Joining of plastic membranes using laser radiation

Application possibilities of laser technology in joining different functional membranes

Developments in processing technologies for the plastic industry have led to more detailed and precise production methods that are being utilized in processing in the membrane technology industry. Membranes are used for many different applications in several markets. In acoustics, for example, electrical signals are transformed into vibrations resulting in sound from speakers. In pumps, the flexing of the membranes results in the flow of the medium through the pump. In other applications, membranes are used for separation of media (e.g. gas from liquid).

A simple definition describes a membrane as a thin material that separates two rooms from each other. Membranes can be subdivided into three basic categories:

1) impermeable
2) semipermeable
3) permeable [1]

The diversity of membrane applications and base materials used in those applications results in the myriad of membranes. Deciding which membrane to use depends on the task being performed. However, no matter what task the membrane has to be joined tightly in order to separate the two rooms from each other. Joining methods can be divided in three techniques:

- thermal joining
- adhesive joining or gluing
- mechanical joining

Membrane applications in the automobile industry

In the automobile industry membranes are often used to seal electronic housings against moisture while allowing pressure equalization. Such is the use in the part shown in the photo on the right side.

Mechanical joining is rarely used on such parts, because additional components are required that would increase weight as well as production and storage costs. Using adhesives may increase the weight imperceptibly, but additional production steps like dispensing and curing raise costs as well. Only by applying a thermal joining method no additional process steps are required. However, thermal energy can affect functions of sensitive membranes and needs to be tightly controlled.

Thermal processes such as ultrasonic or hot plate joining melt large volume simultaneously by penetrating energy deep into the material. This can damage or limit functions of the sensible pores of the membrane. Applying both heat...
and mechanical clamping may cause the melt to be pressed out to the perimeter of the joining area and build a bead, which stretches the membrane and induces tension. In this context membrane functions can be affected, and in the worst case results in rupturing the membrane. On the example part, initial joining tests confirmed that the sensitive geometries of the pores were affected over a large area of the membrane when using hot plate welding. Water could penetrate and the membrane function was no longer present. Ultrasonic joining was successful, but resulted in a high scrap rate due to membrane rupture. Laser joining proved to be the best joining method for this application. With its non-contact energy input, small thermal and mechanical load, short joining times and high process stability it resulted in a strong bond that still allowed full function of the membrane.

Technical requirements for Laser joining of membranes

This joining technology is based on the principle of Laser transmission welding. The laser beam penetrates a plastic part, which is transparent to the radiation, and impinges on an absorbing one. The laser energy is converted into heat and the absorbing material melts. An applied joining force cause contact between the joining partners and heat is conducted into the transparent partner, allowing both partners to melt and create a bond. However, this principle typically works with compatible material pairings with approximately same melting temperatures. [2]

Material of membrane and housing are not always compatible. However, joining of semi-and permeable membranes may still be possible using thermal processes. These membranes are provided with fine pores that can be penetrated with melted plastic material. The melted material flows into the pores due to the clamping force applied during the process. While cooling, the base material shrinks and mechanically clamps the membrane to the housing. The advantage of using laser technology is locally applied energy. The sensitive membrane material is not damaged during the joining process. Tight control of the laser parameters results in a strong bond. A section through the joining area visualizes the permeation of the melt into the membrane.
The heat affected zone of the absorbing plastic is small and the material is only melted at the surface. The small amount of melt penetrates into the membrane, under a small mechanical load, without damaging the membrane. The micro pores of the membrane are fully functional outside of the joining area.

Laser plastic welding techniques (Shown in Figure) induce a smaller heat input than conventional thermal joining processes. The lower heat input reduces the danger of membrane rupture or micro pore damage. This makes laser joining a favorable process for membranes that are sensitive to heat and mechanical stress.

Options of quality control for laser joining of membranes

Which joining technique is best suitable for an application depends on production requirements (i.e. quantity, cycle time, production range, total cost and process monitoring). Process monitoring is strongly desired in many applications as traceability of parts becomes required. Depending on the technique and the product several monitoring methods may be applicable. In contour welding, monitoring or even controlling is possible by using a pyrometer to measure the heat generated in the joining zone. The pyrometer operates in a limited wavelength range, uses the same optical path as the laser beam, and detects the heat locally generated during joining. The thermal measurement and the laser spot are aligned to each other, guaranteeing accurate measurements of thermal radiation.

Using the pyrometer, within an optimized process, may allow detection of welding defects. Gaps between the joining partners could cause a short-term rise in temperature. Whereas, melted material penetrating the membrane may result in fluctuations in the thermal detection depending on the degree of penetration. In preliminary tests, a temperature range, also called envelope curve, is evaluated in which the bond is rated as good. This master curve (Pic 4) is used in quality control for data comparison. A typical temperature profile of a bonded component is set as a master curve (blue) and permissible deviations (red) are determined. Within this range, the process is rated as „good“, everything outside of the allowable values receives the evaluation of „bad“. This quality method requires constant laser power to work.
The control of the laser power by a temperature feedback is another option often used with sensitive material combinations. With a proper parameter setup, thermal impact can be kept constant and damage of the membrane or its functions can be avoided. However, the detected temperature curve is steadier and limits are more complicated to define. Nevertheless, short-term rises in temperature can be detected and compared to an envelope curve set in quality control tab.

Both methods, monitoring and controlling of target temperature, have been used in industry successfully. Other laser welding parameters (i.e. laser power, contact pressure, etc.) can be monitored and also used for process qualification.
Examples of Laser membrane joining

In laser joining of plastics four standard techniques indicating different thermal loads are common:

1) Contour
A spot shaped laser beam is guided along joining pre-programmed contour. The joining process ends after one cycle. The thermal load is small.

2) Simultaneous
The joining contour is adjusted by optical elements. Irradiation of entire weld contour is performed simultaneously with no additional movements. Compared to the other techniques the thermal load is the highest.

3) Quasi-simultaneous
A spot shaped laser beam is guided along the pre-programmed contour using high speed mirrors. Through multiple iterations the joining contour is heated almost at once, quasi-simultaneously. The thermal load is close to simultaneous joining.

4) Mask
A line shaped laser beam is passed over a stencil (mask) of a weld profile. The mask allows radiation only to pass along the open pattern, the rest is reflected. The thermal load is in between the other methods.

An example for mask welding of membranes is provided by Phonak, a medical company. Phonak manufactures disposables for hearing aids using the mask welding technique. In order to ensure the reliability of a good transfer of sound to the In The Ear (ITE) hearing aids, protection against dirt and moistures by cerumen, also called earwax, is required. To accomplish this, a 15 microns thick highly elastic polymer membrane is joined to a small carrier ring. The application requires a high mechanical strength and chemical resistance within a small welding area. The welding width is required to be a maximum 0.2 mm. [3]
In comparison with several different joining techniques mask welding proved to provide the best performance. Some techniques required pre-treatments of the surface (i.e. plasma irradiation and primer or adhesive dispensing) to achieve an acceptable bond. These pre-treatments affected the membrane unfavorably, altering its functionality. The thermal loads of most other welding methods were too high for the sensitive membrane material and therefore not suitable for production.

However, laser welding, using the mask welding technique, managed the requirements. In addition it surprised the customer with how cost-effective the technology was when compared to the alternatives. With the mask technology several parts were able to be welded in one production step. That increases the throughput and optimizes production costs.

In mask welding a line shaped laser beam is guided across a mask that contains information of the welding pattern. The mask is inserted between the laser source and the parts to be welded. The laser is only incident on the components where the laser light is not obstructed by the mask. Mask welding achieves a very high resolution and is suitable for any 2-D structure. In this application the mask is structured with several little rings, allowing production of several million parts per year. The components are positioned in a jig and mechanically aligned to the mask within a clamping device. The small welding area of the parts is only slightly stressed, thermally in near-surface layers and mechanically by small clamping force. The result is a full functional membrane with a strong and hermetically sealed weld.

Further information regarding this application can be downloaded on the Leister homepage, https://www.leister.com.
Pump technology is another large market for membrane applications. To ensure pressure-transmitting, the properties of membranes should be both extensible and strong. The joint between the base material and the membrane needs to be hermetically sealed with a corresponding strength close to that of the membrane’s properties. The miniaturization of pumps results in small mechanisms which transport small amounts of liquid. The pumps still need to be functional regardless of their weight or size. Presently, plastic technology offers production processes to manufacture extremely resilient, thin and sensible membranes that are perfectly designed for laser penetration joining.

Leister presented at the 2015 Medtec Europe exhibition an example of a pump application. The welding technique to produce the ring shaped welding zone had been evaluated between both simultaneous and quasi-simultaneous welding methods. Each method was well suited for the application, however simultaneous welding was preferred because equipment was both more cost-effective and smaller dimensioned. A welding time of less than 1 second for a welding diameter of 23 mm and a weld width of 1 mm, was achieved.

In this application laser radiation heats the entire joining path. The thermal stress is greater than with other laser welding technologies, but still less than all other thermal joining techniques. The functionalities of the membrane are not affected by simultaneous welding. During the Medtec show, visitors successfully proofed the strength of the joint with test equipment. For proving the strength of the weld, the welded sampled was subjected to increasing pressure until it burst. The parts never failed in the welding zone, but rather in the membrane material.

Literature: