Welded from the Ends

Advanced Laser Butt Welding for Joining High-Wall and Same-Material Parts

Thanks to technical advances which have made implementation easier, laser butt welding which was invented in the 1990s is now about to make the breakthrough. Aside from high-wall parts, it can be used to weld same-material polymers using precision laser technology.

Before now, the most commonly employed laser technique for welding polymers was transmission welding. In this, a laser beam passes through one part to be joined, which is transparent to the wavelength of the laser, into a second part which absorbs the radiation and converts it into heat. This absorption is achieved, e.g., by adding carbon black particles. Heating occurs through total absorption near the surface, whereby the laser energy is transformed into thermal energy. As a result of heat conduction, the transparent part in contact with the absorbing partner softens as well.

Advantages and Disadvantages of Laser Transmission Welding

The advantages of laser transmission welding lie in low heat input away from the root face. The technique is also virtually vibration-free and is counted as a particle-free type of welding. The welding process does not lead to any additional impurities in the part. It is therefore widely employed in medical technology and in the electronics industry. The most common variant of transmission welding is quasi-simultaneous welding. In this, the laser beam is guided along the welding contour with the aid of scanning mirrors at a high traversing speed of up to 10 m/s. Due to the high speed of the energy source, which is essentially a point source, the mating surface can be traversed several times, being heated in its entirety and plasticized almost simultaneously [1, 2].

The disadvantage of this technique is that the manufacturing process (injection molding) for the two parts to be joined requires separate material and mold handling. Furthermore, there are restrictions with regard to the shape of the transparent part and, above all, to the thickness of the polymer material. Depending on the material used, the height of the layer through which the laser beam passes may be a few millimeters only, i.e. not too high.

Turn2Weld technique: the newly developed welding machine uses one laser per part and swivels the machine tables through 90° toward the laser scanners with the aid of servo motors (© bielomatik)

Laser welding has several competitors, e.g. heating tool, infrared and hot gas welding, with which it is possible to weld uniformly colored parts having high-wall lids and shells. However, the disadvantage of these is that the heat radiation cannot be focused sufficiently and they can therefore influence sensitive parts both optically and functionally – usually in a relatively uncontrolled manner. Furthermore, these techniques require a part-specific heating medium (heating tool, IR emitter, hot gas heat exchanger and manifold), and that adds to the tooling costs. »

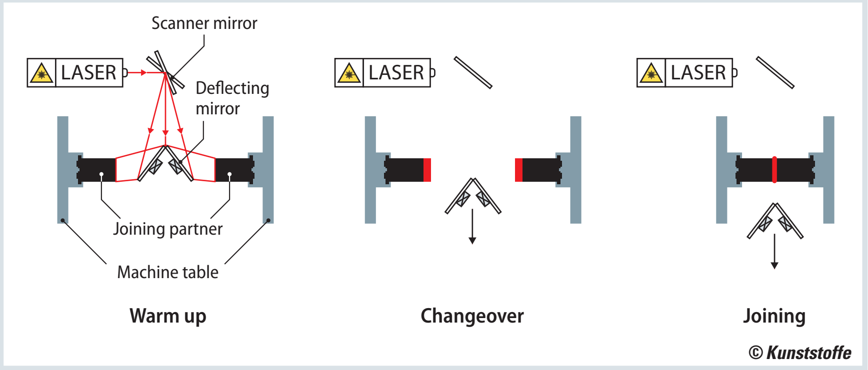

Fig. 1. Functional principle: in conventional laser butt welding, the aligned parts were heated by means of deflecting mirrors which were positioned between them and had to be returned to the home position prior to joining [1, 3] (source: bielomatik)

The Alternative: Laser Butt Welding

In the 1990s, laser butt welding was described as a new variant of laser welding for joining same-material, high-walled plastics with the aid of a laser. It was claimed that it would close a gap in the market at that time. Unlike transmission welding, laser butt welding involves two absorbent parts.

Since it is not technically possible for the parts to be melted and joined in parallel, laser butt welding is a two-stage technique, as opposed to (single-stage) transmission welding. As in conventional welding techniques (e.g. infrared or hot plate welding), the parts to be joined are positioned on two machine tables. During the warm-up phase, deflecting mirrors traverse between the two parts. The beam emitted by the laser is deflected onto the deflecting mirrors by a scanner (**Fig. 1**).

In a manner similar to quasi-simultaneous welding, the scanner mirrors move at high frequency, such that the laser beam heats the weld seam homogeneously. Once the required welding temperature or melt layer thickness has been reached, the deflecting mirrors are moved back to their starting position, the machine tables move together and the two parts to be welded are joined. The result is a pronounced weld bead, like that produced by hot plate welding [3].

Disadvantages of Conventional Laser Butt Welding

Several factors prevented laser butt welding from establishing itself on the market. First, there was a very limited range of laser sources to choose from in the mid-1990s. At the time, polymer welding was usually effected with Nd:YAG lasers. However, these sources suffered from comparatively poor efficiency (< 5 %) and high maintenance costs.

Price-wise, too, because they were a novel development, such lasers were likely very expensive compared with a part-specific heating tool. The scanner technology in use when the process was being developed did not have today's speed, precision and repeatability, and were also inferior in terms of thermal drift and comparable influential factors. The greatest obstacle, from today's point of view, though, was undoubtedly the deflecting mirrors. In a mass production environment involving short heating cycles, lasers of 100 to 400 watts power would have had to be deflected in quick succession, relatively close to the part and therefore close to the point of focus. That calls for special, high-quality and possibly water-cooled mirrors, which are very costly.

Nor is guiding of the laser beam a trivial matter either, because during laser welding the part contour is usually derived directly from the CAD data for the root face. Due to the deflection (45° mirror angle), the software for producing the contour is highly complex because of the need to allow for the angle of incidence and deflection at the mirror and the variable distance between the mirror and the root face. Mechanical movement of the mirrors to reflect the radiation onto the polymer parts also raises the issue of positional repeatability.

Another weak point in the industrial production environment is certainly the

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References & Digital Version

- A PDF file of the article can be found at *www.kunststoffe-international.com/2019-6-7*

German Version

- Read the German version of the article in our magazine *Kunststoffe* or at *www.kunststoffe.de* susceptibility of the deflecting mirrors to dirt pickup. In certain circumstances, the small distance to the parts to be joined can lead to dirt deposition on the mirror surface. In the worst case, dust particles will be burned by the laser and the mirror will be damaged. All these issues and critical points apply to the technique shown in **Figure 1**, but they were never properly resolved because the technique failed to make the necessary breakthrough in industry.

The pneumatic drives used previously to move the mirror and the part axes were also a weak point. The accompanying long changeover and positioning times ran the risk that the heated polymer would cool down too much. In the case of high-melting engineering plastics, especially, e.g. polyamide 6 (PA6) or 66 (PA66), the material would form a skin prior to joining or would not have the necessary flow properties.

Further Development of Laser Butt Welding

The Turn2Weld technique developed by bielomatik (**Title figure**) eliminates the disadvantages of transmission welding (extensive mold handling, thin parts) and laser butt welding (poor positioning, long changeover times, problems with deflecting mirrors). It differs from laser butt welding in that the machine tables pivot. As a result, the deflecting mirrors can be eliminated altogether – removing positioning inaccuracies and leading to considerable technical and economic improvements. The Turn2Weld technique, too, involves two-stage welding. Servo motors swivel the machine tables through 90° toward the laser scanners and, to an extent depending on the machine size, can achieve changeover times of less than 1.5 s.

In order to melt the largest possible joining surface and compensate for differences in material or geometry, there is one laser for each part to be joined. Different laser sources are available to match the material and the absorption characteristics. Diode lasers are used for polymers which have been colored black with carbon black particles, while transparent polymers, such as PMMA and PC, can be welded with CO_2 lasers. It is also possible to combine CO_2 and diode lasers to weld a transparent part to a non-transparent part. Work areas vary with the machine and laser components employed, with up to 400 x 400 mm^2 possible at the moment. A power characteristic matched to the particular polymer varies the power during the warm-up phase, allowing the result to be optimized in terms of heat input, melt layer thickness and process time.

Aside from the laser components, the Turn2Weld technique only requires mounting tools for the two parts to be joined. The laser program can be adjusted by simply changing the program. This opens up scope for "One Piece Flow" production.

The only limitations on weldable parts – depending on the polymer used and the weld seam thickness – are the length of the weld seam. To achieve the same surface temperature with increase in weld length, it is necessary to deliver more laser power (**Fig. 2**). The maximum weld seam length also depends on the geometric properties of the parts to be joined. Studies have shown that the more complex the part geometry (T-joint, corners, edges, curves, folding ...) the slower is the resulting speed of the spot on the part.

In terms of quality requirements, the Turn2Weld technique offers a major advantage over most other types of welding. IR cameras can monitor the surface temperature of the parts throughout the heat-up phase. This is not possible in the case of welding techniques in which the heat source obscures the view of the root face and only snapshots of the temperature distribution after the warm-up phase can be taken after the heating element or IR emitter has returned to its default position. The Turn2Weld technique, in contrast, permits inline monitoring for rapid detection of quality fluctuations and implementation of countermeasures.

Conclusion: Conventional Technique and Laser Welding in Combination

The newly developed Turn2Weld technique is now production-ready, following almost two years of material testing, feasibility studies and prototype welding. It will be on show at the K 2019 trade fair in Düsseldorf, Germany, in October. In addition to high-wall parts, same-material polymers can now be laser-welded. What was previously the exclusive preserve of conventional welding techniques has now been combined with the advantages of a focused laser welding technique, thus closing the gap between laser-based and conventional polymer welding.

The welding technique still needs to be optimized in terms of part properties. Work is currently underway with universities and institutes to develop an irradiation strategy. The goal is to optimize the results for specific polymer materials and part geometries by performing computations and simulations on the welding parameters and the welding process. ■

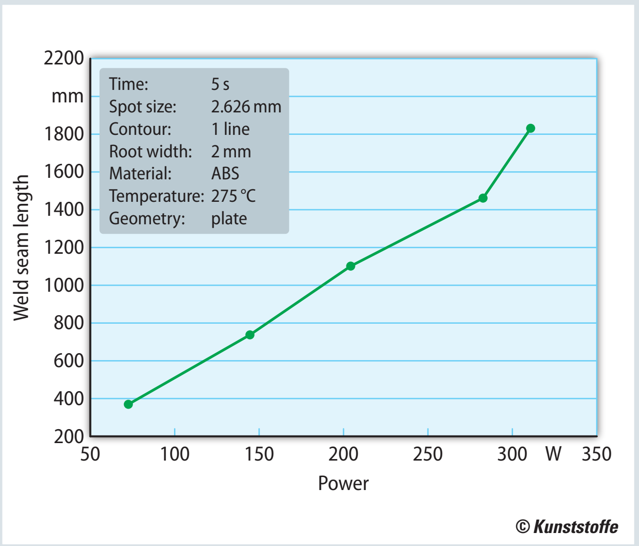

Fig. 2. More laser power is required as the weld seam gets longer [4] (source: bielomatik)