

## Critical factors affecting the properties of thermal-bonded nonwovens with special reference to cellulosic fibres

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The ability to engineer the feel and functional requirements in light- and medium-weight goods without contributing to environmental pollution makes the thermal bonding process an interesting technology of nonwoven production. The manufacturing conditions, processing parameters, and the characteristics of binder fibres have a large bearing on the properties of nonwoven products. Higher calender roller pressure makes the nonwoven product more compact and stiff and increases the strength up to a point. Higher binder fibre concentration also makes the nonwoven more compact and stiff but decreases elongation and crease recovery angle. Studies on the mechanism of bonding reveal that the polymer flow under the influence of temperature and pressure is a complex phenomenon and is also influenced by the process speed. Quench rate has a significant bearing on the properties of thermal-bonded nonwovens. Hence, the critical processing parameters such as binder fibre content, temperature, pressure and speed are to be optimized for the cellulosic blends to achieve the fabric requirements for applications such as interlinings, medical and wipes. Cellulosic thermal-bonded nonwovens with their superior absorption characteristics are ideal for next-to-skin applications.

**Keywords :** Binder fibre, Cotton, Nonwoven, Thermal bonding, Viscose

### 1 Introduction

Thermal bonding technique of nonwoven production is gaining increasing attention in recent years because of the economic and ecological considerations. The process is simple and clean as there are no chemical formulations and the consequent problem of affluent disposal. The process can be maneuvered to impart the desired handle; either stiff and paper like or flexible and textile like feel can be engineered without compromising on the functional requirements. Although thermal bonding is popular for nonwoven manufacture using synthetic fibres, it is interesting to note that an early patent<sup>1</sup> was for the thermal bonding of rayon nonwovens using polypropylene as a binder. In another patent, Drelich and Fehillas<sup>2</sup> described thermally point bonded nonwovens made from cotton and polypropylene fibres. In both the cases it was observed that the greater the polypropylene content, the less stringent are the bonding conditions required to obtain desirable fabric properties. Haldon and Athey<sup>3</sup> used bicomponent fibre having nylon 6.6 core and nylon 6 sheath, and in another case polyester core and copolymer sheath for bonding rayon and pulp webs.

Thermal bonding is emerging as a front line technology for nonwovens and considerable fundamental and experimental work is being

reported. A review on thermal point bonding by Gilmore and Dharmadhikary<sup>4</sup> is reported. In the present paper an attempt has been made to examine critically the factors affecting the properties of thermal calender-bonded nonwovens with special reference to those made from cellulosic fibres.

### 2 Outline of the Thermal Bonding Process

There are two methods of thermal bonding, viz. calender bonding and through hot air bonding. The former makes compact and stronger product and the latter makes loftier and bulky product. The process of thermal bonding by calendaring consists of mixing a small proportion of low-melt binder fibres to the main matrix fibres prior to carding and passing the carded web between two calender rollers, one or both heated to the melting temperature of the binder fibres. Both the rollers may be plain or one of them may be embossed with a pattern or design. The pressure is applied on the top roller through suitable means. As the fibre web, made either by a card or airlay technique, passes through the nip of rollers, the fibres are heated and compressed (Fig. 1). Under the appropriate bonding conditions of temperature, pressure and speed, the polymer in the binder fibre softens, flows and creates a bond between the fibres. On emerging from the nip of the calender rollers the web is passed through the cooling rollers where

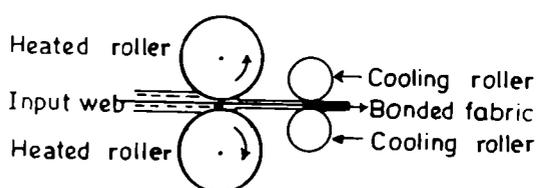


Fig. 1—Schematic representation of thermal bonding

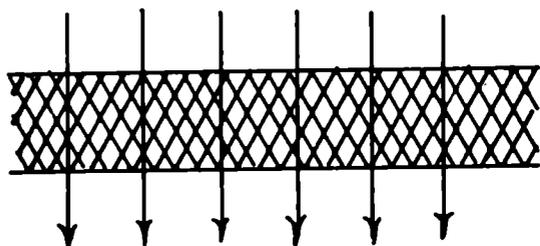


Fig. 2—Straight-through airflow

cohesive bonded fabric is formed. If an embossed roller is used, a softer product will be obtained, while with a plain roller, the product will be stiffer and stronger. In contrast to the contact heating applied in calender bonding system, through-air heating system operates by the application of hot air through the nonwoven cross-section (Fig. 2). The batt of fibres has good permeability to air and is heated rapidly when hot air is passed through its interior layers. Calender bonding is suitable for light-weight nonwovens of 20-80 g/m<sup>2</sup> such as interlinings and coverstocks, while through-air bonding is most appropriate for medium and heavier weight high-bulk nonwovens.

In through-air bonding process, the batt of fibres is carried over a conveyor—a perforated drum or a perforated belt—and the hot airflow through the nonwoven results in attaining the required melting temperature and subsequent bonding. Fleissner Co. of Germany offers perforated drum type of straight-through airflow systems. As the batt of fibres has a good permeability to air, high bulk webs are very sensitive when heated by air. Hence, a uniform airflow and temperature across the working width are critical in order to avoid uneven bonding. The airflow rate across the batt can be influenced by the partial vacuum beneath the conveyor by varying the speed of the air circulating fan. Generally, the Fleissner line of thermal bonding consists of a perforated drum (Fig. 3) and the hot air flowing through the nonwoven is sucked from the end of the drum through a radial fan and repeatedly circulated over the radiant heaters.

### 3 Influence of Various Factors on Thermal Bonding

#### 3.1 Preheating

Schwartz<sup>5</sup>, among the earliest workers on thermal

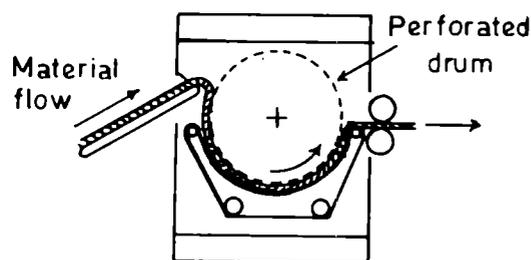


Fig. 3—Through-air bonding (perforated drum installation)

bonding, studied the effect of crystallinity of base fibres and suggested that preheating of unbonded web increases the crystallinity and, therefore, the softening temperature. Hence, more intensive bonding conditions are required to achieve fusion. In the absence of preheating, low crystallinity is maintained and surface fusion is obtained without significant bonding in the interior layers. This is in contrast to the observations of Duckett and Kanagaraj<sup>6</sup> who suggested preheating as one possibility to improve the web bonding; for 100% polypropylene, the roller temperature cannot be raised beyond 165°C without encountering sticking problem. The temperature can, however, be raised to a higher level in cotton/polypropylene blends. Preheating helps in achieving the bonding at normal or below normal temperature of the rollers. Preheating, particularly for heavier webs, may be beneficial to achieve improved bonding.

#### 3.2 Heat Transfer during Bonding

During the calendaring process the web enters the roller nip at room temperature and heat flows through the calender rollers onto the web. Warner<sup>7</sup> studied the heat transfer in the calender process and pointed out that heat transfer by conduction alone is poor. For polypropylene fibres with temperature of rollers at 155°C, the temperature at the centre of the fabric increases only up to 120°C which is substantially lower than the melting point of polypropylene. The large reduction in the thickness of the web under pressure results in deformation-induced heating. The heat of deformation may be sufficient to increase the temperature by 35-40°C. Polymer molecules subjected to compression require a higher thermal input than they do at the atmospheric pressure. The actual melting point of polypropylene is shifted by about 10°C.

#### 3.3 Processing Parameters

The temperature, pressure and processing speed employed during thermal bonding play a decisive role on the fabric properties. The flow of polymer in the nip

is a complex process in thermal bonding. The pressure applied not only increases the melting point but also facilitates flow, transferring heat to bond points. The increase in temperature and pressure enhance flow as well as annealing; the annealing may cause increase in viscosity, leading to reduced flow. The increase in process speed also influences flow since the time of contact is low and this results in lowering of temperature<sup>7</sup>.

Muller<sup>8</sup> stated that for an optimum nonwoven strength, an approximately linear ratio between the production rate and the nip pressure should be maintained. The nip pressure has two functions, viz. improvement in contact heat transfer from roller to web, and joining the molten fibre surfaces together. At higher pressure levels, the rollers tend to flatten in the nip and as a result the line contact between the rollers changes to area contact. The contact width and production rate influence the contact time between the roller and the web. It is during this time that the heat transfer takes place by surface contact. If the nip pressure is increased, the contact time increases due to the increased flattening. An increase in calender roller diameter also increases the contact time because of the smaller curvature of rollers.

#### 3.4 Quench Rate

The rate of cooling the fabric after it emerges from the nip of calender rollers affects the binder fibre recrystallization and higher quench rate leads to increase in tenacity and elongation of the fabric. The consistent evidence of high statistical significance is reported by Shimalla and Whitewell<sup>9</sup>, indicating changes in tenacity, modulus and elongation of fabrics as a function of binder fibre recrystallization. Deakynne *et al.*<sup>10</sup> explained that the increase in quench rate increases the strength of the nonwoven, initially by reducing crystal size. However, at very high quench rates, stress concentrations are frozen into structure, leading to brittleness and reduced strength. The need to quench the fabrics rapidly and permit relaxation of the fabric upon its exit from the nip is also emphasized by other researchers<sup>11,12</sup>.

#### 3.5 Types of Fibres

Wei *et al.*<sup>13</sup>, in their study on different kinds of polypropylene fibres, observed that the fibres with lower birefringence show higher tensile strength and stiffness in thermal-bonded fabrics than the fibres with higher birefringence. The crystalline binder fibres yield bonded fabrics that have higher tenacity, modulus and breaking elongation than the comparable fabrics bonded with amorphous binder fibres<sup>14</sup>. They also observed that shorter the time

taken by a binder fibre to melt at its melting point, the higher are the possible production speeds. The binder fibre should not begin to soften and deform until shortly before reaching its melting point<sup>15</sup>.

A heterofil fibre of the type polyester/polypropylene bicomponent binder fibre could be more advantageous as compared to the polypropylene homofil fibre, since polyester component maintains its integrity throughout the bonding process, thus leading to a stronger fabric<sup>16</sup>. While thermal bonding viscose, better bonding<sup>17</sup> is obtained when vinyl chloride/vinyl acetate copolymer (Wacker-MP) is used as binder fibre in place of a low-melt thermoplastic copolyester fibre (Grilene K 150). As a result, higher tensile strength, lower elongation, increased stiffness and lower crease recovery angle are found with the viscose thermal-bonded products using Wacker-MP binder fibre.

The tensile properties of thermal-bonded fabric are also influenced by the elongation properties of the fibre used. Straining of a bonded fabric containing low-elongation fibres resulted in individual fibres bearing the load and then breaking as a result. On the other hand, straining of a bonded fabric containing high-elongation fibres resulted in large groups of fibres elongating and sharing the load, which, in turn, resulted in much greater strength and elongation to break<sup>11,12</sup>.

#### 4 Cellulosic Fibres in Thermal Bonding

The use of cellulosic fibres, particularly cotton, in nonwovens has received attention in recent years because of the waste disposal problem associated with synthetic fibres and also to exploit the inherent characteristics of cotton fibre which is a renewable and biodegradable fibre and does not consume energy sources in its production. The absorption characteristics, user comfort, skin friendliness, wipe drying and wicking characteristics of cotton are preferred in many nonwoven products such as disposables, personal care products and surgical materials.

In case of products such as coverstocks, synthetic fibres are believed to be better suited because they provide a drier and less irritating fabric next to skin. But the studies with rayon showed that it causes less skin irritation than polyester and polypropylene coverstocks<sup>18</sup>.

Absorbency, strike through time, wicking rate and rewet are the major properties where the cellulosic nonwovens score over the synthetics.

##### *Absorbency*

It is the weight of the liquid absorbed per unit

weight of material and expressed in percentage (EDANA Standards 70.1-72).

#### *Strike Through Time*

It is the time taken for a known volume of liquid, applied to the surface of a nonwoven material which is in contact with a standard absorbent pad, to pass through the nonwovens (EDANA Standards 150.0-84). The nonwoven is placed over a set of fine standard filter papers which serve as absorbent.

#### *Wicking Rate*

The wicking rate measures the rate of capillary rise in specimen strips suspended in the test liquid (EDANA Standards 10.1-72).

#### *Rewet*

This property measures the ability of the material to keep the skin of the wearer dry during use. To measure the rewet property, distilled water is poured through the strike through tester onto the specimen which is superimposed on a standard absorbent pad of filter papers. The specimen is allowed to absorb the liquid for 2 min. Two pre-weighed filter papers are placed over the point of liquid entry and then 1 lb/in<sup>2</sup> (7 kg/100 cm<sup>2</sup>) weight is applied for two min. The filter papers are removed and weighed and the net gain in weight is reported as rewet value.

#### 4.1 Rayon Thermal-Bonded Fabrics

Wooding *et al.*<sup>19</sup> reported that the rayon/polypropylene blends require a higher bonding temperature than the 100% polypropylene and under this condition, rayon contributes to the strength of the bonded fabric. Rayon thermal-bonded fabrics are drapable, softer and smoother. The softness advantage is lost due to linting in viscose thermal-bonded fabrics. However, the rayon blended fabrics show large benefits, by way of absorbency, over 100% polypropylene fabrics.

Studies<sup>17</sup> at BTRA showed that with viscose thermal-bonded fabrics, higher calender roller pressure makes the nonwoven more compact, improves strength up to a point and reduces elongation markedly. Beyond a certain calender roller pressure, the strength improvement is marginal. Bursting strength also improves initially but beyond a certain calender roller pressure it does not improve. Fibre flattening and breakages that occur at high calender roller pressure offset the improvements in strength from better bonding. The fabric stiffness increases and crease recovery angle decreases with the increase in calender roller pressure. Higher proportion of binder fibres makes the fabric compact, increases stiffness and decreases elongation and crease recovery angle.

Trilobal viscose fibre in thermal-bonded fabrics

yields significantly higher absorption characteristics, thickness and cover advantages over the standard rayon. A trilobal structure decreases the contact area between rayon and polypropylene fibres which decreases the fabric strength by about 10%. The higher level of rigidity of trilobal fibres leads to increase in fabric stiffness<sup>20</sup>.

#### 4.2 Cotton Thermal-Bonded Fabrics

##### 4.2.1 Opening and Blending

In cotton/polypropylene blends, the roller clearer cards process polypropylene preferentially over cotton and hence, it is necessary to know if correct blend levels are obtained in the fabric. The binder fibre should be distributed evenly throughout to ensure the uniformity of fabric properties. In this context, attempts have been made to determine the degree of opening achieved in the grey cotton, bleached cottons with various finishes, and polypropylene fibre. Results reveal that all the cottons showed greater openness values than the polypropylene under identical conditions of processing. Among the cottons, bleached cottons with various finishes showed higher openness values; even unfinished bleached cotton showed a higher openness value than the grey cottons<sup>21</sup>.

##### 4.2.2 Effect of Cotton Content in the Blend

The strength properties of thermal-bonded cotton nonwovens deteriorate as the amount of cotton increases<sup>21</sup>. The breaking strength decreases with the increase in cotton content since greater concentration of binder fibres is required to provide a greater potential for stronger bonds between cotton fibres<sup>22</sup>.

Higher level of cotton in the blend results in less stiffness, greater cover, higher absorbency, faster wicking and reduced strike through time in the fabric<sup>21,23,24</sup>. The inherent advantages of cotton fibre properties are exploited in such a situation and hence the superior absorption properties are seen. However, the absorbency of thermal-bonded cotton nonwovens decreases with the increase in area density, binder fibre content and bonding pressure<sup>23</sup>. Bending length, a measure of stiffness, is influenced more by the binder fibre content than the fabric weight<sup>24</sup>.

The wet back (rewet) property, an important quality characteristics with disposable hygiene nonwovens, increases with increase in cotton content and fabric weight. Generally, cotton shows similar wet back property as polypropylene in thermal-bonded nonwovens and hence cotton can be used for coverstock applications<sup>24</sup>.

Similar conclusions for the use of cotton nonwovens are reported in a study on the influence of

cotton content on comfort properties such as thermal conductivity, moisture regain, wicking rate and air permeability. As cotton content increases, the discomfort sensation arising from surface dampness is reduced. This is due to the superior dynamic moisture transmission properties of cotton which lead to a slower build-up of moisture on the fabric surface. Thermal conductivity, air permeability and static water vapour transmission rate are not affected by the cotton content<sup>25</sup>. This study demonstrates the potential advantages in surface dampness sensations by the use of cotton in next-to-skin applications.

#### 4.2.3 Effect of Fabric Weight

In the calendered thermal-bonded nonwovens, the heat flow onto the material is limited by the thickness of the web in the roller nip. Hence, the breaking strength of cotton thermal-bonded nonwovens increases initially up to a point with the increase in fabric weight. Moreau<sup>22</sup> reported an increase in the breaking strength of cotton nonwoven with the increase in fabric weight from 40 to 60 g/m<sup>2</sup> and an increase of lower order with further increase in fabric weight from 60 to 80 g/m<sup>2</sup>. The greater thickness at higher weight levels makes it difficult to obtain optimum bonding conditions even at slow speeds and higher pressure levels. In the case of parallel-laid nonwovens, a fabric of 40 g/m<sup>2</sup> shows a greater strength in machine direction than a 80 g/m<sup>2</sup> fabric in the cross direction, thus indicating that fibre orientation is more critical than fabric weight for the strength property.

Moreau<sup>22</sup> also reported that the stiffness of the fabric increases with the increase in fabric weight and that the fabric weight has a greater influence on stiffness than the bonding temperature.

#### 4.2.4 Effect of Processing Parameters

In the case of cotton/polypropylene blends, the higher the level of polypropylene, the lower is the bonding temperature needed for maximum strength<sup>21</sup>. Further, the increase in bonding temperature increases the breaking strength<sup>22</sup>. The breaking strength decreases as the processing speed increases, since a faster processing speed results in a shorter contact time of web on the calender rollers, leading to poorer bonding<sup>22</sup>. The binder fibre type and bonding temperature are important factors affecting the physical properties of the nonwovens and polypropylene fibres. The bicomponent fibres made of polypropylene fibre sheath are reported to be the best fibre for blending with cotton<sup>26</sup>. Statistically different relationships were found between machine and cross directions for breaking strength, elongation and stiffness.

#### 4.2.5 Single Nip vs Double Nip Bonding

Gilmore *et al.*<sup>16</sup> have investigated the effect of double nip bonding (Fig. 4) on the properties of cotton nonwoven with polyester/polypropylene bicomponent fibre as binder fibre. Their experiments showed that single nip bonding can achieve greater strength without sacrificing softness, thickness and absorbency as compared to the double nip bonding. In the double nip process, the fabric remains in contact with the heated smooth roller at 180° of rotation and during this time, the fibres in the bond point pull apart, resulting in low strength even at high nip pressures and temperatures. This separation is likely due to the stiffness of cotton which forces the bonds apart and to the bending of web as it is wrapped around the smooth heated roller. The higher level of draft the material undergoes in a double nip process also results in a high ratio of machine to cross directional strength in the nonwovens. Gilmore *et al.*<sup>16</sup> also suggested that since the adhesive properties of polypropylene for cellulose are not high, the mechanism of bonding could be mechanical attachment or encapsulation of fibres on polypropylene.

#### 5 Recent Development in Thermal Bonding Machines

Thermal bonding process by calendering is influenced by two critical parameters, viz. pressure and temperature. Both these parameters should be constant across the width of the calender rollers and should be amenable to quick adjustments. The pressure acting on the rollers results in deflection of the rollers. If this effect is not compensated, the nip pressure at the centre of the rollers will be lower than that at the extreme ends. To compensate for this deflection, Ramisch Kleinwefers has designed a

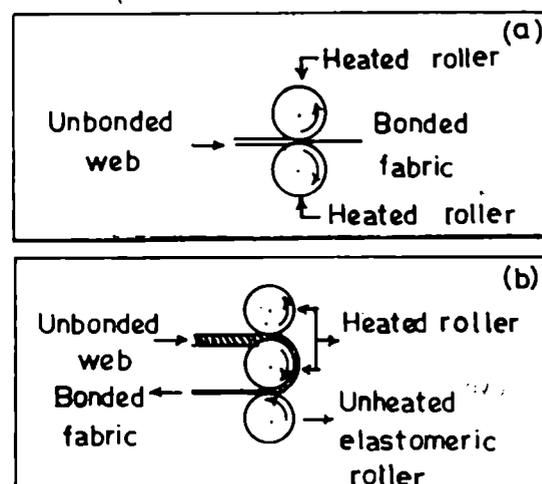


Fig. 4—Single nip(a) and double nip(b) bonding

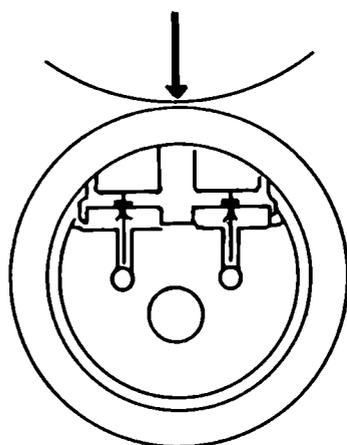


Fig. 5—Schematic diagram of thermo-hydra roller

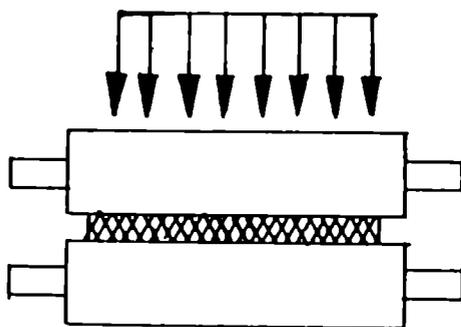


Fig. 6—Uniform pressure distribution achieved using the one-zone thermo-hydra roller

thermo-hydra calender<sup>27</sup> in which the deflection of the calender rollers is compensated by the application of a thin roller shell with internal pressure in the vicinity of the nip of calender rollers. With constant internal pressure, the nip pressure is expected to stay constant. The internal pressure is generated by a system of double piston bearing elements and the oil from a hydraulic unit. The cylinder pistons of the bearing elements produce the required force. Figs. 5 and 6 show the schematic diagram of the thermo-hydra roller and the uniform pressure distribution achieved by the system respectively.

### 6 Comparison of Thermal-Bonded and Chemical-Bonded Viscose Nonwovens

In general, the chemical-bonded viscose nonwovens show comparatively much higher breaking strength and much lower breaking elongation than the thermal-bonded nonwovens<sup>17</sup>. But the bursting strength of chemical-bonded nonwoven is lower than that of the thermal-bonded nonwoven because of the lower elongation of former.

Chemical-bonded nonwovens are superior in respect of stiffness and crease recovery. Shrinkage after washing with detergent is higher while weight loss after boiling is lower for thermal-bonded products as compared to that for the chemical-bonded products.

### 7 Future Outlook

Among the major nonwoven products are the health care, personal and hygiene goods. Products such as coverstocks, wiping cloth and interlinings are the other products normally made by chemical- or thermal-bonding. Thermal-bonded cellulosic products, particularly of cotton, have great scope in all such applications. In addition, surgical wound pads of better quality can be made from thermal-bonded cotton. Cotton has only a modest presence in the nonwoven market. The positive features, inherent in a cellulosic fibre, when combined with a clean process such as thermal bonding are likely to impart a boost for the industry. Low micronaire and immature cottons, comber noils and such fibres which pose problems in yarn manufacture can be profitably employed in the process. Cottons, like Bengal Deshi, which have no spinning value can also be used to produce value added products. Hence, there is a need for further indepth studies on the process and products that can be made by thermal bonding of cellulosic fibres.

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