

Thermal bonding utilizing calenders

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ABSTRACT: *Rapid change in the nonwovens industry has made the products and technology of five years ago unacceptable for use today. A variety of features are now available in calenders used for thermal bonding.*

KEYWORDS: *Bonding, calenders, fabric, nonwovens, paper-making equipment, thermobonding.*

It is important to determine intent in using a calender for thermal bonding. It is neither necessary nor practical to purchase a calender with a full range of capacities when a specific machine will produce the desired end result.

Early in my calendering career, I overheard a remark stated by a fiber producer which I believe reflects a true seeded feeling: "He [the fiber producer] creates a near perfect product, and the nonwoven manufacturers proceed to destroy it." In many situations, the fiber producer is correct. But with each passing year and each new installation, this is becoming less often the case. Today equipment is being manufactured to accommodate the fiber and webs; we are less likely to improvise techniques to utilize existing equipment.

In most instances in the United States, nonwoven installations evolved from an existing paper or textile basis, and the majority of the plants converted or evolved traditional paper and textile calenders to produce a nonwoven web. The ma-

chinery was there, the American machinery manufacturer was willing, and Yankee ingenuity was the rule. Meanwhile, in Europe the same excess capacity did not exist, and when the market acceptability for nonwovens arose, the then-current state of the art was employed to install specific machinery to manufacture these nonwovens.

The complete acceptability of nonwovens in the workplace, building sites, hospitals, and virtually all areas of our life has emerged. We have progressed to the point where the nonwovens consumer will no longer accept the same product that was satisfactory and in short supply only five years ago. Now nonwoven hospital gowns must feel like and look like woven cotton gowns—and they do!

With the growth in the number of nonwovens manufacturers, no longer is "quantity at an acceptable price" the total consideration. Now the consumer wants quality and consistency of performance as well.

As in the textile and paper industries, the American nonwovens manufacturing worker outproduces his European counterpart. For this reason, I don't believe the nonwovens technology of the 1950s, 1960s, 1970s, and 1980s will satisfy the market demands of quantity and quality of the 1990s.

Basic parameters of calender function

In many situations, it is possible to achieve multiple objectives in a single calender with the proper selections of mechanical features. **Table I** lists eight objectives in calendering a nonwoven.

Three basic parameters control the function of a calender: temperature, pressure, and speed. Heat is present in all calender nips, whether induced intentionally or by mechanical interaction of the rolls and the web. Pressure refers to the force with which the calender rolls are loaded together against the web. Speed, also referred to as "dwell time" or "exposure time," is the rate at which the fabric is passed through the nip in the presence of heat and pressure.

In the case of all of these parameters, there exists a point of "diminishing returns," and with each the necessary but minimal level should be used to achieve the desired end result. In many instances, an existing calender may not have the temperature capacity required to produce a given web. With the increase of pressure (to a point) or the

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I. Objectives in calendering a nonwoven

Caliper	To achieve a particular thickness in a substrate.
Density	To achieve a level of compaction and specific weight per area in a substrate.
Strength	To achieve increased strength in the length and width as well as through the web.
Bonding	To bind one or more fibers, filaments, or webs to one another.
Permeability	To achieve a desired level of porosity or permeability in a substrate.
Surface Finish	To alter or affix a desired effect on the surface of a substrate.
Esthetics	To impart an improvement in the appearance of a substrate.
Hand or Drape	To relax or equalize the web construction.

slowing of the speed, the efficiency of heat transfer may be enhanced to the extent required to produce the web.

The ideal specification for a calender to produce a thermally calendered web would include the following requirements.

Temperature

First, employ a system that will adequately supply the necessary Btu/h and efficiently transfer the heat to the web.

Pressure

Next, employ a system that satisfies the pressure requirement of the web, not that of the mechanics of the calender. As a rule, cotton, other natural fibers, and cellulosic synthetics respond to pressure, while thermoplastic fibers are best processed with the proper transfer of Btu. Pressure in a calender roll stack, whether 2 or 16 rolls in a horizontal or vertical pattern or any variation thereof, is the most difficult to control or change. With proper study, the appropriate pressure capability range can be specified and the appropriate calender used. If your product requires loftiness, bulk, or softness, these webs without exception only require a 75–250 pli loading pressure. Pressure beyond these levels

is definitely an adversary. One should use just enough pressure to contain the web while having an impact on the best heat transfer to achieve the bonding required.

With most thermally bonded nonwoven webs, roll crown, regardless of how imparted, is detrimental to the web and must be minimized. As a rule of thumb, typical textile webs tolerate 0.0003 in. crown on diameter; paper and spunbondeds (texturized) tolerate to 0.0002 in.; and lightweight nonwoven webs 0.0001 in. on the diameter of the calender roll face. Crown beyond these levels becomes a calender maintenance and product quality problem.

Speed

Finally, employ a system that can supply the maximum speed for the lb/h throughput capacity of your calender and the ability to regulate the rate (dwell time) of the web through the nip. Avoid the use of prewrapping of rolls, drums, or ovens which approach the melt point of these fibers while the web is not under positive control (in a nip). Also, never push the web through the calender. Always pull the web. In a multiple roll nip, the last roll the web touches must be the master driven roll.

Secondary parameters

In addition to the primary parameters, many secondary parameters of operation exist.

Roll diameters

As diameters of two alike rolls increase, the width of the nip increases (more dwell time); the rate of effect of dwell time with two dissimilar rolls will vary according to the roll's material, diameter, hardness, and reaction to pressure.

Type of roll

Another secondary parameter to consider is the type of roll used. Rolls can be steel or some type of resilient material.

Steel rolls. Various types of steel rolls are available:

1. Forged steel roll. A forged steel roll with a bore to accept various heating systems and all load ranges may reach 3000 pli.
2. Can or drum roll. A can or drum roll, heated with water, steam, or hot oil, is normally used with low pressure such as blanket or screen wrapped.
3. Double shell drum roll. A double shell drum roll has an inner body to permit passage of thermal fluid at the inside diameter of the thin outer shell (0.5–1 in.). It is used in low pli, high Btu/h applications.
4. Double shell roll. This type of roll has an inner forged steel body to permit passage of thermal fluid at the inside diameter of the thick (2–4 in.) outer shell. Grooves may be machined in the inner body, which can afford structural support to the outer shell. Precision welded spirals can also be used on the inner body for lower cost but afford no outer shell support. This design is employed in the instance of heavier pli loading and in some cases to reduce roll deflection for longer face lengths.

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5. Chambered or chilled iron rolls. After going through the bearing journals, the bore of these rolls opens into large ID chambers under the face of the rolls. These rolls can be severely damaged with quick temperature change. Because of their expense and weight, they are generally not practical for thermal bonding nonwoven applications.
6. Multiple drilled steel rolls. These are solid steel mandrel drilled in a pattern to permit passage of a thermal fluid. These rolls, while acceptable for roll bending or skewing, do have limitations in providing Btu/h to the nip when compared to a double shelled steel roll.
7. Variable crown rolls. Here the outer steel shell passes over internal hydraulic rams which are individually controlled to achieve equal loading across the face. This roll does not lend itself to thermal bonding of nonwovens because it is difficult to heat, if at all, above 200°F. Also, the ideal load range for this roll begins at two to three times the typical 75–250 pli required by thermal bonded nonwovens. It could be used on the texturing of spunbondeds, but a typical spunbonded does not require frequent pli changes. Once the pressure specification is set, there is no need to vary this pressure across the nip.

You cannot correct gauge, caliper, or density by varying pli across the nip, except in some cases involving paper or natural cellulose pulp webs which react to pressure. Concurrently, these more and less dense areas can affect the acceptability of the web produced.

Resilient rolls. Various types of resilient rolls are available.

1. Fiber filled rolls. These are commonly referred to as calender bowls. These rolls are made in hydraulic presses which have load-

ing pressures to 7 million psi of pressure in order to compact them to the required density to utilize them as calender bowls (hardness range 75–90 Shore “D”). There are various types of calender roll fillings available, but all calender rolls are very similar in construction.

Some general thoughts when considering what filler to use in a calender roll: The harder the roll, the less resilient it is. That is, its ability to take a deformation from a seam or a web imperfection and then recover is affected by its hardness. On the other hand, while the roll may be less resilient, a harder roll is more resistant to burn because of its increased density, and in many cases, it is far more durable.

Generally speaking, the longer the fiber used in roll filling, the smaller the micronaire or diameter of the fiber. Therefore, smaller diameter fibers can be compacted into a more dense filler. This, of course, takes advantage of the inner-fiber cohesion of these fibers and therefore gives greater strength, heat resistance, and durability to a filled roll.

The most glaze is normally obtained when 100% cotton fibers are used in a filled roll.

Another fiber utilized is wool. Wool rolls at the same hardness as cotton rolls are more resilient but less strong. A normal rule of thumb is that wool kills finish because of the natural scales which are found on wool fibers. Many times it is found that these wool scales will pick or be abrasive to synthetic staple or filament yarns. They will most certainly dull the web face, which may be advantageous for some thermally bonded nonwovens.

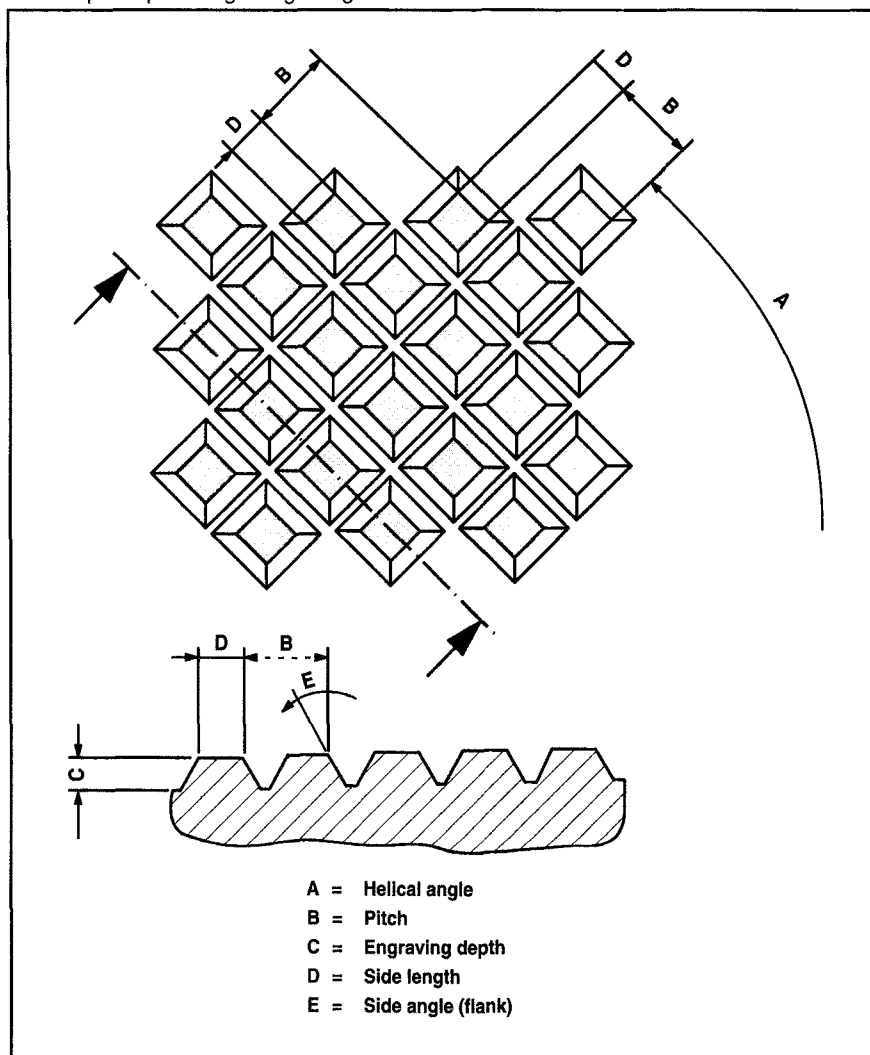
The next type of filler used is a paper type. This filling can be a wool felt paper, which is normally

used in embossing calenders because the short wool fibers are easily broken and will retain the pattern that is pressed into the paper by the top engraved roll. Paper type filled rolls are not as strong as fiber filled rolls, but many times these types of fillers are all that is required in an operation. Because of their resiliency, these rolls are also utilized in texturizing nips, which afford the flexing of the web, yielding enhanced drape and softness.

2. Nylon shell rolls. Nylon shell rolls are an alternate choice for a resilient roll, but in many cases they should be considered as a last choice because they are the most expensive to buy and maintain. It must also be said that in spite of today's modern manufacturing techniques, nylon shells are, at best, unpredictable. Generally speaking, one must always stay within the following parameters: less than 350°F at 30 yards/min and 1000 pli. Variable crown nylon shell rolls are said to permit operation at various tons of pressure, but generally this is not a daily production requirement. A nylon shell's greatest advantage over other resilient rolls is its quicker resiliency at low pressures and temperature, and not its variable crown flexing feature.

As nylon shells are heated, they expand at various levels across the face of the shell (the shell should never be exposed directly to temperatures above 212°F). This results in high (hot) and low (cold) areas transferred to the web or overbond (high) and no bond (low) in these areas. This problem can be overcome by exerting more pli on the nylon shell. Normally 750 pli minimum is required to level the shell and obtain an equal nip across the face for the complete circumference of the roll. This level is excessive for most thermal bonded nonwovens.

1. Example of point engraving design



3. Rubber or silicone shells. These rolls are also utilized, but as with the nylon shell rolls, there are even lower limitations. All of these resilient shell rolls displace in the presence of nip pressure, unlike the filled rolls, which densify. The fuse point of many fibers is the same as many of these synthetic shells.

The use of synthetic fibers for filled fiber rolls has been under investigation since the early 1960s. The problem remains, however, of the lack of interfiber cohesion which allows the stability of the roll in maintaining a given shape.

Engraved patterns

Engraved patterns is the next secondary parameter to be discussed. While the ideal pattern is claimed to be held by many, it is my opinion this thought is the unicorn of our industry. A major fiber company spent in excess of US\$ 2 million to develop such a pattern, i.e., a pattern which in a single pass contacted and bonded the most fibers to one another. At the end of the program, the conclusion was that while the pattern was unique, it was not better than the many squares, diamonds, and dots long available to the vinyl coating industry. In most instances, when it is stated that a certain pattern is "best," the refer-

ence is to its market acceptability more than the superior bonding achieved. I have found that a pattern of 16–20% land area at the proper depth (thickness of web), used with properly specified calender features, always performs successfully. (The finish tolerances of concentricity and cylindricity should be 0.0002 in.)

It is also necessary to decide whether to use the pattern in a random or a sequence method. When one is using a random or "wild" pattern, the entire effect must come from the engraved roll. When using a sequence or "geared" method, a registered effect is imparted to the web from both the engraved roll as well as the backup roll.

Point-to-point bonding uses two matched engraved steel rolls or two opposing pattern engraved rolls which form a figure on the web as it passes between the rolls. When using these methods, consideration must be given to how to sequence the drive of these rolls. Gearing is acceptable for heavy or coarse nonwovens, but "cogging" will likely appear on the lighter, more sophisticated webs. The lighter webs (less than 2 oz/yd) require a roll-to-roll drive, with the slave roll being driven from the master engraved roll through an overriding directional clutch. Of course, each roll could be driven individually, but the speed of the rolls must be matched. This equipment can be expensive to purchase and maintain, and the accommodation for web variances is constant. **Figure 1** illustrates the various aspects of point engraving design.

When addressing roll configurations and combinations in a calender, always establish firm objectives for using a calender. Let the web or product dictate to you what is required. Too many nonwoven producers spend too much money making something work just because it worked for a competitor. In this industry, the technology of fibers and equipment is changing so rapidly

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that if you are doing it the way it was done five years ago, you are probably doing it wrong.

For the lack of ability to get the Btu/h into the nip, much money has been spent on preheating drums, infrared ovens, tenter frames, and exotic tension controls. The web should only be exposed to fusing temperatures while it is under positive control.

Web tension

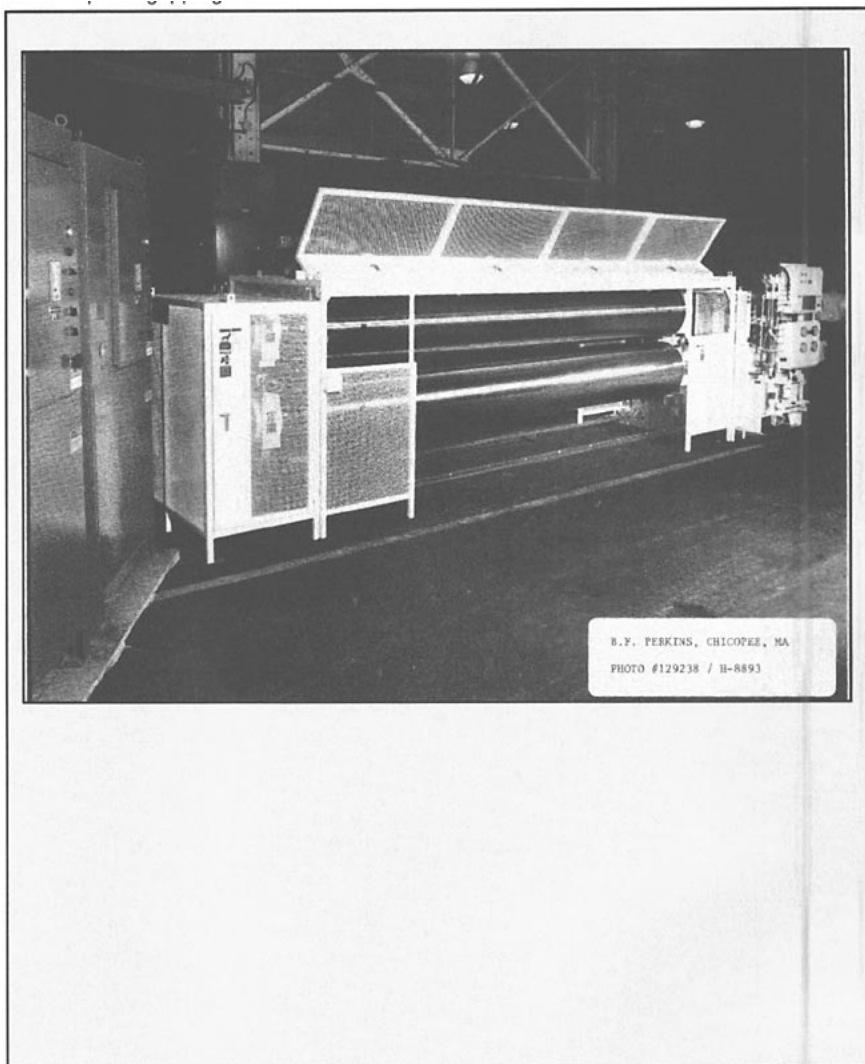
Web tension is another secondary parameter. A calendering nip, when properly designed, performs best and most consistently when the web is presented flat, level, and near-tensionless to the nip. Where the web passes through more than one nip, consideration must be given to web extension or elongation and how each subsequent nip can consume this longer web. Steel vs. steel roll nips, while producing the greatest web extension, have the least ability to consume this extension. Filled rolls create the least web extension and have the greatest ability to absorb the elongation.

A closely related parameter is that of web orientation relative to the calender nip. This problem is more prevalent in the calenders and web width of 40 in. or greater and in lightweight, low structurally fortified webs. An example would be a carded web which may sag concave to the floor while being presented to a calender nip which is convex relative to the level of the floor. This problem may be overcome by the use of bow rolls, expanders, or tensioners, but the problem could be arrested by using a horizontal nip which allows for the fabric to drop evenly and tension-free through the nip, vertical to the floor.

Moisture

Moisture is also a secondary parameter. All webs run best when at or near their standard regain level. This moisture amount always should be very even across the width and

2. Example of gapping of two steel rolls



length of a web. Uneven moisture, whether it be water, antistat, or a fiber lubricant, can cause unequal Btu consumption and will result in unequal bonding.

Thermal crowning

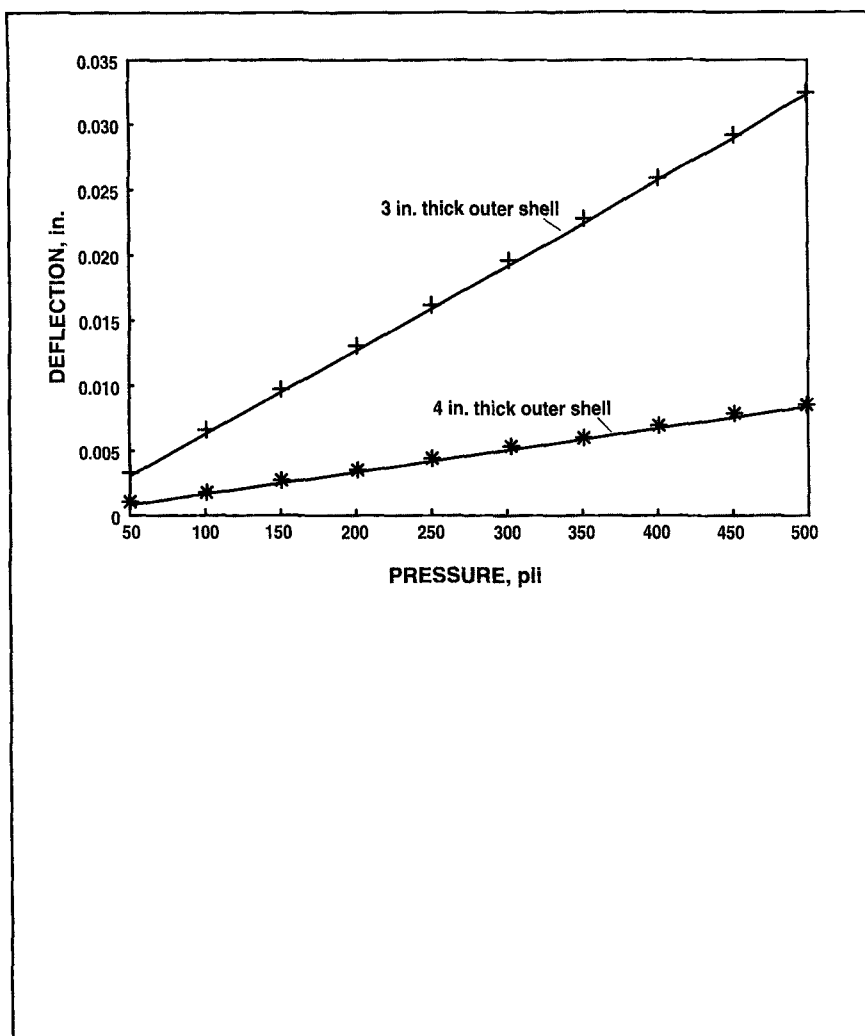
Thermal crowning is a factor that definitely affects the operation of heated steel rolls. A typical steel roll 20 in. in diameter will expand 0.00001 in. in diameter per °F. This can occur on the steel roll outside the width of the web. It could also be caused by a continuously uneven web, since the lighter areas of the web would consume fewer Btu than the heavier areas. The area of the steel roll outside the web contact area could be

ground away upon manufacturing. In the instance of a broad range of web widths, this could be controlled with engineered air showers. The appropriate good quality steel roll will expand at an equal rate across the face and does not require hot grinding. However, a poor quality steel roll or a multiple drilled roll might need to be hot ground because of the variation in the mass of material around the face of the roll, subjected to the same temperature and thus unequal thermal expansion.

Roll spacing

Roll spacing is a secondary parameter which can be most important. Spacing or gapping is a simple

3. Plot of deflection vs. pli



method of loading the roll bearing housing against one another, equally separating the rolls. Roll gapping will keep two steel rolls from contact resulting in damage or severe wear, but more importantly, it allows achievement of the finite level of pressure on the web. This system is best employed in a steel vs. steel horizontal calender, where diameters and the need for crowning are minimized. Variable crown rolls cannot use this method. **Figure 2** illustrates two steel rolls properly gapped.

Surface finish

Surface finish of the rolls used in a calender is a secondary parameter

which can affect the complete operation of the process.

With steel rolls, if a roll is too finely finished (2 rms or better), it may not pull the web through the nip. Also, the release of the web from the roll is more difficult on a fine finished roll because of the surface tension. Webs assume some surface characteristics as the anvil roll.

The same fiber company which spent US\$ 2 million for the ideal engraved pattern spent one-third this amount to determine the best surface finish or coating on steel rolls for thermally bonding nonwovens. Their final determination was, "As long as you use the proper levels of temperature, pressure, and speed, a surface finish of 10–12 rms will af-

ford the necessary levels of release, drive and finish to the thermally bonded nonwoven web." This determination, of course, excludes any web which has tacking chemicals present that bond indiscriminately.

Chrome plating is harder and less porous than the typical metals used and does afford some improved wearing properties, but it does not give a better or different web finish than a nonchromed roll of the same rms level.

Steel roll hardness, while not directly affecting the final nonwoven web characteristics, can affect the long-term ability of the roll to perform as originally intended. Steel rolls are hardened for two reasons—mark resistance and abrasion resistance. Antiwear can be afforded to the roll by chrome plating, nitriding the surface, or by surface or flame hardening.

Flame hardening, nitriding, and plating are far less effective ways to protect the metal roll from marking than through-hardening, because through-hardening protects the roll deeper into the surface. In the case of an engraved steel roll (or to a lesser extent a smooth steel roll that has been surface hardened), it would be possible for the harder spike or crust actually to be driven into the softer base metal and not rebound.

It is also possible to build some shock absorbency into the calender system, but the use of just enough pressure to satisfy the web will minimize the influence of many of these secondary parameters.

Roll deflection

Roll deflection must be addressed with every calender, but it is especially important in the thermal bonding calender. The evenness and intensity of roll-to-roll contact directly affects the thermal transfer efficiency of the entire calender system. In all rolls, there are two areas of simple deflection—mechanical deflection (sag) and deflection due to load. **Figure 3** illustrates the relationship between deflection and pli.

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Roll deflection has the most influence in a steel vs. steel nip; less in a synthetic shell vs. steel nip; and the least in a steel vs. fiber roll nip. The resilient rolls are most accommodating of the roll deflections and nip variances.

Natural or beam deflection can be minimized to a degree by design with a choice of material and sizing and can be virtually eliminated from effect on the web in a horizontal nip.

Deflection due to load can be minimized by again using only the lowest pressure required by the web to be bonded.

Compensating for deflection.

Various methods are used for compensation for deflection. One is profiling or grinding a crown into one or more of the mating rolls. This is more effective with fiber rolls than synthetic shell rolls and least effective with metal rolls. Calender rolls generally deflect in a parabolic curve, where approximately 75% of the crown occurs in the outer 20% of the roll face. In the case of metal vs. metal rolls, the crowns, however precisioned, calculated, and ground, can be altered by various nip dynamics which are unavoidable and unpredictable. Even in the case of multiple placed rams in a variable crown roll, these dynamics are present. The control of rams and the flexing of the shell is crude in comparison to the 0.001–0.004 in. variation that could result from temperature profile, web unevenness, a change in fiber, or any number of other variables that exist. **Figure 4** shows shape factors to incorporate into the roll to accommodate roll deflection.

With variable crown rolls of the "S" type, the shell rotates about an internal fixed shaft. Hydraulic internal pressure is exerted in proportion to the external calender load to present a flat or crowned outer shell.

In the Nipco type, the "S" type roll has in effect one chamber or cylinder. This roll has a series of

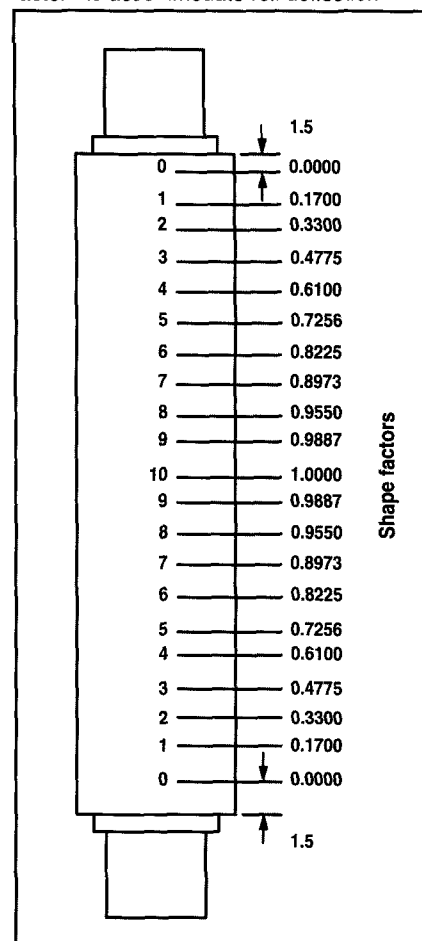
hydrostatic pistons located across the nip face which allow unequal loading of the shell to the mating roll, but equal calipering of the web is achieved. This technique is useful in the paper industry, where sheet thickness takes priority over sheet density and resulting properties. In thermal bonding of nonwovens, however, varying densification of the web results in a product that may vary from rigid in one area (plasticized), to adequate in others, to areas of unbonded web in other areas. With thermal bonding, the place to control web evenness and its associated problems is prior to the calender.

The cross axis or skewing method is where the axis of the mating rolls relevant to the web is crossed or "X'ed." This method in effect wraps the rolls around one another when they are under load. There are limits to how much the loading can be varied, depending on the flexibility of the roll itself, the line of approach of the web, and ultimately the tolerance of the web to the twist or torque generated in the nip. Usually one of the mating rolls will have a ground or permanent crown for a predicted minimum pli operation, and the skewing will then be used for higher pressures or for "trimming" the roll-to-roll contact.

Roll bending is a method of roll deflection compensation where the rolls are externally bent beyond the roll bearings through the use of hydraulic rams to flex the rolls toward each other to compensate for deflection due to load. Many of the same limitations as with skewing exist, with the additional application of the "ox bow" effect which is present in all deflecting rolls but compounded in this instance.

Recently developed is the method of anti-deflection. This is a system where, through the use of an external row of bearings which are separated by a simple hydraulic system, the mating rolls in a horizontal nip remain parallel to one another by using equal and opposing hydraulic forces. This method is only useful to

4. Required crown levels and required shape factors to accommodate roll deflection



counteract deflections due to load in a horizontal nip with loads 0–750 pli, but it presents a flat roll relevant to the web, and unlike roll bending or skewing and variable crown rolls, this anti-deflection method can be used in conjunction with micro-gap roll spacing.

Heating systems

There are many types of heating systems available for calender roll heating. The following is a list of the most popular type systems and their operating limitations.

Steam

Normally with steam, wider roll faces are required in order to obtain the middle roll profile necessary to get the desired Btu transfer. Usually a steam heated roll which has a bore will have a $\pm 10^\circ\text{F}$ variation in heating profile across the roll. (Normal maximum temperature is 150°F ; some go to 360°F .) This system is limited in Btu/h capacity.

Electrical or Cal-Rod heating system

This system is very similar to steam insofar as profile. With electric heating, one can expect to be able to use only the middle 60% of the roll face. While steam heating has a gradual dropoff in temperature at the end of the roll, the electrical heating systems have a more acute dropoff. (Normal maximum temperature is 450°F .) Various methods of using heat-sink chambers, rods submersed in hot fluid, and induction heating have been used, but they are very expensive to buy and to maintain. These rolls are also limited in face lengths and Btu/h capacity.

Gas heating system

This type of heating system normally uses a ribbon or spud type burner in a bored steel roll. Expect to use the middle 80% of the roll surface with this type of system, because the gas heating system profile is normally a $\pm 5^\circ\text{F}$ profile. (Normal maximum temperature is 500°F ; special systems can go as high as 1300°F .) This system employs a "live" flame, which could be a safety problem in many facilities. Also, the burner pipe inside the roll is difficult to manufacture over 160 in. in length to remain straight at these temperatures.

Hot oil heating system

Using a straight turbulator. This turbulator is normally fitted to a bore steel roll. By using a closed loop hot oil system through rotary joints, you turbulate or pass the hot oil through

the spiral and the bore. This is normally a good system for low Btu transfer applications. Expect to utilize 90–95% of the roll face. (Normal maximum temperature is 550°F ; special installations can go to 750°F .) This system can also be used with a multiple drilled roll which has passages closer to the surface of the roll. Because there are alternate masses of steel around the face of the roll, "barring" could be expected as you approach the upper limits of capacity of this roll.

Using a double shell roll. With this system, the roll is constructed by utilizing a solid inner core in which canals are machined into the face of this inner forging. A fitted outer shell is placed over this inner shell, so that when it is fully constructed, hot oil is permitted to pass in through the shaft by a rotary joint and then spiraled out around the inner face of the outer shell. It goes out the opposing shaft by a rotary joint. You should reasonably expect a $\pm 1^\circ\text{C}$ differentiation anywhere upon this roll surface. Therefore, you can use 100% of the face of this designed roll. (Normal maximum temperature is 550°F .) With the use of infrared systems on the face of the roll, temperatures to 750°F can be presented to the web to be bonded.

Examples of thermal bonding and nonwoven calenders

Now we will look at some examples of thermal bonding and nonwoven calenders currently in use.

Laminating calenders

Laminating calenders are used to thermally tack two or more substrates one to another. All types of fibers can be employed. The speeds can be to 2500 ft/min, temperatures to 500°F (with some calenders for Nomex® as high as 625°F), and typical pressure required of 1000–1200 pli. These calenders are normally two rolls with an open front vertical design.

Because of tolerance of these webs to temperature and load profile, a forged steel roll (engraved if required) loaded against a fiber filled roll (filling type according to hand preference) will afford the dwell time required to form these composites.

Various web tension problems can be minimized by presenting the web as a composite rather than the individual webs to the nip.

Surface bonding calender

A surface bonding calender need only be a two-roll calender for one side finishing, and a minimum of four rolls for two-side finishing. The choice of roll combination and types depends upon the web being processed. A horizontal nip is recommended for 750 pli or less and a vertical for pressures required in excess of 750 pli. The side of the web to be finished is next to the heated steel roll, but the surface effect has the same characteristics as that of the anvil or backup roll, i.e., hard and slick if steel or nylon, fibrous and less slick if fiber rolls, and even less glaze if wool fiber is used.

When bonding both sides of the web, a horizontal nip is preferred, because the two nips required can be driven, heated, and loaded independently, and the hand can be controlled as required.

Two mating steel rolls can be used to achieve double-sided finishing, but there is a limitation to softness of hand and variation of load that can be applied. This is because the rolls must be preground to a specific load or the web must be tolerant to skewing or roll-bending. The limitation of the ability to heat a variable crown roll to levels of $325\text{--}425^\circ\text{F}$, which is required, eliminates its use in this type nip.

Compaction bonding

Compaction bonding calenders are very similar to the laminating and surface bonding calenders, except they typically operate at much higher pressure in order to compact

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and in effect "plasticize" the web to a paper-like consistency. To a degree, the hand can be softened by the usage of roll gapping and fiber composition backup rolls. It must be remembered that a steel vs. steel nip is in effect a shear and an extruder, and additional consideration must be given to roll deflections and crown profile variation.

Texturizing and embossing calenders

Texturizing and embossing calenders need only be a two-roll vertical calender and lend themselves by application to be an engraved steel roll heated to a maximum temperature of 425°F loaded against a synthetic shell or fiber filled roll. This type of calender is normally used to process a previously formed web (i.e., spunbonded, chemical impregnated, composite). With both texturizing

and embossing, thermal bonding can occur. The term texturizing is being used in the instance where the engraved pattern is less deep than the web is thick. Also, the pattern roll is not sequenced to the anvil roll. This method will tack some surface fibers and will shift or equalize the construction of the web itself.

This same style calender could be an embossing calender when the engraved pattern depth exceeds the web thickness and the back-up roll actually pushes the nonwoven web into the engraved steel roll. In most cases, the rolls are geared on a 1:1 surface drive, and a fiber filled roll is used that will accept and be the reciprocal of the engraved steel roll.

Point bonding calender

The last type of calender to be discussed is the point bonding calender. This type of calender is the ultimate challenge for the calender manufacturer and the nonwovens manufacturer. In this instance, the object is to bond at specific points an unfortified fibrous web. Because the web can be extremely fragile, i.e., light with very few fibers per cross-section, and because even a very slight unevenness represents a greater percentage relevant to web thickness, the most precise calender nip is required.

The typical specification would be $\pm 1^\circ\text{C}$ temperature variation across the steel roll face, 0.5% variation of fluid heat transfer system controller to roll face, and 0.5 million Btu/h delivered to the nip; the steel roll ground to 0.0002 in. TIR with 0.0002 in. surface deviation, 12 in. station to station non-accumulative, which relates to shape and concentricity and

cylindricity. A specification of 0.5% speed regulation and zero drift in set point relative to the entire line drive is necessary to control web tension.

In every instance except for laboratory (30 in. or less), the evidence is strong that the calender should be a horizontal nip using double shell steel rolls heated with a closed loop fluid heat transfer system.

With such a nip, you can achieve the Btu/h and temperature profile requirements and load the rolls from 0 to whatever pli only as the web dictates (not the pli dictated by the calender roll). The nip will accept the web tensionless and flat because the web is dropped through the calender nip. Since the web path is in the same direction as the calender roll's natural deflection, only the deflection due to load need be considered, and in most instances it is negligible.

I have tried to be objective in this article, but after working with thousands of customers, it is difficult not to form opinions. I am hopeful that you will take the time when the need arises to investigate and determine what specifications your thermally bonded nonwoven requires in a calender.

Many fiber producers, as well as universities, have laboratory or research calenders which should be utilized as an integral part of your determination of what calender is best for your specific needs. **□**

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