Latexes tend to foam, and a small amount of defoamer is required to prevent this. It is important to minimize the amount of defoamer, since excessive amounts could negatively affect wetout. Of course, foaming is encouraged during froth bonding.

Wetting agents or surfactants are added to enhance wetout (binder penetration of the web), to modify the

2. Single-screen saturator. The web is totally immersed in a binder bath. Excess binder is removed by vacuum.



I. Desirable features that can be obtained through manipulation of binder formulations

Hydrophobicity/hydrophilicity	Flame retardation
Heat sealability	Resiliency
Wash durability	Dry-clean durability
Stability (mechanical or salt)	Low-temperature cure
Formaldehyde free	Abrasion resistance
Heat sealability	Pilling resistance
Tear resistance	Redispersible
Rapid cure	Solvent resistance
Absorbency	Softness
Wettability	Rewettability
Convertibility	Opacity
Bulkiness	Antilinting
Porosity	Resistance to ultraviolet
Charge compatibility	

binder's hydrophobicity, and to increase the chemical stability of the binder bath. Wetting agents can be either anionic or nonionic. Both types are good for wetting such hydrophobic fibers as polyester or polypropylene. Anionic wetting agents are particularly useful for imparting rewetting characteristics to a nonwoven. However, anionic agents tend to foam more than nonionic agents. Nonionic agents promote chemical stability, such as when a adding a cationic fluid repellent to an anionic latex.

Curing resins, or crosslinkers, are added to increase crosslink density, which improves durability and resistance to deformation.

Thickeners are added to nonwoven binders less for their thickening action than for their ability to hold water. This promotes stability of the formulation, prevents drying on the applicator roll, and keeps high-density ingredients such as flame retardants from settling. Thickeners are also used where rheology is important, such as when coating or printing on nonwovens that have already been bonded.

Catalysts are used to facilitate crosslinking at lower temperatures or to decrease curing time at elevated temperatures. Thus, catalysts can facilitate flexibility in processing.

Binder additives

A variety of additives can be used in conjunction with latex binders to further enhance nonwoven fabrics. These additives include pigments, flame retardants, wetting agents, antimicrobial agents, softeners, abrasives, opacifiers, soil retardants, fluid repellents, and antistatic agents.

Fluorocarbons are added to provide fluid-repellent properties. Salts are added to promote flame retardation. Ammonia is used to raise the pH of the binder bath to maximize stability at the applicator roll. Dyes and pigments are frequently added to the binder to color a nonwoven fabric. Fillers can be used to reduce the cost of a binder formulation, but they also detract from other binder properties. Clay can be used in small amounts to inhibit tackiness in soft binders to facilitate fabric unwind during conversion. Optical brighteners are used to enhance the brightness and whiteness of nonwoven products. Lubricants are added to prolong the life of sewing needles during conversion.

Special features

A number of desirable features can be incorporated into a latex polymer and/or a nonwoven web by engineering the binder's backbone composition, functionality, formulation, and reactivity. **Table I** lists many of these features.

Binding techniques for disposable nonwovens

There are four widely used techniques for the latex bonding of disposable nonwovens. The four techniques are saturation bonding, froth bonding, spray bonding, and print/pattern bonding.

Saturation bonding

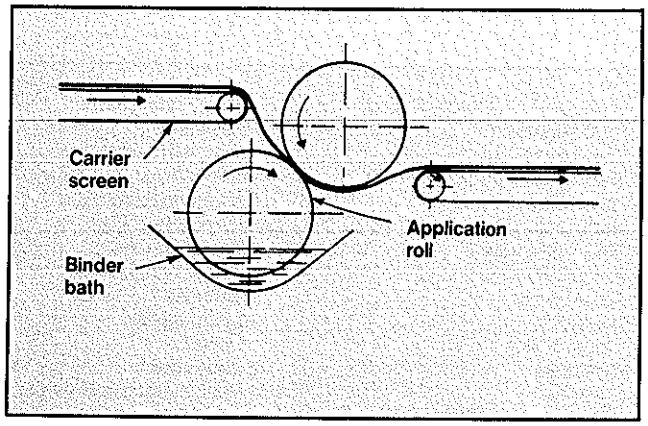
The saturation-bonding method involves nearly complete coverage of the fibers in a web by a latex. This can be done by immersing the web in a binder bath or by transferring the binder from an applicator roll that is immersed in a binder bath.

Figure 2 illustrates a single-screen saturator. The pressing screen drum totally immerses the web in the binder bath. Excess adhesive is removed by either squeeze rolls or by vacuum. The web is supported by a carrier screen when it has insufficient integrity to survive the rigors of total immersion.

Figure 3 illustrates the applicator roll technique. This process, also called the size-press or padding technique, was adapted for nonwovens from high-speed paper saturation. The web does not come into direct contact with the binder bath. Instead, an applicator roll transfers the binder from the bath to the web.

The binder bath is generally low in solids (10–20%) and viscosity. The advantage of saturation is its relative simplicity when compared with other methods. The tensile strength of saturated nonwovens can be controlled by

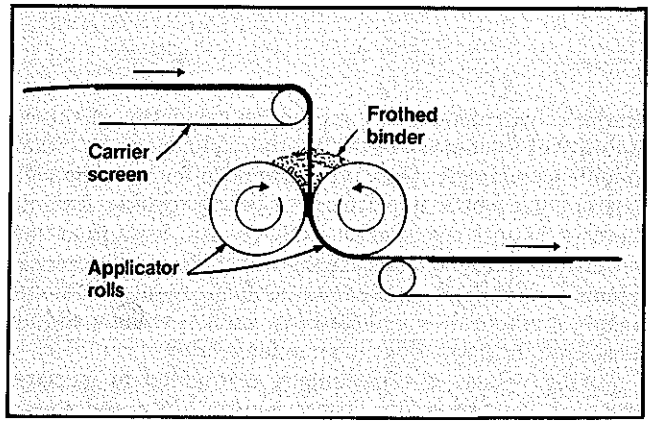
3. Inclined padder. An applicator roll transfers the binder from the bath to the web



4. Saturation-bonded surface (100×)

5. Cross-sectional view of a saturation-bonded web (200×)

6. Froth bonding. An unstable foam is applied at the nip of two squeeze rolls, which crush the foam into the web.



either increasing the amount of binder pickup on the web or by using a binder with a higher T_g. Similarly, softness can be controlled by varying binder amount and T_g.

Figure 4 is a micrograph of the surface of a saturation-bonded web. **Figure 5** is a cross-sectional view of a saturation-bonded web. It is apparent that the fibers are encased in the binder.

The disadvantage of the saturation-bonding process is that the web may have a hand-feel more characteristic of the binder than of the fiber. Another limitation of this process is that the webs cannot be made with any appreciable loft.

Froth bonding

The process of froth bonding is similar to saturation in that it attempts to completely cover the fibers in the web with binder. The major difference here is that the binder bath is partially diluted with air instead of completely diluted with water. Thus, the binder bath is much higher in solids.

Figure 6 illustrates one of many possible ways to froth bond. In this case, an unstable foam is applied at the nip of two squeeze rolls, which crush the foam into the unbonded nonwoven.

The fact that the frothed binder bath is much higher in solids provides some potential advantages. The first obvious advantage is the possibility of using less energy to dry the web, since there is less water to evaporate. The second advantage is that there will be less binder migration. Binder migration is the tendency of the diluted binder to move toward the heat source in the drying process.

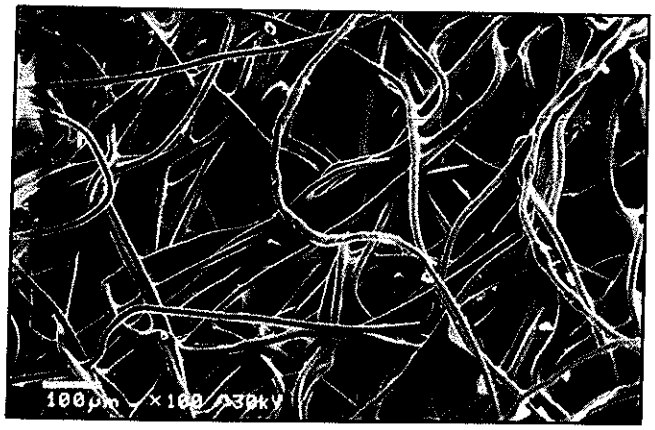
Figure 7 is a micrograph of the surface of a froth-bonded web. **Figure 8** is a cross-sectional view of a froth-bonded web. The surface is similar in appearance to that of the saturated web in Fig. 4. In both cases, the binder has apparently completely encased the fibers in the web. Again, hand and web tensile strength can be varied by varying the amount of binder and T_g. One disadvantage is that the process is more difficult to control and formulate. In addition, some latexes do not readily form a foam.

Spray bonding

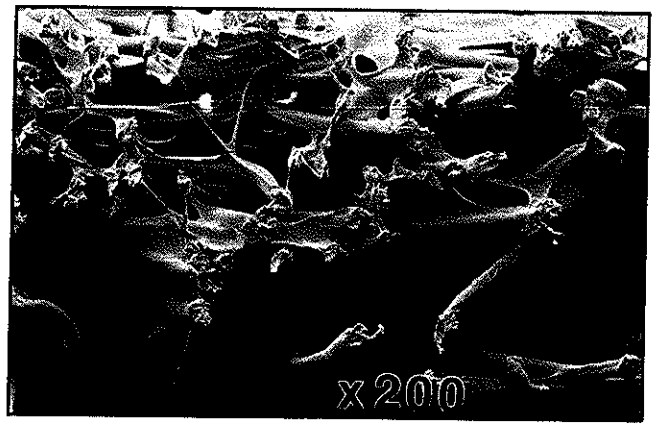
In the spray-bonding process, a dilute latex is sprayed onto a moving nonwoven web. **Figure 9** illustrates a typical spray-bonding system. The nozzles must be engineered so that the binder distribution is uniform. The latex can be atomized by high-pressure air or in an airless system using hydraulic pressure.

The main advantage of spray bonding is the retention of high loft. This is possible because the web is not subjected to the squeeze rolls that are common in other processes. High loft is important in fiber-fill and wipe

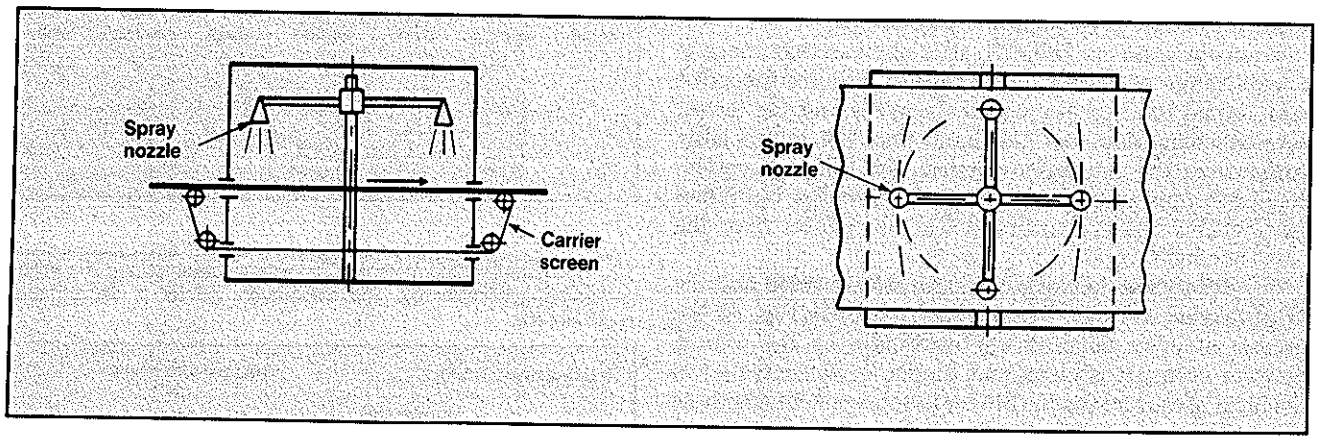
7. Froth-bonded surface (100×)



8. Cross-sectional view of a froth-bonded web (200×)



9. Spray bonding. The side view and the top view illustrate a typical spray chamber with rotating spray nozzles.



applications.

Figure 10 is a micrograph of the surface of a typical spray-bonded web. **Figure 11** is a cross-sectional view of a spray-bonded web. The gross surface coating typical of the saturated and froth-bonded webs is not apparent here. Also, comparing the cross-sectional view of a spray-bonded web in Fig. 11 with that of either the saturation-bonded web in Fig. 5 or the froth-bonded web in Fig. 8 shows clearly the higher loft of the sprayed web.

Print/pattern bonding

Print or pattern bonding can also be described as discrete-area bonding. In this process, high-viscosity, high-solids binder pastes are applied to a web in such a way that they remain in limited areas of the web. Within these domains, the fibers are bound firmly to each other and provide the necessary web strength. The fibers outside these bound areas are free to move relative to each other. This provides the web with a better aesthetic feel or soft hand.

Figure 12 illustrates the typical setup of a print-bonding line. The prewet/prebond section of the process provides the web with enough strength to avoid damage as it passes into the print station. **Figure 13** illustrates two different types of print-bonding equipment, the rotary screen printer and the rotogravure printer. The rotary screen printer is a hollow, perforated applicator roll; the rotogravure printer is an engraved applicator roll. Both methods apply the binder in a discrete pattern as long as the rheology of the binder is formulated to optimize binder transfer and print definition.

Figure 14 is a micrograph of the surface of a typical print-bonded web. The pattern used on this web was a random dot pattern. Clearly, the binder is concentrated in selected areas of the web, and the fibers are free to move in the remainder of the web. **Figure 15** is a cross-sectional view of a print-bonded web. This section shows that the penetration is more than half of the thickness of the web. It also illustrates again the binder concentration at the print point.

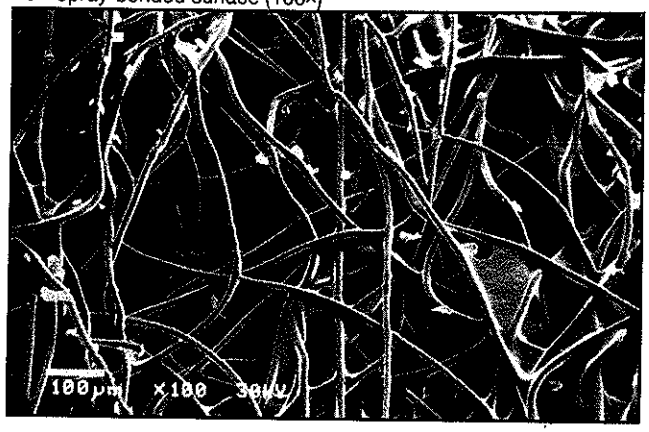
The major advantage of print bonding is its ability to provide both exceptional softness and adequate strength. Strength of the web can be increased even further by using a binder with a higher T_g. Because the binder is limited to the discrete print areas, little softness is sacrificed.

Comparison of binding techniques

To illustrate the relative differences among the four binding techniques, an experiment was conducted. The binder, the fiber/binder ratio, the substrate, and the dry/curing conditions were held constant. The only variable was the resin-bonding technique. Experimental details are provided at the end of this article.

All samples were subjected to tests for wet and dry

10. Spray-bonded surface (100×)



11. Cross-sectional view of a spray-bonded web (200×)

tensile strength, percent elongation, and drapeflex. A panel of six people subjectively evaluated hand. The results of these tests are presented in **Table II.**

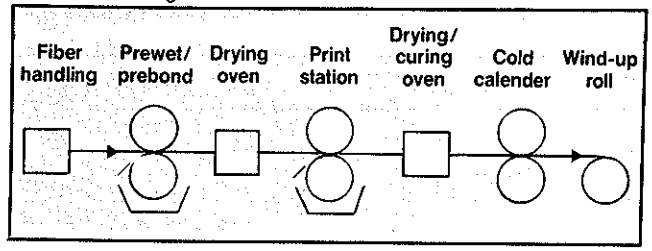
From the data in Table II, it is obvious that there is a wide range of values in the results. The froth-bonded sample had the highest tensile strengths and the lowest percent elongation, but the hand was not appreciably stiffer than the saturation-bonded web. The saturation-bonded sample had the lowest tensile strengths, but it had considerably stiffer hand and less elongation than the print-bonded sample.

The differences between the saturation-bonded and the print-bonded webs are interesting. As seen in Fig. 14, the process of print bonding applies binder on the web in discrete areas. It is clear that binder is concentrated in the print areas and that no binder is apparent outside these areas. The micrograph in Fig. 4 shows a web that was saturated with binder. In this case, the binder is distributed more or less evenly across the entire surface of the substrate. The fibers in the print-bonded substrate are free to move in the areas between the bond points. That is why the print-bonded web is softer than the saturation-bonded web. However, the data in Table II show that the print-bonded web had a higher tensile strength than the saturation-bonded web. This is a surprising result. One would expect that a continuous film of binder would be stronger than a discontinuous film.

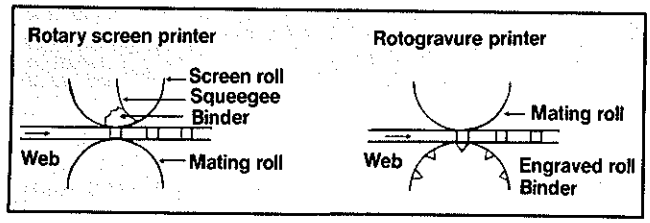
The data in **Table III** illustrate the effect of print bonding with a binder that is much harder. The first binder had a T_g of -14°C. In the second case, everything was held constant except that an acrylic binder with a T_g of +30°C was used. The increase in tensile strength with the harder binder is quite significant, while the sacrifice in hand is not. A comparison of the values in Tables II and III shows that the hand of the web printed with the +30°C T_g binder is still softer than that of any of the other processes. This soft fabric also had the highest tensile strength.

How do we account for the relatively low tensile values recorded for the saturation-bonded web versus those found for the other three processes? The first clue is provided by comparing the micrograph of the saturation-bonded web provided in Fig. 4 with the micrographs of the froth-bonded web in Fig. 7 and the spray-bonded web in Fig. 8. Close inspection shows that there seems to be more binder concentrated at the surface of the saturation-bonded web.

12. Print-bonding line



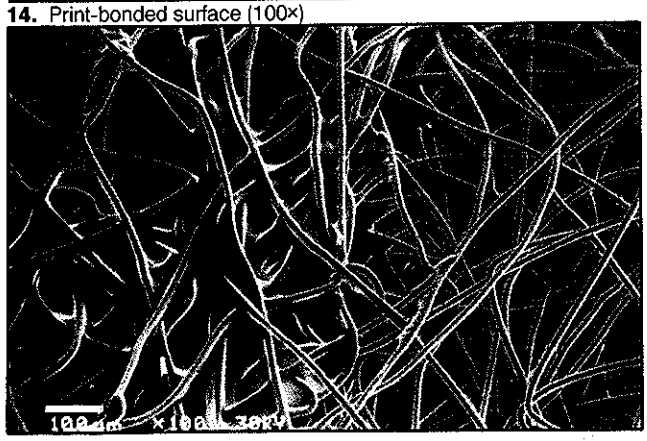
13. Two print-bonding methods. The rotary screen printer is a hollow, perforated applicator roll. The rotogravure printer is an engraved applicator roll.



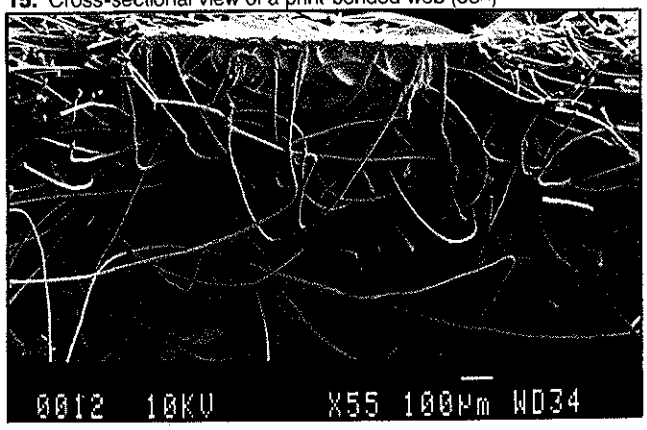
A cross-sectional micrograph of each web was taken to determine the distribution of the binder through the thickness of the webs. Comparing the micrographs in Figs. 5, 8, 11, and 15 shows clearly that the binder in the saturation-bonded web is much more heavily concentrated at the surface of the web than in any of the other webs. The spray-bonded web also appears to have an area in the center of the web that is low in binder, though it is not as obvious as the saturation-bonded web. The cross-sections of the froth-bonded and print-bonded webs exhibit no such tendencies. Thus, it appears that the lower strength of the saturation-bonded web is likely the result of binder migration.

Binder migration is the tendency of the diluted binder to move toward the heat source in the drying process. The bath used in the saturation process is much more dilute (8% binder solids) than the in the spray-, froth-, or print-bonding processes (15%, 28%, and 41.5% binder solids, respectively). The lower the binder solids, the greater is the tendency for the binder to migrate toward a heat source. This migration is driven by the water that is evaporated during the drying stage. Reducing the amount

14. Print-bonded surface (100×)



15. Cross-sectional view of a print-bonded web (55×)



II. Effect of application method on performance[a]

Method	Dry CD tensile strength,[b] g/cm	Wet CD tensile strength,[c] g/cm	Stretch,[d] %	MD Drapeflex,[e] mm	Hand[f]
Saturation	401	252	74.9	80	4
Froth[g]	491	389	65.2	77	4.5
Spray	440	315	73.6	69	3
Print	441	301	112.9	51	1

[a]All formulated with 1.5% NH_4NO_3 and 0.5% Triton X-14 S/S; webs dried and cured at 150°C for 4 min.
[b]Intellect 500, 30.5 cm/min, 5.1-cm jaw gap.
[c]0.5% Aerosol OT™ brushed on mounted strip. Intellect 500, 30.5 cm/min, 5.1-cm jaw gap.
[d](Δ L/L) X 100.
[e]FRL™ cantilever bending tester; low numbers are softer.
[f]Subjective hand panel; 1 = softest, 5 = stiffest.
[g]Binder whipped in Kitchen Aid mixer at indicated solids; density approximately 0.04; frothed binder applied to the supported web at the nip.

of migration would undoubtedly increase the tensile strength of the saturation-bonded web.

Summary

This article examines the major elements of latex binders for disposable nonwovens. The most important of these are the composition of the backbone polymer, the glass transition temperature (T_g), functionality, reactivity, binder formulation, additives, and the addition of special features for specific applications.

Backbone composition deals with the chemistry of the polymer chain itself and greatly influences dry nonwoven properties. Choices in composition include styrene butadiene rubbers, vinyl acetate homopolymers and copolymers, and acrylics. The T_g relates directly to backbone composition and is a measure of how hard or soft the polymer is. Functionality refers to the side-chain chemistry and influences a nonwoven's wet and solvent properties. Reactivity refers to the crosslinkability of the latex, which is an indication of the latex's durability and resistance to deformation. Formulating binders is the art of fine-tuning a binder for a particular end use. It is rare that a binder is used without some amount of formulation. Special features of binders are developed by manipulating the composition, functionality, reactivity, and formulation, to attain a specific desired property. Finally, binder additives are used to attain a specific property for a given end use.

Four major bonding technologies—saturation, froth, spray, and print/pattern—are also examined. Saturation bonding involves immersing a web in a binder bath in an attempt to completely cover each individual fiber with binder. Froth bonding is similar to saturation bonding except that the binder is diluted with air and not water. The resultant unstable foam is crushed into the web and nearly covers each individual fiber. In spray bonding, a dilute latex is sprayed onto a moving nonwoven web. This process is especially good for high-loft products. Print bonding is the process of applying binder on discrete areas of the web. This provides a fabric with a softer feel while maintaining adequate strength. Experimental data and microscopy were used to illustrate the wide range of properties possible by varying nothing other than the bonding process. Each process has advantages that make it particularly suitable in specific end uses.

III. Print bonding at two glass-transition temperatures

Binder T_g,[a] °C	Dry CD tensile strength,[b] g/cm	Wet CD tensile strength,[c] g/cm	Stretch,[d] %	MD Drapeflex,[e] mm	Hand[f]
−14	441	301	112.9	51	1.0
+30	597	551	46.9	67	2.7

[a]All formulated with 1.5% NH_4NO_3 and 0.5% Triton X-14 S/S; webs dried and cured at 150°C for 4 min.
[b]Intellect 500, 30.5 cm/min, 5.1-cm jaw gap.
[c]0.5% Aerosol OT brushed on mounted strip. Intellect 500, 30.5 cm/min, 5.1-cm jaw gap.
[d](Δ L/L) X 100.
[e]FRL cantilever bending tester; low numbers are softer.
[f]Subjective hand panel; 1 = softest, 5 = stiffest.
[g]Binder whipped in Kitchen Aid mixer at indicated solids; density approximately 0.04; frothed binder applied to the supported web at the nip.

There are many possible latex binder formulations and a wide range of properties that can be obtained simply by varying the bonding process. Latex bonding clearly offers utility and flexibility for the manufacturer of nonwoven disposables.

Experimental

The binder, the fiber/binder ratio, the substrate, and the dry/curing conditions were held constant. The only variable was the resin-bonding technique. The binder used was a typical acrylic with a T_g of −14°C. The fiber/binder ratio was held constant at 70 parts fiber to 30 parts binder, or roughly a 43% add-on level. The substrate used was a 1-oz/yard² lightly prebonded polyester web. All of the samples were dried/cured at 150°C for 4 min.

Saturation bonding was performed using a Birch Brothers padder at a pressure of 32 lb. The binder bath contained 8% solids.

A 200-g froth formulation (density 0.038) was whipped at full speed in a Kitchen Aid for 30 s. The froth was applied to the web on a Birch Brothers padder at a pressure of 25 lb. The froth bath contained 28% solids.

Print bonding was performed in one pass on a laboratory magnetic printing machine using a heavy rod. The bath contained 41.5% solids.

Spray bonding was performed using spray nozzles at 100 lb pressure. One side of the sample was sprayed and dried for 1 min at 150°C. The other side of the sample was sprayed and dried for 3 min at 150°C. The spray bath contained 15% solids.

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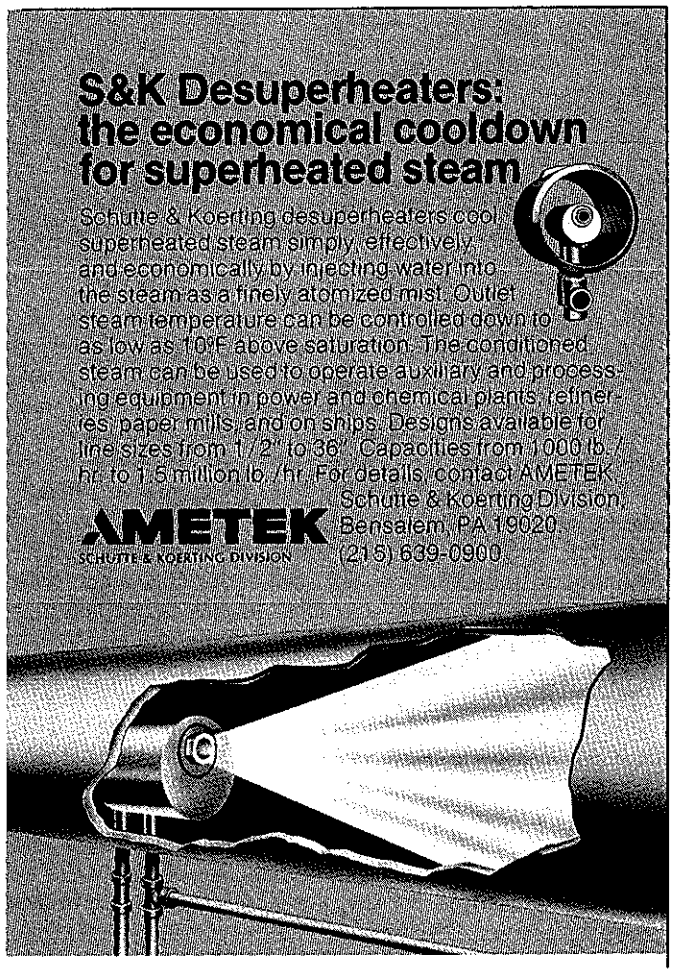

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