JOINING
INNOVATION
AND EXPERTISE

Reduced Vacuum Electron Beam Welding for Monopiles

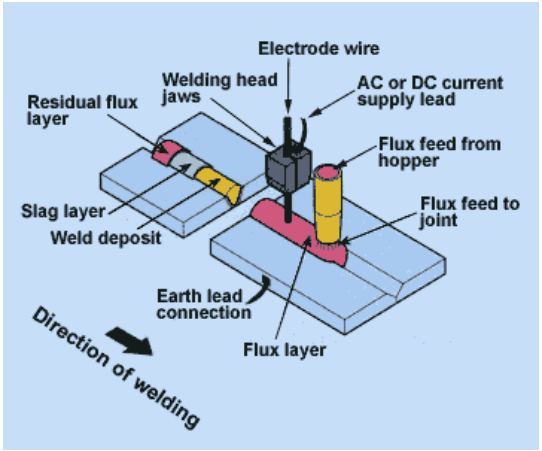
Carol Johnston, TWI Ltd

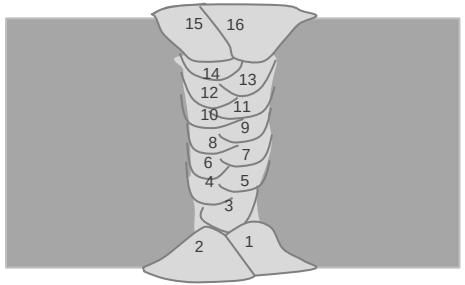
Foundation Ex , 10 May 2022

Welding Monopiles/ Towers/ Transition pieces

- Large diameter
- Longitudinal seam welds
- Circumferential welds
- Typically thickness >60mm
- Conventionally made by Submerged Arc Welding (SAW)
  - High productivity arc welding process

  Requires:
  - Preheat
  - Consumable
  - Flux
  - Machine weld preparation eg V or J bevel
  - Multiple passes
  - Repeated NDE
  - Slag removal

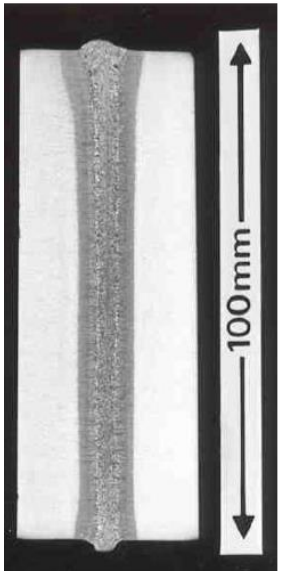




Schematic cross section of multipass Submerged Arc Weld

Electron Beam Welding

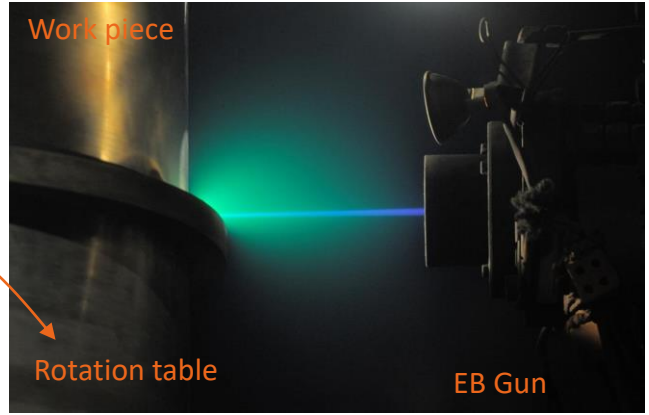
- Use electron beam to melt work piece
- Weld produced in a single pass
- Automated process
- Local vacuum EB welding most suited for thicknesses between 40 and 200mm
- No preheat
- No consumable
- No slag
- Low distortion
- Fast. Welding rate typically:
  - 300mm/min (50mm thickness)
  - 230mm/min (80mm thickness)
  - 150mm/min (100mm thickness)

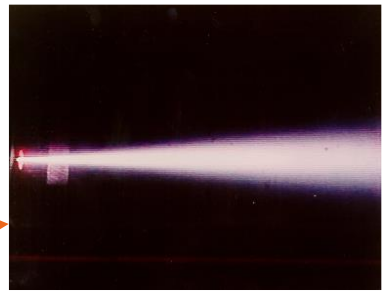


Metallurgy cross section of single pass Electron Beam weld

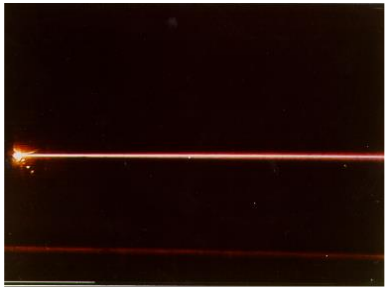
How does EB welding work?

- Edges of work pieces parallel, smooth with a gap of up to 0.5mm
- Focus beam of electrons (typically 1mm spot size)
- Move electron beam relative to work piece (either move work piece or move electron gun relative to work piece)
  - Kinetic energy imparted to work piece
  - Work piece melted
  - Molten metal solidifies to produce joint
- Requires plates to be demagnetised
- Requires vacuum to minimise scatter



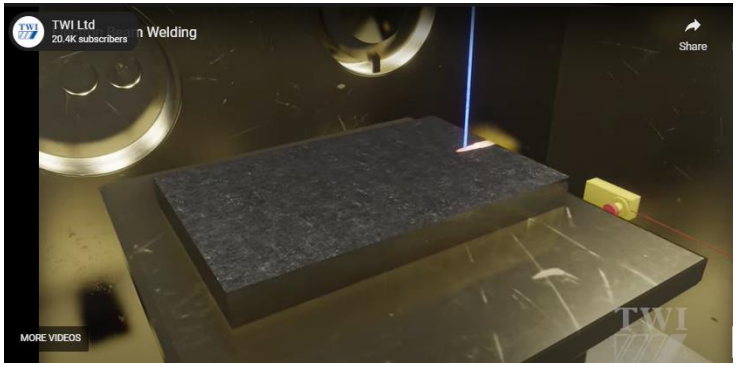


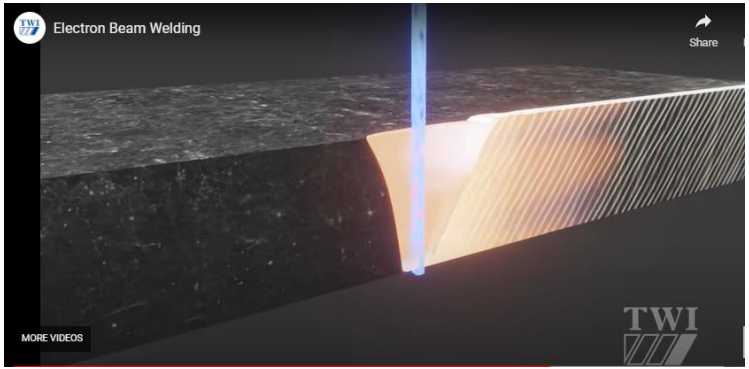
60kW Electron Beam
350mbar vacuum in He

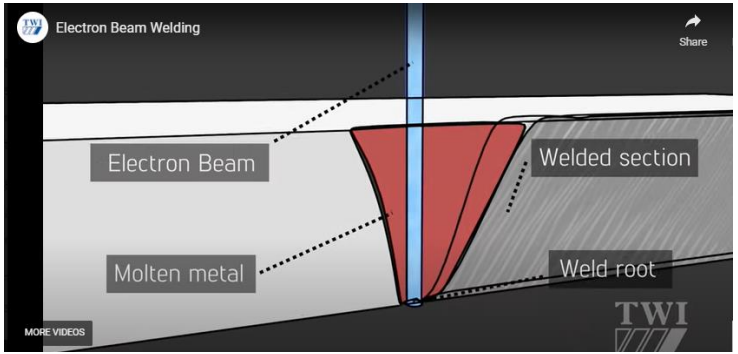


60kW Electron Beam
5mbar vacuum in He

How does EB welding work?
Example: In chamber welding in 1G position





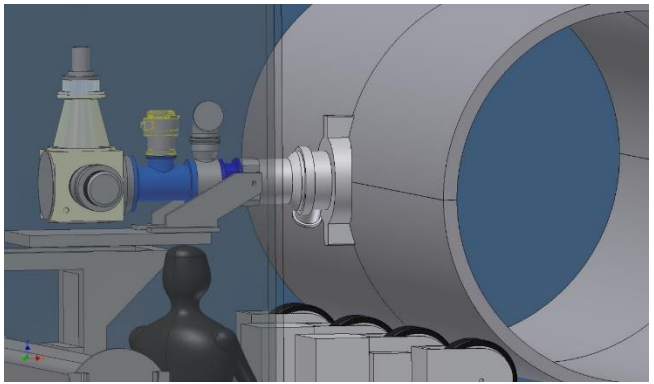


- E-beam melts workpiece progressively.
- Welding parameters apply to specific materials & geometry.
- Once developed, welding process is fully automated.

Video: https://www.youtube.com/watch?v=xYi2x0o--34

How do you create a vacuum?

- Place component inside a vacuum chamber
  - Approach widely used for components in Aero engines
- Produce a vacuum at the surface of work piece
  - Sliding seal system for welding head developed in TWI Core Research Programme
  - Local vacuum EB system ‘ebflow’ commercialised by Cambridge Vacuum Engineering (CVE)



ebflow

Local Vacuum Electron Beam Welding of monopiles

Commercialisation demonstration on 65mm 1.8m diameter S355 carbon steel.
<11 minutes to weld 3m.

Quality Assurance

BeamAssure™ Used in Local Vacuum

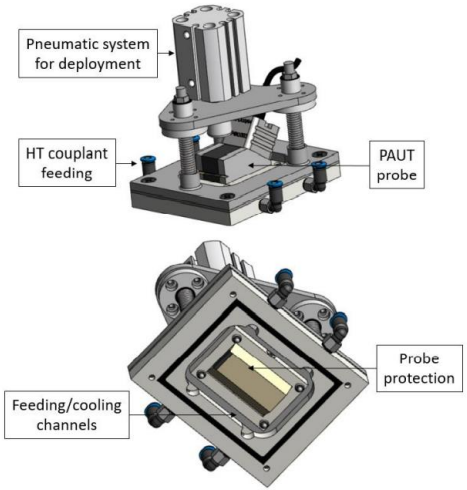
- Quality assurance tool which quantifies & qualifies the consistency of the electron beam
- Gathers long term process data

See https://www.twi-global.com/what-we-do/research-and-technology/technologies/welding-joining-and-cutting/electron-beam-technology/advanced-eb-equipment-and-qa-solutions/beamassure

Online UT monitoring of the LVEB weld

- A CRP project demonstrated that it is possible to use PAUT to inspect EB welds.
- Follow-on work then verified the efficacy of the approach for industrial use.

See TWI Industrial Member report 1134/2020



What is the Fatigue Performance of EB welds?

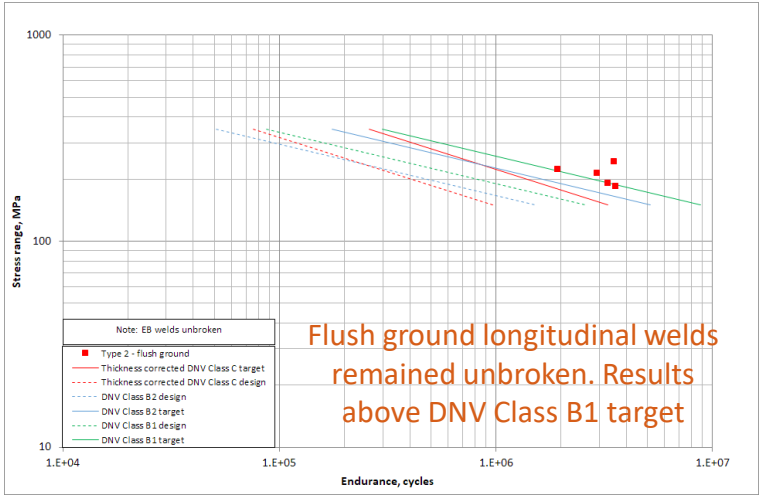
- Fatigue performance is key factor determining life of wind substructures
- Controlled by fatigue performance of welds
- Fatigue design code S-N curves based on performance of arc welds
- How does fatigue performance of EB welds compare?

- Early work at TWI shows Class D performance of traverse EB butt welds in 15mm thick grade 50D steel.
  - Punshon C and Wylde G, 1985: “Fatigue Strength of Electron Beam Transverse Butt Welds in a Low Ni-Cr-Mo Alloy Steel” TWI Industrial Member Report 263/1985.
- Recent Rapidweld project investigated fatigue performance of longitudinal EB welds made in 85mm thick S355ML steel

Rapidweld LVEB Welding for Monopiles

Consortium:

- SSE
- TWI
- CVE
- Sif



Flush ground longitudinal welds remained unbroken. Results above DNV Class B1 target

Type 3 specimen on test in 2500kN capacity fatigue test machine

FATIGUE PERFORMANCE OF LONGITUDINAL SEAM WELDS MADE BY RAPIDWELD ELECTRON BEAM WELDING FOR USE IN MONOPILES, Paper and poster reference P068, WindEurope Annual Event 2022, Bilbao, 5-7 April 2022

Industry acceptance of EB welding

- Further work needed because EB welds were not in the datasets used to derive the S-N curves in current design standards
- Data needed on the fatigue performance of:
  - As-welded longitudinal EB welds
  - Circumferential EB welds (flush, as welded)
  - Effect of seawater
  - etc

- TWI is launching a JIP, to expand the applicability of the technique and produce more fatigue data.
  - Working with DNV and results will be incorporated into a DNV Recommended Practice (eg C401 or C203, depending on the outcome).

Thanks – any questions?

Contact: Carol.Johnston@twi.co.uk

TWI website: www.twi-global.com

TWI Ltd is a Research and Technology Organisation.

We do and advise on:

- Joining,
- Testing,
- Inspection,
- Consultancy,
- R&D,
- Innovation and NSIRC,
- Training and Certification

for our Industrial Members

From top left: CTOD (fracture toughness and materials properties testing; Fatigue testing with ACPD crack length measurements; Automated UT of composites; Arc welding; Electron beam welding; Laser welding; Friction welding; Additive manufacture; Numerical modelling; Surface coatings; Unique full scale testing facilities; Surface engineering; Friction stir welding