DESIGN FOR LASER WELDING

David Havrilla
TRUMPF
Manager – Products & Applications
Contents

- Introduction
- Why employ laser welding?
- Fit-up & basic joint configuration
- Joint bridging techniques
- Joint design & feature considerations
- Summary
Laser applications - Automotive Industry

- Torque Converters, Clutches
- Gearbox
- Engine
- Battery
- IP Beam
- A-Pillar
- B-Pillar
- Tunnel
- Roof
- Roof rail
- Trunk lid
- Rear Center Component
- Side Panel
- Doors
- Seat Rests, Tracks, Recliners
- Differentials
- Bumper
- Cross member
- Driveshaft
- Door enforcements
- Side member
- Side member
- Remote
- Hotforming
- Brazing
- Powertrain
Why employ laser welding?

- Minimum heat input and high aspect ratio resulting in …
  - minimal shrinkage & distortion of the workpiece
  - small heat affected zone
  - narrow weld bead with good appearance

- High strength welds often resulting in …
  - improved component stiffness / fatigue strength
  - reduction of component size / weight  [Design Optimization]

- Ability to weld in areas difficult to reach with other techniques
  - non-contact, narrow access, single sided process

- Flexibility …
  - beam manipulation (beam switching and sharing)
  - variety of part & weld geometries and materials
Why employ laser welding?

- Cost savings ...
  > high productivity >> faster cycle time = less stations & less floor space
  > reduction of manual labor, scrap & re-work
  > reduction of component material and weight
  > can eliminate secondary processes

Laser Welding vs. Resistance Spot Welding

- Reduction or elimination of flanges
  > reduction of component size / weight
  > reduced cost
  > greater visibility / accessibility

- Increased strength / stiffness
  > localized increase of component strength / stiffness / fatigue strength
  > weld shape optimization for component loading / stresses
  > elimination of lower electrode access holes
Drivers - Automotive Industry

Body designed for laser manufacturing

- Process Stability
- Stiffness
- Cost
- Visibility
- Access
- Quality
- Floor space
- Throughput
- Weight
- Maintenance
Laser – The Universal Tool for Welding

- Narrow weld seam
- Min. heat affected zone
- Little metallurgic effects on the material
- Little distortion
- No filler material required
- High process speed
- Non-contact
- No wear
<table>
<thead>
<tr>
<th>Elements</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>relatively wide / narrow</td>
<td>When would you want wide? When narrow?</td>
</tr>
<tr>
<td>continuous / stitch / spot</td>
<td></td>
</tr>
<tr>
<td>through / partial</td>
<td>What benefits does partial penetration have?</td>
</tr>
<tr>
<td>line / optimized shape</td>
<td>Why would you want a shape that is not a straight line?</td>
</tr>
<tr>
<td>conventional / remote</td>
<td></td>
</tr>
<tr>
<td>multiple layers</td>
<td></td>
</tr>
</tbody>
</table>
Material selection

1. Causes of porosity, underfill, undercut:
   - Volatile constituents (e.g. S, P)
   - Volatile coatings/surface contaminants (e.g. Zn, oil based lubricants)

Notes for welding of Zn coated steels in overlap configuration

a. Increased weld length may compensate for porosity in non-critical components
b. Electro-galvanized & electro-galvaneal are better than hot dipped galvanized
c. Bare to Zn is often okay (especially electro plated)
d. Zn to Zn configurations usually require a gap and/or Zn exhaust path for reasonable results (e.g. dimples, shims, knurling, fixture/tooling, leading pressure finger, part design, joint design)
e. Watch out for patent infringements!
2. Britteness & cracking:
   - Can occur in steels when >0.3%C (>0.4%C equivalent)
   - 6000 series aluminum

3. Reflectivity
   With high reflective materials (e.g. Al, Cu) – 1 micron wavelength has greater absorption than 10.6 microns
Seam and joint types

Lap weld on lap joint

Seam weld on butt joint
# Seam and joint types

<table>
<thead>
<tr>
<th>Name</th>
<th>Example</th>
<th>Characteristics</th>
</tr>
</thead>
</table>
| Seam weld on butt joint   | ![Butt Joint Illustration](image) | + **Weld Fusion Area**  
• less material = weight & cost savings  
• faster or less power  
• less HAZ / distortion  
• no issues w/ Zn  
• no step  
- **Positioning Tolerance**  
• edge requirements  
• fit up can be more difficult to obtain  
| Lap weld on lap joint     | ![Lap Joint Illustration](image) | + **Positioning Tolerance**  
• larger process window  
• can have aesthetic underside  
- **Weld Fusion Area**  
• more energy required = slower or higher power & more distortion / HAZ  
• inefficient process  

*Think about a positive & negative characteristic of both the butt & lap weld configurations.*
## Seam and joint types

<table>
<thead>
<tr>
<th>Name</th>
<th>Example</th>
<th>Characteristics</th>
</tr>
</thead>
</table>
| Seam weld on stepped lap joint      | ![Example](example1.png) | + weld fusion area  
- positioning tolerance |
| Seam weld on T-joint                | ![Example](example2.png) | + weld fusion area  
- positioning tolerance |
# Seam and joint types

<table>
<thead>
<tr>
<th>Name</th>
<th>Example</th>
<th>Characteristics</th>
</tr>
</thead>
</table>
| Lap weld on T / border joint      | ![Example](example1.png) | + positioning tolerance  
- weld fusion area |
| Seam weld on flange               | ![Example](example2.png) | + weld fusion area  
- positioning tolerance |
| Lap weld on formed seam           | ![Example](example3.png) | + positioning tolerance  
- weld fusion area |
Fit-up requirements

Butt joint configuration:
- Gap: 3-10% thickness of thinnest sheet
- Offset: 5-12% thickness of thinnest sheet

Overlap joint configuration:
- Gap: 5-10% thickness of top sheet

Why is this general guideline not absolute?
(What influences the amount of gap that can be bridged?)
- Focus spot size
- Edge geometry for butt weld
- Strength requirements
The importance of good fit-up

- For autogenous laser welding, weld strength is a function of weld joint fit-up.

- A gap (or mismatch) reduces weld strength because it can yield an underfill and/or undercut which …
  
  a. Reduces weld area \( S = F/A \)
  
  b. Creates a stress riser

\[ F \]

Stress concentration

Lines of force
Tolerance compensation
Tolerance compensation
Joint bridging techniques

**Autogenous**
- **Larger focus spot**
  - slower, more heat input
- **Twin spot**
  + 2x higher power density
  + Less wasted energy
  = faster!!
  - Directionality

**Non-autogenous**
- **Hybrid (laser + MIG + wire feed)**
  - cost, complexity, may require vision system
- **Wire feed**
  + gap & metallurgical bridging
Design features

View turned by 180 degree

1 x s

F

Patent pending
Design features

Material fit of a K-Joint

Patent pending
Design features

Weld Seam on a K-Joint

Patent pending
Design features

Different Applications of a K-Joint

Patent pending
Design features

K- Joint in Application / Flange-reduced Design
Design features

Specialized cutting & bending of tubes

Multiple bend tubes:
Allows 3 dimensional structures.

Bend tubes:
Allows high quality on corners.
Design features

Specialized cutting & bending of tubes w/ positioning aids

Special bent tubes techniques create connections with the need of only a few welds.

Positioning aids
Design features

Positioning tabs & bayonets for tubes

Perfect interface for welding operations

Bayonet coupling ensures orientation and reduces need for precision fixturing.

Precision location
Design features

More Tube Interfaces

- Coding system to avoid possible assembly mistakes, accurate position.
Design features

Positioning tabs for tubes & plates

Mounting plate to tube:
Well suited for welding
High positioning accuracy

Accurate sheet flange to tube design
Design features

Interlocking tabs for tubes
Design features

Integrating locating & interlocking features
Design features

Concept for an Underbody design with K-Joint & Interlocked Joints
Tolerance Compensation

K-Joint & Interlocked Design for Underbody
Design & re-design components for laser welding

- Reduce component weight & cost by reducing or eliminating flange widths (*enabled by single sided, narrow beam access*)

- Increase vehicle accessibility & driver visibility by reducing or eliminating flange widths (*enabled by single sided, narrow beam access*)

- Reduce component weight and cost by reducing gage thickness (*enabled by increasing strength through optimized weld shapes and/or continuous weld seams in high stress locations*)

- Reduce component weight and cost, and increase strength (*enabled by elimination of RSW lower electrode access holes in structural reinforcements*)
Design for laser welding summary (pt. 2)

- Know & employ the strengths of the full variety of weld joint styles
- Realize there are several ways to bridge the gap, … but don’t start there
- Consider the variety of design features when designing for laser welding (e.g. K-Joint, positioning aids, tabs, bayonets, interlocking joints, tolerance compensation planes, etc.)
Continuous Education / Improvement

Laser Welding
Christopher Dawes
*Abington Publishing* (1992)

Laser Welding
Walter W. Duley
*John Wiley & Sons* (1999)

Laser Material Processing – Fourth Edition
William M. Steen / Jyoti Mazumder
*Springer* (2010)

AWS Welding Handbook
Welding Processes, Part 2
Ninth Edition, Volume 3

LIA Handbook of Laser Material Processing
John F. Ready – Editor in Chief
*Laser Institute of America* (2001)
Please Join Us!

Thursday, May 17th

5:30 – 9:00 PM

5:30-6:00 Registration

6:00-6:20 Keynote address by Gary Vasilash

6:30-9:00 Machine Demonstrations

Open House

Held in conjunction with the Advanced Laser Applications Workshop (ALAW)

May 17, 2012 – 5:30 p.m.
TRUMPF Laser Technology Center
47711 Clipper Street
Plymouth Township, MI 48170

Keynote Address featuring Gary S. Vasilash, Editor-in-Chief, Automotive Design & Production

With more than 20 years of experience writing about the automotive industry, best practices and new technologies Gary Vasilash’s work has appeared in a variety of publications, ranging from The Wall Street Journal to Lightworks, a journal of contemporary art. He has made numerous presentations at a variety of venues ranging from the annual meeting of the Association for Manufacturing Technology (AMT) to the Center for Constructive Alternatives at Hillsdale College.

Please join TRUMPF for Advanced Laser Applications Workshop (ALAW) and Open House

Open House Schedule

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>5:30 pm</td>
<td>Registration</td>
</tr>
<tr>
<td>6:00 pm</td>
<td>Keynote Address Followed by Q&amp;A</td>
</tr>
<tr>
<td>6:30 pm</td>
<td>Machine Demonstrations</td>
</tr>
</tbody>
</table>

Machine demonstrations will include:

- High speed 2D cutting (CO₂ laser)
- Robotic remote welding and cutting (disk laser)
- High precision cutting (fiber laser)
- Automated pulsed welding (pulsed laser)
- Precision laser marking (marking laser)

RSVP

Please RSVP with your NAME, COMPANY, and CONTACT INFORMATION by May 10, 2012 to felix.brinkmann@us.trumpf.com

Please feel free to extend this invitation to your colleagues.
Thank you

TRUMPF Laser Technology Center
Plymouth, MI
(734) 454-7200
Design optimization

- Flange Reduction or Elimination (flangeless design)
- Better Accessibility
- Less Interference
Principle of time sharing

- Throughput maximization & manufacturing flexibility
Principle of energy sharing

- Reduced distortion
Continuous weld & strength optimization
Advantage: Programmable Weld Shapes

Customized weld patterns for optimal joint strength:

- Distribution
- Orientation
- Shape
Elimination of lower electrode
Goals reached:

- Increased process speed (joining)
- Increased productivity
- Increased strength compared to alternative joining methods
- Reduced heat distortion
- Narrow or no flange => Weight reduction
- High flexibility via sharing & back-up of lasers into different work cells
- Reduced floor space

<table>
<thead>
<tr>
<th></th>
<th>Golf IV</th>
<th>Golf V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor space Side panel</td>
<td>2816 $m^2$</td>
<td>1472 $m^2$ (-50%)</td>
</tr>
<tr>
<td>Floor space Underbody</td>
<td>480 $m^2$</td>
<td>320 $m^2$ (-33%)</td>
</tr>
<tr>
<td># of Weld spots</td>
<td>4608</td>
<td>1400</td>
</tr>
<tr>
<td>Length of laser weld</td>
<td>1.4 m</td>
<td>70 m</td>
</tr>
</tbody>
</table>
Wide vs. narrow

**Wide**

- Overlap welding
- Poor edges
- Poor fit-up
- Poor beam to seam location tolerance

**Narrow**

- Low distortion, high speed welding with minimum power for butt welding configurations
- ... but, good edges, excellent fit-up, & good beam to seam location tolerance required
Partial penetration vs. full penetration

**Partial**

- Aesthetics on back side of component
- Mating part considerations (fit-up & friction)
- Thickness of lower part (through penetration may be impractical or impossible)
- Protection of heat or spatter sensitive components
- Higher speeds (or lower laser power) w/ less HAZ & distortion

**Full**

- Visual weld verification possible
- Larger fusion area for butt weld configuration

**Compared to through penetration weld …**

**Compared to partial penetration weld …**
Advantage: Programmable Weld Shapes

Stress = \frac{F}{A}
Advantage: Programmable Weld Shapes
Zn coated material: Gap for out gassing

- Evaporating temperature of zinc < melting temperature of steel
- Vapor pressure causes expulsion of molten steel in upper sheet
- Result: Welding seam becomes highly porous and weak
Gap for out gassing: Laser dimpling

- Pre-treatment of one sheet to generate 0.1-0.2mm standoff between sheets
- Use of same laser equipment and optics
Gap for out gassing: Laser dimpling

- Constant dimple height (depending on zinc layer approximately 0.15 mm)
- Dimple height adjustable via laser parameter
Step 1: Laser Dimpling

Step 2: Placement of upper sheet

Step 3: Scanner Welding

Gap for out gassing: Laser dimpling