Packaging with Ultrasonics

Sealing. Ultrasonic sealing is a reliable and economical alternative to typical contact heat sealing. Narrow seams, tight seals in spite of product contamination and high efficiency in terms of energy usage characterize the latest technology that provides optimal protection for the fill goods.

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Various methods are employed to join thermoplastic packaging materials or composite materials with a thermoplastic sealing layer. In the past, most methods involved heat contact, and all accompanying processes, including the packaging material, were optimized accordingly. There is a distinction between contact and noncontact joining methods, which differ in the manner by which energy is introduced and how the thermal energy is generated (Table 1).

In the case of hot sealing, composite materials with an outer thermoplastic layer are joined by applying heat and pressure. The thermoplastic sealing layers bond together. The type of packaging material and the joining method affect characteristics such as sealing time, cooling time, sealing temperature and sealing pressure.

In the case of cold sealing, also called pressure-sensitive bonding or contact bonding, a substrate (carrier) material coated with an adhesive is bonded through application of pressure.

Given that – regardless of whether mono materials or composite materials are being joined ultrasonically – only the joining zone is heated and melted to any extent, the process of ultrasonic joining is subject to the technological conditions for sealing of packaging. Thus, the expression ultrasonic sealing can always be used no matter what the structure of the packaging material is.

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Acoustic Principle Converts Mechanical Energy into Heat

Ultrasonic welding is based on the conversion of mechanical sound waves in a thermoplastic into frictional heat, resulting in material bonding at the molecular level. Sound represents the propagation of the smallest pressure and density fluctuations in an elastic medium (gases, liquids, solids). Frictional heat in a thermoplastic is generated by internal friction within the molecular structure as the result of deformation processes, absorption and reflection, and by external friction between the surfaces in contact with one another. Ultrasound encompasses the acoustic frequency range between 16 kHz and 1 GHz, with frequencies between only 20 kHz and 70 kHz finding use for technical joining applications.

Ultrasonic vibrations are introduced into materials in the form of longitudinal waves (Fig. 1). The amplitude of vibration is one-half of the amplitude of oscillation and for typical joining application lies between 5 and 50 µm.

Ultrasonic Vibrations from a Reverse Piezoelectric Effect

The frequencies are created in an ultrasonic generator. The line voltage is con-

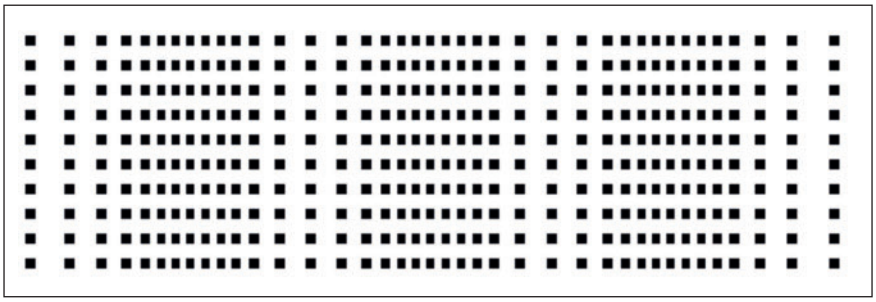

Fig. 1. Longitudinal waves are pressure waves where zones under compression or expansion propagate. The atoms or molecules in the substance vibrate back and forth in the direction of propagation by the amount of the amplitude

verted into a high voltage that oscillates at an ultrasonic frequency. In the converter, the oscillating high voltage is transformed into a longitudinal mechanical vibration through use of piezo ceramics that exploit a reverse piezoelectric effect, causing a mechanical resonator to vibrate.

Noncontact methods		Contact methods		
Radiation	**Convection**	**Friction**		**Heat contact**
		Internal friction	External friction	
• Infrared • Laser • UV	• Hot air	• Capacitive high frequency • Inductive high frequency	• Rotational friction • Oscillatory friction	• Continuous heating • Pulsed heating
		• Ultrasonics		

Table. Overview of the established joining processes

The resonator consists usually of a converter that is firmly connected to the sonotrode, or a converter, a booster and a sonotrode (Fig. 2).

The sonotrode is the active, vibrating and "cold" sealing tool, and introduces the vibrational energy directly into the packaging materials to be joined under the applied pressure.

Contact Area Determines Seam

In the sealing process, the packaging materials with the sealing layers to be joined are placed (facing one another) between the sonotrode and anvil. The ultrasonically generated frictional heat is created as the machine drive brings the resonator into contact with the packaging materials and introduces the mechanical energy into the sealing zone. The shape of the anvil and/or sonotrode, in conjunction with the small contact area between the sonotrode and anvil, focuses the energy on the desired area and causes the material to melt (Fig. 3). The anvil, which is usually contoured and has a reduced contact area, serves as a passive tool and must be decoupled vibrationally for optimal results. The contact area on the anvil defines the sealing zone, and thus the location where ultrasonically induced melting first occurs and from which the sealing layer of the packaging material is converted into the liquid state. When the ultrasonic energy is no longer introduced, the material in the sealing layer solidifies. Pressure is maintained as the melt cools for a material- and machine-dependent holding period. Following this, the machine drive retracts and the packaging materials are firmly bonded to one another. If there were a large contact area between the sonotrode and anvil, only irregular and random melting would occur. For this reason, ultrasonically created seams are narrower than heat contact seams, but are just as tight and as strong and conserve material as well.

Manner Used to Generate Melt Increases Hot Tack

The hot tack characterizes the strength of the seam immediately upon conclusion of the thermal joining process prior to cooling. The highest possible values are important, especially for vertical form, fill and seal machines (VFFS), since the seams are subjected to a high load from the filling immediately after sealing. The major difference between ultrasonic sealing methods and heat contact methods can be seen in the temperature distribution (Fig. 4). With heat contact methods, the packaging materials are heated by means of continuously heated or pulse-heated sealing tools. The sealing temperature and pressure can be adjusted to suit the packaging material. The temperature is transferred from the surface of the packaging material into the interior of the seam, which is why the decomposition temperature of the substrate and barrier layer determines the temperature that can be used. Since the ▶

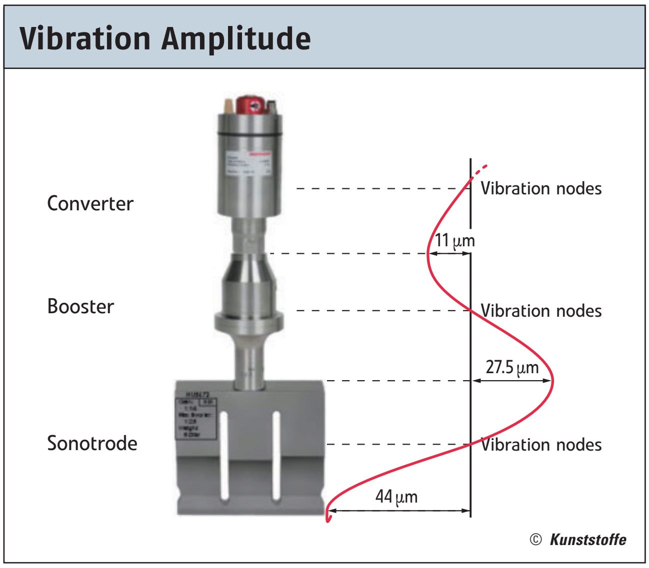

Fig. 2. The amplitude of vibration generated in the converter can be varied by using different mass ratios for the booster and sonotrode, and matched to the particular sealing task

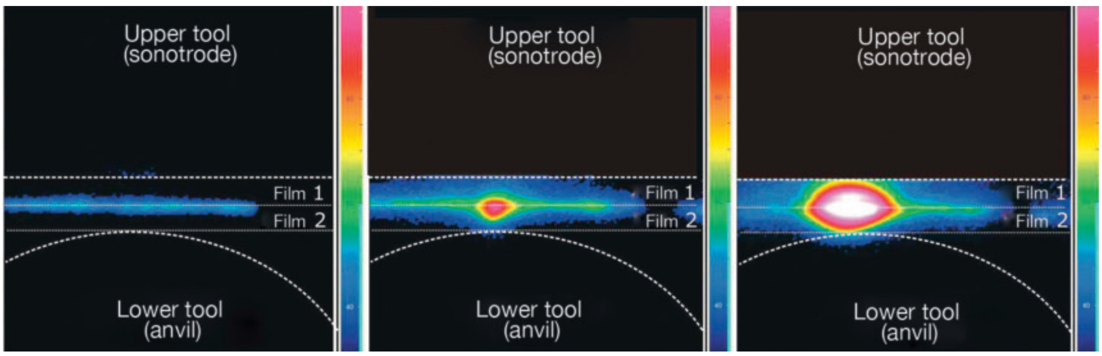

Fig. 3. Thermography – conversion of energy in the sealing layer (source: TU Dresden, Processing Machinery/ Process Technology Department)

Temperature Distribution

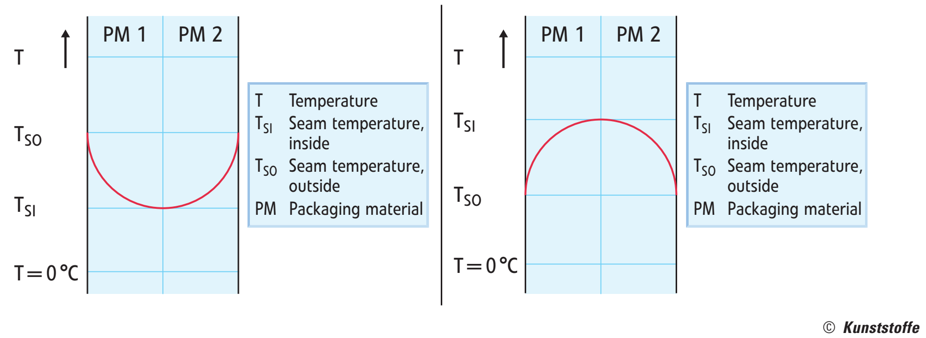

Fig. 4. Temperature distribution for heat contact method (left) and ultrasonic sealing (right)

temperature at the surface of the packaging material is higher than in the sealing zone, heat continues to flow into the interior of the seam after the sealing tool is removed. The hot tack is initially low, and a cooling period is required to achieve a strong seam. Furthermore, excessively high sealing tool temperatures cause thermal degradation of the packaging material (shrinking or burns), adhesion to the sealing tools or damage to the contents.

With ultrasonic sealing methods, the heat needed for melting is generated in the sealing zone only inside the seam (sealing layer). The substrate (carrier) layer remains practically cold, and when energy is no longer introduced, the heat dissipates to the outside more quickly because of the temperature difference between the substrate and sealing layer. The hot tack is considerably higher. The radar chart presents a comparison of advantages and disadvantages of the two joining methods (Fig. 5).

Tight Seams even with Product Contamination

The mechanical vibrations that are introduced into the small contact area of the joining zone by the sonotrode or anvil contour create the effect of "hammering". This mechanically drives any possible

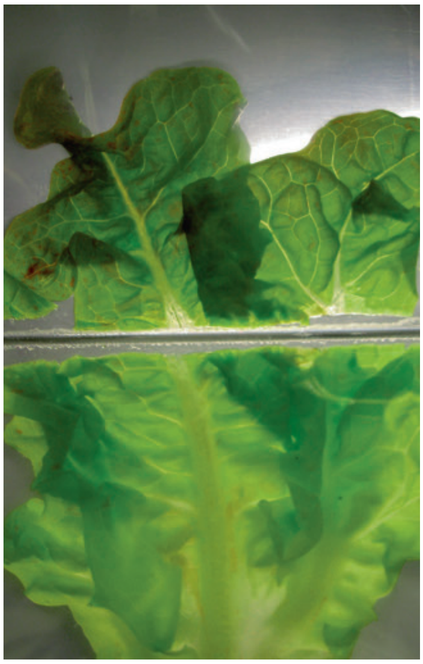

Fig. 6. An extreme example of reliable sealing of surfaces contaminated by the product

product contamination out of the sealing zone without trapping any residual package contents in the melt. This ensures a tight and strong seam even when the sealing layers are contaminated by the product (Fig. 6). Reliable sealing of surfaces contaminated by the product translates into considerably fewer leaky packages.

Since the tools are cold, the packaging material and package contents are subject to almost no thermal load. The time and effort required for cleaning is reduced and, even in the event of malfunctions during the filling process, the sealing tools do not become soiled, which is especially beneficial with temperature-sensitive products with a low melting point such as chocolate-containing or chocolate-coated contents. Use of non-stick coatings such as Teflon tape can be dispensed with.

Comparison

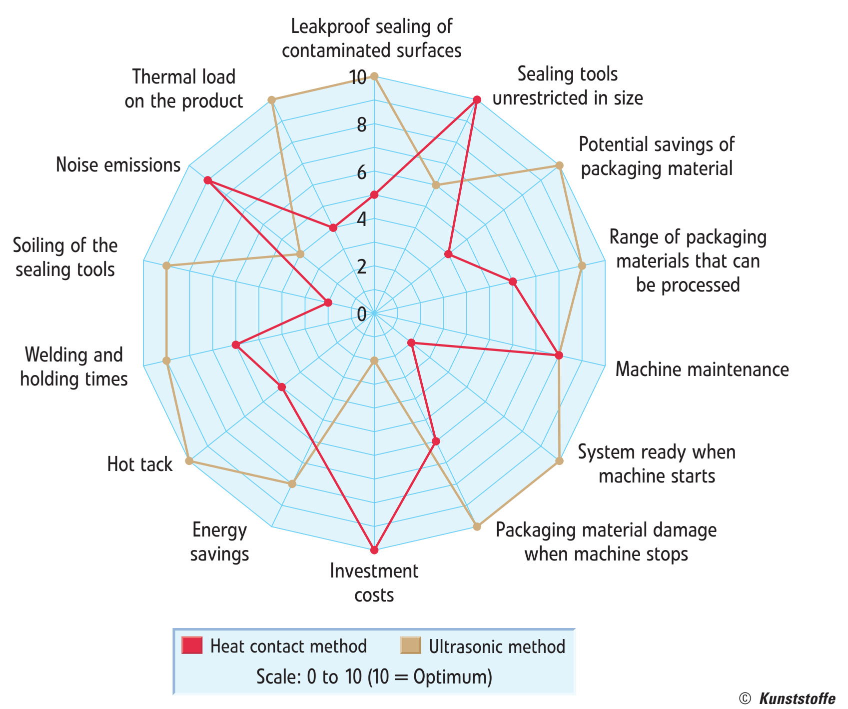

Fig. 5. The radar chart shows a comparison of the heat contact and ultrasonic methods (source: Bosch Packaging Technology)

Process Optimization and Troubleshooting

Ultrasonic sealing processes are defined by the following parameters:

- Sealing time,
- sealing pressure/force,
- generator power output,
- amplitude of ultrasonic vibrations,
- sealing energy,
- holding time/cooling time.

Thanks to the ability to adjust parameters to the sealing process, variations in layer thickness, moisture content, sealing force buildup and temperature differences can be recognized and compensated for within certain limits. The ultrasonic generator stores all data and through a comparison of reference and actual values permits a qualitative evaluation of the sealing process. Documentation, process improvements and troubleshooting are thus simplified.

Sophisticated Requirements for Machine Builders

In terms of investment, ultrasonic sealing systems are more expensive than tooling for heat contact methods and because of the controlled introduction of mechanical energy set high standards for processing machines, especially with regard to the quality of guide elements, the parallelism of sealing tools and the uniformity and adjustability of sealing force buildup. Because of the physical relationships between frequency and the speed of sound in the mechanical resonating unit, ultrasonic sealing tools are larger and heavier than typical heat contact sealing tools (Fig. 7).

Fig. 7. Ultrasonic sealing module for top sealing of standup pouches

Ultrasonic sealing systems are characterized by high energy efficiency, since energy is needed only while introducing the ultrasonic vibrations and, with sealing times between 80 and 200 ms, short cycle times are possible. These benefits become obvious, above all, when thick packaging materials or combinations of injection molded packaging materials and film are being sealed.

In contrast to the continuously heated tooling employed with heat contact methods, ultrasonic sealing systems can be operated immediately after they are switched on. By storing the sealing parameters in the ultrasonic generator's memory, it is possible to switch automatically between parameter sets. The changes take effect immediately with the start of the next sealing operation, which means no lost production time. Intelligent adjustment of the sealing parameters to changes in ambient conditions or the sealing process (for instance, slight heating of the ultrasonic tools) ensures uniform sealing quality.

Conclusions

Ultrasonic sealing is characterized by a number of beneficial features: Short cycle times with minimal dependence on the condition of the packaging material and high efficiency mean low costs for each sealing operation. This helps to lower operating costs. Neither the packaging material nor the package content is subjected to thermal loads or degradation. Stored parameters are readily available in the event of a product change. Reliable monitoring of quality is assured by documentation and comparison of reference and actual values. Seams are tight and strong, even when the surfaces are contaminated by the product. In addition, the hot tack is high. And finally, the narrow seams conserve packaging material. ■

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