Design for Laser Welding

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• Introduction
• Why employ laser welding?
• Fit-up & basic joint configuration
• Joint bridging techniques
• Joint design & feature considerations
• Summary
A vast array of applications
Automotive: Typical Laser Applications

- ID Numbers & Signposts
  - Marking

- Airbag
  - Cutting and Welding

- Airbag Sensors
  - Welding

- Instruments & Switches
  - (Day & Night Design)
  - Marking

- Dynamic Balancing System
  - Welding

- Interior
  - Cutting and Seaming

- Fuel Pipe / Box
  - Welding

- Roof
  - Welding

- Car Body
  - Cutting

- Hydroformed Parts
  - Cutting

- Door Construction
  - Welding

- Seat Frames
  - Welding

- Tailored Blanks
  - Welding

- Gearbox Parts
  - Welding

- Key Housing
  - Welding

- Electric Bulb
  - Cutting and Welding

- Valve Lifter
  - Welding

- Antilock Brake System
  - Welding

- Shock Absorber
  - Welding

- Torsion Spring
  - Hardening

- Gearbox Parts
  - Marking
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*
Laser – The Universal Tool for Welding

- HF
- MIG
- TIG
- EB
- Plasma
- MIG
- MIG
- TIG
- TIG
- EB
- EB
- EB
- EB
- Seam welding
- Spot welding

Laser 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
### Laser as a tool

<table>
<thead>
<tr>
<th>Feature</th>
<th>Question</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>
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</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!
Galvanized Steel Welding With Dimples
2. Brittleness & 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

Think about a positive & negative characteristic of both the butt & lap weld configurations.

<table>
<thead>
<tr>
<th>Name</th>
<th>Example</th>
<th>Characteristics</th>
</tr>
</thead>
</table>
| Seam weld on butt joint       | ![Diagram](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         | ![Diagram](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 |
# 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    | ![Steped Lap Joint Example](example.png) | + weld fusion area  
- positioning tolerance       |
| Seam weld on T-joint              | ![T-joint Example](example.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
How can we estimate the weld length of a laser “stitch” to give the same strength as a resistance spot weld?

1. Determine average RSW nugget diameter
2. Calculate nugget area
3. Determine the average weld width at interface of the laser welded component
4. Set nugget area (A) equal to the weld length (L) x the weld width at interface (w)

\[ A = L \times w \]

\[ L = \frac{A}{w} \]

Typical values of w are 0.8-1.0 mm
Typical values of L are 18-25 mm
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 + GMAW)**
  - cost, complexity, may require vision system
- **Wire feed**
  - gap & metallurgical bridging
Design features

K- Joint in Application / Flange-reduced Design
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

More Tube Interfaces

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

Interlocking tabs for tubes
Design features

Integrating locating & interlocking features
Design features

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

- Cross Member (Seat)
- K-Joint
- Integrated Longitudinal Enforcement
- Interlocked Joints
- Tunnel
Design for laser welding summary (pt. 1)

- 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)
Thank you for your attention.

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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 m²</td>
<td>1472 m²</td>
</tr>
<tr>
<td>Floor space Underbody</td>
<td>480 m²</td>
<td>320 m²</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 w/ minimum power for butt welding configurations
- ... but, good edges, excellent fit-up, & good beam to seam location tolerance required
 Compared to through penetration weld …

- 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

 Compared to partial penetration weld …

- Visual weld verification possible
- Larger fusion area for butt weld configuration
Advantage: Programmable Weld Shapes

Stress = \( \frac{F}{A} \)
Advantage: Programmable Weld Shapes

Peel

Peel
Zn coated material: No 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
Gap for out gassing: Laser dimpling

- **Step 1:** Laser Dimpling
- **Step 2:** Placement of upper sheet
- **Step 3:** Scanner Welding