Trends & Keys to Success
In Laser Welding

Fraunhofer International Laser Symposium 2016

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EWI Introduction

- Contract research company focused on advanced manufacturing technologies
- Not-for-profit organization founded in 1984 in Columbus, Ohio
- Initial focus on materials joining technologies
- 240 member companies, 165 Employees
- ~ 80% Commercial & 20% Govt. funded projects
 EWI’s Place in Laser R&D?
-leverage our welding foundation -

◆ Tough Competition for a small company

Laser Materials Processing R&D f.t.e.

- Universities
- Corp. R&D
- Laser Suppliers
- Contract R&D (other)
- Fraunhofer
- EWI
“I should be very delighted if you could accept my invitation to give a plenary talk on joining.”

First, panic!
Laser Welding...Where to Start?
- so many topics! -

- Additive material welding
- Aero engines
- Aircraft panels
- Auto Body-in-White
- Auto transmissions
- Batteries
- Beam absorption
- Brittle cracking
- Chemistry
- Conduction welding
- Deep penetration welding
- Distortion
- Electronics

- Fatigue performance
- Focal shift
- Formability
- Fuel cells
- Gas dynamics
- Gas shielding nozzle
- Glass welding
- Ground turbines
- Hermeticity
- Heat affected zone
- High-speed welding
- History
- Hot shortness
And a few more....

- Humping speed limit
- Hybrid welding
- Inspectability
- Key-hole welding
- Laser types for welding
- Liquid metal embrittlement
- Medical devices
- Melting efficiency
- Metallurgy
- Metals welding
- Multi-materials welding
- Optics
- Plasma physics
- Plastics welding
- Porosity
- Process monitoring
- Remote welding
- Seam tracking
- Shielding gas type
- Ship panels
- Spatter
- Tailored blanks
- Weld appearance
- Weld bead shape
- Weld zone hardness
- Zinc expulsion
Eye safety?

- Ruby laser, 50 years ago
- “Production welding”
- Dissimilar metal welded
- Joint preparation noted
- Fixturing challenge noted
- Process alignment noted
A few years later...early ‘70s

- U.S. Air Force & Navy funded major laser welding projects
  - Sciaky Bros. at Avco Everett Research Laboratories
  - United Technologies Research Center

ESTABLISHMENT OF A CONTINUOUS WAVE CO₂ LASER WELDING PROCESS

SCIAKY BROS. INC.

SEPTEMBER 1976

TECHNICAL REPORT AFML-TR-76-158
FINAL REPORT FOR PERIOD JULY 1973 — JULY 1976

Distribution limited to U.S. Government agencies only; Test and Evaluation statement applied April 1975. Other requests for this document must be referred to AFML/LTM, Wright-Patterson AFB, Ohio 45433
Early focus on laser welding basics

- Shielding gas types and devices
- Steels, stainless, aluminum & titanium
Research groups had both “industrial” and military lasers available for welding trials.
Auto identified early as key target - but surprisingly limited expectations for the future -

- 1977 Brochure for 10kW “industrial” laser
An early, very bold welding attempt
- too much, too soon -

- The laser was not “production ready”
- The parts were not weld ready
- The auto industry was not “laser ready”
A few more years... and a little more success

- Still CO₂ lasers
- Built-for-laser robot
- Top-down executive motivation

Chevrolet Caprice 1988 Radiator Support

Spectra-Physics 5kW with L-100 robot
57 welds in 48 sec.

Chevrolet Beretta 1985 roof

Courtesy of Belforte Associates Archives
In the meantime...
- from the 70’s through to today -

- Powertrain laser welding flourishes
- Excellent part fit-up
- High volume
The 90s milestone in laser welding - tailor welded blanks -

- Every car company wanted them.
- Multiple welding suppliers emerged.
- CO₂ and YAG laser competed.
- 6-Sigma quality became the norm.
- “Commodity pricing” ($/m) quickly emerged.
Laser welding “efficiency” - important for competing in a commodity -

Empirical study
- Identify laser welding parameters that yield the most productive weld volume/energy
Evaluate >100 laser welds - weld cross sections required -

- Measure weld nugget
  - Depth
  - Area
- Calculate melting rate
  - Weld area
  - Weld speed
  - Volume/sec
- Calculate “efficiency*”
  - Volume/sec/power
  - mm³/kJ
- Plot and look for trends

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* Tab. 1: Laser butt welding data set

<table>
<thead>
<tr>
<th>Author Name*</th>
<th>Laser Type</th>
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<tbody>
<tr>
<td>Weld Date*</td>
<td>Manufacturer</td>
</tr>
<tr>
<td>Country Location*</td>
<td>Power on Work*</td>
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<tr>
<td>Joint Type*</td>
<td>Beam Quality</td>
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<td>Raw Beam Diameter</td>
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<td>Polarization</td>
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<td>Work Location</td>
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<tr>
<td>Edge 2 Preparation</td>
<td>Plasma Gas Orifice Diam.</td>
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<tr>
<td>Gap</td>
<td>Plasma Shield Gas Type</td>
</tr>
</tbody>
</table>

* minimum data required

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* Fig. 1: Laser weld nugget data

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* Yes, it’s actually not “efficiency” but more like melting productivity
After all those measurements...

- Highest observed efficiency \( \sim 60 \text{ mm}^3/\text{kJ} \)
- Stainless steel slightly better than mild steels
- No relationship to laser power
- No relationship to weld penetration
Finally, some direction...

- High aspect welds appear to be more efficient
- How does this affect laser weld design?

Fig. 6 Welding efficiency vs aspect ratio
Even under very different conditions... these limits still seem to apply.

- Katayama
- JWRI, Vol. 40
- 304 SS
- 0.3 m/min
- 0.1 kPa vacuum
- 26 kW disk laser
- 55 mm$^3$/kJ

Fig. 3 Welding efficiency vs power

Fig. 5 Welding efficiency vs penetration
Basic weld joint considerations

- **Butt weld**
  - Most efficient
  - Least distortion
  - Hardest to prepare
  - Hardest to fixture
  - Hardest to align

- **Lap weld**
  - Least efficient
  - Easiest to align
  - Problematic with zinc coating

- **“Fillet” weld (not really)**
  - Uncertain alignment
  - High residual stress
An important weld joint to consider
- tailored blanks represent major welding activity -

What does the efficiency analysis tell us here?
1. Make the best weld joint preparation
2. Fixture the parts properly
3. Keep the laser on the weld joint
Remember what that guy said?
- 50 years ago -

- Ruby laser, 50 years ago
- “Production welding”
- Dissimilar metal welded
- Joint preparation
- Fixturing
- Process alignment

“The 3 Things”
Simple keys to success
“The 3 Things”

Most laser welding problems stem from 3, simple, mostly mechanical things:

- Part preparation
  - Joint preparation
  - Cleanliness
- Fixturing
  - Joint alignment
  - Gap
  - Restraint
- Process alignment
  - Beam aligned to weld joint
  - Focus at correct location

Most Common Problem

Nearly complete lack of fusion
So how are we doing, 50 years later?

- Not too badly, much of the time....
Imaging assists in understanding laser welding behavior

316L stainless steel
- 16 mm square-butt
- 15 kW
- 2.0 m/min (80 ipm)

HY-80 Steel
- 0.5-in. square-butt
- 12 kW
- 2.0 m/min (80 ipm)

Videos
200 mm/s, 0.1 mm weld width
Other times, we’re not so great
- so many ways to fail -

- cracking
- poor fit-up
- missed joint
- porosity
But there are great successes - another milestone in laser welding -

- Large ship panel welding
- Major corporate commitment
- Massive equipment
- Strong focus on “the 3 things”
Speaking of success...
- laser battery welding -

- Longstanding laser application
- Movement to fiber & disc lasers
- Mastering fit-up
Example Welds in Battery Materials

- Ni-Plated Steel on Ni-plated Steel
  CW Fiber Laser

- Aluminum on Aluminum
  CW Fiber Laser

- Ni Plated Steel to Steel
  CW Nd:YAG Laser

- Copper on Copper
  CW Fiber Laser

- Aluminum to Aluminum
  Pulsed Nd:YAG Laser
Newer battery challenges - many solved with SM fiber lasers -

- Dissimilar metals
- Thinner metals
- More and more copper to weld

High Speed Helps
Growing and shrinking - medical devices -

◆ Market is growing
  – More old folks
  – More implantable applications

◆ Devices are getting smaller
  – Less intrusive
  – More laser welding challenges
  – Smaller and smaller welds to make

Image courtesy of: Medtronic
Smaller welds to make
- making “the 3 things” very difficult -

- Challenging joint preparation
- Difficult fixturing
- Critical beam alignment
- Strong pull from consumer electronics
Back to the auto industry
- another major milestone -

- VW Golf laser body-in-white welding
- Top-down decision and commitment
- Nearly 600 welding lasers at VW worldwide
- Spear-headed the remote laser welding trend
Many remote welding options

- Trumpf
- Rofin
- Kuka
- Comau
- Utica
- Omega
- LasX
- Scanlab
Strong growth in remote welding - mostly in the EU -

- North America auto manufactures slow to change
- Increased experience & availability should help
Important Enabling Technology

- for remote laser welding -

Seam Tracking

Fillet Weld Seam Tracking

- High speed camera with on-axis illumination and observation
- Auto-focus of camera along z-axis through scan head
- Edge detection with a resolution of ~0.1 mm
- Dynamic correction of welding position for “on-the-fly” processing

Omni-directional 3D on-the-fly welding with tracking

BLACKBIRD
ROBOTERSYSTEME

EWI
We Manufacture Innovation
Remote laser + vision + fixturing
- great merging of technologies -

Door Edge Welding with Seam Tracking

Video courtesy of BMW Group
What are we not doing well?
- mostly things related to high power -

- Not paying enough attention to beam delivery.
- Not mastering plume/plasma region.
- Still suffering with focal shift.
The most challenging and significant issues for high-power (>10kW) 1-μm laser welding are:

- Focal Shift (time dependent)
- Spatter Contamination
High power welds are expensive

- mid-process failure not an option -

- High cost of capital equipment to make welds
- Long welding times for expensive parts
- High quality welding performance required
- High consequences of weld process failure
EWI’s most expensive laser welds
- aerospace blank welds -

- Inconel 718, 10 mm thick
- 3.65 meter long butt weld
- 13 kW fiber laser
- 109 second weld time
- 11 panels required
- No porosity permitted
- Reflective focusing optics
- Manage everything!

Huge Success!
Continuing optics development - Targeting long duration welds @30 – 50+ kW -

- Third generation of reflective focusing optic*
- Excellent imaging performance
- Stable over time

First 20 kW Weld

* Patented optic design
Two very important optical tools - essential for welding performance analysis -

The “Gold Standard” in focal spot measurement
Primes Focus Monitor
Beam sampling
Photo-diode based

Unlimited power
Time-based measurement
Ophir-Spiricon BeamWatch
Non-contact
Camera-based (real-time)
Real-Time laser weld monitoring  
- demanded but frequently ignored -

- Consistently in the “top 5” of requested production capabilities, as reported by EWI’s Industrial Advisor Board.
  - Increasing quality concerns
  - Higher consequence welding
  - “Lights-off” operation

- Too often found under-supported, misunderstood, and actually ignored in production environments.
  - A management problem!
Laser welding is a wonderful, complex, & enormous topic!
Lasers are no longer “suspect” as manufacturing tools.
The automotive industry is responsible for much of the growth and breadth of laser welding applications.
Introduction of laser welding in industry can sometimes occur through upper management directives.
Expansion of laser welding applications will take place at higher powers and in smaller devices with tiny welds.
Expect more copper, cast iron, aluminum, and non-metals to be targets of laser welding.
Remember “The Three Things”
EWI is the leading engineering and technology organization in North America dedicated to developing, testing, and implementing advanced manufacturing technologies for industry. Since 1984, EWI has offered applied research, manufacturing support, and strategic services to leaders in the aerospace, automotive, consumer electronic, medical, energy, government and defense, and heavy manufacturing sectors. By matching our expertise to the needs of forward-thinking manufacturers, our technology team serves as a valuable extension of our clients’ innovation and R&D teams to provide premium, game-changing solutions that deliver a competitive advantage in the global marketplace.