Exploitation of power beam welding of thick section steel

PUBLISHABLE SUMMARY

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Background

In this project, the application of three prominent power beam technologies was addressed. Ytterbium (Yb) fibre laser-MAG hybrid welding, reduced pressure electron beam (RPEB) welding and non-vacuum electron beam (NVEB) welding were examined from the perspective of achievable weld quality and properties in a range of engineering steels, in a variety of strength levels and thicknesses.

Laser and hybrid laser-arc welding processes have already been demonstrated to be capable of high quality welding. For the fabrication of larger structures, hybrid welding can be particularly attractive, as it combines the low heat input, penetrating nature of laser welding, with the fit up gap bridging ability and superior weld profile of arc welding. Furthermore, and as with MAG welding, the filler wire addition from the arc process can also be used to help control weld metal properties, eg weld metal toughness. As the source behind these two processes, the Yb fibre laser still represents one of the highest power laser technologies available for industrial welding, making laser welding of thicker sections more commercially attractive. Power outputs can exceed other high power lasers, with the process flexibility of optical fibre delivery, whilst having capital investment costs (per kW) in line with comparable laser technologies. In addition, post-purchase running costs are reduced, as the wall plug efficiencies are in excess of those of many other laser sources.

When considering electron beam processes for thicker section welding, neither RPEB nor NVEB welding require a vacuum chamber around the components being joined, unlike conventional EB welding. This can lend these processes a commercial advantage when compared with in-chamber welding. With sufficient beam power, both processes remain capable of penetrating material thicknesses in a single pass of tens of millimetres, in excess of those possible using a laser.

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Objectives

The objectives of this project were:

- To develop and evaluate hybrid Yb fibre laser-MAG welding procedures for structural steel grades in thicknesses between 6 and 25mm.
- To develop and evaluate hybrid Yb fibre laser-MAG welding procedures, and/or out-of-chamber EB welding procedures, for pipeline steels in thicknesses between 12.7 and 50mm.
- To determine for which steel and welding process combinations weld qualities and mechanical properties can be demonstrated to meet industrial requirements.
- To thus document process capability and applicability of hybrid Yb fibre laser-MAG welding and out-of-vacuum chamber EB welding, to facilitate appropriate process selection by the end-user.

Project Outcome

Out-of-chamber electron beam welding

The overall conclusions of the EB welding trials carried out in the project can be summarised as follows:

- NVEB welding was capable of achieving weld penetration depths of >35mm in steel.
- NVEB weld quality was limited by persistent weld root cracking problems.
- NVEB welds were mechanically tested and, in general, their properties met with Sponsor requirements, with the exception of unacceptably low impact toughness.
- Conversely, RPEB welding was capable of producing crack-free welds.
- Furthermore, RPEB welds were mechanically tested and met with Sponsor requirements, with the exception of unacceptably low impact toughness in the case of welds made in X80 plate.

Hybrid Yb fibre laser-MAG welding

The overall conclusions of the hybrid welding trials carried out with the 7kW Yb fibre laser used in the project can be summarised as follows:

- Unlike EB welding, hybrid welding was generally limited to making the root pass, of a subsequent multi-pass weld, in the steels and thicknesses addressed by the project.
- Hybrid welding was capable of producing acceptable quality root runs in X80 plate, with a maximum root face thickness of 6mm with the laser used.
- Furthermore, a root gap tolerance of ~0.8mm was demonstrated, owing to the wire addition inherent in the hybrid process.
- Root runs made in X80 plate up to 22mm in thickness, appeared to have mechanical properties in line with Sponsor requirements.
- Conversely, root runs made in X65 pipe up to 17.5mm in thickness were unacceptably hard for sour service use, and further steps (e.g. preheating) would be required to reduce hardness to within acceptable limits.
- Despite the successful results in X65 and X80 steels, at the end of this project, hybrid root welding of other steel grades (S420, S690 and 9%Ni steels) still required further development.

Benefits

By participating in this project, the Sponsors gained an early appreciation of the capabilities and merits of these emerging power beam welding processes, accessing outline welding procedures for common structural, pipeline and cryogenic steels.

The general benefits of these processes would include:

- Reduced distortion when compared with conventional arc welding with, in turn, reduced rework and its associated costs.
- Improved productivity, from the higher joint completion rates possible.
- Improved joint consistency and quality, and reduced labour requirements, from the automatic nature of the processes used.
- Reduced usage of welding consumables, and associated cost reductions.

Participants

The Sponsor group comprised:

- ArcelorMittal.
- Baoshan Iron and Steel Co Ltd.
- Cambridge Vacuum Engineering.
- Heerema Marine Contractors Nederland.
- Mangiarotti SpA.
- POSCO.
- Saipem SpA.
- Sumitomo Metal Industries.
- Technip UK Ltd.

Scope of Work

Out-of-chamber electron beam welding

An extensive NVEB process development programme was undertaken. Butt welds were then produced in test coupons, using materials supplied by the Sponsor group, and quality evaluations and mechanical tests undertaken. However, given the persistent problems encountered with cracks in the NVEB welds, a number of coupons were also welded using the RPEB process. This second set of coupons was also then subject to quality evaluations and mechanical tests. A summary of the findings from these two sets of tests is given in the Project Outcome section above.

Hybrid Yb fibre laser-MAG welding

The hybrid welding trials carried out also had to overcome a number of difficulties that were encountered, including:

- Inconsistent root bead profile, related to laser keyhole instability. This was improved by:
  - Restricting the root face thickness to ≤6mm (with the specific laser used, at least), and/or
  - Introducing a 0.5mm wide root gap, and/or
  - Introducing a small chamfer along the bottom edges of the abutting joint edges.
- Unacceptable top bead appearance and internal quality, related to improper arc welding set-up. These problems were alleviated by:
  - Using an appropriate wire electrode stick-out, and a short, stiff arc, to prevent arc wander, and
  - Using an appropriate flow rate of arc shielding gas, to ensure adequate arc stability.

Making these changes ensured Class B or Class C quality hybrid root welds (to ISO 13919-1) were possible in X65 or X80 steels. Root butt welds were then produced in test coupons of these steels, using materials supplied by the Sponsor group, and mechanical tests undertaken. A summary of the findings from these tests is given in the Project Outcome section above.

Welding trials were also made along butt joints with fit-up gaps introduced deliberately; indicating that these root weld qualities could be maintained over joints with gaps up to 0.8mm in width.

Hybrid root welds of an acceptable quality were not produced between S420, S690Q and 9%Ni steel plates, and at the end this project, further procedure development work was still required to achieve this.

Price and Duration

The project had a duration of 3 years and a budget of £180,000. It was funded by 9 Sponsors each making a contribution of £20,000. The fee for additional companies buying back into the project results is £20,000.

Further Information

For further information on how a Joint Industry Project (JIP) runs please visit:

http://www.twi.co.uk/services/research-and-consultancy/joint-industry-projects/

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