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# Advanced quasi-simultaneous welding – a new approach to laser welding of polymers

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**Abstract**

Evosys Laser GmbH is developing a new variant of laser plastic welding, the so-called Advanced Quasi-Simultaneous Welding (AQW). It combines two monochromatic laser beam sources of different wavelengths in a sequential time pattern. By using two different wavelengths in a quasi-simultaneous welding process, the specific deposition of radiation energy and heat into each joining partner can be better controlled. This results into a more reliable welding operation with an enlarged process window.

Trials employing the new AQW process show that a significant improvement in weld seam quality is possible compared to the standard process with only one laser source. Due to the wavelength of the secondary laser, more energy is deposited in the transmissive joining partner. The increased volume of plasticized material in this part is leading to an increased weld strength. Furthermore, it facilitates processing high-performance thermoplastics which often impose challenges to the laser welding process.

Keywords: Laser Plastic Welding; Laser Transmission Welding; Quasi-Simultaneous Welding

## 1. Introduction

Due to its numerous advantages, the laser beam welding of polymers is an established and preferred joining technology in plastics engineering. The commonly applied principle is the so-called laser transmission welding, where the parts are joined in an overlap alignment with one single laser source. The joining parts therefore need to have differing optical properties: the laser beam is focused through the laser transparent

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upper layer onto the contact area of the laser absorbing lower layer. Most of the radiation energy is absorbed and transformed into heat in the lower part and again it is distributed into the upper layer by heat transfer. As a result, both parts are plasticized, and the relative motion of the laser beam creates the weld seam. Preferred laser sources are diode lasers emitting within a wavelength area of approx. 800 nm to 1000 nm. In this range, most of the engineering thermoplastics are transmissive enough to be used as the transparent joining part, whereas the absorption properties are usually adjusted by the addition of laser absorbing additives, e.g. carbon black. (Klein, 2011; Frick, 2007)

This process principle and dependency on the heat transfer from one joining partner to the other carries along various disadvantages. Especially in the case of the contour welding process, the parts need to be geometrically very accurate in the contact area. With contour welding, the laser is moving along the welding path only once, so gaps can hardly be bridged. Secondly, the temperature gradient between the two components is comparatively high during the welding process which has an impact on residual stresses in the joint area, in particular with highly transmissive, amorphous polymers such as polycarbonate (PC) or polymethylmethacrylat (PMMA). These disadvantages limit the process window, for example with regard to the maximum possible feed rate and hence minimum processing time. (Klein, 2011)

In order to reduce the drawbacks of the laser transmission welding method, the so-called hybrid welding technique adds a secondary radiation to the primary processing laser. For example, the secondary radiation can consist of polychromatic light, with the aim that certain portions are absorbed and transformed into heat in the upper joining partner. This part is not significantly affected by the primary laser wavelength, because most relevant polymers show a higher absorption rate at typically longer wavelengths of the radiation. In conclusion, the upper layer is not only warmed through heat transfer from the lower layer and the temperature field is more homogenous which again allows for a more robust process. (Hofmann, 2006)

A new approach to employing multiple beam sources is currently being developed by Evosys Laser GmbH. In contrast to the state of the art method, the work piece is not irradiated simultaneously by both of the primary and the secondary sources, but the radiation is sequentially switched in between both in a certain time pattern. By this strategy and a purposeful selection of the applied wavelengths, the selective deposition of radiation energy into the upper and the lower joining part can be better controlled and adjusted to the desired process results. Since this development especially targets at a quasi-simultaneous welding process, a monochromatic laser is used as secondary radiation source. It facilitates the integration into the commonly used beam guiding systems, such as a galvanometric scanner based system.

The following chapters describe the investigations made by Evosys Laser GmbH applying this technique and employing a 980 nm diode laser as primary source and a 1940 nm fiber laser as secondary source. At the wavelength close to 2 µm, the used materials polycarbonate (PC) and polybutylene terephthalate (PBT) have a significantly higher absorption rate compared to the primary radiation (Fig. 1 exemplary shows the absorption spectrum of PC).

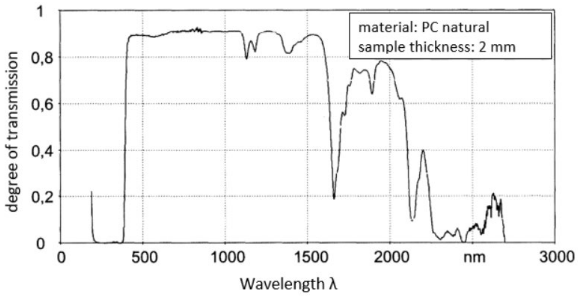


Fig. 1. Transmission spectrum of PC [Hofmann, A., 2006]

The main target of this processing method again is to push today's process limits and to enlarge the process window by warming up the transmissive joining partner with the secondary laser source. This allows for more complex applications as well as a more efficient, reliable and faster welding operation. In the following, it is called the "Advanced Quasi-Simultaneous Welding" (AQW).

The experiments were carried out in two steps. The first investigations were conducted with a comparatively basic setup. Because of the promising results, a highly automated system for the new Advanced Quasi-Simultaneous Welding was developed in the second step to investigate the process and its benefits further.

In both setups, a T-joint geometry is selected in order to simulate the typical joint alignment of a quasi-simultaneous welding process. Two flat plates represent the joining parts, which are fixed and pressed onto each other using a clamping tool. A defined clamping force ensures the thermal contact and fusion in the joining area. The (quasi-)simultaneous plasticization of the entire weld seam allows for a movement of the laser transparent layer towards the absorbing part which results into the so-called welding collapse. It is a commonly used process parameter and is measured by a tactile distance measuring sensor. The sequential time pattern of the radiation of the two beam sources is realized by a control unit based on a real time microcontroller system. It is switching the emission between the primary radiation and the secondary radiation with a defined frequency.

## 2. Preliminary tests

### *2.1. Setup*

The setup of the first tests is displayed in Fig. 2. Both lasers are focused onto the joining area. The work piece is moved with a set feed rate by a high performance electric axis. In order to simulate a typical quasi-simultaneous laser welding process, several overruns are being applied. Collapse and welding time are measured.

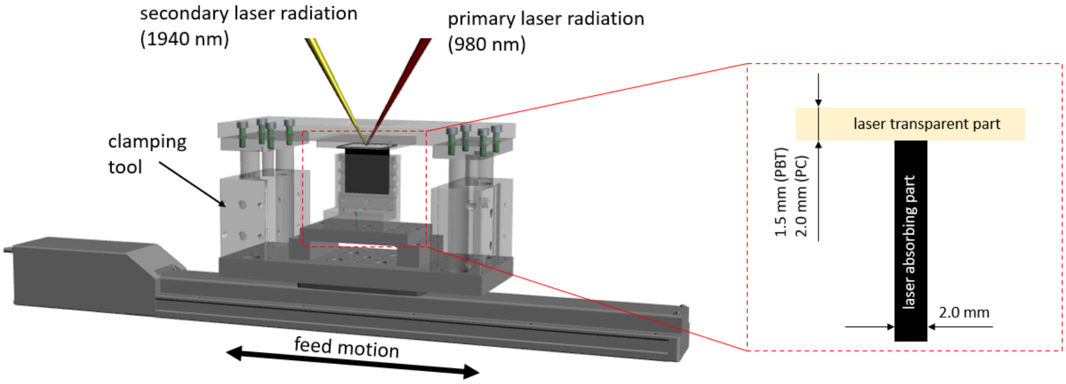


Fig. 2. Test setup, clamping tool mounted on an electric axis

### *2.2. Materials*

The material specimens are flat plates of two different thermoplastic groups. The thicknesses are shown in Fig. 2. One material is PBT, a semi-crystalline thermoplastic, commonly used in the automotive industry for parts with high strains during usage. Because of its high crystallinity and comparatively low transmission rate, the existing process window is limited with the risk of surface burn marks on the laser transparent part at higher laser energy inputs. The second material is PC, an amorphous, optically highly transmissive polymer that is especially used for displays, lighting or other applications, which require a high transparency. Apart from the carbon black coloration of the laser absorbing part, both materials do not contain any further relevant additives.

### *2.3. Parameter variation*

To examine the impact of the AQW on the welding time improvement, the standard process is compared to the new process. Several frequencies for switching the lasers are tested as well as different laser power settings of both lasers.

### *2.4. Preliminary results and conclusion*

The results of the preliminary tests indicate that welding with AQW can lead to a significant reduction of the weld time when welding PBT and an increased tensile strength of PC compared to the standard process with only one laser source.

Because of these promising results, a system with additional components was developed to investigate the process and its benefits further which is describe in the next chapter.

## 3. Current Investigations - AQW system

### *3.1. Setup and system technology*

The system developed for Advanced-Quasi-Simultaneous Welding differs from the setup of the preliminary tests. For greater flexibility and broader application possibilities, a galvanometric scanner is used instead of the electrical axis. Hence, in this setup the working piece is in a fixed position whereas the laser beams are moving.

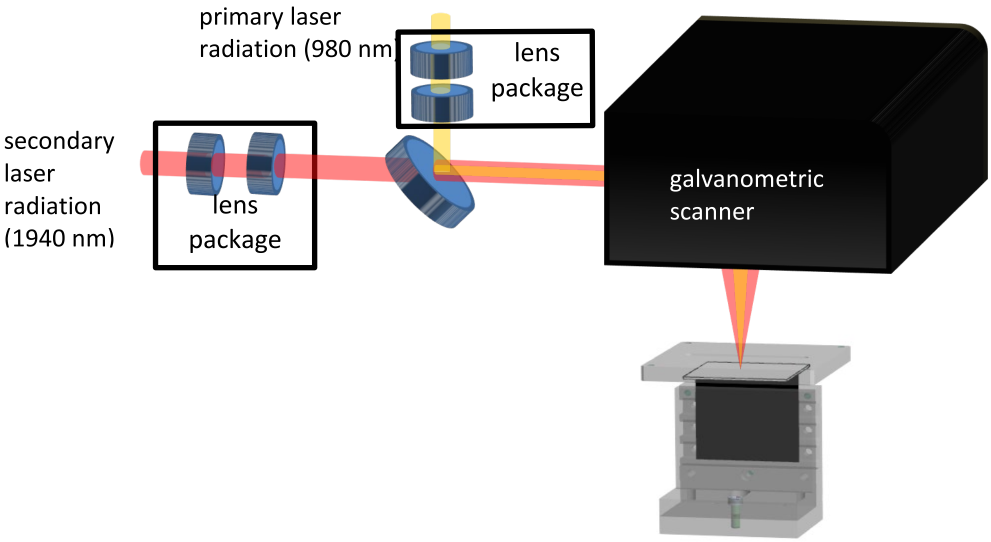


Fig. 3. Setup of the AQW system

Since both laser beams have to be deflected by using only one scanner, they have to be focused separately and combined before the scanner as shown in Fig. 3. Focusing each laser individually is leading to greater variability. The beam of the primary source can be defocused when necessary. For the secondary beam source, a specially selected lens combination works as a beam expander in order to adjust the beam diameter from 3 mm to 6 mm.

The system technology of the AQW process is more sophisticated than the one of a conventional process, because both lasers have to be very well adjusted temporally and spatially to apply a precise amount of energy into each joining part. One challenge is that the beams have to be perfectly aligned, another is to switch the individual lasers exactly alternately, since they have different delays when being switched on and off. If the individual pulses overlap temporally, this leads to an excessively high power density in the material potentially causing thermal damage. If the pulses are too far apart, however, the material cools down considerably, leading to an increased welding time. For this reason, the switching behavior of the two lasers has to be investigated in detail.

With the aid of two photodiodes and an oscilloscope, this can be analyzed. The photodiodes are placed close to the beam path where they detect scattered light, thus indicating the emittance of the laser. The diagram in Fig. 4 a) shows the signals of both diodes when the laser-on signals are triggered. The emission of the lasers overlap by some milliseconds due to the delayed reaction when switching off the lasers. By comparing the delay between the laser-on/laser-off signal to the actual emission, the delays can be accurately measured, allowing them to be compensated in the program of the microcontroller system. The emission of the beam sources after correction is shown in Fig. 4 b).

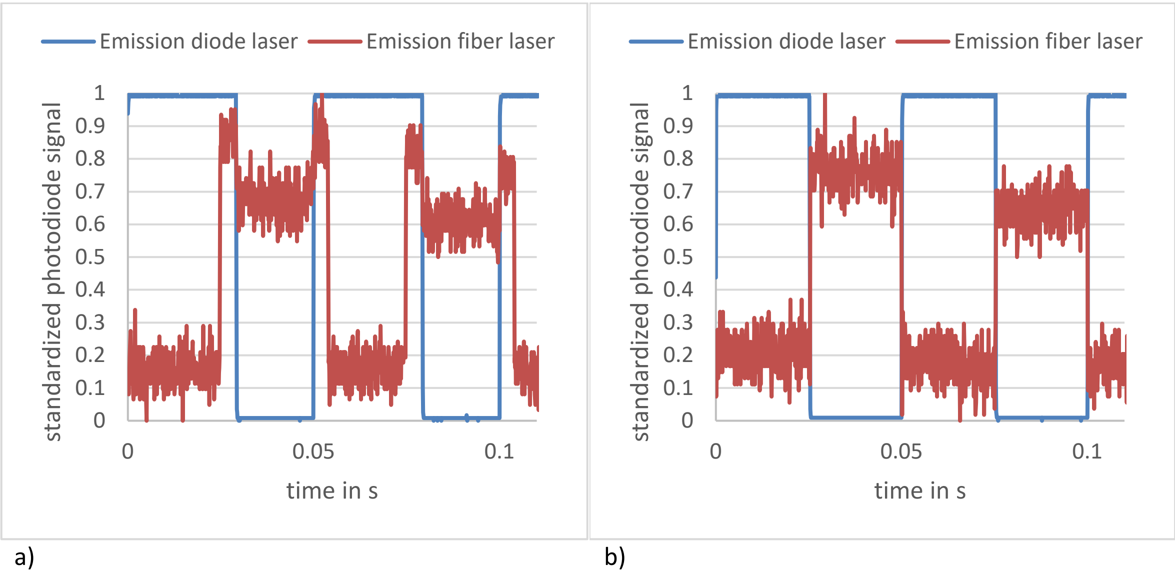


Fig. 4. Measurement of the laser emission with photodiodes: a) without correction, b) with correction

### *3.2. Material and parameter variation*

The first tests are carried out using similar PC samples as in the preliminary investigations. To reflect a process that is common in industrial mass production, a feed rate of 800 mm/s and a collapse-controlled process with a set collapse of 0.2 mm are chosen. This means that the process is stopped when a welding collapse of 0.2 mm is reached. The welding time is measured as well as the total collapse after a certain cooling time.

To examine the improvements by AQW, first the upper limit of the conventional process window is determined with both lasers separately. This limit is defined by the highest laser power that can be applied without negative effects like burn marks on the surface or overheating the expelled melt. Afterwards, both lasers are set to this laser power and alternated in a sequential time pattern. Different frequencies for switching the lasers are tested.

In order to determine the weld seam strength, a tensile strength test is done to analyze the breaking-off force of the weld seam.

### *3.3. Results*

The upper limit of the process window for a welding collapse of 0.2 mm is reached at a laser power of 50 W for the diode laser and 51 W for the fiber laser. Further increase of the power leads to burned melt, therefore reducing the welding time by increasing the laser power is not possible. Through the altering radiation of both lasers using these parameters together with a switching frequency of 100 Hz, a significant decrease of the welding time is achievable (see Fig. 5). A reduction of the welding time by approx. 10 % is measured. A trend towards the increase of the total collapse when using AQW can be seen although it is not significant.

The reduction of the welding time is not limited to individual feed rates but can be reproduced at different feed rates as well.

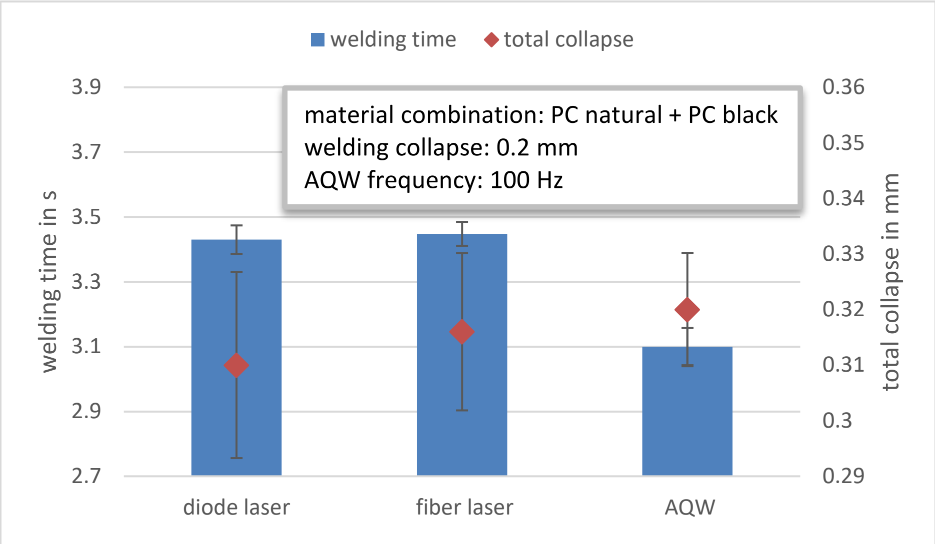


Fig. 5. Welding time and total collapse of conventional processes and AQW process

Tensile strength tests show that the weld seam strength of all components is in a similar range. Although the welding time is significantly decreased, the weld seam strength is maintained.

## 4. Discussion and Conclusion

Due to the wavelength of the fiber laser and the material properties, more energy is absorbed in the transmissive joining partner compared to the diode laser. By switching between these two beam sources, the deposition of energy in the two joining partners is better controlled. This leads to lower process times at comparable weld seam strengths. It can be assumed that more energy of the secondary laser source is absorbed in the transmissive joining partner resulting into an increase of plasticized and fused material volume of the transmissive part. Furthermore, the warming up of the upper joining part leads to a more homogenous heat distribution in the assembly, reducing the temperature gradient and thus leading to lower residual stresses. This is advantageous with regard to the weld seam strength. To prove these assumptions, in further experiments the tensile strength of conventional and AQW welded parts will be examined in more detail. In addition, the positive effect of AQW on welding other materials, like high-performance polymers, will be investigated.

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