HYBRID LASER WELDING OF POLYMERS

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Abstract

Hybrid laser plastic welding is a process to enhance the limitations of conventional laser plastic welding in order to provide a joining technology for large, three dimensional parts. Because of existing tolerances of injecting moulded parts it is necessary to provide a maximum gap-binding capability of the welding process. The poor capability of bridging gaps between the joining partners at contour laser welding and long cycle times are still limiting the range of applications.

At hybrid welding, the energy that is being deposited into the material is provided by a semiconductor laser and a secondary source of radiation, e.g. a halogen lamp, at the same time. A hybrid welding head provides one focal point of the laser and a secondary radiation source. The polychromatic emission spectrum of the halogen lamp causes a volumetric absorption of the incident radiation in the upper joining partner. This leads to a more symmetric temperature distribution around the welding plane and different lateral heat fluxes compared to conventional laser welding processes. This paper will discuss the effects of the larger temperature field and will disclose the benefits compared to conventional laser welding. Experimental results are showing that a larger process window and faster feed rates are possible. Compared to conventional laser welding the seam strength is in spite of a faster feed rate conspicuously improved. The gap-binding ability is rising with a hybrid welding system threefold. In consequence of the secondary radiation and the modified temperature distribution there are less residual stresses because the ability of the material to creep is stopped. The hybrid welding process is comparable to a laser welding process and a tempering of the material at the same time.

1 Introduction

The worldwide annual sale of plastic welding systems is predominantly made up by machinery employing either a friction or a hot plate welding technology [1]. Both technologies provide versatile and cost-effective welding systems. The use of these systems necessitates a contacting operation of the application-specific tool with the workpiece, either causing high mechanical loads implied on the workpiece or material partially adhering to the tool.

Once these deficiencies are a decisive criterion at the choice of a joining method, the contactless through-transmission welding technology with infrared radiation promises to be an auspicious approach. In this variant of radiation welding, the laser radiation penetrates the overlapping top layer, with little damping, and passes through to the joint zone where it is absorbed by the lower part. Thermal conduction, promoted by the clamping pressure, into the transmitting partner also leads to local plastification of the polymer there and thus ultimately to positive-type joints, as shown schematically in **fig. 1**.

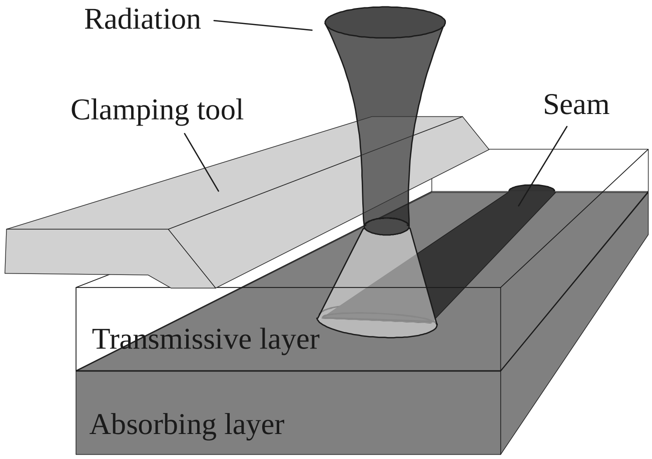

***Fig. 1**: Principle of through-transmission welding*

The first implementation of this principle dates back before the 1970's [2] employing incandescent lamps as a source of radiation. Due to the low levels of irradiance that are obtained from such lamps, the attainable feed rates have been limited to only a few mm/s [3].

In the 1990's, transmission welding using lasers as a source of radiation has been found to be especially suitable for welding electronic housings [4]. The well controllable energy deposition into the material combined with a satisfactory beam intensity contributed to an increased stability and efficiency of the welding process. Although various efforts have been taken to extend laser transmission welding on large, complexly shaped contours, none such application has been published up to the present day. In particular, the necessity of a permanent thermal contact imposes restrictions, as larger injection molded parts are afflicted with higher geometrical deviations that need to be compensated.

Hybrid welding of polymers is an approach to overcome this limitation. At hybrid welding, the energy that is being deposited into the material is provided by a semiconductor laser and a secondary source of radiation, e.g. a halogen lamp, at the same time. Thus, the required laser power, and subsequently to that, the costs for the laser beam source can be reduced.

2 Hybrid welding

Hybrid welding combines the advantages of laser welding, in the following referred to as "primary radiation" and infrared welding with halogen lamps, qualified as "secondary radiation".

2.1 System configuration

A big challenge is to pool the primary radiation and the secondary radiation in one focal point. The primary radiation, generated by a diode laser, is focussed by common optical elements such as fibers and lenses.

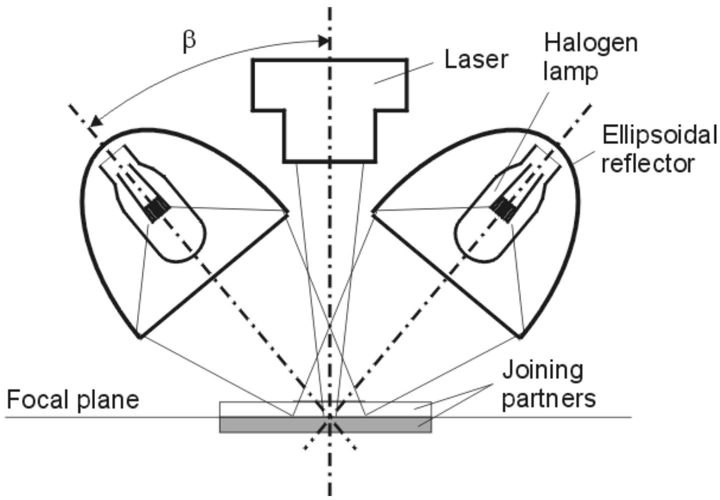

Fig. 2*: Alignment of primary and secondary radiation*

To focus the secondary radiation is achieved by putting the lamp filament into one focal point of an ellipsoidal reflector with its second focal point coinciding with the welding plane and the focus of primary radiation, **fig. 2**. Since the secondary radiation is non-coherent a short working distance between the welding seam and the lamp filament is decisive. Thus a maximum level of energy can be achieved to the focal point. The inclined alignment of the ellipsoidal reflectors causes the secondary radiation to be spread over a larger, elliptical cone section compared to the circular focus at perpendicular incidence. The minimal angle of incidence β is limited by the space required for the reflectors. The maximum potential intensity is reached by 81%. The total maximal level of irradiance of secondary radiation is obtained by a superposition of all the three sources. The spot diameter that can be obtained from this configuration has been measured to be approximately 10 mm.

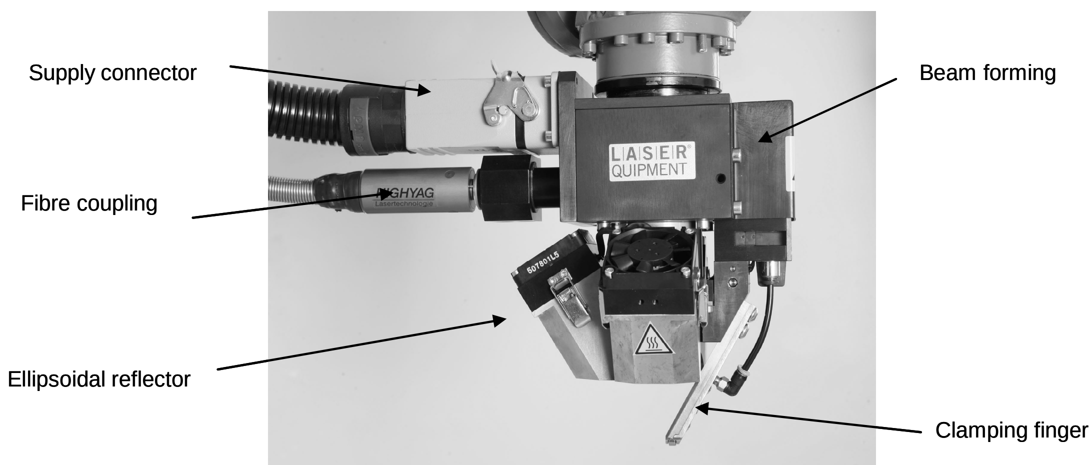

Fig. 3*: Hybrid welding head*

The hybrid welding head, as it is in industrial use, including halogen reflectors, laser optics and clamping tool is shown in **fig. 3**. In order to move the hybrid welding head along the complex three-dimensional contours it is mounted on a robot hand.

2.2 Process

Monochromatic laser radiation at typical diode laser wavelengths between 808 and 980 nm passes through a polycarbonate sample specimen of 2 mm thickness without being affected substantially (see **fig. 4**). The heat affected zone is being located at the absorbing joining partner. Previous investigations have shown that the strength of the weld seam increases with the depth of molten polymer in the transmissive layer [5].

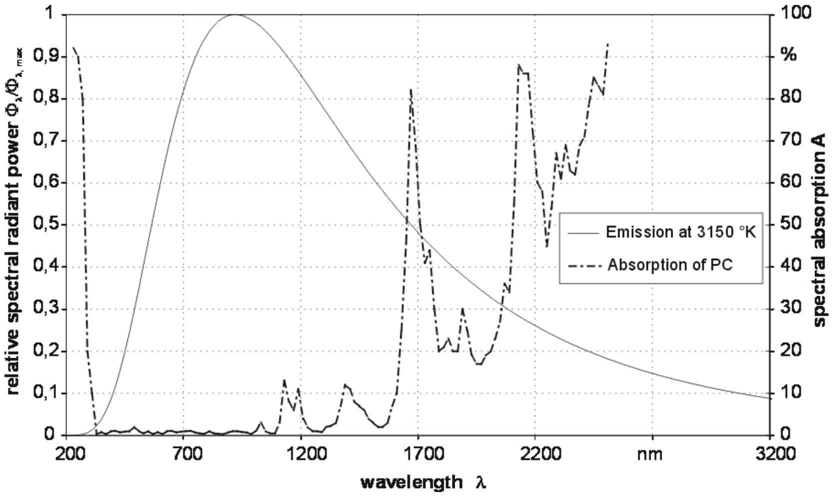

Fig. 4*: Spectral radiated power and absorption of PC*

An extended heat affected zone in the upper joining partner using the hybrid welding process is not only caused on heat conduction but also due to volumetric heating by the secondary radiation.

A further advantage can be deduced from the different interaction of both types of radiation with light-scattering inclusions in the polymer, such as crystallites in semi-crystalline polymers or commonly used reinforcing glass fibers. The scattering that takes place in the semi-crystalline polymer homogenizes the secondary beam rather than to attenuate it. Nevertheless, the absolute level of irradiance is still higher at the employed laser radiation than at the secondary radiation by the order of a magnitude.

2.3 Experimental results

Experimental investigations have been carried out to determine whether the aforesaid predicted improvements are taking effect or not. Therefore, sample specimens made from black and natural polycarbonate, sized 40 x 20 x 2 mm^3 have been welded in an overlapping T-like alignment. The seam strength has been determined in a conventional tensile test, with the seam area being limited to 80 mm^2 by the thickness and the length of the absorbing joining partner. If a broadening of the seam occurred due to a deformation of the absorbing sample specimen at high rates of energy input, it has been taken into consideration while calculating the figures presented below [6].

Fig. 5 is a comparison of the tensile strength observing at a conventional laser welding process. It is used a laser power of 5 W with a hybrid welding process that additionally employed 160 W secondary radiation.

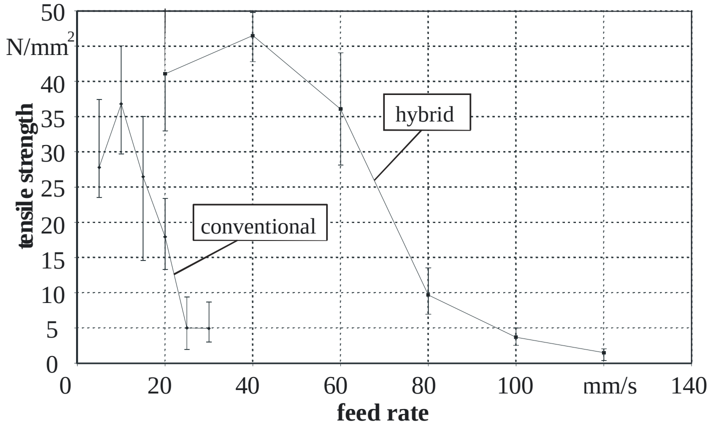

***Fig. 5**: Tensile strength of PC specimens*

Both processes are carried out with the hybrid welding system described above. Shifting the maximally attainable tensile strength to higher feed rates can be expected due to the secondary radiation that is superimposed to the laser radiation. Remarkably enough, the process has been accelerated by four times, whereas the total level of irradiance has only been raised by approximately 50 %. Additionally, a higher maximum tensile strength can be observed at the hybrid welding process.

Due to the existing tolerances of injecting moulded parts it is necessary to provide a maximum gap-binding capability of the welding process. In order to figure out the possibility of gap-binding samples are prepared with different gap depth. The length of the gap is 50% of the whole seam length. With the hybrid welding process it is possible to reach a seam strength of 71% with a gap depth of 0.2 mm. Higher gap depths prevent a compound of the joining partners. Using a conventional laser welding process a gap-bridging is impossible at deeper gaps than 0,1 mm. By using a clamping device together with hybrid welding a gap-bridging of 0.4 mm deep gabs is achievable.

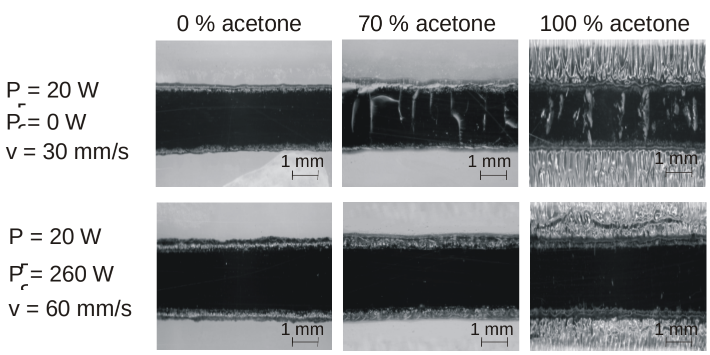

***Fig. 6**: Stress crack test using solvent*

Stress cracks result from residual stresses caused by the cooling of the welding seam. To reduce residual stresses welded parts are often tempered after the joining process. **Fig. 6** shows sectional views of the welding seam after 5 minutes dipping in a solvent. It is obvious that a hybrid welding reduces residual stress enormously. Tempering after the welding process is no more required.

2 Application report

One of the predestined fields of application for laser hybrid welding of plastic parts redisplayed sealed joints of tail lights for modern motor vehicles. Conventional joint technologies like adhering or vibration welding which are used in this area are often adverse. Joint lines have to be concealed to cover visual unsightly joint areas.

Alternative laser welding procedures for the welding of three dimensional plastic components have been compared with hybrid welding in a benchmark test by south Korean Automotive supplier SL Corporation, doing various tests with tail lights in the last months. The result is hybrid welding meets the requirements best in terms of optical appealing joint lines and a high firmness of the joint lines at highest process rates. The tail light housing had to be joint together with the cover glass by producing a visual appealing joint line.

The housing of the tail light is made from Polymethylmethacrylate (PMMA) coloured with black, grey and red pigments. The material for the lens is clear or red colored Polycarbonate (PC). All colours have to be welded with the same welding equipment. The length of the weld seam is approximately 1000 mm. To achieve an equal weld seam quality along the complete welding contour it was necessary to make small modifications on the design of the rear lamp. For example the stiffness of the housing was increased to avoid a movement of the housing during clamping.

The combination of a clamping finger and sequential clamping technology (shown in **fig. 7**) showed the best results, while introducing the clamping pressure. The exclusively use of a clamping finger is not possible due to the default design. The tail lights acute angle is less than 45°. Therefore to draft the clamping finger to the lens is impossible, during welding the outer edge of the tail light.

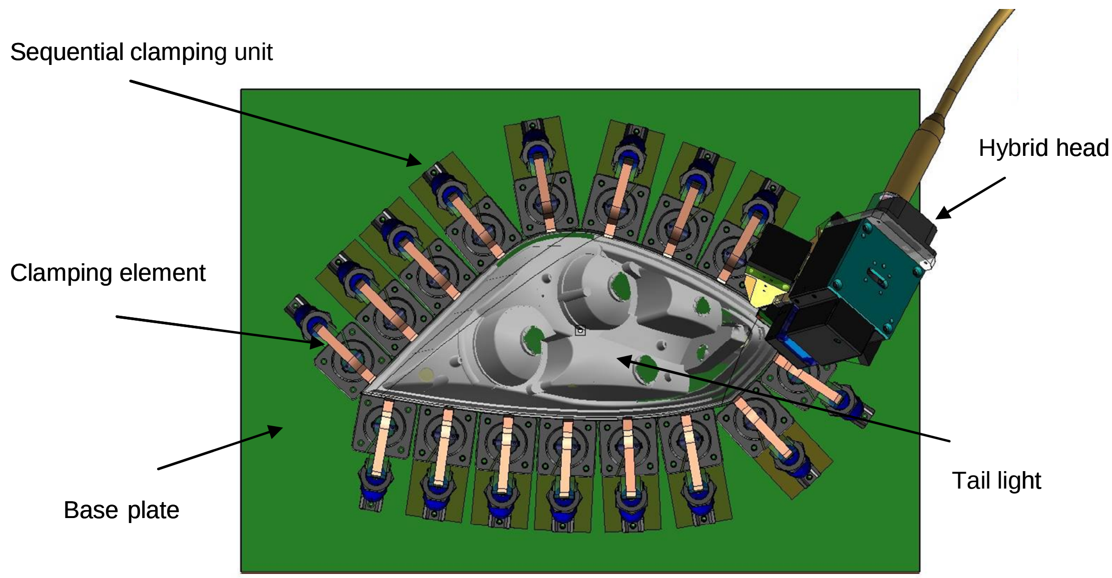

Fig. 7*: Sequential clamping module*

The resilience can be reached with several sequential clamping elements. The high pressure of the clamping finger that is directly mounted to the welding head causes a material motion of the lens material in the welding direction. The sequential clamping elements counteract this material motion to keep the assembly in place.

Numerous tests confirm the previously mentioned advantages using secondary radiation to the welding process, in the cause of process comparison of joining the described tail light. The welded tail lights excel in a visually appealing joint line and a high steady monotone quality. There is no blistering in the melt throughout the whole joint line length.

The process speed of hybrid laser welding is approximately five times higher than using a conventional laser welding process, also assuring a higher joint firmness. The presented tail light can be welded completely within 30 seconds, independent of the colouring of the absorbing joint partner. A following thermal treatment to avoid internal stress is not necessary.

Conclusion and outlook

Conventional laser transmission welding has proven to generate weld seams with a reliably high tensile strength, extending the range of applications of this welding method on large, complexly shaped three-dimensional parts is still missing.

The combination of laser radiation with the polychromatic radiation emitted by halogen lamps does provide certain improvements of the conventional laser welding process. This Hybrid process allows the energy being absorbed by *both* parts being welded together to be controlled and changed, not just the IR absorbing part. Hence, the processing window for welding is much larger which offers a higher gap-binding capability and less residual stress at the weld seam. The feed rate can be increased by 2-5 times without any loss of seam strength. The maximum reachable tensile strength has been observed to be much higher utilizing the hybrid welding process.

The ability to vary the amount of energy being absorbed by both parts being welded independently has initiated investigations into welding materials with dissimilar melt characteristics such as PC-PP, which is not feasible with conventional laser welding technology.

The huge advantages of the hybrid welding show that this process is a new step in joining technologies. The welding of large, three dimensional parts is now possible with this guiding technique.

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