Thick section laser welding

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Materials Joining and Engineering Technologies
How thick is thick?

Possible applications

Advantages and challenges of thick section laser welding

‘Traditional’ thick section laser welding techniques
  - CO₂ laser welding with plasma control
  - Hybrid CO₂-MIG/MAG welding

Newer techniques
  - 1µm laser source welding with plume control
  - Hybrid welding with 1µm laser sources
  - Multi-pass welding
  - Reduced pressure welding

Conclusions
How Thick is “Thick”?...

$t < 1\text{mm}$?
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☓

 Courtesy of Fiat

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How Thick is “Thick”?

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- $t < 2\text{mm}$?
- $t > 100\text{mm}$?

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Advantages and Challenges

Advantages
- Deep penetration
- Low heat input
- Low distortion
- Often single pass
- Often single-sided
- Narrow welds
- Non-contact
- Vacuum not essential
- Automated
- Robotic
  - fibre-delivered lasers

Challenges
- High power systems
- Investment
- Running costs
- Beam safety
- Process caveats, including
  - Part preparation, positioning and fit-up
  - Weld pool control
  - Plasma or plume control
‘Traditional’ High Power Laser Welding

- CO₂ laser sources
  - High powers possible
  - Plasma build-up between keyhole and beam
  - Can attenuate power arriving at workpiece
  - Needs replacement with a gas which is hard to ionise: He
  - Single-sided welding to 12mm
  - Double-sided to 25mm
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Hybrid Laser-Arc Welding

- Advantages over laser welding
  - Filler metal addition
  - Improved fit-up tolerance
  - Improved weld quality and profile
  - Control of weld microstructure
  - Control of hot cracking

- Advantages over arc welding
  - Higher speed
  - Deeper penetration
  - Higher productivity
  - Lower distortion
  - Lower rework
  - Lower per part manufacturing costs
Hybrid Welding for Shipbuilding

- Hybrid CO₂-MIG/MAG welding used in ship panel fabrication

Image courtesy FORCE Institute
Hybrid Welding for Shipbuilding

- Hybrid CO$_2$-MIG/MAG welding used in ship panel fabrication

![4mm butt weld](image1.png)

![4mm sub-arc weld to same scale](image2.png)
Hybrid Welding for Shipbuilding

- Hybrid CO$_2$-MIG/MAG welding used in ship panel fabrication
Hybrid CO₂-MIG/MAG welding used in ship panel fabrication
A range of engineering alloys can be welded to high quality
- Optimisation of parameters (power, focused spot size, welding speed etc) essential
- Materials exhibit a maximum thickness beyond which a given welding approach will no longer produce acceptable quality welds
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Thick Section Welding with 1µm Sources

- Plume dispersion (e.g. using a high mass flow gas jet) *can* then be required for process/keyhole stability and weld quality.
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Thick Section Stake Welds made through dissimilar steels, using plume dispersion.
Hybrid Welding with 1µm Sources

- Hybrid welding also possible using high power fibre-delivered fibre and disc laser beams

High speed, low distortion hybrid fibre laser-MIG butt welds in Al box sections
Hybrid welding also possible using high power fibre-delivered fibre and disc laser beams

- Vertical-up hybrid welding of thick Al alloy plate
Hybrid Welding with 1µm Sources

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Butt weld, 8mm S355 steel

Butt weld, 6mm 304L

Root weld in steel pipe
Multi-pass welding

- Suitable for materials typ. >25mm in thickness
- TWI has completed butt joints in materials up to 60mm in thickness
- Joint completion strategy can comprise
  - Double sided root weld
    - Using keyhole welding
  - Subsequent fill and cap sequence
    - Using conduction-limited beam melting of a wire feed, in to a narrow groove preparation
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Multi-pass root welding

- Single or double-sided root welding possible, depending on access

- Overall root face thickness needed depends on parameters used
  - e.g. laser power

8mm single-sided root

13mm single-sided root
Multi-pass root welding

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13mm single-sided weld
20mm double-sided weld
Multi-pass fill welding

- Conduction-limited melting of wire into groove using defocused beam
- Power, speed and wire feed rate optimised for high quality fills
  - Two examples using 5kW laser shown
- Method can complete joints in 60mm thickness material
- Transfer of method to other materials possible
Multi-pass fill welding

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Multi-pass weld qualities and properties

- **Following process development**
  - **Quality**
    - Welds free of cracks, pores and lack of fusion
    - Positive cap and root profiles
  - **Properties**
    - Welds strength over-matched (in steels)
      - Rp(0.2%) $\sim$ 400MPa, UTS $\sim$ 560MPa, $\varepsilon$ $\sim$ 23% (for S355 steel)
    - Without preheat
      - Root welds can be unacceptably hard (dep. on codes), $\leq$ 400HV10
      - Parts of welded joint can be unacceptably brittle, CVN $\geq$ 22J at -20°C
Multi-pass weld economics

- Based on coupon trials, when compared with arc welding
  - Joint completion comparable with or faster
  - Uses less gas shielding and filler wire
  - Five-fold running cost savings estimated possible
- Energy usage not excessive
  - Laser wall-plug efficiency improving
  - Beam on times short, given joint completion rate
- Joint completion still faster with EB
  - But EB requires a vacuum!

![Graph showing welding time, min, for 1m long butt in 40mm plate]
Reduced pressure welding

- Atmospheric pressure welding
  - 10µm source = plasma
  - 1µm source = plume
  - Both can attenuate beam
  - If attenuation varies during welding, process can be unstable

- Welding in vacuum
  - Boiling point significantly suppressed
  - Plasma: temperature and density reduces
  - Plume: beam attenuation also measurably reduces

Reduced pressure welding

- These changes can also occur at reduced pressure.
- TWI has been applying its sliding seal technology developed for reduced pressure EBW to LBW.
Reduced pressure welding recently demonstrated using a small-sized, robot-manoeuvrable, sliding seal chamber.
Conclusions

- Thick section laser welding relevant to land, sea and air transport applications, and vessels and pipelines
- Advantages include single pass deep penetration welds, introducing little distortion
- Traditionally done by high power CO\textsubscript{2} lasers, often requiring plasma control
- Process hybridised with arc welding, e.g. for fit-up tolerance

- High power disc and fibre lasers now have the same or better capabilities, albeit plume control can still be needed
- New processes also being developed, including multi-pass and reduced pressure welding
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