

Ultrasonic bonding of nonwovens

Gary Flood

Ultrasonic methods for improved bonding of nonwovens go back 20 years, but applying these to current challenges can still benefit producers.

The commercial use of ultrasonic energy in the nonwovens industry is a relatively new event, although other industries have been enjoying the benefits of this unique form of energy for many years. The practical benefits of ultrasonic energy were first realized during World Wars I and II in the form of SONAR, as used for tracking submarines. Commercial uses were found in the following years in a number of different industries.

Historically, one of the most successful uses has been in the field of nondestructive testing, specifically for measuring thicknesses, detecting flaws, and inspecting welds and braze joints. Using echo signal techniques, we can detect flaws, cracks, and other defects without damaging the product being examined. The laboratory knowledge of 20 years ago came to fruition in nondestructive testing to give us an almost indispensable inspection tool for mass production (1).

Nondestructive testing established ultrasonic energy as a practical commercial process for industry. Soon several other ultrasonic techniques made an impact on industry in other areas, such as ultrasonic cleaning, machining, metal welding, chemical processing, and rigid plastic welding.

Today, ultrasonic energy is a well-established tool of any industry using thermoplastic materials. The first major use of this technology in fabric and fiber bonding goes back to 1970 and is probably best known in the textile industry for ultrasonically formed mattress pads and bedspreads using the Pinsonic™ process. The Pinsonic process established the foundation for using ultrasonic energy to laminate and form nonwoven fabrics and products. Ultrasonic bonding has much promise in the nonwovens industry because of the advantages inherent in the welding of thermoplastics by ultrasound. Ultrasonic welding is fast and efficient. It shows good bond integrity, it eliminates consumables, and it can be automated (2).

Ultrasonic equipment

There are many patents relating to the continuous bonding of thermoplastic fibers and blends, and the list grows daily. Our patent search revealed many interesting concepts, but

their usefulness was limited by the available technology. In 1966, when Ronald Bull received his patent, the most powerful ultrasonic equipment for welding fibers was limited to about 100 watts, and ultrasonic horn technology was limited to horns of about 1 in. in diameter.

Today, improvements in ultrasonic equipment are broadening the scope of practical applications. The ultrasonic horn is a key element in the bonding system, since it delivers energy to the bond site. The horn must be able to operate continuously day after day, and it must also maintain even amplitude along its entire work face. Patented horn designs that meet these requirements are now available. Horns from 7-9-in. long are in production today and performing reliably on a 24-h/day schedule.

Ultrasonic power supplies are also important factors in a total bonding system. Today, we have extremely reliable power supplies capable of generating over 3000 W of power and featuring automatic frequency control and the ability to supply current at a constant amplitude regardless of load. Additionally, some of these units are microprocessor controlled to monitor power levels, to control amplitude, and to coincide with today's material handling machinery for computer-integrated manufacturing. The combination of new horn technology, power supply development, and accumulated experience in bonding pattern design has enabled machinery builders to make production equipment available that can take advantage of the innovative thinking that has and is still occurring (2).

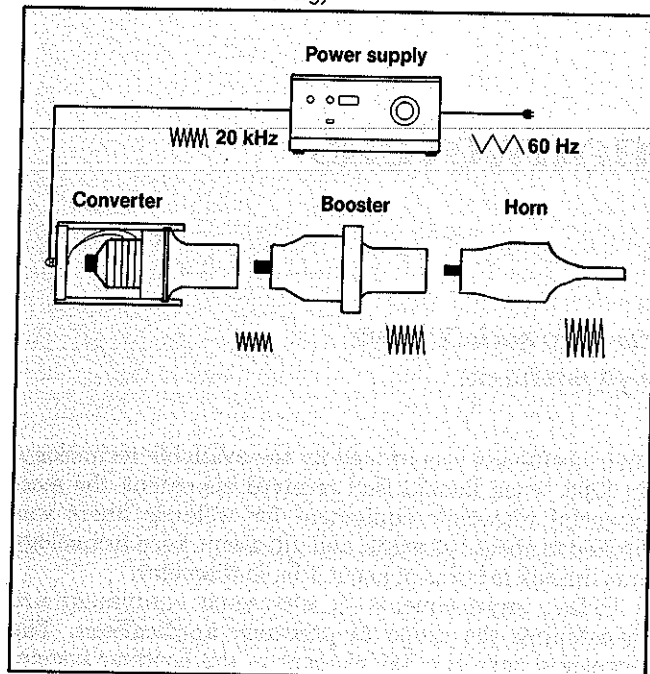
Theory

Ultrasonic energy is simply mechanical vibratory energy which, by definition, operates at frequencies beyond audible sound. These frequencies exceed 18,000 Hz, the upper threshold of the normal human hearing range, and they span a wide range. When melting and reforming thermoplastic is involved, as in the bonding of nonwoven fibers, the frequency most commonly used is 20,000 Hz (3). Frequency selection is based on power levels required and the size of the ultrasonic tools, both of which are affected by frequency. It is easier to generate and control high power levels at the low ultrasonic frequency, and ultrasonic tools are resonant members whose size is inversely proportional to frequency.

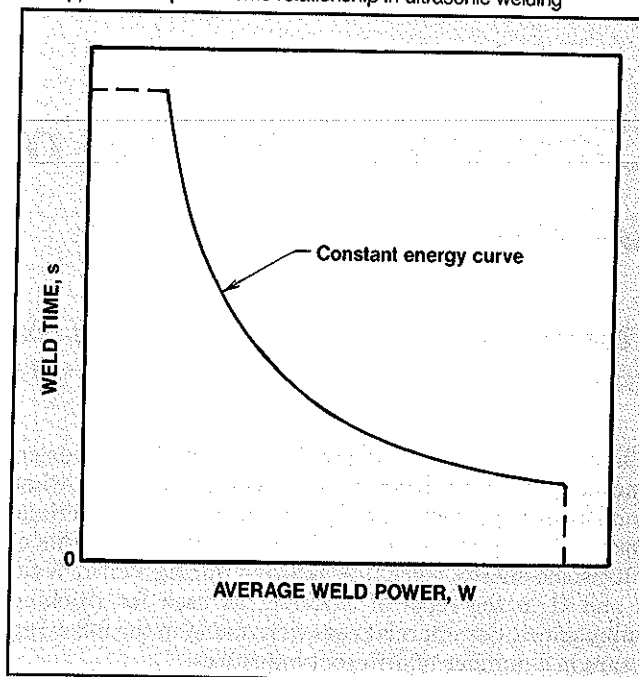
The generation of ultrasonic energy starts with the conversion of simple 50- or 60-Hz electrical power to 20,000-Hz electrical energy by a solid-state power supply.

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1. Generation of ultrasonic energy



2. Approximate power-time relationship in ultrasonic welding



The power supply also controls the amplitude and the frequency of vibrations. High-frequency electrical energy is conducted to an electro-mechanical converter, or transducer, where electrical energy is converted to mechanical vibrations, which are then amplified by an amplitude transformer (booster) and the ultrasonic tool (horn) before being applied to the workpiece (3). The final working amplitude of the horn face is typically 100 μm (Fig. 1).

Ultrasonic process variables

There are only three ultrasonic process variables: amplitude, pressure, and time. Our objective is to supply energy to melt and bond fibers. This energy is a function of the power used and time, where the power used is a function of the amplitude of the horn vibration and pressure.

These process variables are roughly established by experience and are adjusted to meet the specific needs. In actual production, these variables are easily controlled. Amplitude is determined by selecting the booster and the horn design and is automatically and accurately controlled or by regulating the electronic power supply. Pressure is usually generated by a pneumatic press and is easily adjusted and regulated. Time is a function of throughput speed, which determines the dwell time of the fiber under the ultrasonic horn.

Other variables, which become fixed, are weld area, fiber type, and the amount of fiber. Within certain limits, the ultrasonic variables can be changed in relation to one another to get the same result (Fig. 2). However, a change in one ultrasonic variable (such as in fiber type, blend, or weight) will require changes in one or more of the other ultrasonic variables to ensure that adequate energy is supplied to the bond area. Since the goal is to ensure constant energy input per unit area of the material to be bonded, all variables must be established and controlled.

The process

The process for welding or bonding thermoplastic fibers is simple. Pressure and vibration are applied to the area to be bonded, which causes intermolecular mechanical stress. Thermal energy is released, which, in turn, causes softening to occur at points of limited contact where stress is at a maximum (Fig. 3). Exposure time is controlled to ensure that adequate energy is delivered into the material to achieve a bond.

Since we are mainly interested in continuous bonding, the concept can be expanded by changing the stationary fixture to a rotary anvil (Fig. 4). By controlling the throughput speed (the time of exposure), energy input is controlled to optimize bonding. Various patterns are designed to give specific results based on material qualities and product use. A simple extension of the rotary anvil idea to a rotary drum with multiple ultrasonic horns across its length opens the door to the laminating, or forming, of wide webs (2).

Bond site dynamics

Bonding thermoplastic fibers with ultrasonic energy requires that the fibers be simultaneously exposed to pressure and vibration to meet the simplified power formula:

$$P = F A \quad (1)$$

where

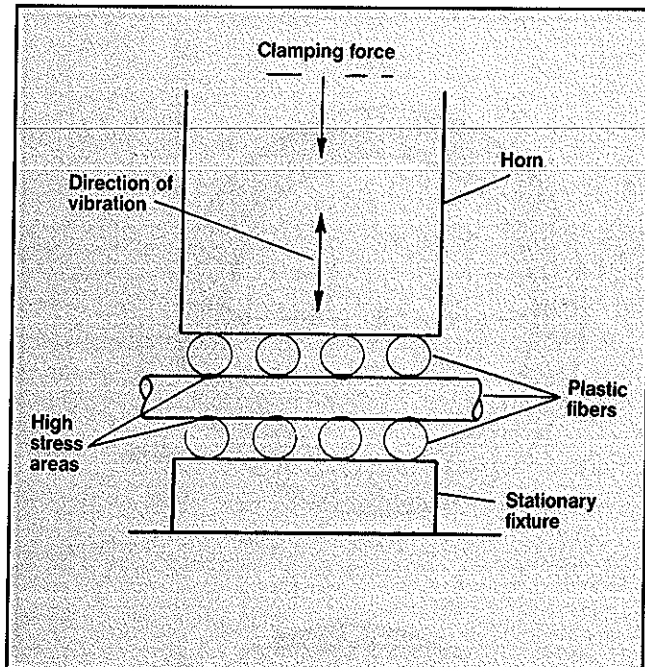
P = power

F = force

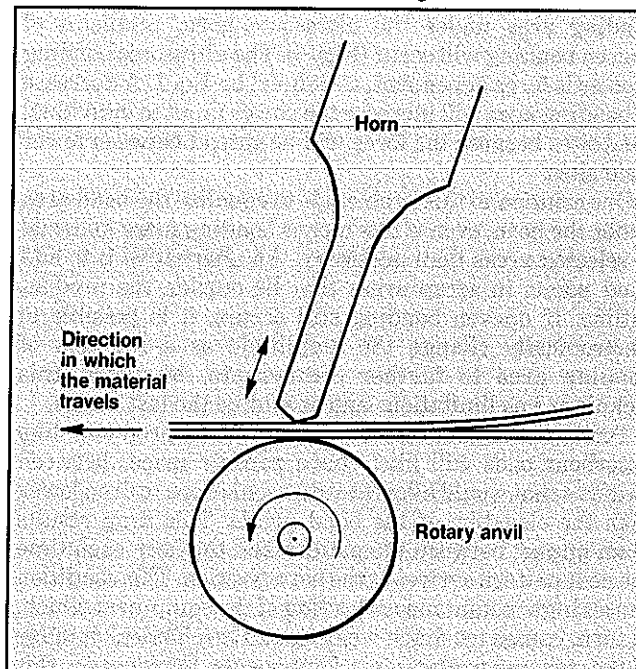
A = amplitude of vibration.

Adding a fourth component, time, completes the energy formula:

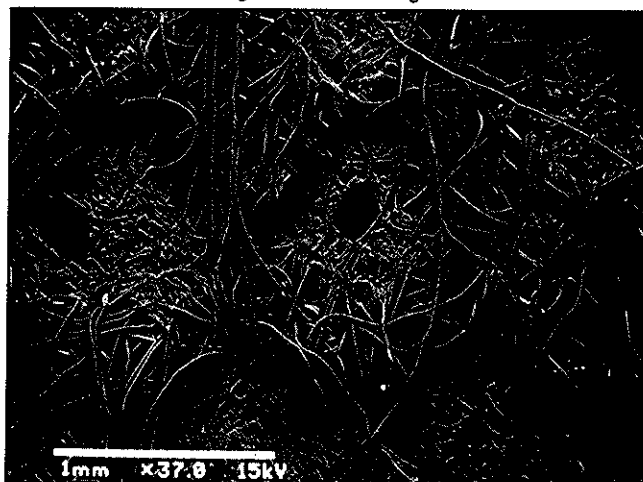
3. Textile joint with melting at high stress areas



4. Rotary anvil concept for continuous welding



5. A bond site with enough fibers for a strong bond



$$E = P T \quad (2)$$

where

E = energy

P = power

T = time.

Each individual weld or bond site requires a specific amount of energy to achieve a satisfactory bond, and the bond site should be sized to achieve the optimum bond requirement. If the site is too large, energy (and by definition, time) is wasted. Too small a bond site results in inadequate bonding. When an optimum number of fibers are involved within the smallest possible bond site, enough fibers are captured to achieve web integrity and strength (Fig. 5). These fibers are bonded with the

minimum energy required; thus, the bond site fibers retain much of their original characteristics, and fibers adjacent to the bond site are unmodified.

Other considerations

Elevation of the bond point

Another important factor relating to bond-point dynamics is the elevation of the bond point from the primary surface of the drum. Generally, the higher the loft of the web or the higher the basis weight of the web, the higher should be the bond-point elevation. In light of Eq. 1, there is a possibility, depending on the bond-point elevation, of adding undesirable power to the areas between bond sites. If the bond-point elevation is too low relative to the web thickness, force could be applied to the web between the vibrating ultrasonic horn and the primary surface of the drum. The result would be some modification of the web surface in these areas and a corresponding waste of energy. There may be cases where this intermediate bonding is desirable, but it should be planned as part of the design and not achieved by mere accident.

How high a bond point can be depends on its overall shape. A truncated cone or pyramid could be quite high. However, straight sided projections are currently limited to about 4 mm in a pinned Pinsonic™ drum. Bond point height is limited by the increasing tendency of the projection to flex and fatigue.

Uneven surface area and gaps

These considerations about bond point are directly related to regular, high-density bonding patterns intended for wide web forming or laminating. Two additional factors must be considered when designing drum patterns for the bonding of small, two-dimensional products like an absorbent pad or a glove. These factors are (a) uneven bonding area and (b) gaps between patterns.

If the bonding pattern causes large changes in the bonding area under the ultrasonic horn, problems of uneven bonding will occur (Fig. 6). The ultrasonic bonding process is force dependent, as defined by Eq. 1. A decrease in bonding area will increase the power input to individual bond sites because the force will be spread between fewer bond sites.

One solution to this problem is to equalize the bond area under the horn, even if this means bonding more material in selected areas than necessary. An alternative is to add bond points in scrap areas that lie outside the product outline. If uneven bonding still occurs, it is possible to electronically change the amplitude as a function of bonding area to further compensate. However, this technique has limitations and should be the last choice.

Tooling designed to bond individual products like absorbent pads will likely have gaps or spaces between patterns that would allow the ultrasonic horn to drop lower than the elevation of the bond points. This drop results in an impact between the pattern and the horn each time the next pattern arrives at the horn position. This condition causes high instantaneous loading of the equipment which, in turn, causes too much welding and mechanical damage to the web and to ultrasonic components. Fortunately, this serious problem can be solved. The preferred solution is to use a cam to lift the ultrasonic horn above the surface plane of the bond points when the gap is passing and then precisely lower it again as the next pattern approaches. This solution can be carried out with great precision using known cam design technology (2).

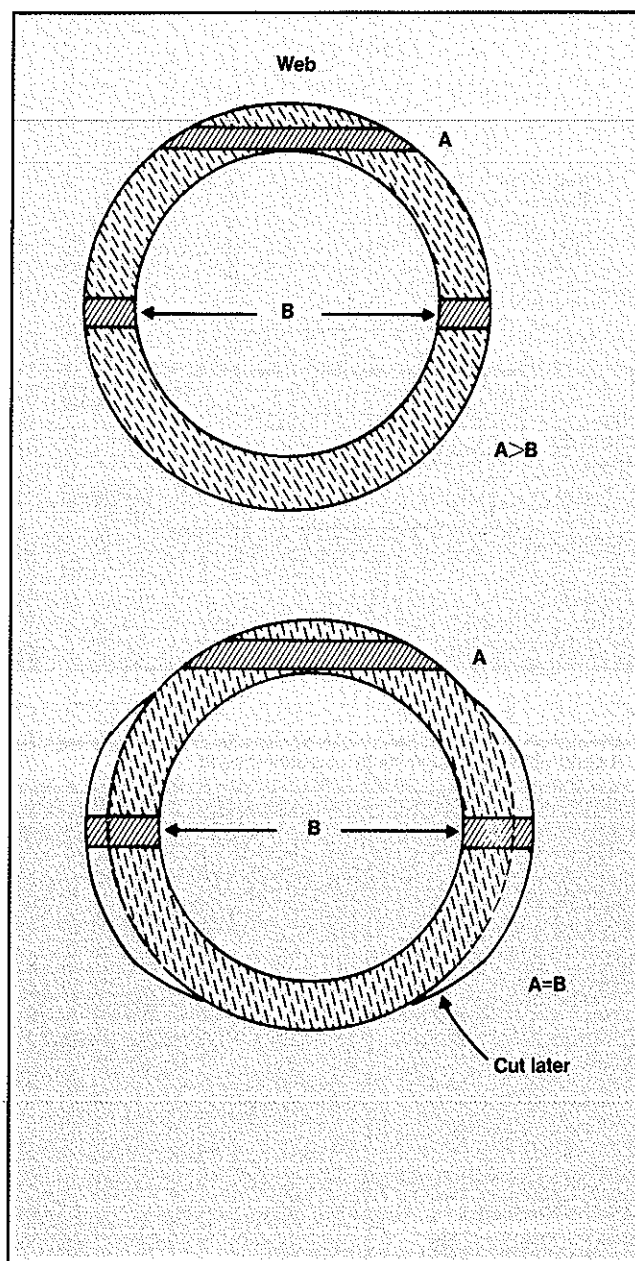
Benefits of ultrasonic bonding

Understanding what ultrasonic energy is and how it is generated and controlled is fine. However, a fair question now is—so what? Why use it when there are so many other techniques for forming, or laminating, or bonding? What is the difference between ultrasonic bonding and other techniques such as stitch bonding, needle bonding, chemical bonding, or thermal bonding?

The answer is that ultrasonic bonding can compete with or complement some of the more common processes because, first, no consumables such as chemical binders or needles and thread are required. Second, energy is only needed and expended at the precise location and area of the bond site. Third, heat energy is *not conducted* through the fiber to be bonded but instead is generated within the fibers, minimizing the degradation of materials through excessive heat. (This is a major difference between ultrasonic and thermal bonding.) Finally, compared to some processes and fabric weights, the ultrasonic process is faster with reported speeds approaching 150 m/min (2).

Specific benefits are realized when bonding fibers of low melting temperature, particularly the olefins. The low softening and melting temperatures of these fibers makes temperature control an even more critical variable. Since the ultrasonic process does not involve thermal conduction and the tooling is relatively cool, it is much easier to maintain bonding energy within desired limits, and there is little danger of web damage outside of the bond site area from hot tooling. Even slow startup speeds and temporary slow downs will not cause damage to the web. This same benefit is achieved where a film with a low melting

6. Correction of uneven bonding by enlarging bond area



temperature is combined with a fibrous web.

Further, since thermal conductivity is not a variable, bond-point elevations can be much higher, making possible the bonding of high loft products that exhibit soft hand. This circumstance is particularly pertinent with spunbonded olefins.

A final benefit is the conservation of energy. Analysis of the energy input into a single bond point under typical bonding conditions shows that an ultrasonic system, delivering 500 W of energy to a web of 15% bond density provides an equivalent energy density of 814 W/cm² while using only 2.12 W per bond site. By comparison, a thermal calender must provide between 6 W and 25 W per bond site (considering lost heat) in a typical bonding application. (See the appendix.)

Appendix: power calculations for a typical example

The bond pattern has a density of 15%, or 58 points in an area of 1 cm². Therefore, a bond point has an area of:

$$\begin{aligned}\text{bond point} &= 0.15 \times (1.00 \text{ cm}^2/58 \text{ points}) \\ &= 0.0025 \text{ cm}^2\end{aligned}\quad (\text{A1})$$

Ultrasonic horn

The machine is running at 76.25 m/min with polypropylene-carded web at a basis weight of 68 g/m². The ultrasonic horn has an area of 1.2 cm × 18.42 cm. The instantaneous contact area for two rows of bond points is

$$\begin{aligned}\text{inst. contact area} &= 0.221 \text{ cm} \times 18.42 \text{ cm} \\ &= 4.07 \text{ cm}^2\end{aligned}\quad (\text{A2})$$

The instantaneous bond area then is:

$$\begin{aligned}\text{inst. bond area} &= 0.0025 \text{ cm}^2 \times 58 \text{ points/cm}^2 \times 4.07 \text{ cm}^2 \\ &= 0.614 \text{ cm}^2\end{aligned}\quad (\text{A3})$$

The ultrasonic horn uses 0.5 kW of power. Each bond site uses

$$\begin{aligned}\text{power/site} &= 0.5 \text{ kW}/(58 \times 4.07) \\ &= 2.12 \text{ W}\end{aligned}\quad (\text{A4})$$

Calender

A typical calender uses 10–40 kW/m² of surface area (4). Assume that the calender has a circumference of 80 cm. The surface area is

$$\begin{aligned}\text{area} &= 18.42 \text{ cm} \times 80 \text{ cm} \\ &= 1473.6 \text{ cm}^2\end{aligned}\quad (\text{A5})$$

The power used then is found by

$$\begin{aligned}\text{power} &= 0.1474 \text{ m}^2 \times 10 \text{ kW/m}^2 = 1.47 \text{ kW} \\ \text{power} &= 0.1474 \text{ m}^2 \times 40 \text{ kW/m}^2 = 5.89 \text{ kW}\end{aligned}\quad (\text{A6})$$

The power per bond site is

$$\begin{aligned}\text{power/site} &= 1.47 \text{ kW}/(58 \times 4.07) \\ &= 6.23 \text{ W} \\ \text{to} \\ \text{power/site} &= 5.89 \text{ kW}/(58 \times 4.07) \\ &= 24.9 \text{ W}\end{aligned}\quad (\text{A7})$$

The potential range, therefore, is 6.23–24.95 W per bond site.

Applications

Without a doubt, the oldest application of ultrasonic bonding of this type is the familiar Pinsonic process for laminating webs of nonwoven fabric, fiberfill, and woven shell fabric in the formation of mattress pads and bedspreads. About half of the pads and bedspreads used in the United States are now produced by this process. Ultrasonic bonding is particularly attractive for these fabrics because it eliminates the mechanisms and costs associated with needles and thread and it allows us to run virtually any pattern design without compromising productivity or quality. In fact, the product is more durable because there are no threads to snag or pull.

When ultrasonic quilting was begun over 15 years ago, productivity went from 2 m/min to 10–20 m/min. This

difference does not include the downtime for needle and thread maintenance inherent in conventional sewing.

Other than bedding, there are a number of interesting production applications. For example, sanitary napkins with end seals can be produced ultrasonically on a rotary drum. Production speeds are 350–400 napkins/min. An advantage in using ultrasonic bonding is the fact that the tooling is relatively cool. A thermal bonding technique, on the other hand, can present serious problems if the machine jams, because thermoplastic material will melt and stick to the tooling, which then has to cool before it can be cleaned. This situation cannot occur with ultrasonic bonding.

Another interesting product is a high-density quilt formed from three plies, including a knit fabric, a fiber batt, and a film. The combination of high loft and material

would make thermal bonding difficult, and sewing would be slow, but quilting of this sort is simple for the ultrasonic process.

A point-bonded lamination of cover stock fabric and a thin nonwoven insulating web are the basis of a glove liner. In this case, dissimilar materials are successfully bonded because the insulating web melts and flows into the cover stock fiber of high melt temperature, forming an excellent mechanical bond.

A unique use of the process involves an absorbent pad bonded around its periphery on a rotary drum. Here, bonding takes place through the absorbent nonthermoplastic fiber. Heat is generated internally, and external pressure is applied, forcing molten thermoplastic into the nonthermoplastic fiber. No burning or degrading of the materials occurs. In the drum design, careful attention was given to instantaneous bond area. The bond width is varied strategically to achieve as much even loading of the ultrasonic system as possible.

Another example is a specialty fabric consisting of four plies. Two outside plies of thermoplastic nonwoven fabric and two inner plies of cellulose form the basic fabric for a clean room wipe. The result is a soft, absorbent product with relatively high loft. Production speed easily exceeds 60 m/min.

The future

What does the future have in store for the ultrasonic bonding process? Much depends on the needs of the market, but the unique method of energy transfer makes it likely that the process will be used more extensively in high-loft filter fabrics, geotextiles, and fabrics requiring qualities designed for human comfort. As new thermoplastic fibers are developed, particularly as low-melt and natural fiber substitutes, ultrasonic bonding would be a natural consideration for combining them with natural fibers, which do not transfer heat well.

Summary

By reviewing the patent history, we can learn how creative minds viewed the use of ultrasonic energy for bonding fibers containing thermoplastic. Many of these ideas were ahead of the technology and markets that would have made them economically feasible. However, refinements of these ideas, the development of the ultrasonic technology, and the accumulated experience in designing and operating tooling for the processes have made these ideas a practical reality. The ultrasonic process is a viable, practical process to be considered for broader use. □

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