5. THERMAL BONDING METHODS ................................................................. 2
5.1. Structure and properties of thermal bonded nonwovens ................................ 2
1.7.1. Structure and properties of bicomponent fibers bonded web......................... 2
1.7.2. Structure and properties of thermoplastic agents bonded web - fibers, powder, grating, foil........................................................................................................................................... 2
5.8. Technologies ........................................................................................................... 2
1.8.1. Powder bonding ............................................................................................. 3
1.8.2. Through-air bonding ...................................................................................... 4
1.8.3. Calender bonding .......................................................................................... 6
1.8.4. Ultrasound bonding ...................................................................................... 12
1.8.5. Microwave bonding ...................................................................................... 14
1.8.6. Radio-frequency heating ................................................................................ 18
5.9. Thermal constants of choice polymers (λ) .......................................................... 20
2. CHEMICAL BONDING METHODS ........................................................................... 21
5.7. Structure and properties of latex and foamed latex bonded webs ................. 21
5.8. Device for saturation of latex, foamed latex, solution and paste ................ 21
2.8.1. Dispersion preparation .................................................................................. 21
2.8.2. Print bonding .................................................................................................. 23
2.8.3. Spraying .......................................................................................................... 24
2.8.4. Foam bonding ................................................................................................ 25
2.8.5. Saturation bonding ........................................................................................ 26
5.9. Felting .................................................................................................................. 27
3. WEB CONVERSION METHODS .............................................................................. 28
5.7. Coating and Laminating ..................................................................................... 28
3.7.1. Hot-melt coating and laminating ..................................................................... 30
3.7.2. Flame laminating ............................................................................................ 35
3.7.3. IR heating ......................................................................................................... 37
5. THERMAL BONDING METHODS

5.1. Structure and properties of thermal bonded nonwovens

1.7.1. Structure and properties of bicomponent fibers bonded web

The lower melting part of bicomponent fiber melts and creates the point join between two bicomponent fibers or bicomponent fiber and basic fiber that has higher melting temperature.

![Point structure](image)

*Figure 5.1: Point structure*

1.7.2. Structure and properties of thermoplastic agents bonded web - fibers, powder, grating, foil

![Agglomerate structure](image)

*Figure 5.2: Agglomerate structure*

5.8. Technologies

Thermal method uses the thermoplastic properties of certain synthetic fibres to form bonds under controlled heating. In some cases the web fibre itself can be used, but more often
a low melt fibre or bicomponent fibre is introduced at the web formation stage to perform the binding function later in the process. There are several thermal bonding systems in use. Calendering uses heat and high pressure applied through rollers to weld the fibre webs together at speed. Through-air thermal bonding makes bulkier products by the overall bonding of a web containing low melting fibres. This takes place in a carefully controlled hot air stream. Drum and blanket systems apply pressure and heat to make products of average bulk. Sonic bonding takes place when the molecules of the fibres held under a patterned roller are excited by high frequency energy which produces internal heating and softening of the fibres.

There are many materials that can be used as a binder for thermally bonded nonwovens. Important characteristics of the binder polymers are efficient melt flow, good adhesion to the carrier fiber, lower melting point than the carrier fiber, appropriate stiffness/elasticity.

**Binding fibers**

Single-component and bi-component fibers, as binder fibers, are most widely used in thermal bonding of nonwovens. Single-component fibers are the least sophisticated and most economical because the fibers are often already in existence and low in cost. The type bond that is formed is dependent on several factors including fiber chemistry, morphology, linear density, staple length, crimp and processing conditions. The major disadvantage encountered when using 100 percent single-component fibers is the narrow temperature range that is necessary when thermal bonding. If the temperature is too low, there is inadequate bond strength. If the temperature is too high, the web will melt excessively and lose its identity as a web. When bi-component fibers are used to produce thermal bonded nonwoven, the acceptable temperature range for bonding may be as great as 25°C. When thermal bonding, the high melting portion of the fiber maintains the integrity of the web, while the low melting point portion melts and will bond with other fibers at the fiber cross-over points. The product produced tends to have bulk and exceptional softness.

**Binding powder**

Powdered polymers are sometimes used in thermal bonding of nonwovens. The most prevalent use is powdered polyethylene. The powder can be applied between layers of fibers when cross-laying, air laying, or as an after treatment. A short exposure in an oven is sufficient to melt and fuse the powder. It is often used when a light weight and open structure is required with a soft hand or when a reinforced, molded product is necessary.

**Binding web**

A very open-structured, low-melting-point thermoplastic fabric is placed between the webs and, during thermal bonding between the calender rolls, the fabric melts completely bonding the webs together. The nonwoven produced by this technique is considerably soft and bulky. Thermoplastic coatings and hot melt print bonding have been used to a limited extent in controlled porosity filters, impermeable membranes and other items. However, the use of this method of bonding is not expected to achieve a high level of importance.

**1.8.1 Powder bonding**

In powder bonding, the adhesive powder of thermoplastic polymers is applied onto webs. Polyesters and polyolefins with low Tg's and molecular weight can be used as powder binders. A typical bonding line is illustrated in fig. 5.3. The advantages are the bulky structure
of dense nonwovens and the applicability of polyester or polypropylene webs. The
disadvantage lies in difficulties of suitable particle sizes and ranges, and their distribution.

**Figure 5.3: Powder adhesive sprinkling**

1.8.2. Through-air bonding

Through-air bonding technology can be ideal for process heating a wide range of air-permeable products such as nonwovens. In this through-air device, heated air is supplied to
the interior of the device enclosure through a perforated plenum mounted above the product
line. A suction plenum beneath the line mechanically pulls hot air through the product and the
conveyor for high heat transfer throughout the fabric (see fig. 5.4). Heat transfer is almost
instant and, most importantly, throughout the thickness of the product. Air drawn in through
the suction plenum is returned to the burner chamber for reheating and re-use. For products
that are heated in an indexing operation, an air bypass system can be used to keep the heater
at operating temperature cutting recovery time to a bare minimum and reducing energy costs.
This method results in very efficient, very fast energy transfer.

**Figure 5.4: Through-air bonding with horizontal belt.**
The temperature of the air is set above the melting temperature of the added melt fibers, so that the molten fiber polymer attaches to the other fibers and interconnects them. In case of bi-component fibers used as melt fiber, the outer shell of the fiber is molten only, giving even better stability to the nonwoven. The potential double belt is adjustable to achieve calibrated nonwoven product with a specified thickness and density. Three operating parameters mainly influence the thermo bonding process. They are energy distribution, temperature profile, and air velocity in the oven. The higher the air velocity is, the better and faster is the heat transfer from the air to the fibers. The product characteristics depend on types and percentage mix of waste/recycle fibers, type and percentage of low melt fibers, operating parameters of the web forming process, operating parameters during the thermo bonding process. The final product may be slit longitudinally and then is either wound into rolls or cross cut into panels that are stacked in an automatic stacking unit.

Nonwovens made of through-air thermobonding find their application in various fields:

1) Home textile: carpet backing, upholstery padding, mattress protection
2) Automotive heat insulation
3) Automotive sound insulation: air intake, bulkhead units, power train tunnel, bonnet liner, outer and inner dash
4) Cleaning wipes for industrial application
5) Protective wrapping material
6) Building material: heat insulation, sound insulation

Nonwoven properties: Thickness 2 - 280 mm, Width up to 4000 mm, Density 6 - 300 kg/m³, Capacity 300 - 2500 kg/h.

Through air bonding with perforated drum is a technic where the hot air flows through the nonwoven and holes in a perforated drum. Pulling the air through the nonwoven fabric allows much more rapid and even transmission of heat and minimizes fabric distortion. (Fig.5.5).

---

**Figure 5.5: Through-air bonding with a drum.**
Binders used in through air oven bonding include crystalline binder fibers, bi-component binder fibers, and powders. When using crystalline binder fibers or powders, the binder melts entirely and forms molten droplets throughout the nonwoven's cross-section. Bonding occurs at these points upon cooling. In the case of sheath/core binder fibers, the sheath is the binder and the core is the carrier fiber. Products manufactured using through-air ovens tend to be bulky, open, soft, strong, extensible, breathable and absorbent. Through-air oven bonding followed by immediate cold calendering results in thicknesses between a hot roll calendered product and one that has been through-air bonded without compression. Even after cold calendering, this product is softer, more flexible and more extensible than area-bond hot calendered material.

1.8.3. Calender bonding

There are three main types of hot calendering.

− Area bonding
− Point bonding
− Embossing.

This process involves the use of a calender with a hot metal roll opposed by a wool felt, cotton or special composition roll. Two, three or four roll calenders can be used, depending on the weight of the web to be bonded and the degree of bonding desired. The three roll calender has the heated roll in the middle while the four roll configuration has the heated rolls on the top and bottom, with the two composition roll in the middle. The amorphous or co-polymeric binder fibers used in this process provide bonding at all cross-over points between the carrier and binder fibers. The resultant product - commonly used in electrical insulation and coating substrates - is smooth, thin and stiff. The material is always two sided, but this effect is most apparent in material processed through two and three roll calenders. Four roll calenders minimize this effect.

The application of heat from the outside produces a material whose inner area is less bonded than its outer surface. This becomes more pronounced as the product weight increases beyond 35 g/m² and can become detrimental unless corrective measures are taken. These include increasing heat, slowing speed, or increasing the binder/carrier fiber ratio. The two-roll calender is used for low-to-medium weight products with light-to-medium bonding. The three-roll calender is used for special bonding and finish effects on a single surface. The four roll calender produces the widest weight range of materials because it provides more flexibility in the application of heat.

![Figure 5.6: Smooth roll calendering.](image)
Area-bond hot calendering is influenced by five factors:

**Heat**
Bonding occurs at the surface of the metal roll, which obtains its heat by conduction from heated oil circulated through its center or from restrictive heating. The composition rolls obtain their heat from contact with the heated metal roll. Before the start of a production run, the roll stacks are operated until the composition rolls achieve dynamic heat equilibrium.

**Pressure**
Bonding occurs through simultaneous application of heat and pressure. The heat causes the fiber binder to become thermoplastic. The pressure enhances mechanical bonding by forcing the binder polymer to flow in and around the carrier fibers.

**Speed**
The speed at which the nonwoven passes through the calender, combined with heat and pressure conditions, determines the degree of bonding in the nonwoven. It also determines the throughput rate of the entire nonwoven line and is a critical factor in product cost. The faster the rate, the lower the cost. This is the primary reason for the recent development of lower melting binders.

**Roll combination.**
The only practical roll combination for area bonding is a metal roll-felt roll. The metal roll applies the heat. The surface resilience of the felt roll enables even application of pressure to all the minute surface thickness variations throughout the product.

**Cooling rolls**
The product is warm and thermoplastic as it leaves the calender nip. If the product were to be wound while it was still hot, the tension applied to eliminate wrinkles would stretch the web and introduce unrelied stresses. This would lead to shrinkage whenever post-heat treatments were used. A set of two cooling rolls placed immediately after the calendering stage eliminates these unwanted side effects.

**Point-bond** hot calendering is the main method of thermally bonding in disposables as diaper, sanitary products, and medical products. This method involves the use of a two-roll nip consisting of a heated male patterned metal roll and a smooth or patterned metal roll. This second roll may or may not be heated, depending on the application. In a typical production line, the web is fed by an apron leading to a calender nip and the fiber temperature is raised to the point at which tackiness and melting cause fiber segments caught between the tips of engraved points and the smooth roll to adhere together. The heating time is typically of the order of milliseconds. The fabric properties are dependent on the process temperature and pressure and other parameters like the contact time, quench rate and calender pattern. Experimental results show that for a given nip line pressure and calendering speed, the breaking strength reaches a maximum at a critical bonding temperature; on keeping the nip line pressure constant, the critical temperature was found to be a function of the calendering speed.

The maximum strength achieved is influenced by the nip line pressure. This influence depends on the melting behavior of the fiber. If the maxima occurs in the softening region, higher pressure yields higher strength. On the other hand, if maximum occurs in the early melting region, a low calendering pressure is desirable. The degree of product bonding depends on the pattern of bond points on the roll surface. Bonded areas are compressed and
densely compacted. Unbonded area in between are very open, breathable and porous. The products formed range from thin, closed, inelastic, strong, and stiff to open, bulky, weak, flexible and elastic depending on the number density, the size and the pattern of the bond points.

The **Embossing** method is a figured or sculptured area-bond hot calendering. In this case, though, the area bonding is three dimensional. A "bulky but thin" product can be made in any pleasing or functional construction, depending on the faces of the embossing rolls. The calender roll combination has a male patterned heatable metal roll and a matching female patterned felt roll.

![Diagram of Embossed Roll Calendering](image)

**Figure 5.7: Embossed roll calendering.**

Embossing/calendering rollers are employed in the non-wovens industry for the bonding of non-wovens. The most diverse of calender roller types (peripherally drilled or centre-bore with displacer) can be used. An exclusive technique patented by Wetzel is employed for engraving. The technique causes no additional stresses on the roller surface.

Their speciality are geometric shapes such as squares, rectangles, ovals and rhombuses. The technique achieves the best possible surface roughness at the profile edges, which reduces the incidence of fibres adhering or catching. Some engraving profiles can be applied directly to induction-hardened surfaces.
Modified rollers for prevention of their deformation

Constant material width and adjustable line force through x-crossing of the rolls are characteristics of the CX-Calenders. They are used for thermo-bonding as well as laminating and flat embossing.

The Swimming Roll makes it possible to compensate for the deflection of the roll over a wide line pressure area and to carry out edge corrections. They are an essential component when large material widths need to be run at high speeds.

Thermo-bonding, laminating and embossing at high speeds and high temperatures are operations for which Hot S-Roll Calenders are used. Variable line force is another characteristic of these calenders. S-Roll Calenders, which are based on our Swimming Roll technology, offer a higher degree of flexibility, particularly due to their continuously adjustable line force, but also in material widths. This flexibility manifests itself in a whole range of capabilities and effects:

Figure 5.8: Surfaces of embossed calender.

Figure 5.9: CX-Calenders – offset axes rollers.
Smoothness and density are easily achieved with this calender type as well as precision, flat and relief embossing.

Figure 5.10: Swimming Roll.

Figure 5.11: Deflection compensation by Swimming Roll.

The advantages of the HyCon-Roll with hydro-static pressure control are variable line force, variable pressing width to suit change of fabric width, and the option of edge relief of the FlexRoll Sleeve, which prevents overheating of the edges at high temperatures of the steel roll.
Figure 5.12: Deflection compensation by HyCon-Roll.

Figure 5.13: Support elements installed in axle of HyCon-Roll.

The vertical arrangement of the hydro-static pressure controlled rolls in the **HyCon-I Calender** allows for precision embossing.
By the L-shaped arrangement of its rolls, the **HyCon-I Calendar** enables two very different line forces in the top and in the rear nip that can be adjusted infinitely and independently of each other. Thus two different effects can be achieved in one passage of the fabric, e.g. density and high lustre in one nip and excellent handle in the soft nip.

1.8.4 **Ultrasound bonding**

During the ultrasonic processing, the weld horn and anvil drum heat up and expand, resulting in an undesired reduction of the gap between the weld horn and the anvil drum.
Especially when cutting, when the gap is reduced to less than 1 micron, this can lead to damaging contact between the weld horn and the drum.

![Image](image_url)

**Figure 5.16**: Ultrasonic bonding. The material passes between the weld horn and the anvil drum.

![Image](image_url)

**Figure 5.17**: Structure of US bonded textile.

**Automatic gap control through inductive Sensor**

An inductive sensor can be mounted in the anvil drum. Signals are transmitted wireless from the sensor to the controller. Differences of the target value are detected and compensated immediately. The gap between weld horn and anvil drum remains constant. Damaging contact between the weld horn and the drum is eliminated.
1.8.5. **Microwave bonding**

In dielectric heating the energy of high-frequency electromagnetic field is being transferred to thermal energy. It happens due to the effect of alternating electromagnetic field to the polar molecules of the material.

The molecular dipoles are permanently altering following the current field orientation up to billion times per second. During that two essential effects apply: the intermolecular friction surpassing the molecular attraction forces and the hysteresis occurring between the field and induced electric feedback caused by inertia depending on electric charge, mass and shape of the molecules. Due to these effects the product heating is extremely rapid and proceeds in the whole volume of polar material effected by the electromagnetic field.

The principle of dielectric heating has been discovered consequently to the radar development immediately after the WW2 finding the commercial application only after more then twenty years.

Although microwave heating does not apply to gasses in general - the microwave drying is widely used – employing the microwave energy for evaporating bringing its specific advantages. Microwave energy is frequently used as a source of ionized matter => plasma generators. Less often the MW energy can be used for melting.
For a substance to be microwaveable it must possess an asymmetric molecular structure, as in the case of a water molecule. The molecules of such substances form electric dipoles which, when exposed to an electric field (Figure 5.19), assume an orientation relative to the direction of that field. It is this orientation polarisation that is responsible for energy generation.
Figure 5.19: Molecule polarisation due to the microwave heating.

The loss mechanism is characterised by the relative loss factor, where the losses at microwave frequencies are due to re-orientation polarisation.

The essential elements for generating heat in a volume are the electric field strength of the microwave field, the frequency, and the dielectric properties of the material represented by its loss factor. The loss factor depends on both frequency and temperature.

\[ p'''' = 2\pi f \varepsilon_0 \varepsilon_r \varepsilon'' E^2 \]

where:
- \( p'''' \) is volume energy density measured in W.m\(^{-3}\)
- \( f \) is operating frequency measured in Hz
- \( \varepsilon_0 \) is permitivity of free space = 8.85 \( \times 10^{-12} \) A.s.V\(^{-1}.m^{-1}\)
- \( \varepsilon_r \) is dielectric loss factor = imaginary part
- \( E \) is electric field strength measured in V.m\(^{-1}\)

The higher the loss factor of a substance is, the better the substance can be heated in a field of microwaves. Water and all aqueous substances possess a high loss factor and therefore absorb high frequency energy and microwave energy exceedingly well. Depending on their absorption behavior towards microwave radiation, materials can be classified into three groups:

- **Absorbers**, e.g. water (\( \varepsilon_r = 12 \) at 25 °C), aqueous substances (practically all foodstuffs), diverse sorts of plastics
- **transparents**, e.g. porcelain quartz glass ($\varepsilon_r = 0.0023$), Teflon
- **reflectors**, e.g. metal, graphite)

Down to a loss factor of about $\varepsilon_r = 0.01$, substances, may still be heated in a microwave field. If the loss factor should be below this value, there might still be the possibility to blend in additives with higher loss factors which, however, should not change the desired properties of the substance.

Multimode resonant applicators consist of a metallic enclosure into which a microwave signal is coupled through a slot and suffers multiple reflections as shown in Fig. 5.20.

The superposition of the incident and reflected waves gives rise to a standing wave pattern or mode. In a given frequency range such an applicator will support a number of resonant modes.

![Diagram](Figure 5.20: Microwave heating.)

When the material is heated unilaterally, the microwave used is swiftly absorbed, the power density will decrease exponentially from the surface to the core region. The penetration depth is used to denote the depth at which the power density has decreased to 37 % of its initial value at the surface.

**Table 5.2: Penetration depths of microwave energy of various materials at 2450MHz**

<table>
<thead>
<tr>
<th>Material</th>
<th>Temperature in °C</th>
<th>Penetration depth in cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>25</td>
<td>1.4</td>
</tr>
<tr>
<td>ice</td>
<td>-12</td>
<td>1100</td>
</tr>
<tr>
<td>bread</td>
<td>25</td>
<td>2 ... 5</td>
</tr>
<tr>
<td>potato, raw</td>
<td>25</td>
<td>0.9</td>
</tr>
<tr>
<td>Material</td>
<td>Power Density (W/m³)</td>
<td>Loss Factor</td>
</tr>
<tr>
<td>-------------------------</td>
<td>----------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>mashed potato</td>
<td>25</td>
<td>0.8</td>
</tr>
<tr>
<td>peas, carrots</td>
<td>25</td>
<td>1</td>
</tr>
<tr>
<td>meat</td>
<td>25</td>
<td>0.9 ... 1.2</td>
</tr>
<tr>
<td>paper, cardboard</td>
<td>25</td>
<td>20 ... 60</td>
</tr>
<tr>
<td>wood</td>
<td>25</td>
<td>8 ... 350</td>
</tr>
<tr>
<td>caoutchouc</td>
<td>25</td>
<td>15 ... 350</td>
</tr>
<tr>
<td>hollow glass</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>porcelain</td>
<td>25</td>
<td>56</td>
</tr>
<tr>
<td>polyvinylchloride20</td>
<td>20</td>
<td>210</td>
</tr>
<tr>
<td>epoxy resin(Araldite CN-501)</td>
<td>25</td>
<td>4100</td>
</tr>
<tr>
<td>teflon</td>
<td>25</td>
<td>9200</td>
</tr>
<tr>
<td>quartz glas</td>
<td>25</td>
<td>16000</td>
</tr>
</tbody>
</table>

Products with huge dimensions and high loss factors, may occasionally overheat a considerably thick layer on the outer layer. To prevent such phenomenon, the power density must be chosen so that enough time is provided for the essential heat exchange between boundary and core. If the thickness of the material is less than the penetration depth, only a fraction of the supplied energy will become absorbed.

Yet, this is only true if the energy which is not absorbed were to effuse freely from the material after leaving it. The unabsorbed microwave radiation is however reflected from the metal walls of the application chamber and penetrates the material more than once.

1.8.6. Radio-frequency heating

Scientifically speaking, there are several ways that a dielectric material absorbs energy from the oscillating electric field. The two most important mechanisms are molecular rotation and electrical conduction. Some dielectric materials' ability to conduct electricity (moderate resistivity) is good enough that an amount of RF (radio-frequency) or microwave current will flow and heat the material. This mechanism is especially important at lower frequencies and with semiconducting materials.
The other mechanism, molecular rotation, occurs in materials with polar molecules. A material capable of being heated with RF or microwave energy is said to be polar, referring to the fact that its molecules have both positive and negative opposing charges (dipolar). In practical application an electric field is applied to the material causing its molecules to rotate and line up with their corresponding fields. RF and microwave energy fields alternate much like an electric motor, between positive and negative, at their specified frequency of operation thus causing the molecules of the material to rotate. The friction generated by the molecules rubbing together as they rotate generates heat. This method of generating heat within a material is termed dipole rotation and can be used to heat solids, liquids, or gases.

The Behaviour of Dielectric Media

Dielectric heating depends on the interaction between polar groups in molecules of non-conductive materials and the alternating electric field of electromagnetic oscillation. The atomic carriers of charges prevailing in fluid and solid materials are not able to move upon imposing an electric field, instead, they may only be slightly dislodged from their initial position. The effective force is proportional to the electric field strength, and due to this displacement, negative and positive surface charges arise at the terminal sites.

Dielectric displacement and the electric field are in phase. This correspondence is eliminated in an alternating electric field.

Energy transformation in the molecule

Under the influence of an alternating field, the dipole molecules undergo oscillations in response to the high frequency field's polarity changes. The intermolecular friction produces high-frequency energy which is first absorbed then transformed into thermal energy. Substances with a symmetrical molecular structure, such as benzene, cannot be heated in a high-frequency field, since they lack the necessary dipole characteristics. Apart from the dipole molecules, freely movable ions can also be influenced by an alternating electric field. They move to and fro in response to the high-frequency polarity changes, and thereby collide with each other. In the course of these actions, high-frequency energy is again absorbed and transformed into thermal energy. Generally, this proportion of transformed energy - especially
at the almost exclusively employed frequency of 2450 MHz - is relatively small compared to
the proportion produced by dipole oscillations. However, electrolytes, salt solutions, glass and
ceramics are an exception at high temperatures. As for these substances, a considerable
amount of heat increases upon a reduction of the frequency, this may be attributable to ion
movement.

5.9. Thermal constants of choice polymers ($\lambda$).

Table 5.3: Thermal Conductivity of Polymers

<table>
<thead>
<tr>
<th>Polymer type</th>
<th>Thermal conductivity (W/m.C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teflon</td>
<td>0,25</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>0,14</td>
</tr>
<tr>
<td>Cork</td>
<td>0,039</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>0,33</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>0,12</td>
</tr>
<tr>
<td>Acrylonitrile-Butadien styren</td>
<td>0,33</td>
</tr>
<tr>
<td>Polyoxyymethylene</td>
<td>0,23</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>0,2</td>
</tr>
</tbody>
</table>

Table 5.4: Thermal Conductivity of Polyamide

<table>
<thead>
<tr>
<th>Polymer type</th>
<th>Thermal conductivity (W/mC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyamide 6</td>
<td>0,58</td>
</tr>
<tr>
<td>Polyamide 6.6</td>
<td>0,40</td>
</tr>
<tr>
<td>Polyamide 6.12</td>
<td>0,18</td>
</tr>
</tbody>
</table>

Table 5.5: Effect of Temperature on Thermal Conductivity of Polymers

<table>
<thead>
<tr>
<th>Polymer type</th>
<th>Thermal conductivity (W/m.C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30°C</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>0,1</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>0,24</td>
</tr>
<tr>
<td>Polyamide 6.6</td>
<td>0,58</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>0,20</td>
</tr>
<tr>
<td>Polyacetal</td>
<td>0,27</td>
</tr>
</tbody>
</table>
2. CHEMICAL BONDING METHODS

5.7. Structure and properties of latex and foamed latex bonded webs

![Segment Structure](image)

Figure 6.22: Segment structure.

5.8. Device for saturation of latex, foamed latex, solution and paste

2.8.1. Dispersion preparation

Chemical bonding mainly refers to the application of a liquid based bonding agent to the web. There are many ways of applying the binder. It can be applied by impregnating, coating or spraying or intermittently, as in print bonding. Print bonding is used when specific patterns are required and where it is necessary to have the majority of fibres free of binder for functional reasons.

In operation, a metering pump accurately meters liquid polymer directly into Acrison's unique Dispersion-Injector, where the polymer disperses into a thin, fine conical stream while simultaneously, mixing with vigorously flowing water. The output solution from the Dispersion-Injector discharges into a specially designed Static Activation Chamber where final and complete polymer activation occurs.
In the central section of the unit, polymer enters from around a spring-loaded ball causing the polymer to disperse into a thin, fine conical stream that instantaneously blends with the vigorously flowing water, exiting the Dispersion-Injector as a "pre-blended" solution at the end opposite the water inlet. In addition, the spring-loaded ball completely seals and isolates the liquid polymer from contact with water anytime the polymer pump is off or the Preparation Module is shut down.

Acrison manufactures Polymer Dispersion-Injectors with several different water flow throughput capacities in order to accommodate various liquid polymer flow rates. Dispersion-Injectors are also self-cleaning and corrosion-proof, and clear synthetic housings provide visual observation of their internal operation.

The Activation Chamber consists of a clear synthetic housing filled with synthetic media specifically designed to produce a gentle, yet effective mixing action; it does not contain any moving parts.
Pre-blended solution discharging from the Dispersion-Injector enters the Activation Chamber in a swirling flow pattern, passing directly into the mixing media, then exiting as a final, active and homogeneous solution.

2.8.2 Print bonding

Print bonding applies binder only in predetermined areas. It is used for fabric applications that require a part of the area of the fabric to be binder-free, such as wipes and coverstocks. Many lightweight nonwovens are print bonded. Printing patterns are designed to enhance strength, fluid transport, softness, hand, absorbency, and drape. Print bonding is most often carded out with gravure rolls. Binder addition levels are dependent on engraved area and depth as well as binder-solids level. Increased pattern versatility can be achieved with the use of rotary screen rolls. Drying and curing are carried out on heated drums or steam-heated cans.

There are two types of printers: rotary screen and rotogravure printers. Binders are applied through a hollow applicator roll in rotary screen printer, while in rotogravure printer they are applied by an engraved applicator roll as shown in fig. 6.4 and 6.5. The main advantage is that outstanding softness of nonwoven fabrics with adequate strength can be achieved.

![Figure 6.25: Rotary screen printer](image-url)
In spray bonding, binders are sprayed onto moving webs. Spray bonding is used for fabric applications that require the maintenance of high loft or bulk, such as fiberfill and air-laid pulp wipes. The binder is atomized by air pressure, hydraulic pressure, or centrifugal force and is applied to the upper surfaces of the web in fine droplet form through a system of nozzles.

Lower-web-surface binder addition is accomplished by reversing web direction on a second conveyor and passing the web under a second spray station. After each spraying, the web is passed through a heating zone to remove water, and the binder is cured (set/cross-linked) in a third heating zone. For uniform binder distribution, spray nozzles are carefully engineered. Typical spray bonding is illustrated in fig. 6.6.
2.8.4. **Foam bonding**

Foam bonding is a means to apply binder at low water and high binder-solids concentration levels. The basic concept employed involves using air as well as water as the binder diluent and carrier medium. Foam-bonded nonwovens require less energy in drying, since less water is used. The foam is generated by introducing air into the formulated latex while mechanically agitating the binder solution.

Air/latex dilutions or blow ratios in the order of 5:25 are practiced for various products. With the addition of a stabilizing agent to the binder solution, the foam can resist collapsing during application and curing, and the bonded fabric will exhibit enhanced loft, hand, and resilience. Non-stabilized foams are referred to as froths; froth-bonded fabrics are similar in properties to some saturation-bonded nonwovens. One example of this bonding is illustrated in fig. 6.7. The advantages include less energy required to dry the web, less binder migration and controllable softness by choices and amount of binders. The disadvantages are difficulties in controlling process and adequate foaming.

*Figure 6.27: Spray bonding*
2.8.5 Saturation bonding

Saturation bonding is used in conjunction with processes which require rapid binder addition, such as card-bond systems, and for fabric applications which require strength, stiffness, and maximum fiber encapsulation, such as carrier fabrics. Fiber encapsulation is achieved by totally immersing the web in a binder bath or by flooding the web as it enters the nip point of a set of pressure rolls. Excess binder is removed by vacuum or roll pressure.

Three variations of saturation bonding exist: screen, dip/squeeze, and size-press. Screen saturation is used for medium-weight nonwovens, such as interlinings. Dip/squeeze saturation is used for web structures with strength sufficient to withstand immersion without support, such as spunbonds. Size-press saturation is used in high speed processes, such as wet-laid nonwovens. Drying and curing may be carried out on steam-heated drying cans or in thru-air ovens or perforated-drum dryers. Binder addition levels range from 20% to 60%. Two techniques, single screen saturator and applicator roll technique, are illustrated in fig. 6.8 and 6.9. Advantages of this method are simplicity, controllable tensile strength and softness by choice and amount of binders. The disadvantages are the great influence of binders on softness, and the limitation in loftiness.
Felting

The physical structure of the outer scaly layer of the wool fiber contributes to wool’s unique property of felting. Under the mechanical action of agitation, friction and pressure in the presence of heat and moisture, the scales on the edges of the wool fibers interlock, preventing the fiber from returning to its original position. Felting shrinkage is irreversible. The felting property of wool is both an advantage and disadvantage. In a controlled situation the felting quality is called fulling or milling and creates a softer finish for woven wool fabric. Felting is also an advantage because it provides for a wide variety of non-woven felt fabrics for hats and for industrial uses. Felting is a disadvantage because it makes the washing of untreated wool fabrics difficult. Treatments have been developed to prevent felting shrinkage, allowing wool garments to be machine-washed. The process involves a mild chemical
treatment applied to the fiber to form a microscopic film of resin that spreads evenly over the fiber surface. The film reduces friction and thus eliminates entanglement. The resin can’t be washed or worn off; it is held in place permanently by chemical adhesive bonds.

**The Five Factors of Felting**

When wool fibers are subjected to an alkaline solution with heat, the fibers start to do some peculiar things. It starts to swell and uncurl and the scales open up. When we add the third component of agitation to the mix we then have the stage set for good fulling. In general it is agreed that there is no one factor that causes wool to felt, but rather a combination of a number of factors.

The first and most common is the interlocking of the epidermal scales on the surface of the wool fiber. As the fibers are worked against one another the scales become locked. That is logical but it does not explain why some fiber with good scale profile felts poorly.

The second is creep. Under external stresses the fiber tends to migrate, or travel, towards it's root ends pulling adjacent fibers with them.

The third is that in a low alkaline solution the wool fiber has excellent elongation and recovery properties. The theory is that under certain conditions and with a number of fibers in the same space, the fiber will stretch and recover forming a tighter and tighter mass with its neighbors.

The fourth is the natural twist of the fiber. When placed in water or in a saturated atmosphere the fiber tends to twist and revolve quite rapidly until they come to rest. When that same fiber is placed in a dry atmosphere it wants to return to it's original dry form and will twist and revolve back trying to get there.

The fifth is similar to the fourth but looks at the difference between how the cuticle and cortex of the fiber react under wet conditions. The theory is that the cortex tends to contract more than the cuticle under wet conditions and therefore causes a curl of the fiber that it gives up when dried.

### 3. WEB CONVERSION METHODS

Theoretically any thermoplastic could be a hot melt. In practice the polymer needs ideally to be solid up to 80°C.

### 5.7. Coating and Laminating

Coating is a basic and exceptionally important form of finishing for non-woven bonded fabrics. The way in which the coating is carried out depends on the substrate, the machinery available, the substance that is to be applied and, also on the effect desired. Slop padding: It is one of the best known methods of direct coating. The coating is put on with a rotary roller, the surface of which is covered in the substance to be applied. The slop padding roller is fed directly with the laminating float by being dipped into it or using special feed rollers.

—Powder point method
Figure 7.31: Powder point coating.
-Coating by rotary screen printing

Figure 7.32: Coating by rotary screen printing
-Spreading or squeeze
Laminating is the permanent jointing of two or more prefabricated fabrics. Unless one or other of the fabrics develops adhesive properties in certain conditions, an additional medium is necessary to secure bonding.

Wet laminating: Adhesives used in the wet process are dissolved or dispersed in a suitable solvent. The simplest form of wet laminating consists of applying the adhesive to one of the lengths of material that is to be joined, and to put the second length on it with the required amount of pressure. Then drying, hardening or condensing the material that has been joined together is carried out. The solvents can be macromolecular natural or synthetic substances and water.

Dry laminating: All kinds of thermoplastics are used for dry laminating. These include powders, plastisols, or melt adhesives, and are applied to the substrates that are to be joined together using suitable machinery. Dry laminated non-woven fabrics have a soft feel.

3.7.1 Hot-melt coating and laminating

The non-contact DispensJet module dispenses small dots onto a variety of substrates at cycle rates of 12 to 15 milliseconds. Adhesive or coating material is fed into a chamber where it is temperature conditioned for optimal machinability.

Using a ball and seat design, the coating material fill the void left by the ball as it retracts from the seat. As the ball returns, the force breaks the stream of material jetted though the nozzle. The broken stream of material strikes the substrate and forms a dot. The DispenseJet module is a self-contained valve that incorporates a syringe to supply the material into the jet. The valve is designed to deliver unprecedented dot repeatability of ±3%.
One of laminators is the "Roll Laminator". This style of laminator uses rolls of laminate that are pressed between two rubber or silicon rollers to apply the laminate to the document. Size of the laminator can vary from 12" to 80" in width with as many features as there are sizes. Among these laminators there are two types, which are "Hot" or "Cold". A "Hot" laminator has the advantage of using either hot or cold laminates, whereas the "Cold" laminators only use cold laminates. Even though they may look identical, they're not!

Hot laminators heat the roller or rollers up to temperatures that can exceed 240 degrees. The heated roller(s) activates the glue of the laminate as it is being fed through the machine. This laminator can also use cold laminates by not heating the roller(s). One option that you may have is that both the upper and lower rollers can be heated. A distinct advantage when encapsulation is needed. The dual heated rollers allow for encapsulation of a printed item in one pass, similar to the above mentioned "Pouch" laminators. There are specific roll laminators that are designed for dye sublimation processes. The laminator is outfitted with steel rollers that can reach temperatures greater than 400 degrees.
Hot laminate

Heat activated adhesive (glue)

Heated roller

Laminate face

Cold laminate

Removable liner

Adhesive (glue)

Roller

Laminate face

Roller

Figure 7.35: Hot and cold laminating.
In Küsters' Thermo-laminating Ranges two or more fabric webs are bonded by temperature and pressure between two rolls. This can be done either all-over with smooth rolls or partially with an engraved roll. If, additional to pressure and temperature, a bonding agent is used, different kinds of materials can be laminated. Various speeds and variable line forces are possible.

Figure 7.36: Principle of laminating calender

Coatings available include polyethylene, polypropylene, polyester, metalloccenes, and other specialty polymers. Custom-matched colors available, including light-opaque carbon black.

Various types of coater/laminators, a solventless adhesive laminator are available. The complementary silicone coaters are intended for paper production and extrusion coater/laminators focused primarily on producing coated and laminated nonwovens in rollstock and sheets for medical, automotive and related applications.

Various type of polymers and copolymers can be used to laminating. The polymer can be coated on one substrate or the second substrate may be added (fig7.7).
Figure 7.37: Solventless Adhesive Laminating

It is possible that the polymer is coated between two layers simultaneously (fig. 7.8).

Figure 7.38: Plastic Extrusion Laminating

**Spray laminating**

A reactive polyurethane glue is heated until it becomes liquid. This requires a temperature of about 150°C. The liquid glue is pumped to a number of specially designed spray nozzles (see fig. 7.9). These nozzles atomize the polyurethane glue uniformly over one of the two substrates to be laminated. Immediately after the glue has been applied the second substrate is pressed onto the first one. The polyurethane glue is cross-linked by the moisture in the air. After about 6 hours the laminate is suitable for further processing. As the glue is
finely distributed by the spray nozzles a very thin layer of glue can be applied. As little as 1.5 g.m\(^{-2}\) is possible. The process control in the spray technology is such that the extremely thin layer of glue is distributed over the full surface, while the dosed amount can be set very accurately.

![Spray coating/laminating diagram](image)

**Figure 7.39: Spray coating/laminating.**

### 3.7.2 Flame laminating

By flame-lamination one understands the making of a compound of 2 or 3 components; single-lamination (fig.7.10), sandwich-lamination (fig.7.11) by using the adhesion characteristics of the foam which is melted by the line-gasburner.
Figure 7.40: Flame-laminating. One burner using.
Flame-laminating-machines are used to join thermoplastic materials like foam made of polyester, polyether, polyethylene or various adhesive foils and textile, PVC-foils, artificial leather, nonwovens, papers or other materials. Depending on the machine construction, single- or sandwich- laminations can be made. The materials are taken from bales or plates (flat-base-laminating-machine).

3.7.3 IR heating

The IR energy is passed through the translucent material and collected by the colored material. The energy is then passed back to the translucent material by conduction, causing both materials to melt and upon cooling, form a very strong bond. IR welding of polymers is fast, relatively inexpensive, and readily adaptable to containers of various sizes and shapes.
Figure 7.42: IR laminating.