Laser Welding Applications

Micro Technology
Medical Technology
Electronics
Small-lot Production

Sources: Branson; ILT; Marquardt
Applications
Oil-Sensor with Integrated Electronic

Customer: Continental Temic
Material: Ultramid® A3WG6
LT black 23229 with
LS black 23189
Features: High vibrational load
Oil contact
Temperatures up to 150°C
Requirement: Hermetically sealed cap

Source: Temic, Ingolstadt
Laser Principle

Laser Medium: CO2, Nd-YAG, Ruby, Excimer

- Active laser medium
- Output Coupler
- High reflector
- Laser pumping energy
- Laser Beam
**LASER WELDING**

**WAVELENGTH - Micrometers**

- **COPPER VAPOR**: 0.51-0.57
- **Nd: YAG/Glass (Doubled)**: 0.53
- **ARGON**: 0.49-0.51
- **Alexandrite**: 0.72-0.8
- **Ti Sapphire**: 0.68-1.13
- **Nd: YAG & Nd: Glass**: 0.85-0.9
- **Raman Lines**
- **Ruby**: 0.69
- **Ge: As**: 1.06
- **Ho: YAG**: 2.06
- **Dy: CaF**: 2.35
- **HF**: 2.6-3.0
- **DF**: 3.4-4.0
- **CO**: 5.0-7.0
- **CO2 (Doubled)**: 5.3
- **CO2**: 9.2-11

*from Wikipedia*
### Radiation Sources for the Processing of Engineering Plastics

<table>
<thead>
<tr>
<th>Type of laser</th>
<th>Wavelength*</th>
<th>Penetration</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>10.6 µm (IR)</td>
<td>µm</td>
<td>Cutting, Drilling</td>
</tr>
<tr>
<td>Nd:YAG</td>
<td>1.06 µm (NIR)</td>
<td>µm - mm</td>
<td>Marking, Welding</td>
</tr>
<tr>
<td>Diode</td>
<td>0.8 – 1.0 µm (NIR)</td>
<td>µm - mm</td>
<td>Welding</td>
</tr>
<tr>
<td>Excimer**</td>
<td>0.19 – 0.35 µm (UV)</td>
<td>nm - mm</td>
<td>Structuring, Marking</td>
</tr>
</tbody>
</table>

*Wavelength of Visible light ranges from 0.4 to 0.7 µm (4000 – 7000 nm)

** Excited-Dimer: Fluorine (F2)
A Simple Diode Laser Unit

A packaged laser diode with penny for scale

Image of the actual laser diode chip (shown on the eye of a needle for scale) contained within the package shown in the above image.
Laser Transmission Welding Principle

1. Laser radiation is absorbed and converted to heat
2. Absorbing material melts and swells
3. Melt comes into contact with other half of joint
4. Heat transfer takes place, causing the other half of the joint to melt
Laser Transmission Welding

Transmitting material

Absorption of laser energy

Laser radiation absorbing material

Laser beam

Weld joint
Typical Welding Methods

- Contour Welding
- Simultaneous Welding
- Quasi-Simultaneous Welding
- Mask Welding
Riveting by Means of Laser

Source: Branson
Advantages of Laser Welding

- Parts are not subjected to mechanical stress
- Small and localized heat affected zone
- Controlled melt flash (No dust or loose flash formation)
- Non-contact process
- Almost wear-free process
- Generally a highly flexible process
  - Integration into automated production lines is possible
- Inconspicuous weld lines possible
Disadvantages of Laser Welding

- Process can only be used to join materials with dissimilar absorption properties at the laser wavelength*
- Gap between joining surfaces limited to < 100 µm
- Contouring technique in particular only allows thin layers of melt to be produced
- High demands placed on the material and molding process (Narrow tolerance limits-Low Warpage)
- Capital equipment may be relatively expensive

*Butt Joints are possible
Joint Design I

- Butt-joint
- Lap-joint
- Split Lap-joint
- "T" Joint
- Scarf-joint
- Split Scarf-joint
Joint Design II

Interference fit with 0.1 mm over lapping
## Comparison Of Different Laser Welding Technologies

<table>
<thead>
<tr>
<th></th>
<th>Contour welding</th>
<th>Simultaneous welding</th>
<th>Quasi-simultaneous welding</th>
<th>Mask welding</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flexibility</strong></td>
<td>very high</td>
<td>low</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td><strong>Welding time</strong></td>
<td>long</td>
<td>short</td>
<td>moderate</td>
<td>moderate-long</td>
</tr>
<tr>
<td><strong>Complexity of weld profile</strong></td>
<td>very high</td>
<td>moderate</td>
<td>high</td>
<td>moderate</td>
</tr>
<tr>
<td><strong>Gap Tolerance</strong></td>
<td>none</td>
<td>possible</td>
<td>possible</td>
<td>none</td>
</tr>
<tr>
<td><strong>Investment</strong></td>
<td>moderate</td>
<td>very high</td>
<td>high</td>
<td>moderate-high</td>
</tr>
<tr>
<td><strong>Type of Laser</strong></td>
<td>Nd:YAG Diode</td>
<td>Diode</td>
<td>Nd:YAG Diode</td>
<td>Diode</td>
</tr>
</tbody>
</table>
Material Characteristics
Influence of Material Characteristics on the Laser Welding Process
### Optical Properties of Plastics

<table>
<thead>
<tr>
<th>Type of Material</th>
<th>Specific Gravity</th>
<th>Refractive Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA6</td>
<td>1.13</td>
<td>1.538</td>
</tr>
<tr>
<td>PA66</td>
<td>1.14</td>
<td>1.544</td>
</tr>
<tr>
<td>Amorphous PA</td>
<td>1.13</td>
<td>1.562</td>
</tr>
<tr>
<td>PC</td>
<td>1.2</td>
<td>1.586</td>
</tr>
<tr>
<td>PBT</td>
<td>1.31</td>
<td>1.52-1.55</td>
</tr>
</tbody>
</table>
Comparison of Amorphous and Semi-crystalline Thermoplastics

- Random polymer chain order
- Less warpage
- High transmission (no deflection; optical isotropic)

- Creation of a crystalline structure (like spherolites)
- Scattering and reflection at crystalline surfaces
- Warpage depending on processing, material, additives, ...
- In some cases high processing temperatures (melt point)
Basics of Processing

I. Adhesion/Physical Locking

II. Optimal process window

III. Material Degradation/Thermal decomposition

* Up to TG or TM only Adhesion

Weld strength vs. Energy per length unit

Semi-crystalline

Amorphous
Interaction Radiation / Polymer: Optical Properties

Amorphous
- Reflection
- Absorption
- Transmission

Semi-crystalline
- Reflection
- Absorption
- Scattering
Interaction Radiation / Polymer Changes in the Beam Characteristics

Laser beam diameter in mm

- 1,0
- 0,8
- 0,6
- 0,4
- 0,2
- 0

Laser beam diameter (Thickness=2mm):
- Reference: 1,73 mm
- SAN: 1,75 mm
- POM: 4,39 mm
- PBT: 5,29 mm
Comparison of Amorphous and Semi-crystalline Thermoplastics

Required laser power per unit weld

Amorphous thermoplastics (PC, PS, PMMA): 5–10 W/cm
Semi-crystalline thermoplastics (PP, PE, PA): 10–40 W/cm

Source: W. Lotz, 2000
Effect of Crystallite Diameter on the Absorption Behaviour

PBT, $d = 2\text{mm}$  
PA66 + 30% glass, $d = 2\text{mm}$

Source: W. Lotz, 2000
Effect of Crystallite Diameter on the Absorption Behaviour

Source: W. Lotz, 2000
## Influence of Additives on Laser Energy Transmission

<table>
<thead>
<tr>
<th>Additives</th>
<th>Influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mold release agents</td>
<td>little direct influence, interactions not know at this time</td>
</tr>
<tr>
<td>Lubricant</td>
<td></td>
</tr>
<tr>
<td>Anti-oxidations</td>
<td>little direct influence, but interactions possible</td>
</tr>
<tr>
<td>Stabilizers (UV-, Thermal-)</td>
<td></td>
</tr>
<tr>
<td>Flame retardants</td>
<td>partial to significant influence</td>
</tr>
<tr>
<td>Fillers</td>
<td></td>
</tr>
<tr>
<td>Pigments</td>
<td></td>
</tr>
<tr>
<td>Dyes</td>
<td></td>
</tr>
</tbody>
</table>
Influence of Glass Fibers

- Thickness: 2 mm
- $\lambda$: 1064 nm

PBT: -30%
PA6.6: -35%
PA6: -17%
PES: -70%
Optical Properties as a Function of Glass Fiber Content

Source: ILT, Aachen
Influence of Flame Retardants

Transmission in %

- PBT w/o FR
- PBT w/FR (Ph)
- PA w/o FR
- PA w/FR (Br)

Thickness: 2 mm
\(\lambda: 1064\,\text{nm}\)
# Laserwelding Practice with FR Products

<table>
<thead>
<tr>
<th>Material Combination</th>
<th>Welding Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>A3K nat. &lt;-&gt; B3UG4 sw. 23215</td>
<td>40 mm/s</td>
</tr>
<tr>
<td>A3K nat. &lt;-&gt; A3X2G5 sw. 23187</td>
<td>30 mm/s</td>
</tr>
<tr>
<td>A3K nat. &lt;-&gt; C3UG4 sw. 23079</td>
<td>28 mm/s</td>
</tr>
<tr>
<td>A3K nat. &lt;-&gt; B3UG4 grau 22985</td>
<td>9 mm/s</td>
</tr>
<tr>
<td>B3UG4 nat. &lt;-&gt; B3UG4 sw. 23215</td>
<td>6 mm/s</td>
</tr>
</tbody>
</table>

* l = 1064 nm; Thickness = 2 mm
Influence of Moisture Content (PA6GF30; Tensile Shear Specimen: Dry)
Weld Quality as a Function of the Joint Gap-width

Luran®378P (SAN)
Combination: natural/black

Laser power = constant

Source: ILT, Aachen
Welding Defects

- Dry joint
- Porous joint
- Good joint

1 mm
Weld Quality (Ultradur B4300G6)

- Plane of joint
- Potential Crack Initiation Sites

1 mm
Factors Affecting the Weld Quality

**Material properties**
- Spectral absorption
- Molecular structure / Cross linking
- Crystallinity / Size of crystallites
- Filler (glass fibers, carbon black)
- Colorant
- Additives (e.g. flame retardant)
- Moisture content
- Thermal conductivity / Heat capacity
- Heat of fusion / Melting temperature
- Heat of vaporisation
- Surface structure

**Other factors**
- Wavelength
- Energy density
- Welding technology
- Welding speed

**Part design**
- Wall thickness
- Welding tool / nest
- Clamping
- Joint gap-width
## Thermoplastics for Laser Welding

<table>
<thead>
<tr>
<th>Thermoplastic</th>
<th>Optical properties</th>
<th>Welding characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polystyrene (PS)</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Polyamide (PA)</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Polybutylene terephthalate (PBT)</td>
<td>o</td>
<td>+</td>
</tr>
<tr>
<td>Styrene-acrylonitrile (SAN)</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Polysulfone (PSU)</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Acrylonitrile-butadiene-styrene (ABS)</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Combination PC + ABS</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Combination PMMA + ABS</td>
<td>++</td>
<td>++</td>
</tr>
</tbody>
</table>

++ very good    + good    o satisfying
# BASF-Products in comparison*

<table>
<thead>
<tr>
<th>BASF-Product</th>
<th>Welding velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrason E2010</td>
<td>50 mm/s</td>
</tr>
<tr>
<td>Ultrason S2010</td>
<td>45 mm/s</td>
</tr>
<tr>
<td>Ultradur B4040G6</td>
<td>30 mm/s</td>
</tr>
<tr>
<td>Ultramid B3WG6</td>
<td>24 mm/s</td>
</tr>
<tr>
<td>Ultraform N2320</td>
<td>20 mm/s</td>
</tr>
<tr>
<td>Ultramid A3WG6</td>
<td>19 mm/s</td>
</tr>
<tr>
<td>Ultradur B4300G6</td>
<td>10 mm/s</td>
</tr>
<tr>
<td>Ultradur S4090G6</td>
<td>4 mm/s for 1 mm thickness</td>
</tr>
</tbody>
</table>

2 mm are not weldable

* \( \lambda = 1064 \text{ nm} \); Thickness = 2 mm
Possible Material Combinations

<table>
<thead>
<tr>
<th></th>
<th>PP</th>
<th>POM</th>
<th>PBT</th>
<th>PBT/ASA</th>
<th>PA6</th>
<th>PA6.6</th>
<th>PES</th>
<th>PSU</th>
<th>ABS</th>
<th>ASA</th>
<th>SAN</th>
<th>MABS</th>
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</thead>
<tbody>
<tr>
<td>PP</td>
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<td>PBT/ASA</td>
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<td>PA6.6</td>
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<td>MABS</td>
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<td>√</td>
</tr>
</tbody>
</table>

No “new“ combinations possible with conventional welding process!

**BUT**
Laser welding is more tolerant for differences in:
- Melt temperature
- Viscosity
- Stiffness / Hardness
New Developments
Laser Absorbing Films

PS 2710 white 744
(with TiO²)

Thickness: 1 mm

Field of application:
Home appliances
LET Measurement System
Customer Benefits from High Laser Transmissibility

- Shorter welding time
- Higher process reliability
- Higher product safety/Quality improvement
- More flexibility in part design and wall thickness
LET Measurement Method at BASF SE

Transmission [%] = \frac{\text{Laser beam power with test plate [W]}}{\text{Laser beam power without test plate [W]}} \times 100

- Rotating Mirror
- Nd:YAG-Laser with $\lambda = 1064\ \text{nm}$
- Test Plate
- Laser beam power sensor
LET Measurement Method at BASF SE
LET Measurement Method at BASF Corp.
Portable LET Measurement Instrument-Hand Held Unit

Prolas-IRSpec I

Prolas GmbH
Internet: www.prolas.de

Only relative LET values can be obtained.
Good for a routine quality check for a given material
Beam Size and Port Size are very small. Glass reinforced material testing Difficult.
Evaluation of Weld Joint Quality
Test Specimen
Overlap- / Shear-Joint

- Easy to do / BASF internal resources
- Low cost
- Failure not in the joint but in the specimen near the joint
- No information about the “real” joint strength / correlation with the material or the LET
- Low resolution
- Not useful for Quasi-Simultaneous welding
Test Specimen
Pot-Lid Configuration

- Useful for all process
  (good for process comparison)
- Can be done internally
- Burst pressure and tensile test possible

- Results not 1:1 transferable to real parts / customer application
- In case of good welding, crack can appear near the joint (stress crack at the edge), than low resolution
Test Specimen

T-Joint (with plates)

- Useful for all process (good for process comparison)
- Better resolution of material influence than for overlap- / shear joint
- In case of good welding, crack can appear near the joint (stress crack at the edge), than low resolution
- High influence of plate alignment (for contour/quasi-simultaneous welding)
Test Specimen
*T-Joint (modified; similar to AWS)*

- Useful for all process (good for process comparison)
- Good resolution of material influence
- Less critical than T-Joint with plates
- High influence of alignment (for contour and quasi-simultaneous welding)
Test Specimen for Welding Trials
BASF Laserwelding Evaluation Part

View from Transmitting Layer

View from Absorbing Layer
Laser Weld Joints Details

- Flat to Flat
- Flat to Bead
- Bead to Bead
Quasi-Simultaneous Laser Welding Machine Setup

- Laser Scan Box
- Upper Platten in open position
- Upper Platten in Clamped Position
- Lower Table
- Lower Platten
- Hydraulic Lift
Diode-Based Simultaneous Welding Fixture

Laser Beam through the wave guide

Beam guide & clamp Fixture

Lower clamp Fixture

W**
**2mm Flat Flange on 3 mm Flat Flange**
## Infrared-/Laser Welding Equipment for Thermoplastics

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Trade Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convergent Energy</td>
<td>Dart</td>
</tr>
<tr>
<td>Bielomatik</td>
<td>Laser-Tec</td>
</tr>
<tr>
<td>Branson</td>
<td>IRAM</td>
</tr>
<tr>
<td>Fraunhofer</td>
<td>DL, System</td>
</tr>
<tr>
<td>Rofin-Sinar</td>
<td>Proscan</td>
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<tr>
<td>Leister</td>
<td>Novolas</td>
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<td>Limonics</td>
<td>Impact</td>
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<td>Sonotronic</td>
<td>Focus One</td>
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<td>Tampoprint</td>
<td>SK-90</td>
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<td>Votan</td>
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<td>LPKF</td>
<td>Laserquipment</td>
</tr>
<tr>
<td>Prolas</td>
<td>Proweld</td>
</tr>
</tbody>
</table>
Effect/Complexity Matrix for Laser Welding

Degree of Complexity

- Transparent/Black
- Color 1/Color 2
- Color 1/Color 1
- Color/Black
- Black/Black
- Transparent/Black
- White/White
- Transparent/Transparent
- Color 1/Transparent
- Color 1/Black
BASF Lumogen Pigment for Black to Black Laser Welding

Wave lengths of interest
<table>
<thead>
<tr>
<th>Transmitting Component</th>
<th>Absorbing Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>Black</td>
</tr>
<tr>
<td>(L) Ultramid®</td>
<td></td>
</tr>
<tr>
<td>A3WG6 LT sw*</td>
<td>A3WG6 sw LS 23189</td>
</tr>
<tr>
<td>B3WG6 LT sw*</td>
<td>B3WG6 sw LS 23189</td>
</tr>
<tr>
<td>(L) Ultradur®</td>
<td></td>
</tr>
<tr>
<td>B4300G6 LT sw*</td>
<td>B4300G6 sw 15073 Q16</td>
</tr>
</tbody>
</table>

LT: specific coloration with laser transparency
(L) Limited supply
In Closing

BASF Engineering Plastics
Thanks you for Participating

For all your Plastics Needs,
Contact us or use our website:

www.plasticsportal.com