Institution: 10007822

Unit of Assessment: 12

Title of case study: A new joining process for deep sea pipelines

1. Summary of the impact (indicative maximum 100 words)

Automated dry hyperbaric (high pressure) gas metal-arc welding (GMAW) is used in deep-sea pipelines for remote repair and “hot-tap” connections to operating pipelines. Cranfield’s process can be used for depths of up to 2,500 metres. The process has been applied in production with a new joint being made at a depth of 265 metres on a live gas pipeline. As part of the Åsgard Subsea Compression project, it will improve the recovery from the Mikkel and Midgard reservoirs by around 280 million barrels of oil equivalents, worth more than 28 billion dollars at today’s prices.

2. Underpinning research (indicative maximum 500 words)

Cranfield identified that fully automated dry hyperbaric welding for deep-water applications was going to be a major requirement for the sustainability of UK and world fossil fuels. Deep-water hydrocarbon recovery had grown steadily since 1990 to become a significant fraction of offshore oil and gas production by this time. This production is likely to grow significantly over the coming decade due to depletion of reserves in shallow waters. Cranfield established a facility, unique in the world then and now, to enable the study and development of arc welding, in all positions, up to a gas pressure of 250 bar, equivalent to 2,500 metres water depth (P1 & G1). Following the establishment of this facility, Cranfield conducted extensive research into gas metal arc and plasma welding at high pressures (P2-5, G2, 3).

Cranfield’s initial work focussed on the behaviour of welding arcs and metallurgy at elevated pressures in the downhand position, i.e. the electrode located above the job (P2, 3, 5, G2). As expected, we found significant departures from conventional welding. At high pressures, operating parameters are constrained by stability considerations, leaving limited scope for weld pool and weld property modification. Despite this, robust and tolerant GMAW and plasma operating parameters were found for positional welding that were largely insensitive to orientation.

The problems we encountered included arc instability and poor metal transfer characteristics due to high gas pressures, high susceptibility to hydrogen cracking and other defects due to the high cooling rate in a moist environment. We arrived at solutions to these problems by systematic study of the arc characteristics, determination of thermal cycles and an investigation of welding consumables with varying alloy compositions (P5, G3). The result of these studies was a new power source control strategy with high capability power source configurations, optimised electrical transients and waveforms, combined with optimised filler materials (P5, P6, G3).

Key Researchers	Post details and dates	Research
Dr I M Richardson	Lecturer (May 1991 – Sept 1996) Senior lecturer (Oct 1996 – June 2001)	Arc physics and hyperbaric welding
Professor J Billingham	Professor of Marine Technology (May1984 – Aug 1998), Head of School of Industrial Science and Engineering (Sept 1998 – Sept 2004)	Offshore engineering, hyperbaric welding
J H Nixon	Principal researcher (Oct 1985 – Sept 2007)	Welding processes

3. References to the research (indicative maximum of six references)

Evidence of quality – Peer reviewed journal papers

P1 * Nixon, J.H. and Richardson, I.M., ‘Deepwater Welding and Intervention Technology’, Underwater Technology, **21**(3), pp. 3-7, 1995.
doi: 10.3723/175605495783326432

P2 Ducharme, R[a]., Kapadia, P[a].; Dowden, J[b].; Richardson, I.M. and Thornton, M. ‘A Mathematical Model of TIG Electric Arcs Operating in the Hyperbaric Range’ J. Phys. D: Appl. Phys, **29**(10), pp. 2650-2658, 1996.
doi: 10.1088/0022-3727/29/10/016)

P3 * Ducharme, R[a]., Kapadia, P[a]., Dowden, J[b]., Thornton, M. and Richardson, I.M., ‘A Mathematical Model of the Arc in Electric Arc Welding, Including Shielding Gas Flow and Cathode Spot Location’ J. Phys. D: Appl. Phys, **28**(9), pp. 1840-1850, 1995.
doi: 10.1088/0022-3727/28/9/012

P4 * Ogunbiyi, B., Nixon, J., Richardson, I. and Blackman, S., ‘Monitoring indices for assessing pulsed gas metal arc welding process’ Science and Technology of Welding & Joining, **4(**4) pp. 209-213, 1999.
doi:10.1179/136217199101537798

P5 Hart P., Richardson I. M. and Nixon J. H. ‘The Effects of Pressure on Electrical Performance and Weld Bead Geometry in High Pressure GMA Welding’, Welding in the World, **45**, No. 11/12, pp25-33, 2001.

<u>Key to Papers</u>
a) Physics Dept. University of Essex; b) Mathematics Dept. University of Essex

Evidence of quality – underpinning research grants

G1 EPSRC (GR/J93153/01), PI: J. Billingham, CIs: I Richardson and J. Nixon, ‘Design, construction and commissioning of a 250 bar hyperbaric welding research facility’. 1994 –1996 £500,000.

G2 EPSRC (GR/K70656/01), PI: I Richardson, CIs: J. Billingham and J. Nixon, ‘Arc welding processes for deepwater hyperbaric welding’, 1996 – 1998, £210,319.

G3 EPSRC (GR/M32689/01), PI: I Richardson, CIs: J. Billingham and J. Nixon, ‘Deepwater hyperbaric welding - the influence of welding position on arc stability and weld pool control’, 1999 –2000, £272,373.

4. Details of the impact (indicative maximum 750 words)

Cranfield's research into gas metal-arc welding has led to new ways of connecting and repairing subsea pipelines that are changing the nature of off-shore hydrocarbon operations. The technology allows pipeline operations in increasingly deeper waters, making it possible for the development of previously inaccessible hydrocarbon reserves.

The continuous increase in demand for oil and natural gas resulted in sustained growth of off-shore oil and gas production. Offshore crude oil production can be broadly classified in three categories based on the depth of water; shallow water (< 400 m), deep water (400 to 1500 m) and ultra-deep water (> 1500 m). Since the mid-1960s, the rate of offshore production of oil and natural gas growth was on a rise till about middle of 1990s, when offshore production reached a plateau. This could be attributed to the depletion of fossil fuel in the shallow water region as deep-sea exploration showed a significant growth during that period. Concurrently deep-water recovery has dramatically increased and now comprises more than 20% of total offshore production. This figure is likely to rise significantly over the coming decades as shallow reserves are further depleted.

Critical to all offshore oil and gas recovery are pipelines for connecting well heads and for transporting hydrocarbons to vessels or onshore. A process known as a hot tapping is required when an operator wants to expand the coverage of an oilfield. In this process a T-connection is welded to an existing pipeline while oil or gas continues to flow [C3]. In addition, subsea pipelines can require maintenance, often requiring repair if they are suffering from, e.g. cracking due to environmental degradation or occasional accidental damage. For larger pipe diameters, beyond depths where divers can operate, this may be achieved by the sleeve repair method. In this operation, the pipeline is cut, a sleeve pre-welded onto a spool piece is slid over the subsea pipe end and this is welded, subsea, using dry hyperbaric welding. The only viable welding method for these operations beyond diver depths is remote dry hyperbaric GMAW [C4]. The operation involves lowering a specially designed subsea habitat around the pipe to be welded and filling the habitat with inert gas to displace the water. Remotely operated tools are then used to align the pipes, prepare the pipe surfaces before performing the welding operation.

Following the detailed research programme and process development, subsea remote welding equipment and welding procedures were specified by Statoil. Offshore field trials took place in 2011 in a Norwegian Fjord at world record depths of 350msw for the remote hot tap and 970msw for sleeve repair. This involved further extensive detailed studies of process sensitivity, repeatability (in all positions) and further optimisation for both remote hot tap and sleeve repair applications at various water depths with different consumables. In 2012, further fully integrated offshore trials with the remote hot tap equipment, validated the welding process for production application [C5].

Formal specifications for hyperbaric weld procedures, arising from Cranfield's research, have now been approved by Det Norske Veritas (DNV) for different applications as a part of a standard [C6].

The first production application was a remote hot tap installation carried out in connection with the preparations for the Åsgard Subsea Gas Compression project in the Norwegian Sea. The remote Tee was welded on to the Åsgard B production flowline at a water depth of 265 metres. Sophisticated remotely operated subsea tools and a subsea welding tool installed the Tee on a live gas pipeline [C1, 2]. Completion of the Åsgard Subsea Compression project will take place in

2015, as the first of its kind in the world. Compressors will be installed on the seabed, instead of on a platform. This will improve recovery from the Mikkel and Midgard reservoirs by around 280 million barrels of oil equivalents, worth more than 28 billion dollars at today's prices.

There are many beneficiaries of the research, both economic and environmental. Economic benefits arise through significant additional oil recovery. This benefits governments through taxes (including the UK), oil & gas companies through profits and society in general through lower energy prices. Other beneficiaries include the pipeline operators who lay and maintain pipelines and companies who manufacture and maintain the equipment associated with the processes. Environmental benefits arise through the ability to repair subsea structures at great depths. As illustrated by the recent Deepwater Horizon oil spill in the Gulf of Mexico, it is difficult to deal with catastrophes of this nature at these depths. The new repair processes developed at Cranfield provide ways to avoid future events and to deal with them should they occur.

5. Sources to corroborate the impact (indicative maximum of 10 references)

C1 Subsea gas compression to boost Åsgard volumes http://www.statoil.com/en/NewsAndMedia/News/2011/Pages/16Aug_SubseaGasCompression.aspx- access date 16th September 2013

C2 Remote-controlled world record at Åsgard http://www.statoil.com/en/NewsAndMedia/News/2012/Pages/13Sep_hottap.aspx - access date 30th September 2013

C3 Woodward N., Apeland K. E., Berge J.O., Verley R. and Armstrong M., 'Subsea pipelines: the remotely welded retrofit tee for hot tap applications', Proceedings of the ASME 2013 32nd International Conference on Ocean, Offshore and Arctic Engineering, OMAE2013, June 9-14, 2013, Nantes, France, OMAE2013-10765

C4 Contact: Welding Specialist, Isotek Oil & Gas Ltd, Leeds, England

C5 Contact: Department Manager, Statoil ASA N-4045 Stavanger, Norway

C6 Det Norske Veritas, 2012, DNV-OS-F101 Submarine Pipeline Systems (Offshore Standard)