THE USE OF FIBER LASERS FOR WELDING POLYMERS
Rolf Klein, GENTEX Corporation, Carbondale, PA 18407-0315, USA
Anssi Jansson, VTT, Lappeenranta, Finland
Saara Kouvo, Lappeenranta University of Technology, Lappeenranta, Finland
Tony Hoult, SPI Lasers, Southampton, UK

Abstract

One of the recognized procedures for laser welding of thermoplastic materials is transmission laser welding, where the upper plastic part is transparent to the laser light and the lower part is absorbing. The laser light is absorbed first to the bottom plastic and the absorbed radiation is converted into heat. Heat is transferred to the upper part via heat conduction, both plastics are melted and the weld is formed. The use of diode- and Nd:YAG-Lasers has become a well-established processing method for joining thermoplastic components in industrial applications.

Recently fiber lasers have become a commercially viable alternative to diode and Nd:YAG lasers. This new laser technology is attractive due to its compactness, efficiency and beam quality. However, the fiber laser operates at a different wavelength than diode or Nd:YAG lasers, typically at 1090 nm. This paper will examine the results obtained with a Fiber laser in conjunction with commercially available lasers, absorptive coatings and polymer additives. A comparison of welding strength achieved with fiber, diode and Nd:YAG lasers will be given.

Introduction

Laser Welding Plastics

Welding with diode- or Nd:YAG-lasers using Transmission Laser welding has become a well-established processing method for joining thermoplastic components in industrial applications. Transmission laser welding is a process where the materials are lap jointed and laser radiation passes through a “laser transparent” upper layer and is absorbed in the lower layer. The absorbed radiation is converted into heat at the interface of the lower layer and by heat conduction the interface of the upper layer will be heated, too. The materials melt at both interfaces and generate the weld seam after solidification.

Typically, the transmission laser welding process uses some colorants or additive to increase the low absorption of natural plastics. Carbon black is used as an absorbing additive in a wide field of industrial applications of laser welding thermoplastic components. Unfortunately, the dark color of carbon black is not always desired because some plastic products need to be transparent or lightly colored.

To allow free choices in coloration and also to be able to weld transparent or opaque plastic material with NIR-lasers TWI Ltd. has, in conjunction with GENTEX Corporation, developed the Clearweld® process. In the Clearweld® process special organic NIR-absorbers are used as additives in coatings or polymers.

In the coating process, two laser transparent materials will be welded by using a thin absorbing Clearweld® coating at the interface of both materials. The layer is created by applying a coating containing the absorber dye on the surface of one material. After applying the coating it dries rapidly to leave a very thin absorbing layer on the surface. The coating has slight coloration in the visible range before laser exposure. To create the weld the laser radiation is absorbed by the Clearweld coating and simultaneously converted into heat. The material at the interface of the coating is heated and melted by heat conduction and the weld seam is formed after solidification. During heating, the absorber decomposes and the coating loses visible coloration completely. The result is a clear and transparent weld joint with transparent plastics.

As an alternative to the coating process, the absorber can be directly incorporated as an additive into the plastic material. This is similar to the use of carbon black, but with much more color flexibility. Clearweld® additives have high absorption in the spectral range of the used laser radiation and some low absorption in other parts of the optical spectrum.

To match the wavelength of commonly used lasers, various absorber materials are available. The best absorptive material is dependent on the laser utilized and other application requirements including required color of the final part. This paper deals with Clearweld coatings and resins designed to absorb at the fiber laser wavelength of 1090nm.

Advantages of Fiber Laser

Today fiber lasers have grown from laboratory tools to commercially viable laser sources for material processing. They have started to be an alternative to commonly used lasers sources like CO₂- and solid state lasers for industrial applications. Fiber lasers are available in a limited number of wavelengths in the NIR spectrum and have optical output power up to some kW depending on the type of the fiber laser. In the field of welding thermoplastics, fiber
lasers could be an interesting alternative to diode- and Nd:YAG lasers.

A typical fiber laser unit comprises diode lasers as pump sources, the fiber laser module, electrical drivers, thermal management and an optical fiber delivery cable with a collimated output beam. Page: 2

In a fiber laser, the optical cavity consists of a small diameter single mode fiber with reflecting components incorporated into the fiber itself. Page: 2

The pump light from the diodes is coupled into the fiber using one of a number of different proprietary coupling techniques (Figure 1) and the ultra low divergence laser beam is emitted from one end of the fiber. The laser beam is coupled into a beam delivery system for guiding the beam to a focusing device.

Main advantages of fiber lasers compared to other lasers are:

- Very versatile and compact style,
- High beam quality,
- High beam stability over a broad power range,
- No thermal lensing effects,
- Low electrical consumption,
- Air cooled or low cooling water consumption and
- Maintenance-free operation.

For material processing these advantages have positive results like:

- The high beam quality of the fiber laser allows the use of long focal length lenses that increase welding process envelope.
- No thermal lensing means fewer variables to control; hence reduced process development time.
- Laser output power stability leads to a more stable welding process.
- No use of flash lamps means lower maintenance costs.
- Fiber lasers are very compact and occupy far less floor space than a standard solid state laser system and may be easily integrated into laser workstations.

For the work described in this paper a 100 W fiber laser was used in comparison with diode- and Nd:YAG-laser at the same rated power. The diode and Nd:YAG-lasers had direct beam delivery while the delivery fiber from the fiber laser delivers the laser beam directly to compact focusing optics. A comparison of typical features of the three laser sources is given in Table 1.

The diode laser is compact with slightly higher electrical efficiency than the fiber laser, but has a much poorer beam quality, which results in a larger spot size and lower intensity using the same focal length for the focusing unit (see Figure 2 and Table 1).

Experimental

The evaluation of welding with the fiber laser was done with Clearweld coatings and with weldable resin samples. Table 2 gives a summary of the used materials. The base materials for the coating samples are Polycarbonate (PC), Polymethylmetacrylate (PMMA) and Polypropylene (PP) with approximately 25 mm x 100 mm plate dimensions and approximately 2.5 mm thickness. The sample plates were cut from extruded plate material in the case of the coating samples. Extruded sheets have some molecular orientation of the polymer chains. The extruded direction was not taken into consideration when cutting the samples. The welding technique used in all experiments was contour welding.

The coatings used are acetone and ethanol based with different concentrations of absorbing additive.

The acetone solutions gave a wide range of absorber densities in the coatings on the parts. The ethanol provides a difference in substrate-solvent interaction; the acetone will “etch” into the PC, whereas the ethanol will not. In addition, the two dry differently on the PP.

The coating samples were prepared for welding with a coating width of 3 mm. The surface of the samples was cleaned but not machined or polished. The welding set up was an overlap joint as shown in Figure 3. Fixation of the samples was done by a pneumatic clamping device. In the upper part of the clamping device a glass plate was integrated, which has app. 91 % transmittance for the incident laser radiation. The focused laser beam was lead through the glass and through the upper sample into the weld zone.

For welding with fiber laser and diode laser the samples were moved by a linear drive relative to the focused laser beam. Experiments with the Nd:YAG-laser was done with a scanner device which moved the laser beam. In all applications the focused laser beam was adjusted to a circular Ø 3 mm spot width at the weld zone. For all three lasers the laser power was set to 80 W and 100 W with varying welding speed between 8.5 mm/s and 102 mm/s.

Additional to the coated samples, ABS/PC copolymer with incorporated Clearweld absorber was used for welding with the fiber laser. The absorber was added to the PC/ABS in three different concentrations. The welding set up was also an overlap joint. The molded samples were of 60 mm x 64 mm size with each 1 mm thickness in the welding area. The top layer was made from PMMA in same dimensions.

The laser power was varied between 20 W and 100 W and the welding speed between 8.5 mm/s and 102 mm/s. Some additional trials were done with weld width of 1 mm within the same parameter window as the 3 mm width.
Results and Discussion

The analysis of the achieved welding quality was done by manual optical inspection and tensile testing. Criteria for the optical inspection were the appearance of the joint in terms of constant weld width, overheating by appearance of bubbles in the joint and the loss of coloration of the coating. The tensile strength of all welded samples was also tested.

Because of the overlap joint geometry the results of the tensile testing creates values which are a combination of tensile and rotational load to the joint area. So in any case the measured tensile load values are below the real tensile strength of the parent material. Nevertheless the joints with good optical appearance broke in the most cases beside the weld seam in the parent material and not across the weld seam. Figure 4 shows a welded PMMA samples with detail of the weld zone and typical samples of PMMA, PC and PP samples after tensile testing.

A comparison of the tensile strength values of coated samples achieved with the different laser sources (wavelengths) are shown in Figure 5 to 7.

Figure 5 shows the tensile load for PC, PMMA and PP with coating LD220B used in acetone as a function of the deposited laser energy density. In most cases the tensile load values with same material of the different lasers are close together with slightly higher values for the fiber laser. The maximum achieved tensile strength on PC was approximately 30.6 N/mm² for fiber laser (1090 nm), 29.9 N/mm² for Nd:YAG (1064 nm) and app. 28.8 N/mm² for Diode laser (940 nm). For PMMA the maximum values are 13.1 N/mm² (1090 nm), 11.6 N/mm² (1064 nm) and 12.7 N/mm² (940 nm) and for PP 22 N/mm² (1090 nm), 20.9 N/mm² (1064 nm) and 19.5 N/mm² (940 nm).

Figure 6 shows the tensile load values of PC samples with acetone based coating as a function of the coating concentration (LD220A, LD220B and LD220C). In this case, the highest strength was achieved with lower coating concentrations. Decreasing the deposited laser energy density leads to decreasing load values. The load value decreases with increasing concentration. This should be optimized by using higher energy densities for welding.

Figure 7 shows a comparison of achieved tensile load values for PC using different absorber coatings in acetone (LD220A, LD220D and LD220C). The energy density used in this graph is 2.1 J/mm². The load values for LD220D are slightly higher than the values for LD220. Maximum values for diode laser were 28.8 N/mm² (LD220) and 29.9 N/mm² (LD240), for Nd:YAG laser 29.0 N/mm² (LD220) and 30.6 N/mm² (LD240) and for fiber laser 31.6 N/mm² (LD220) and 32.8 N/mm² (LD420). The achieved values using fiber laser were app. 10 % higher than using diode laser.

Summary

The welding experiments were done using comparable parameters and not to find best conditions for the welding parameters. The achieved load strength should not be the maximum values reachable with laser welding but allow a comparison between the used laser sources for welding the samples.

Using the same materials and conditions the fiber laser yields higher tensile strength compared to the use of diode laser. However, it should be noted that the Clearweld absorbers used in this experiment were aimed more specifically at the fiber laser wavelength.

The results achieved with the fiber laser show that this laser type is an attractive alternative to diode and Nd:YAG lasers for plastic welding application. The advantage of fiber laser is the ability to very easily achieve small spot sizes, which will be needed for small contour welding and the possibility of long depth of focus for the use of large size parts with quasi simultaneous welding. As with most options, the best choice is dependent on specific application details. If a highly focused beam is not required for the application, diode lasers may still be the favorable laser source for plastic welding.

Nomenclature

PC – polycarbonate
PC/ABS – Copolymer from polycarbonate and acrylonitrile-butadiene-styrene
PMMA – polymethyl methacrylate
PP – polypropylene

Acknowledgements
The authors would express sincere gratitude to the laser lab of Branson Inc. for their hospitality during carry out welding test in their lab.

References

6. Normann, St., et. al.,” Latest development of high power fiber lasers in SPI” Photonics West, 2004

Key Words

Thermoplastics, Fiber laser, Clearweld, weld strength

<table>
<thead>
<tr>
<th>Laser</th>
<th>Diode</th>
<th>Nd:YAG</th>
<th>Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power / [W]</td>
<td>150</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Wavelength / [nm]</td>
<td>940</td>
<td>1064</td>
<td>1090</td>
</tr>
<tr>
<td>Beam Parameter Product (BPP) / [mm mrad]</td>
<td>60</td>
<td>12.5</td>
<td>1</td>
</tr>
<tr>
<td>Fiber core diameter / [mm]</td>
<td>direct</td>
<td>direct</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Spot diameter at f = 100mm / [mm]</td>
<td>0.4 x 1.2</td>
<td>0.08</td>
<td>0.065</td>
</tr>
<tr>
<td>Intensity at focal spot / [W/mm²]</td>
<td>2.08 10²</td>
<td>1.99 10⁴</td>
<td>3.01 10⁴</td>
</tr>
<tr>
<td>Electric consumption (with cooling) / [kW]</td>
<td>1.5</td>
<td>2.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Overall Efficiency / [%]</td>
<td>30</td>
<td>4.5</td>
<td>24</td>
</tr>
</tbody>
</table>

Table 1: Features of the used laser sources

<table>
<thead>
<tr>
<th>Substrate Material</th>
<th>Clearweld Coating</th>
<th>Clearweld Additive</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>acetone based</td>
<td>LD240F</td>
</tr>
<tr>
<td>PMMA</td>
<td>ethanol based</td>
<td>LD220A, LD220B, LD220C</td>
</tr>
<tr>
<td>PP</td>
<td>acetone based</td>
<td></td>
</tr>
<tr>
<td>PC/ABS-copolymer</td>
<td>LWA290 with three different concentrations</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Clearweld Coatings and Additive used for examination

Figure 1: Fiber laser schematic

Figure 2: Difference between high and low beam parameter product (BPP) laser beam
Figure 3: Clamping unit and weld geometry

Figure 4: Welded samples, left PMMA sample after welding, right PMMA, PC and PP sample after tensile testing. The detail shows the welded zone.

Figure 5: Tensile load for PC, PMMA and PP with absorber LD220B

Figure 6: Tensile load values of PC samples with LD220 coating on acetone basis as a function of coating concentration.

Figure 7: Comparison of tensile load values for PC using LD220 and LD420 coating, both in acetone.

Figure 8: The tensile load values of welded PMMA-PC/ABS copolymer samples as a function of the deposited laser energy density.