TWI

JOINING
INNOVATION
AND EXPERTISE

Business Review 2019

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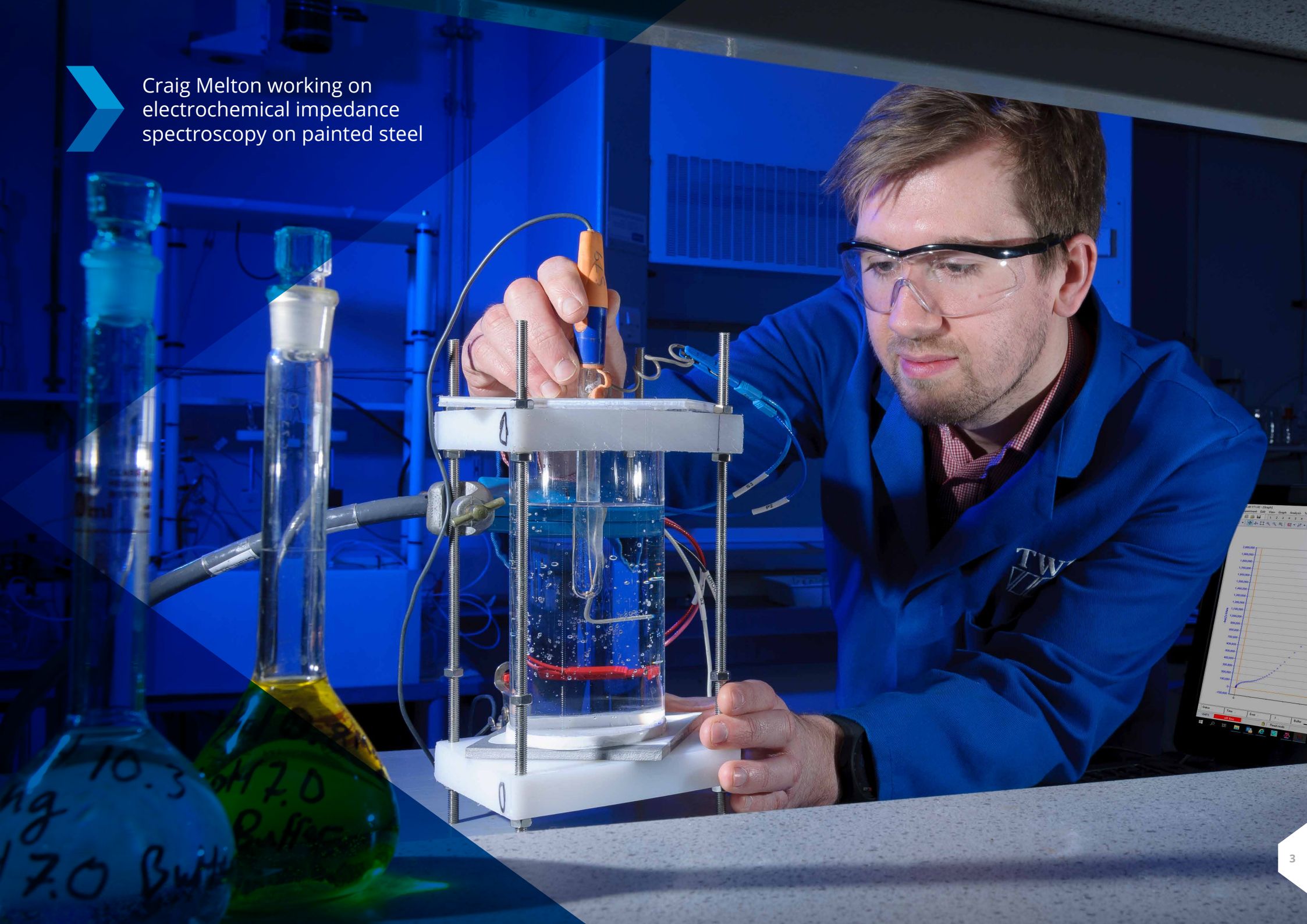


Craig Melton working on electrochemical impedance spectroscopy on painted steel

Introduction

Aamir Khalid
Chief Executive

TWI has a 70-year history of serving the needs of our Industrial Members, and this continues to lead the direction of our work to this day. However, as the needs of industry change, so too must TWI's support to meet the challenges of an ever-changing landscape. This has meant more Member companies being invited to work under the same roof alongside TWI's experts, as well as various universities who operate collaboratively within the structure of a number of innovation centres.

Our experts not only support university and industry-driven innovation, but also work to create underpinning technology and research to develop products that are ready to bring to market by subsidiary companies.

These twin approaches to the development of innovative new solutions align with a broader strategy by the UK government to address future developments in areas such as artificial intelligence and data, the ageing society, clean growth, and the future of mobility. It is here that TWI's strengths can be seen as we invest in developing expertise and innovation in these key areas, while continuing to support the wider needs of our Members on a regional and international level.

Of course, none of this is possible without the staff to undertake such work and, again, TWI offers assistance through our respected training and certification programmes to deliver the next generation of trained and competent employees for industry. This is further supported by the development of staff through the TWI Masters Programme, our apprenticeship scheme, diversity and inclusion initiatives, and the National Structural Integrity Research Centre.

Finally, as with any business, we have a responsibility to the wider community, which is addressed through TWI's corporate and social responsibility work. This includes educational outreach programmes designed to promote science, technology, engineering and maths (STEM) in schools, offering tours of our facilities, supporting educational opportunities for future generations, and a commitment to caring for the environment.

While the needs of industry, the environment and the global population changes year after year, TWI continues to remain at the forefront of providing innovative solutions to tomorrow's problems.

Aamir Khalid - Chief Executive

TWI Council

The Council is the governing body of TWI and consists of elected representatives from Industrial Member companies and Professional Members.

Paul Tooms – Kosmos Energy LLC – Chair of TWI Council
Eur Ing Nigel Knee – EDF Energy – Vice-Chair of TWI Council

Dr Stephen Beech CEng, FRSA, FIMMM, FWeldI – Professional Member
Dr Peter Boothby CEng, FWeldI – Rosen Group
Dr Ruth Boumphrey BSc – Lloyd's Register Foundation
Iain Boyd CEng, IWE/EWE, FWeldI – Professional Member
Eur Ing Professor Norman Cooper CEng, CSci, FIMMM, FWeldI – BAE Systems Marine Ltd
Eur Ing Alan Denney BSc, MScm CEng, MIMMM, FWeldI – Professional Member
Eur Ing Jackie Dixon BEng(Hons), MSc, CEng, FWeldI – Rolls-Royce Plc
Jeffrey Garner CEWE, CEng, FWeldI – Professional Member
Professor John Irven MA, CSci, CChem, FRSC, HonFWeldI – Consultant
Professor Steve Jones CEng, FWeldI - NAMRC
Professor Scott Lockyer CEng, MIMMM, MWeldI – Uniper Technologies Ltd
Eur Ing Andrew MacDonald CEng, IWE, MIMMM, AWeldI – Lloyd's Register Foundation
Dr David Mallaburn CEng, CPhys – EDF Energy Generation
Eur Ing David Millar CEng, CEWE, FWeldI – Professional Member
Dr John O'Brien CEng – Chevron Corporation
Ian Perryman BSc, MSc, CEng, SenMWeldI – Perryman Engineering Ltd
Dr Brian Robb CEng, FIMMM – Rolls-Royce Plc
Eur Ing Dr David Taylor CEng, FWeldI - Professional Member
Dr Chris Thornton MA, PhD, CEng, MWeldI – Professional Member
Simon Webster CChem, FRSC, FRSA – BP Plc
Stephen Webster CEng, FIMMM, FWeldI – Professional Member

Council Boards Governing TWI Activities

Board/Committee	Chair
Research Board	Professor John Irven
Finance and General Purposes	Paul Tooms
Professional	Professor Steve Jones
Certification Management	Julio Tolaini

TWI Council, left to right:
Chairman of Council: Paul Tooms / Vice Chairman: Nigel Knee

TWI Executive Team

CEO and Executive Directors:

Professor Aamir Khalid BSc, MSc, MBA, PhD, CEng - CEO
Mrs Gillian Leech FAIA, MBCS - Finance Director
Dr Paul Woollin FREng, MA (Cantab), FIMMM, FWeldI - Research Director
Dr Mike Russell MEng, PhD, CEng, MWeldI - Operations Director

(From March 2019)

Dr Steve Shi BSc, MSc (Eng), CEng, EWE, MIMMM, SenMWeldI – Industrial Members Director
Dr Shervin Maleki PhD, CEng – Global Development Director
Eur Ing Professor Tat-Hean Gan BEng (Hons), MSc, MBA, CEng, CMgr, FIET, FCMI, FWeldI, FInstNDT, IntPE, FISEAM, FISCM - Innovation and Skills Director

TWI Executive Board CEO and Directors – left to right:
Tat-Hean Gan / Gillian Leech / Paul Woollin / Aamir Khalid / Shervin Maleki / Mike Russell / Steve Shi

Support to Members

Steve Shi
Director, Industrial Members

Chris Eady
Associate Director,
Professional Affairs and
Certification

Industrial Membership

TWI's Industrial Members continue to be the primary focus of our R&D and consultancy support efforts. Membership remains a diverse mix of industry sectors, since all continue to rely on the optimal application of welding, joining and inspection, together with maintenance of product or asset performance. The energy sector continues to take the largest share of our Membership (35%), with transport (automotive and aerospace), construction and equipment/consumable suppliers accounting for ~15% each.

Throughout 2018, a total of 86 companies came into Membership, spread across all industry sectors; from areas across the world, including the UK, Europe, the US, Japan and China.

Whilst the provision of rapid technical support (via our duty engineer and information services functions) continues to be a key benefit, there is an ongoing effort to add value to Industrial Membership. This included the introduction of our Welding and Joining Exhibition during May 2018; enabling equipment and consumable manufacturers to promote their capabilities to the wider Membership and other companies. We will look to introduce new Member benefits moving into 2020 and beyond.

Professional Membership

The Welding Institute is the leading professional engineering institution for our industry and we support and represent our Members throughout their careers, assisting with their continuing professional development. The Welding Institute is a licensed member of the Engineering Council, assessing eligible members for registration at Chartered Engineer (CEng), Incorporated Engineer (IEng) and Engineering Technician (Eng Tech) registration. In 2018, it was positive to see that we increased our student Members by 55% with an increase of 6% in interim Engineering Council registration.

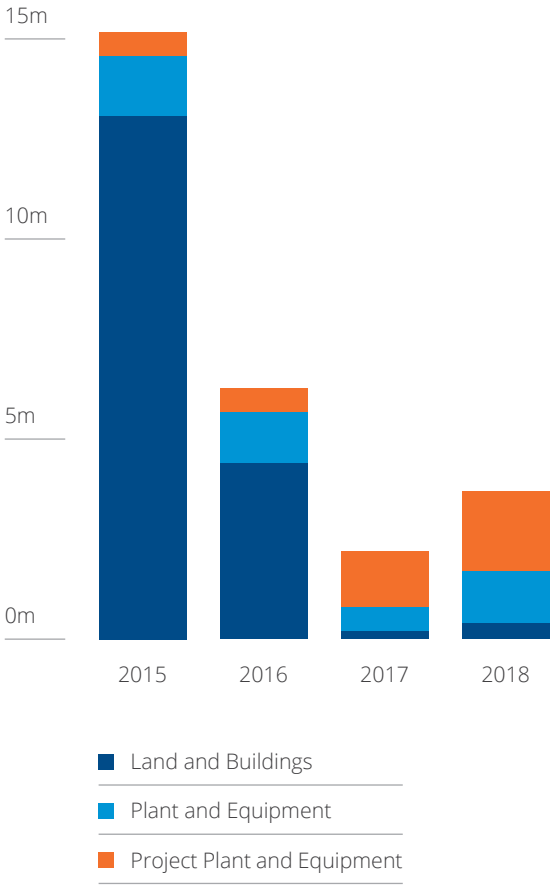
We are focusing effort on student membership because we are acutely aware of the reported global skill shortages in our industry and we are working to improve our age demographic, so 2018 saw us continuing our educational outreach work to engage more young people in understanding how creative and exciting a career in our industry can be. Alongside the outreach, we are also embedding The Royal Academy of Engineering Diversity and Inclusion Framework to enable Members to achieve their career ambitions and aspirations. The Institute accredits and approves qualifications and has supported the creation and implementation of a number of Trailblazer apprenticeship standards.

With local branches in the UK and across its global network, the Institute provides a wealth of practical professional support to its Members; providing information, guidance, training and networking, which is all created to support our Members' individual professional development. We also serve as the voice for the industry, contributing to consultations and informing policy decision through such bodies as the British Standards Institution, the Royal Academy of Engineering, the UK government, and the European Commission.

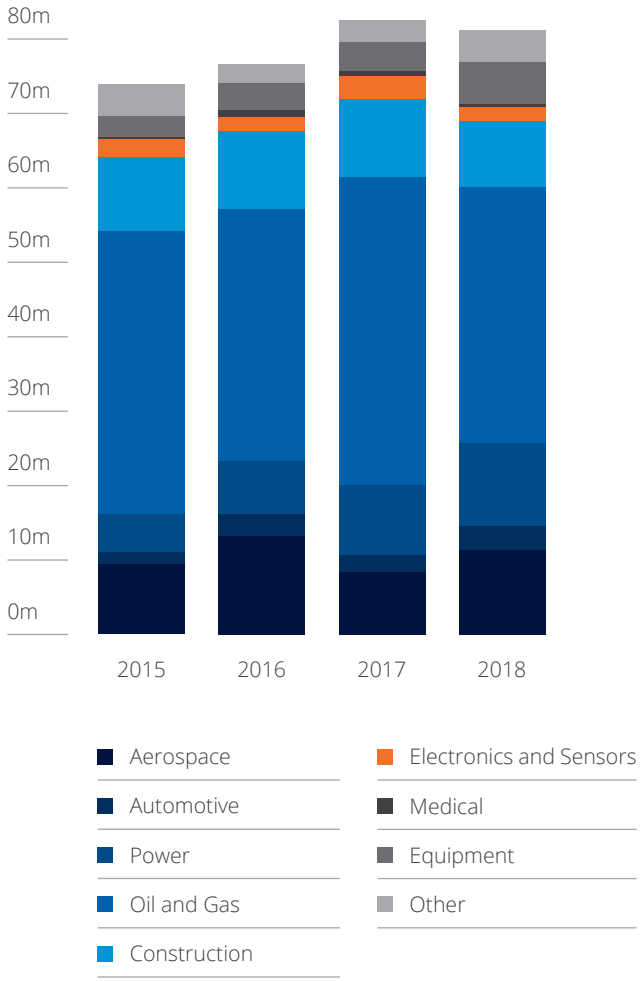
Business and Financial

Gillian Leech
Director, Finance and Services

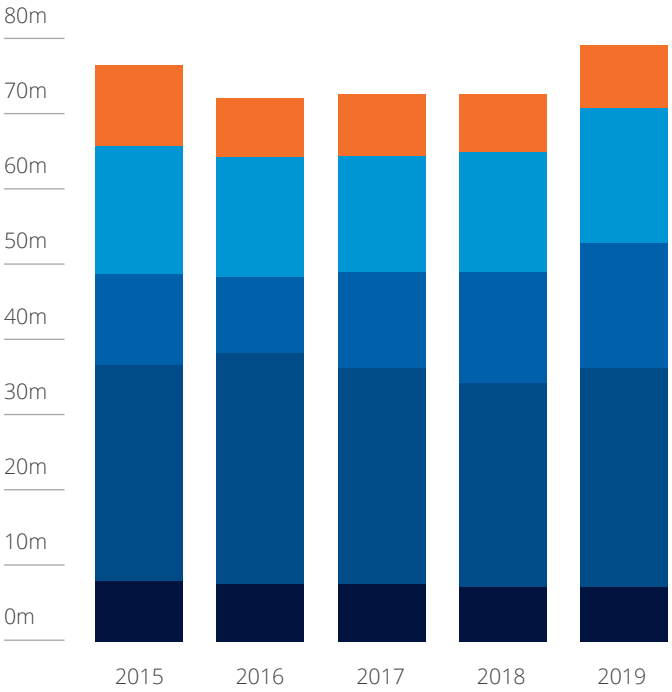
Asset Acquisition



Order Intake by Industry Sector



Product Income



Projects per Annum

635 SINGLE CLIENT

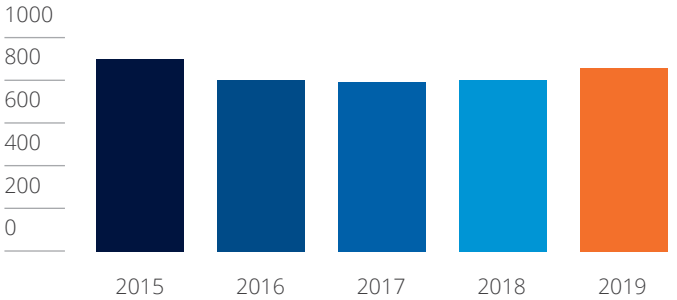
58 PHD AND MSC

133 COLLABORATIVE

12 JOINT INDUSTRY

60 CORE RESEARCH

Group Staff Nos



Business and Financial

TWI Group

The Welding Institute (holding company)

TWI Ltd
TWI Technology Centre North East
TWI Technology Centre Yorkshire
TWI Technology Centre Wales
TWI Aberdeen
TWI Certification Ltd
The Test House Ltd
NSIRC Ltd
SIRF Ltd
Plant Integrity Ltd
Granta Park Estates Ltd

TWI Azerbaijan
TWI Bahrain
TWI Canada
TWI China
TWI Greece
TWI India
TWI Indonesia
TWI Malaysia
TWI North America
TWI Pakistan
TWI Thailand
TWI Turkey
TWI United Arab Emirates

TWI Networks

11
GROUP OR ASSOCIATED COMPANIES

600
INDUSTRIAL MEMBER COMPANIES WORLDWIDE

140
NSIRC AFFILIATED UNIVERSITIES

10
ON-SITE INNOVATION CENTRES

38
UNIVERSITY PARTNERSHIPS

5225
PROFESSIONAL MEMBERS IN 18 BRANCHES

4
PRIVATE TECHNOLOGY INNOVATION PARTNERSHIPS

Research and Innovation

Paul Woollin
Director, Research

Tat-Hean Gan
Director, Innovation and Skills

Overview

TWI's mission is to help industry solve its problems by providing impartial advice, knowhow and safety assurance through engineering, materials and joining technologies. TWI solves today's problems through expert advice and by assisting with the application of available technology. Additionally, TWI works with industry to understand future challenges, and develops new expertise, processes and products to address them.

This requires an ongoing commitment to research and innovation, which is carried out via three mechanisms: exploratory projects, the Core Research Programme (CRP), and publicly funded collaborative projects. Exploratory projects are internally funded and support preliminary investigation of innovative technologies. The CRP invests approximately half of the Industrial Membership subscriptions to develop capabilities to underpin future products and services for Industrial Members. It is balanced across technologies (manufacturing processes, material property characterisation, inspection and quantification of structural integrity) and includes both disruptive and incremental technology development. TWI's internal research activity is supplemented by collaborative projects, publicly funded via Innovate UK and the EU Framework Programmes. These projects are focused on the development of new technology that can be readily exploited by industry, often via prototype products. In 2018, TWI's research funding included £0.7m of exploratory projects, £3.4m of CRP and £15.0m of collaborative projects.

It is essential for TWI to leverage its internally funded research using collaborative projects in order to create new capabilities in a cost-effective way, and to ensure that benefits arising from collaborative projects can be exploited by TWI's Industrial Members. TWI's Research Board, drawn from the Industrial Membership, plays a key role in overseeing the CRP and in identifying technology themes to drive the research and development carried out under the three mechanisms.

In addition, TWI has developed a mechanism for aligning postgraduate student research to the needs of industry via the NSIRC student cohort at TWI and via TWI Innovation Centre partnerships with universities and industry. These mechanisms develop fundamental knowledge to underpin other research activity, and allow co-ordinated development of technologies across the full range of Technology Readiness Levels (TRLs).

These mechanisms combine to drive the creation of industrial impact, via the exploitation of new technology by the Industrial Membership. This remains the focus of TWI's research and development activities.

Collaborative Projects

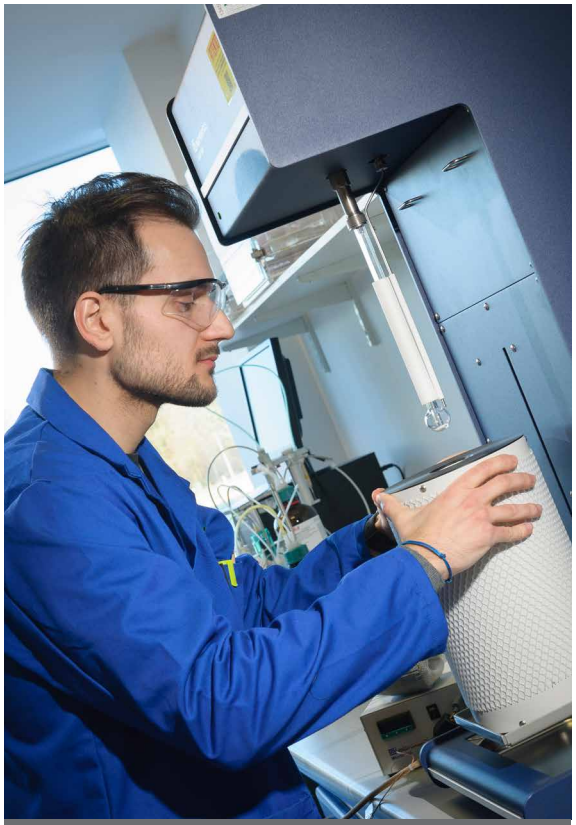
Publicly funded projects via Innovate UK and the EU Framework programmes bring a valuable perspective to TWI's research and innovation activity, reflecting the industrial priorities identified by the respective funding bodies. Collaborative projects are delivered by TWI as part of a consortium, and bring a number of benefits:

- Access to facilities, equipment and expertise at other organisations in the consortium
- Development of strategic partnerships
- Establishment of supply chains for new technology, to the benefit of TWI and Industrial Members
- Addressing market failures in order to drive innovations up the Technology Readiness Level (TRL) scale, to bring them closer to exploitation by Industrial Members

With respect to collaborative projects, TWI makes use of its Research Themes in two ways:

- To work with industry to steer funding calls to address important industrial problems. This is done by leading and contributing to the preparation of reviews, roadmaps, white papers, etc, in order to influence policymakers in the UK and EU
- To steer TWI's preparation of proposals to calls that address Industrial Member requirements

In the field of additive manufacturing, for example, TWI has assisted in the preparation of a number of key documents to influence UK and EU funding. Following competitive calls, TWI is now working on several large collaborative projects including Industrial Members as consortium partners.



Angelo La Rosa looking at the surface area and porosity of nanomaterials

Research and Innovation

Research Board

The Research Board consists of representatives from Industrial Member companies with two co-opted chairs. It approves the content, guides the progress and peer reviews reports of the Core Research Programme.

Chairman, Research Board:
John Irven – Consultant

Chairman, Engineering Committee:
Bob Ainsworth – University of Manchester

Chairman, Materials Committee:
Gareth Hopkin – Office for Nuclear Regulation

Chairman, Joining and Fabrication Committee:
Ernst Miklos – Linde Group

Abdulaziz Al-Meshari – Saudi Basic Industries Corporation (SABIC)
Tareq Al-Sabti – Saudi Aramco
Rob Backhouse – Rolls-Royce
Julien Banchet – Areva
Carl Boettcher – Rolls-Royce
Martin Bolander – Westinghouse Electric Sweden AB
Marcel Buckley – GKN Aerospace
Julien Chapuis – CNIM
Gary Coleman – The Boeing Company
Chris Dash – Conoco Phillips Company
Suleyman Deveci – Borouge PTE
Nabil El Barbari – GF Piping Systems
Fernando Fernandez – Embraer
Dan Graham – GKN Aerospace
Alain Guinot – CNIM
Brett Hemingway – BAE Systems
Bill Hewlett – Costain
Peter Hilton – Shell
Craig Hunt – Air Products
Jimmy Johansson – GKN Aerospace
Pierre Klein – Framatome
Shinji Koga – Kawasaki Heavy Industries
Zhiqiang Li – AVIC
Mario Macia – ExxonMobil Production Company Siak
Manteghi – BP Exploration Operating Co. Ltd
Ian Merchant – TechnipFMC
Kevin Millican – Shell
David Milliken – The Boeing Company
Kelly Moran – The Boeing Company
Roberto Morana – BP Exploration Operating Co. Ltd
David Panni – J C Bamford Excavators Ltd
Holly Phillips – RNLI
Cheryll Pitt – Ministry of Defence
Marcelo Piza Paes – Petrobras
Howard Price – BAE Systems
Javad Safari – TechnipFMC
Andrew Schofield – BAE Systems
Abdullah Shahrani – Saudi Aramco Technologies Company
Gina Strati – Canadian Nuclear Laboratories
Abderrazak Traidia – Saudi Aramco Technologies Company
Naoki Urai – OTC Daihen Europe
Jitesh Vaja – AWE
Germán Romero Valiente – Navantia SA
Richard Varvill – Reaction Engines Ltd
Darren Wilson – Smith & Nephew UK Ltd
William Wistance – Lloyd's Register Group
Darren Wood – Framatome
Zhuyao Zhang – Lincoln Electric

Josh Barras working in the laser DED robot cell

Research and Innovation

Core Research

The Core Research Programme (CRP) develops new capabilities (expertise, processes, equipment, methodologies) to underpin future TWI products and services for Industrial Members. Over 60 core research projects and 30 PhD studentships were supported in 2018. The value of the CRP was £3.4m, representing about one tenth of TWI's total research and technology income. Fourteen Industrial Member Reports and five Technical Literature Reviews were published, including:

Industrial Member Reports

- Advancements in Quantitative Guided Wave Inspection of Pipes
- Establishing Baseline FSW Data for Aluminium Alloys up to 75mm Thick
- Evaluation of Methods to Determine CTOD from SENB Specimens in Steels with Different Yield to Tensile Ratios
- Validation of BS 7910:2013 and R6 Fracture Assessment Procedures
- Mechanical Behaviour of Austenitic Stainless Steels in High Pressure Hydrogen
- The Electron Beam Surfi-Sculpt® Process and Mechanism, Considering Potential Industrial Applications
- In-Bore Multi-Positional Laser Welding
- Evaluation of a New Corrosion Under Insulation Test Method
- Development of Robotic Bobbin and Stationary Shoulder Friction Stir Welding

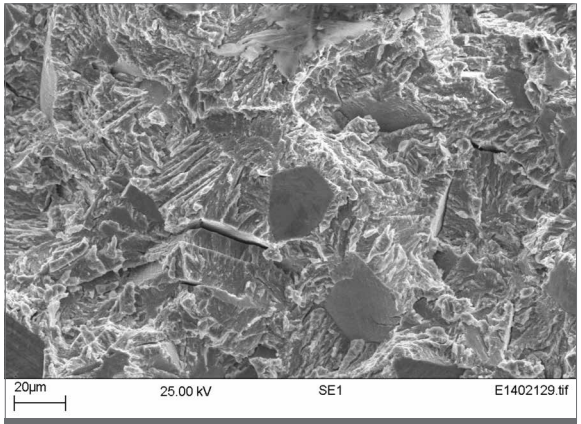
Technical Literature Reviews

- Elastic Follow-Up in the Context of Fracture Assessment
- Flaw Sizing Techniques using Guided Waves
- Guided Wave Focusing Techniques
- Laser Welding of Crack Susceptible Materials using Tailored Energy Distributions

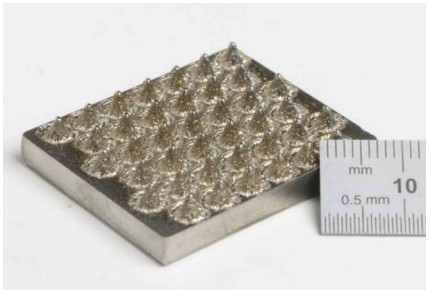
Following a review of industry needs and preparation of a gap analysis for various Research Themes, the following new CRP projects have been approved by the Research Board and are now underway:

- Hybrid Composite-to-Metal Joining
- Development of Engineering Critical Assessment Methodology for Polyethylene using Micro-Computed Tomography to Assess Suitability of Accelerated Test Methods that Generate Slow Cracks
- Damage Evolution at Corrosion Pits
- Development of Laser Assisted Cold Spray
- REACH Compliant Coatings (Cadmium Replacement)
- Comprehensive Evaluation of Fatigue Performance Enhancement through Elimination of Porosity in Selective Laser Melting
- Intelligent Arc Welding Robots
- Fatigue Strength of Large Bolts

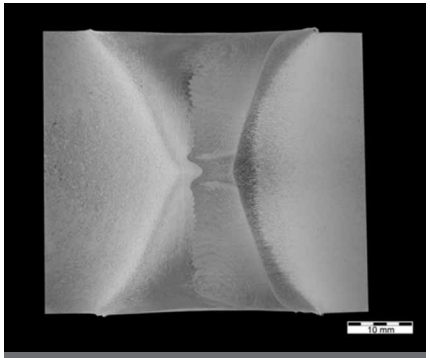
- Microstructure Models for Open Architecture Additive Manufacturing
- Integrating Diverse Approaches to Reliability of Engineering Structures
- Deposition and Repair of High-Temperature Materials using Additive Manufacturing
- Managing CTE Mismatch in Dissimilar Material Joining
- Optimisation of Heat Treatment for Additive Manufacturing
- Coatings of Fasteners for Dissimilar Materials Joining
- Influence of Roughness on Non-Wetting Behaviour
- Development of Non-Destructive Ultrasonic Residual Stress Measurement Method for On-Site Industrial Measurements
- Environmental Fracture Mechanics Testing of Dissimilar Metal Welds
- Automatic Defect Classification using Machine Learning and Computer Vision Techniques for Ultrasonically Acquired Data



Brittle fracture in low-nickel 304L austenitic steel tested in 400 bar hydrogen at –50°C



Cone-shaped Surfisculpt® features on 5mm Ti-6Al-4V substrate



Friction stir weld in 50mm thick section aluminium alloy using the simultaneous double sided welding technique

Research and Innovation

Standards Development

TWI's involvement with standards development work increased in 2018, with more than 50 members of staff now representing TWI and its Industrial Members on over 140 national and international committees and working groups. TWI's work has influenced or directly contributed to new standards in various disciplines and industry sectors. Additive Manufacturing was the "hot topic" of the year, with TWI staff participating actively in working groups and committees (ASTM, AWS, ISO, CEN, BSI) created to provide much-needed standardisation to one of the fastest growing disciplines in manufacturing. Other notable examples include:

- Production of a new draft revision of ISO 18595, 'Resistance Welding — Spot Welding of Aluminium and Aluminium Alloys — Weldability, Welding and Testing.' This document is based on new knowledge for resistance spot welding aluminium, a significant amount of which was generated by TWI. It will be balloted by ISO in 2020
- Knowledge resulting from the Core Research Programme, single-client and collaborative project work on Full Matrix Capture /Total Focusing Method (FMC/TFM) imaging for non-destructive testing was included in a new IIW draft standard ISO NP 23864, which will be balloted by ISO in 2019
- The PolyTest™ inspection system, developed by TWI to reliably detect flaws in joints in polyethylene pipes using ultrasonic testing, formed the basis of a number of new standards written or reviewed by TWI: ASTM E3170/E3170M-18 (published in December 2018), ISO DTS 16943 and ISO DTS 22499 (both approved in 2018)
- Work carried out on flaw assessment has influenced the next revision of BS 7910 ('Guide to Methods for Assessing the Acceptability of Flaws in Metallic Structures'), led by TWI (expected in 2019). Research by a number of NSIRC students produced data that is being used to support a re-drafting of ISO 12135 ('Metallic Materials — Unified Method of Test for the Determination of Quasistatic Fracture Toughness') and future versions of BS EN ISO 15653 ('Metallic Materials — Method of Test for the Determination of Quasistatic Fracture Toughness of Welds')
- TWI staff are supporting the revision of ISO 25239: 'Friction Stir Welding — Aluminium (Parts 1-5)' and the parallel American Standard AWS D17.3: 'Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications.' A small team, including TWI and Industrial Members Boeing and Kawasaki Heavy Industries, drafted ISO 18785: 'Friction Stir Spot Welding — Aluminium (Parts 1-5),' which was published in December 2018

Patents Highlights

SurFlow™

SurFlow™ transmits data in the form of electromagnetic waves that travel through composite parts. The system uses no wires or fibre optics and, unlike wireless data transfer, cannot be intercepted remotely. The technology integrates a data network into a component's physical structure, and can transmit data at up to 6Gbps, continuing to function even if the composite part suffers damage.

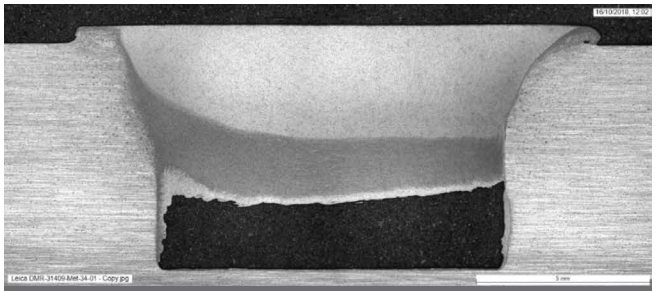
Potential applications for smart composites exist in many sectors. In the transport sector, where use of composites is rapidly growing, the technology could significantly reduce the complexity of a vehicle's internal communications network. Other sectors interested in the technology include oil and gas, robotics, sports, and consumer electronics.

Members of TWI's Surflow™ team with the Composites UK award (left to right: Mihalis Kazilis, Stuart Lewis, Jasmin Stein, Chris Worrall and Paul Burling)

TWI is carrying out further fundamental research on SurFlow™, in addition to single client projects for Industrial Members to develop specific applications. The process received the Composites UK 2018 award for Innovation in Composite Design.

Friction Stir Channelling

TWI recently filed a patent application for a new FSW-based derivative called Friction Stir Channelling (FSCh). The main benefit of this process is the ability to produce continuous sub-surface channels, with complex trajectories, within metallic components. FSCh is seen as a promising technology for industrial applications such as the manufacture of novel, reduced part count heat exchangers, by incorporating serpentines within plates, tubular or block components for internal fluid flow. Other potential uses include the production of channels to embed instrumentation, wiring or mechanisms, as well as networks for lubrication, fluid storage or hydraulics. FSCh can also be considered as a weight reduction technique, by fabricating cored panels or structures for lightweight assemblies.



Cross-section of a channel produced by FSCh

Research and Innovation

Research Outputs

TWI research is disseminated via peer-reviewed Industrial Member reports, workshops, webinars, and around 100 industry-focused articles per year. More importantly, the research creates a pipeline of new technical experts for our Industrial Members to consult, and prototype processes and products for the use of Members, plus the creation of new industry standards to advance the effectiveness of the joining and integrity of structures across a range of industry sectors.

Corporate Impact

10,000
VISITORS TO TWI OFFICES

20,000
PEOPLE TRAINED

1,869
LIBRARY ENQUIRIES

400+
WELDING SOFTWARE LICENCES

40+
TECHNOLOGY CONFERENCES AND SEMINARS

3,000+
STUDENTS REACHED VIA EDUCATION OUTREACH

3,000
NEW WELDASEARCH ABSTRACTS

Berenika Syrek at an alternating immersion corrosion test rig

Structural Integrity Research Foundation

Shenghui Hou sprays a durable easy clean coating (Solar Sharc®) onto solar panels for field testing

SIRF and the TWI Innovation Network (TWIIN)

TWI's Innovation Network aims to provide mechanisms for collaboration on research activity in the fields of materials, joining and structural integrity. It is made up of:

1. Ten Innovation Centres, where universities place part of their campus activities with industrially focussed post-graduate work at the TWI site in Cambridge

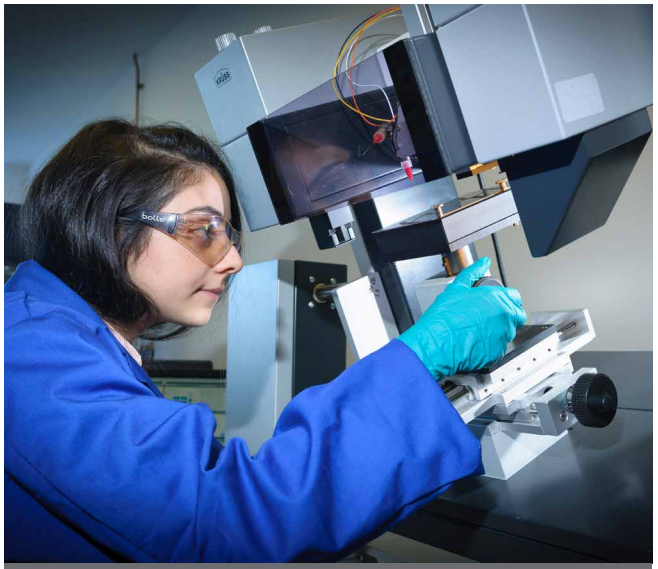
2. The National Structural Integrity Research Centre (NSIRC), which is a state-of-the-art postgraduate engineering facility established and managed by TWI

3. The Structural Integrity Research Foundation (SIRF), which was formed in 2012 as an industry funded partnership to facilitate and enable research and development in structural integrity. The founding partners are Lloyd's Register Foundation, BP, and TWI

4. Private Technology Innovation Partnerships (PTIPs) are operated by TWI on behalf of Industrial members to develop solutions in collaboration with customers, address long-term customer and industry needs, keep pace with the changing innovation landscape to adopt future technologies, and provide access to state-of-the-art facilities and world leading experts

5. Technology Acceleration Programmes (TAPs) focus on the innovation interests of TWI, innovation centres and partner organisations to create new project concepts and ideas which can become successful applications, technologies or industrial systems/solutions

During 2018, an independent economic assessment of the impact of SIRF was conducted by Oxford Economics. This found that the economic value of the initiative had reached £189m on the demand side of the UK economy, and had generated £107m of intellectual value on the supply side of the economy. This demonstrates the many multiples of benefit that can be achieved by embarking on such a collaborative partnership in the field of innovation, research and technology.



Taraneh Moghim characterises surface repellency of super-hydrophobic coatings

Structural Integrity Research Foundation

TWI Innovation Centres

Having successfully introduced the concept of Industry-University collaboration, TWI has become the pathway for innovation in different research areas.

2018 was another good year for the Innovation Centres, having secured new projects and expanded the teams.

In 2018, TWI launched 2 new Innovation Centres, the Polymeric Materials Engineering and Research Innovation Centre (PolyMERIC) in collaboration with London South Bank University, and the Additive Manufacturing Innovation Centre (AMIC) in collaboration with Lancaster University.

In 2019, TWI is looking at setting-up new centres in hot research topics such as artificial intelligence and the hydrogen economy.

The Brunel Innovation Centre (BIC) was the first established centre in collaboration with academia, and has made significant achievements in research and innovation. The centre is celebrating its 10th anniversary in October this year.

Brunel Composites Centre (BCC) was launched by Brunel University to focus on composites following the success of BIC. So far, BCC has secured 4 collaborative projects, recruited 2 members of staff and aligned 2 PhD students to the centre.

The London South Bank Innovation Centre (LSBIC) is the first centre established in collaboration with London South Bank University and has been able to secure £3m of funding from Innovate UK and the European Commission. LSBIC is looking to commercialise the prototypes realised by the research team based at TWI.

The Advanced Resins and Coatings Innovation Centre (ARCTIC) is the second centre launched by London South Bank University, and has proven the success of the collaboration between both partners, securing £1.7m of funding towards collaborative research projects.

The Healthcare Innovation Centre (HIC), established in collaboration with Teesside University, has won 5 Innovate UK and European projects worth over £1.3m. The centre has recruited 4 staff so far and is looking at recruiting more in 2019.

Joining 4.0 Innovation Centre (J4IC) was established in April 2017 with Lancaster University. J4IC has secured £200k of funding for an Innovate UK project, and hired 5 PhD students and a Research Fellow.

Materials Innovation Centre (MatIC) has done very well since its establishment in the last quarter of 2017. The centre has secured over £500K of funding from Innovate UK and the European Commission to deliver collaborative research projects, and is looking at recruiting more staff and PhD students.

Polymeric Materials Engineering and Research Innovation Centre (PolyMERIC) is the third Innovation Centre launched by London South Bank University to carry out world-leading research to select and evaluate functional and smart polymers for new applications, including metal replacement, recycling and welding of polymers and polymeric components. PolyMERIC won an Innovate UK project to address the problem of persistent plastic waste and lack of adequate recycling solutions, which pose a significant challenge to current and future generations.

The Additive Manufacturing Innovation Centre (AMIC), launched in March 2019, is the most recent Innovation Centre established by TWI and Lancaster University to carry out world-leading research in additive manufacturing technologies.

Artificial Intelligence Innovation Centre. TWI launched recently the Artificial Intelligence Innovation Centre in collaboration with Essex University, the centre will lead research in artificial intelligence, robotics and embedded systems applied to real world problems.

Habiba Lais (Research Assistant at Brunel Innovation Centre) is operating high power ultrasonic transducer testing for non-invasive pipeline fouling removal for the HiTClean project

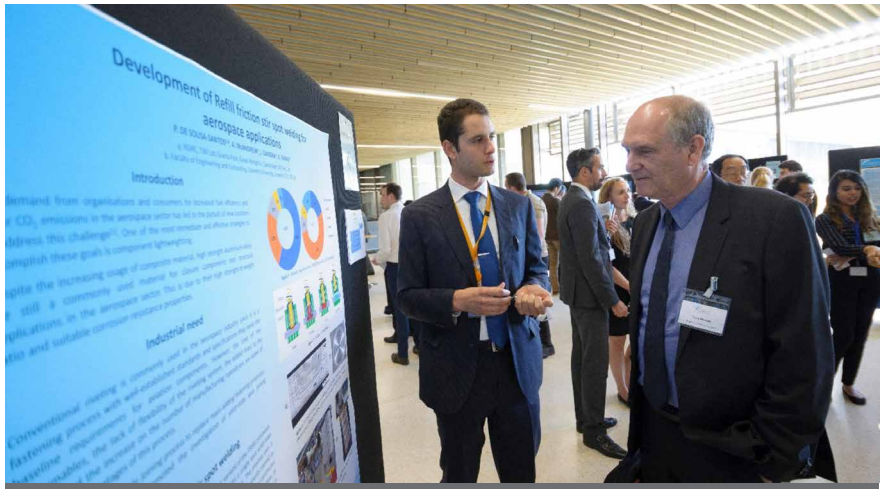
Structural Integrity Research Foundation

The National Structural Integrity Research Centre

The National Structural Integrity Research Centre (NSIRC) is a state-of-the-art postgraduate engineering facility established and managed by TWI. NSIRC unites academia and industry, working closely with lead academic partner, Brunel University, London, and more than 35 other respected universities worldwide, as well as founder sponsors BP and Lloyd's Register Foundation. The collaborating partners provide academic excellence to address the need for fundamental research, as well as high-quality, industry-relevant training for the next generation of structural integrity engineers.

NSIRC aims to deliver 530 postgraduate students over a ten year period (2012-2022). With almost 140 PhD and over 100 MSc students enrolled so far, NSIRC is exceeding its targets and is projected to repeat that success again in 2019/20.

NSIRC offers MSc programmes in structural integrity and oil and gas with Brunel University London, and Engineering Leadership and Management with Aston University. Its alumni are now working around the world in top engineering and research organisations, including at TWI and many of its Member companies. A number have also gone on to PhD study with NSIRC.



NSIRC PhD student Pedro Santos presenting his research to Prof Luiz Wrobel, Brunel University London at the NSIRC Annual Conference 2018

NSIRC PhD students conduct research across the full range of joining, materials and engineering technologies. For example:

- Digital twin technologies to build intelligent maintenance systems
- Fatigue performance of flanged bolted connections for offshore wind turbines
- Approaches to Industry 4.0 implementation for electron beam quality assurance
- Barrier layer formation in PE-RT for H2S, CO2 and water vapour in the presence of hydrocarbons

NSIRC PhD students come from a wide variety of backgrounds. Over 30 countries are represented in the student population and almost one-third of the students are female, which is significantly higher than the national average of 9%.

To date, NSIRC students have dissmeninated their research by writing more than 300 papers for peer reviewed journals and conferences. They have won international awards and secured prestigious work placements at leading technology institutes.

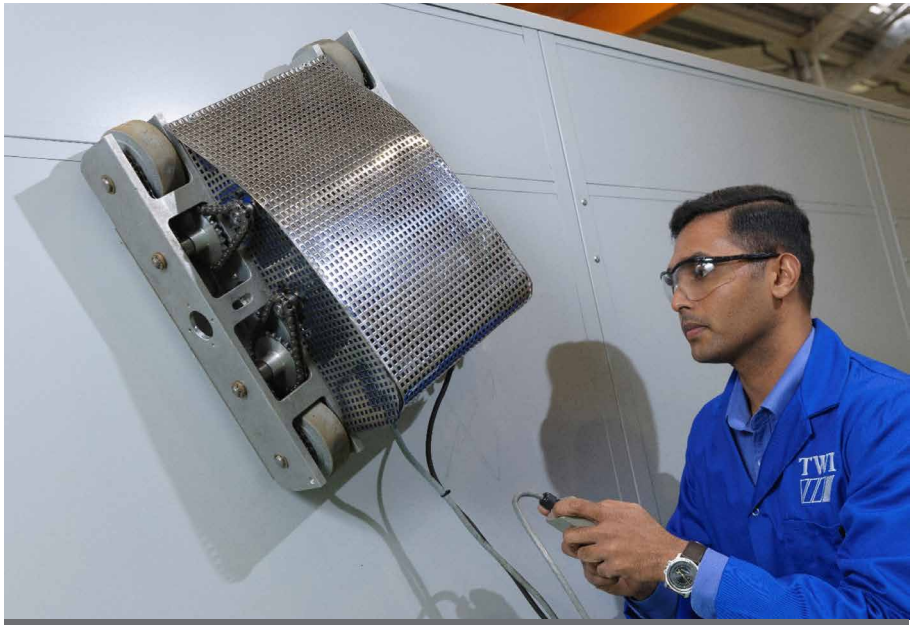
NSIRC PhD student Faranak Bahrami presenting her research at the NSIRC Annual Conference 2018

NSIRC PhD student Marion Bourebrab has completed her research on a hydrophobic and fire retardant treatment with silica particles applied on hemp shiv

Structural Integrity Research Foundation

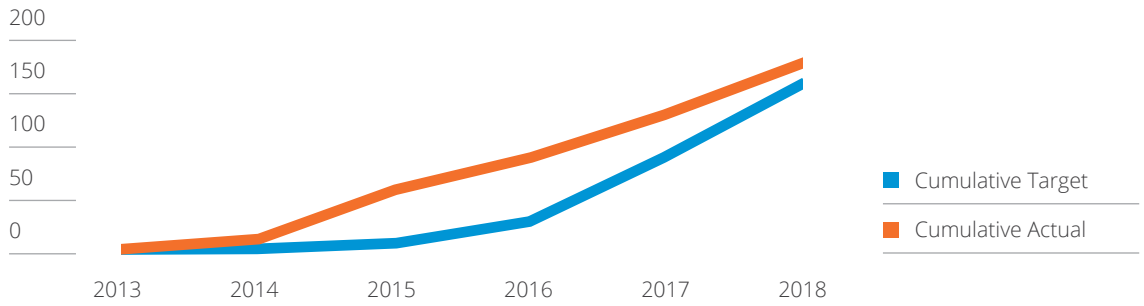
NSIRC celebrates and presents the PhD students' research at the NSIRC Annual Conference. In 2018, 170 delegates from across industry and academia attended to hear presentations and view posters from over 50 students. The 2019 Annual Conference will continue this tradition and see a further 50 students presenting their work and demonstrating their industry-ready skills.

NSIRC has now seen 27 of its PhD students graduate, and another 20 are expected to submit their theses within the year. To date there is a 100% employment rate amongst the graduates, with all of them securing jobs in their specialist fields upon completion of their research.

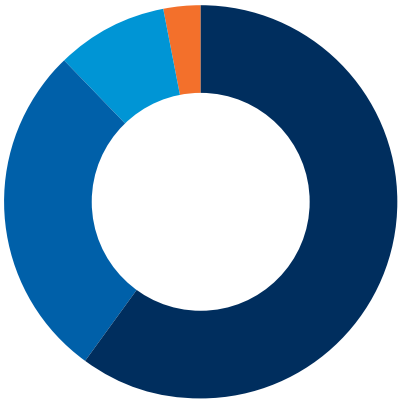


Mahesh Dissanayake working with a payload carrying magnetic adhesion climbing robot

Cumulative Total NSIRC Students



NSIRC PhD Student Madie Allen [left] was part of the award winning team in the International Additive Manufacturing Benchmark Simulation Challenge organised by the U.S. National Institute of Standards and Technology (NIST)

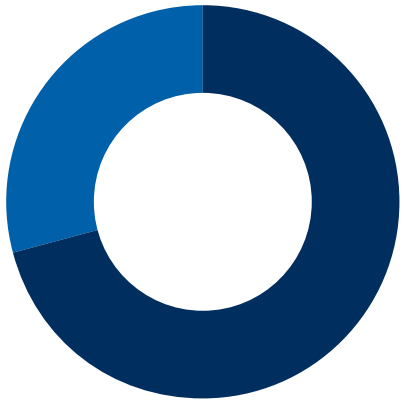


NSIRC PhD Alumni Destinations

- **60%** TWI
- **28%** Industry
- **9%** Academia
- **3%** Other

NSIRC PhD Students by Nationality

- **22%** UK
- **32%** EU
- **46%** International



NSIRC PhD Students by Gender

- **71%** Male
- **29%** Female


NSIRC Annual Conference 2018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Advancing Engineering Excellence Through Industrially-Led Research
Prof Tat-Hean Gan
Director of Technology
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Driving engineering excellence
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Prof Tat-Hean Gan
Director of Technology
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2018 Annual Conference
www.nsirc.com
Agenda

Focus on Industry
Oil and Gas

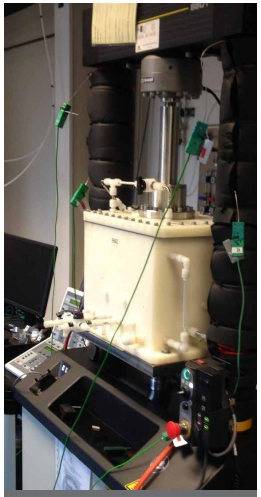
Achievements

- Several major failure investigations of pipelines in sour environments conducted by TWI in 2019
- Continued fatigue qualification work on steel catenary risers and connectors using TWI-designed full scale resonance testing
- Completion of a major joint industry project (JIP) on the fatigue performance of mooring chains in seawater
- Successful organisation of the 'Woodside Grand Challenge,' an industry-wide event on high productivity welding of pipes
- Deployment of non-destructive testing (NDT), welding repair and materials experts from TWI at short notice to Members in the Middle East and the Far East to support fabrication of large offshore structures
- Launch of the non-metallic innovation centre (NIC) in partnership with Saudi Aramco Technologies and ADNOC. NIC is a platform that connects composite manufacturers, academic institutions, and industrial partners to conduct research and development aimed at raising the performance of composites and polymeric materials for the transport of hydrocarbons

Fracture Mechanics Based Weld Flaw Assessment Acceptance Criteria for C-Mn Steel Pipelines in Sour Service

Background
The use of engineering critical assessment (ECA), prior to the installation of a pipeline, to define flaw acceptance criteria for inspection is becoming more widespread. Such an approach is aimed at allowing larger imperfections to be permitted than would typically be permitted by traditional workmanship standards. In turn, the extent of rework at the time of installation can be reduced and costs minimised. However, this approach does not provide flaw sizes for sour service which are consistent with industry experience using workmanship criteria, thus the benefits above cannot be realised in sour service applications.

A joint industry project (JIP) was devised to gain an enhanced understanding of the performance of welded C-Mn steel pipes in sour environments and to develop an improved approach and guidance for conducting ECAs for pipes in sour service.



Sour service testing

Objectives
- Enhance understanding of the influence of test and material parameters upon the derivation of over-conservative conventional KISSC values for welded C-Mn steel pipelines operating in sour service
- Define an improved approach and guidance to material testing and assessment of flaws in welded C-Mn steels exposed to sour service, to permit reliable fracture mechanics-based ECAs to be carried out

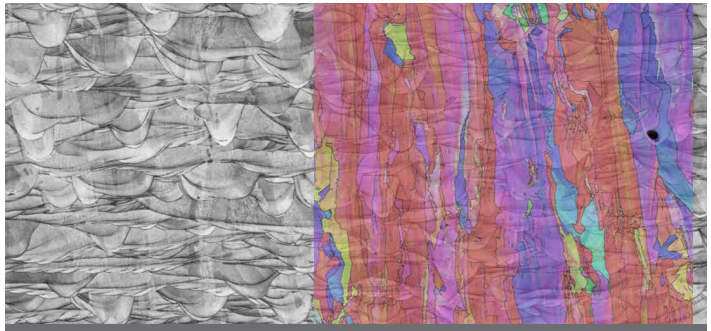
Benefits
Improved reliability of ECAs for sour service provided:
- Improved confidence in the safety of pipelines in service
- Cost savings during pipe laying due to avoidance of unnecessary repairs, of the order of 2-3% for large projects.

Achieving Code Compliance for Additively Manufactured Materials

Additively manufactured technologies offer a means of significantly reducing lead-times and costs by enabling repair and production of near-net-shape components. Despite the significance and usefulness of these processes in terms of rapid production of complex geometries, there were no codes and standards providing guidance for the assessment of AM materials and their performance in the oil and gas industry.

The aim of the project was to unlock the potential of AM for reducing costs associated with production, repair and replacement of parts. Specifically, the project generated material property data and understanding of 316L stainless steel deposited by three leading AM processes; selective laser melting (SLM), wire plus arc AM (WAAM) and laser metal deposition (LMD). This data was used to fast track the acceptance of AM materials by oil and gas standards bodies.

The project focused on 316L stainless steel, and ran for over a year with seven industrial sponsors, including key energy industry players. The project momentum continued to grow since launch, with three additional sponsors joining the project, and the creation of the first API standard task group on additively manufactured materials.



The microstructure of SLM deposited 316L stainless steel as viewed with light microscopy and EBSD, showing the melt pool profiles and grain structure of the material respectively

Focus on Industry
Oil and Gas

Path to Acceptance
Lloyds Register have completed assessment of the standards selected by the initial members of the sponsor group. They have also defined test plans for powder consumables and the mechanical and metallurgical testing of the components produced. TWI have undertaken numerical modelling of the SLM and WAAM processes to facilitate the design of a test piece, from which test specimens will be extracted.

Property Determination
A 316L stainless steel test programme has been specifically designed to produce data relevant for oil and gas industry standards, including API 6A CRA, API 20A, ASME B31.3, API 610 and PD5500. Assessment includes metallurgical characterisation and determination of mechanical, corrosion and fracture toughness properties.

Service Performance and Life Prediction of Polymer Lined Steel Pipe – 'Polymer Lined Pipe and Oil Country Tubular Goods (OCTG)'

There was notable interest in deriving confidence in the use of polymer lined carbon steel pipe for sour hydrocarbon production applications. The requirements for the thermoplastic liners change with service temperature and the nature of the produced fluid that is being conveyed. Failure of the combined system through liner collapse, a phenomenon that is an enduring concern to industry, can be prevented by the implementation of an internally vented system.

The objective of the joint industry project was to determine the degree of corrosion of a carbon steel surface protected by an extruded thermoplastic liner polymer or built composite liner from a sour (H2S containing) fluid environment.

Polymer lined carbon steel pipe being dissected after 180 day sour hydrocarbon fluid exposure time

A fluid containing a mixture of carbon dioxide, methane, hydrogen sulphide, water, toluene, cyclohexane and heptane, as described in ISO23936-1:2009(E), was pumped through a polymer lined pipe section for a period of 180 days, followed by a rapid gas decompression event. Examples of liners under test at maximum temperature of use included grades of polyamide, polyvinylidene fluoride and raised temperature polyethylene.

Upon completion of the 180 day conditioning period, the lined pipe system was dismantled and the assembly examined visually for liner collapse. Subsequently, the pipe was sectioned to allow both the polymer, polymer-carbon steel interface and bulk steel to be analysed at TWI.

Internal Inspection of Unpiggable Buried Oil Pipelines

Summary
TWI was part of a consortium of organisations behind an EU-funded project that created a new inspection system for buried oil pipelines. The PIGWaves project developed an inspection tool for in-service non-destructive testing (NDT) of unpiggable pipelines, which also provided an alternative to existing methods of inspection for piggable pipes. The new system delivers drastically reduced data storage time, greater (robot) inspection speed and far quicker availability of inspection results after robot recovery.

Innovations and Developments
The PIGWaves system performs total volume inspection far more rapidly and accurately than existing methods of ultrasonic NDT inspection. Long-range ultrasonic testing (LRUT) is ideal for pipeline inspection as it only requires probe adjustments every 50 metres – the typical attainable propagation range of LRUT in pipelines.

Key features of the system:

- Neutrally buoyant robot performs a total volume inspection far more rapidly and cheaply
- Enables inspection of pipelines with reduced diameters caused by obstacles or sharp bends
- Probes deployed approximately every 40–60m, depending on the pipe configuration, reducing measurement times by several orders of magnitude
- Much reduced data collection requirements for LRUT, compared with conventional UT, means that data storage from long pipes and data analysis is faster
- Indication of different types of damage due to changes in received signal amplitude of the A scans compared to the time-baseline
- Detected corrosion defects with thinning greater than 10% of wall thickness
- Wireless in-pipe communication; robot communicates with base station at entry point to send NDT data and location

CAD model of the inspection tool

Guided waves allow rapid screening of long lengths of pipe to detect external or internal corrosion. Large cracks and corrosion are both detectable with guided wave technology. Depending on the position of the crack, when using only one guided wave mode, the feature can go unnoticed. Corrosion can be detectable from 10% of cross section loss only under certain conditions. The accuracy of detection is decreased by many factors, such as distance, attenuation, scattering, absorption or leakage.

SubSeaLase – Underwater Laser Cutting for High-Speed and Lower Cost Decommissioning of Offshore Structures

Oil and Gas UK forecasts the market value of decommissioning the North Sea to be ~£30Bn by 2040. Approximately £1.8Bn of this is related directly to subsea cutting activities, with main operators requiring cutting technologies which are flexible, fast, reliable, deployable remotely and safe. As such, there is an industrial need and market opportunity for a significantly quicker approach to lower cost decommissioning in deep and hazardous waters than exisiting solutions.

The SubSeaLase project addressed this need by developing and demonstrating a novel underwater laser cutting system which can be initially used for cutting offshore structures and underwater pipelines at depths up to 200m. The system consists of an underwater laser cutting head, with the laser source and gas compressor remaining topside, deployed on a modified ROV.

Underwater laser cutting of offshore structures

Through Innovate UK support, we designed, developed, demonstrated and validated the system with an alpha main operator (McDermott) providing high-level industrial guidance.

We expected our approach to be 4 times faster than conventional cutting approaches; significantly reducing deployment costs and increasing the competitiveness of the UK decomissioning supply-chain.

Having established the benefits of the approach, we envisage it can be further developed and applied to deep water (i.e. 1000m) decommissioning (i.e. Gulf of Mexico) as well as non oil and gas applications (i.e. offshore wind structures).

Focus on Industry
Power

Achievements

- First successful global use of remote laser cutting for decommissioning of a redundant, highly-active nuclear reactor pressure vessel
- Continued operational support for existing UK nuclear power plant - urgent time critical projects during planned outages completed successfully
- Initiation of several large projects developing coatings for mitigation or wear and corrosion in Geothermal energy and heat recovery applications
- TWI has secured with the Science and Technology Facilities Council (STFC) a contract to develop crucial Nb RF cryomodules at the heart of the PIP-II accelerator
- Investigation and supervision of remediation activities on defective welds in steam raising plan for power generation

Cost-Effective Drilling Technology and Corrosion Management for Geothermal Systems

TWI has a long track record of addressing materials and engineering solutions for oil and gas exploration and production, including drilling and piping. Geothermal is currently the most underutilised of renewable resources, principally due to high costs associated with the deep geothermal drilling and corrosion, erosion and scaling issues.

TWI has teamed up with experts in geothermal technology to develop novel and cost-effective drilling and corrosion mitigation technologies for geothermal systems. Several projects, funded by the European Commission H2020 programme under Research and Innovation, aim to develop 'holistic' technologies that have the potential to drastically reduce the cost of drilling to large depths and at high temperatures and to mitigate corrosion of Geothermal plant.

These projects aim to enhance the growth of geothermal energy as they will enable exploitation of both deep and shallow geothermal energy sources to generate electricity and provide heating, while significantly reducing the environmental impact by reducing the capital expenditure (CAPEX).

The associated specific scientific and technical targets are to develop:

- Wear and corrosion resistant coatings for carbon steel for economic wear and corrosion mitigation
- A new down-the-hole (DTH) mud hammer (percussion drill)
- A drill monitoring system based on 3D printed sensors combined with simulators
- Advanced materials and coatings to prolong lifetime of drilling components
- A Knowledge-Based System (KBS) to reduce technical, financial, and environmental risks and costs

A geothermal plant

The concept is based on four technology pillars:

- Reduced drilling cost through hydraulic DTH fluid/mud hammer
- Advanced drill monitoring through low-cost and robust 3D printed sensors
- Improved component life through advanced materials and coatings
- Novel coatings for erosion, wear and corrosion mitigation

The strength of these technologies will be combined to meet the unified objective of developing novel drilling and associated technologies to significantly reduce the cost of deep geothermal energy, with targeted depth of ~5 km and temperatures ~250°C and higher.

Laser Decommission of Highly Active Nuclear Reactor Components

TWI has been developing laser-based decommissioning technologies since 2009, which resulted in deploying this technology at Hinkley Point A in 2015 and at Sellafield in 2016 to perform size reduction of active components. In 2018, TWI has furthered the application of this technology to a reactor pressure vessel (RPV) at Magnox's Winfrith site.

At the beginning of 2018, TWI worked in partnership with Industrial Member OC Robotics, to deploy the lasersnake technology, developed by OC Robotics and TWI with R&D funding from the NDA, for removing the Purge Gas Pre-Cooler (PGPC) from the DRAGON reactor. The PGPC is a critical component of the RPV structure and is a ~400mm diameter carbon steel tube with a ~25mm wall thickness. Two mock-ups were cut on-site at TWI Cambridge, prior to the system being deployed at the DRAGON reactor site to perform single-sided cutting of the PGPC through a borehole in the bioshield, enabling the PGPC to be removed from the RPV structure.

Laser decommissioning of Dragon reactor at Magnox's Winfrith site

Later in 2018, TWI delivered a turnkey laser cutting system to Magnox, which will be deployed for size reduction of the remaining DRAGON RPV in 2019 and beyond. The system will be deployed on the end of a master-slave manipulator, and used to rapidly cut materials up to 100mm in thickness and tubular components of various dimensions.

Focus on Industry Aerospace

Achievements

- TWI Wales achieved Nadcap approval for digital radiography to support our turnkey NDT work for a major aerospace company
- 2 major projects were won for the European Space Agency on ‘Advanced Forming Technologies for Spacecraft Propellant Tanks’ and ‘Powder Metallurgy Based Materials for High Wear Resistance, High Hardness and High Temperature’
- First project won from the Aerospace Technology Institute (ATI) on ‘Open Architecture Additive Manufacturing,’ with new additive manufacturing equipment being purchased for TWI Yorkshire as part of the project
- Several Clean Sky collaborative projects won to support TWI’s customer base in the UK and Europe

TWI Group Manager Chairs 2018 Aeromat Conference

Richard Freeman (Industry Group Manager and Associate Director) was Chairman of the 2018 ASM Aeromat conference. This was the first time a non-US person had presided as Chair in the 30 year history of the event.

Richard had acted as the Technical Programme Chair at the 2016 conference in Seattle, then Vice Chair for the 2017 Conference in Charleston. He presided over the successful 3 day conference in Orlando that was co-located with the International Thermal Spray Conference (ITSC), attracting over 1000 attendees to both events.

The 2018 event featured three days of technical programming, networking events, and an exposition. Technical sessions included additive manufacturing, light metals technology, titanium technology, high temperature materials, coatings, welding and joining, composite materials, space materials and applications, emerging processes and materials and advanced forming. There were a number of panel discussions throughout the event, including a very well attended session on the status of additive manufacturing and future parts qualification.

He still sits on the Conference Organising Committee that is working on future Aeromat conferences. They will take place in Reno, USA in May 2019, Palm Springs, USA in May 2020 and Quebec City, Canada in May 2021.

Richard Freeman (centre) at the Aeromat Conference social event alongside previous past Conference Chairs (left to right); Mike Niedzinski (Constellium), Brian Boyette (NAVAIR), Gary Bray (Arconic) and Mike Shemkunas (Boeing)

Focus on Industry
Transport

Achievements

- An electric vehicle battery welding cell was set up at TWI Cambridge to support a major automotive OEM, with over 1 million welds made to date
- Development of a comprehensive mechanical fastening laboratory to support the transport sector
- Significant work with the defence sector in the UK and Europe to support their product range

Fabrication of EV Battery Trays by High Speed Robotic Friction Stir Welding

TWI is supporting its Industrial Members in the automotive industry with the rapid transition from internal combustion engines to battery electric vehicles. One of the key challenges with battery technology is the charging power, which is currently limited to 50 or 100kW in most vehicles. In order to increase the charging rate, efficient cooling of the battery cells is critical. As part of TWI's core research programme on robotic friction stir welding, TWI supported Hydo Extruded Solutions with the development of a low cost aluminium battery tray.

The entire tray consists of only three different aluminium extrusion types and is produced by only two joining processes, i.e. friction stir welding and cold metal transfer. The battery tray design is scalable to suit different battery pack sizes and has integrated liquid cooling channels in the floor. Due to the high volumes required, welding speed is an important factor in the fabrication cost. The development of new stationary shoulder friction stir welding tools with low friction coatings allowed a reduction of process forces, while increasing the welding speeds to 3.5m/min and a joint strength in excess of 90%, relative to the parent material.

Low cost aluminium battery tray produced by friction stir welding

Mechanical Joining Solutions at TWI

Mechanical joining is the oldest family of joining processes; clasping, binding and form fitting joints have been around since humans first started making tools. Today, rivets, bolts, screws, clips and clasps are broadly used in nearly all industry sectors. In recent years, many new advancements in mechanical joining technology have been made. TWI's mechanical fastening theme has focussed on pushing these technologies to their limits, in particular the joining of high strength and dissimilar materials. Studies have looked at challenging combinations of steels in excess of 1500MPa, high strength aluminium and carbon fibre reinforced polymers.

At TWI a new suite of capabilities have been developed to help industry achieve high speed, low cost, high integrity joints, including numerous processes that are tailored to specific materials or applications. A particular driver for this has been the growth of multi-material structures in transport applications. Recent work has looked at self-piercing rivets, clinching, clinch rivets, solid punch rivets, flow drill screws, friction element welding, resistance element welding, blind rivets, friction drilling blind rivets, high speed tacking / nailing, and many more. These processes have been used to address a wide range of industrial challenges as standalone process or in combination with structural adhesives.

Henrob self-piercing rivet gun

A range of mechanical joining elements used for high volume joining in the automotive sector

Focus on Industry
Construction and Engineering

Achievements

- Major work programmes on welding and NDE for European submarine manufacturers
- Inspection of armoured vehicles for UK M.O.D. contractor
- Major test programme for multi-national off-highway vehicle manufacturer
- The OPTRAIL Innovate UK project was presented at the recent RAILTEX Conference

FIBRESHIP project

TWI is one of 18 organisations involved in an €11m Horizon 2020 project called FIBRESHIP. It is concerned with the engineering, production and life-cycle management for the complete construction of large-length fibre-based ships. The aim is to create a new EU-market to build complete large-length ships in FRP (Fibre-Reinforced Polymers). TWI is heavily involved in the work packages on assessment of joining techniques to be used in FIBRESHIP applications, and a report on the assessment of life cycle performance of FIBRESHIP concepts and recommendations based on the assessment.

With regard to the joining techniques, a comprehensive analysis of the different joining techniques and their application to different engineering fields has been conducted, with a review of the aerospace industry, as they have a lot of past experience. An innovative joining technique – built-in disassembly mechanism, "Disbond on demand," will be tested. This consists of placing a carbon fibre implant in the adhesive bondline. When a potential is applied across the implant, the current flows through the carbon fibres and generates heat that facilitates the bond disassembly.

FIBRESHIP demonstrator under construction

A fishing vessel has been chosen as the demonstrator to develop a composite material vessel as part of this three-year project ending in 2020. There have been numerous presentations at maritime events, including most recently at the 57th Congress of Marine Engineering and the Maritime Industry in Valencia in October 2018.

FIBRESHIP website **www.fibreship.eu**

SHIPLYS project

SHIPLYS (Ship Lifecycle Software Solutions) aims to transform the early-stage design of ships by developing simulation and modelling tools designed to streamline and improve the processes involved. This is through developing software applications that provide a life cycle perspective at the design stage itself, including a software platform enabling the integrated use of such applications. The project, which has participation from a variety of stakeholders involved in different stages of a ship's life, will help minimise ship lifecycle (design, production, operation and maintenance, and end of life) costs. SHIPLYS is a three-year project that started in September 2016 with funding by the European Commission under Horizon 2020. The project brings together a team of 12 leading maritime companies and research facilities, from 7 countries, coordinated by TWI Ltd.

The consortium met at Lloyd's Register EMEA in London to discuss key developments in the project. At this stage in the project, most software applications are close to completion. The next steps include testing the integration and validating results.

The SHIPLYS consortium had a successful biannual project meeting

In the next 6 months, the SHIPLYS consortium will be holding several workshops to demonstrate the software capabilities and gain insightful end-user feedback. These workshops are planned to be held in shipyards in Spain and Bulgaria, enabling us to engage directly with industry.

More information on the project available at: **www.shiplys.com**

Focus on Industry Electronics and Sensors

Achievements

- Defect analysis and on-site production process review for very high volume metering system
- Hermetic sealing process issue investigation for high reliability electronics package product
- Development of resistance heating / brazing process for Litz wire termination for motor and battery applications
- Establishment of heavy ultrasonic wire and ribbon bonding and testing facility for battery and power electronics interconnection development

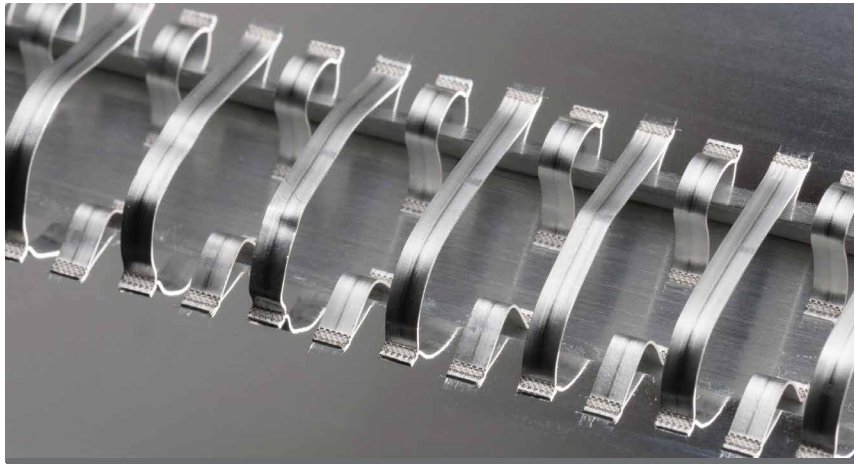
Battery Technology Development

TWI is at the forefront of several aspects of battery technology development. From development and optimisation of cell interconnection processes to module assembly, thermal management, battery integration into structures and, more latterly, cell chemistry development. Application focus for R&D projects ranges from large batteries for static energy storage to electric vehicles, consumer electrical products, and small-scale power sources for wearable electronics and medical devices.

Collaborative research is underway at TWI to address the requirement for thin, flexible primary batteries with improved power densities (>3mAh/cm2), higher peak current (>1mA) and lower cost (<£0.30/unit).

Corrosion issues preclude use of high-conductivity metals as a replacement for conventional carbon-based current collectors used in flexible Zn based battery designs. Use of metallic-based contacts would result in lower internal resistance and thus improved battery performance. The aims of the research are to develop new graphene-based corrosion resistant coatings for metallic current collectors, and use electrochemical corrosion and performance monitoring techniques to help develop a new thinner, more flexible, higher energy Zn-MnO2 thin-film battery design.

Successful development of this technology will enable miniaturised electronic product design, as well as improved performance and cost benefits for current applications and innovative products. In particular; electronic wearables (e.g. disposable diagnostics and sensors for medical and health and fitness sectors); smart packaging and RFID (e.g. labels for logistics and storage that measure temperature or monitor spoilage of foodstuffs/pharmaceuticals); smart objects for 'Internet of Things (IoT)' applications; structural health monitoring sensors and Smart cards.



Aluminium wire bonding for battery joining

Focus on Industry Equipment, Consumables, Materials

Achievements

- Progressive industrialisation of wire arc additive manufacturing
- Highly successful TWI-led UK Welding Exhibition
- Focus on materials sub-sectors – for example – new collaboration with the Aluminium Federation
- ‘Friction stir channelling’ offers new business opportunities for equipment makers

Arc-Based Additive Manufacturing at TWI

TWI is proud of its track record in metal additive manufacturing (AM) technology development since its introduction in the 1990s.

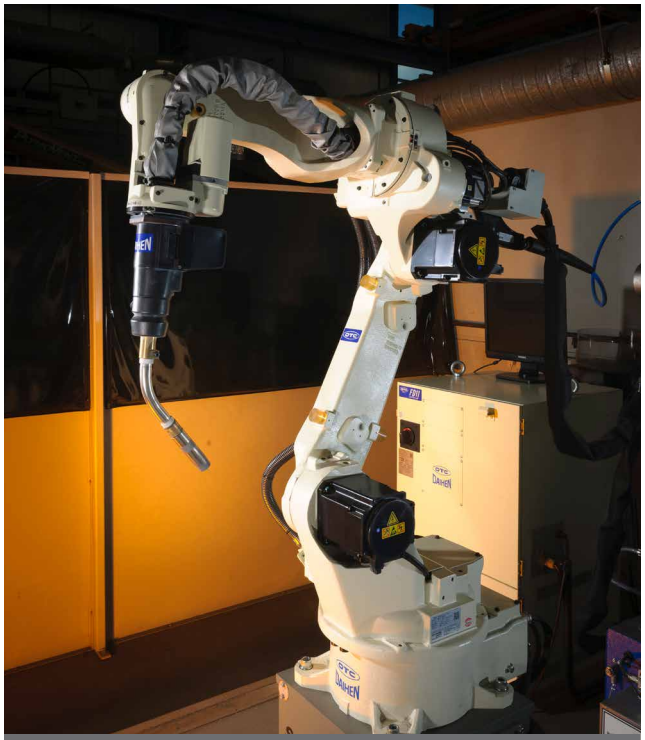
Driven by our Industrial Members across sectors, we have built significant AM knowhow and investment, which enables capabilities ranging from fundamental technology development through to production and commercial exploitation.

Arc-based AM, using wire consumables, represents a key and growing technology area for TWI and its Members in the equipment, consumables and materials sector. TWI's long established experience in arc welding, materials science, modelling, testing and validation, makes it uniquely attractive to both suppliers and end users of arc based additive manufacturing. We can offer a 'one–stop' resource within the full technology lifecycle – from development to industrialisation.

Highlights in this field over the past year have featured several industry driven projects. For example, the use of automated arc equipment in high productivity/high accuracy applications.

We have also investigated a range of geometries, using arc based AM, including the development of optimised process procedures and characterisation of microstructural and mechanical properties.

This research has demonstrated potential new market opportunities in additive manufacturing for welding equipment and materials suppliers. It has also confirmed TWI's position as a valuable technical and commercial interface for all stakeholders in this technology.



Robotic arc-based additive manufacturing system

Regional and International Impact

Mike Russell
Director, Operations

Regional Development – TWI Technology Centres

TWI Technology Centre North East

TWI North East is home to TWI's dive tank, training facilities and specialist engineering and laboratory space. Located in Middlesbrough for over 25 years, TWI moved into a new purpose-built facility in 2016 which houses staff from the certification, training and technology groups. Over the last 12 months the centre has continued to grow. The building has been further upgraded to accommodate more staff, and investments have been made to support TWI's numerical modelling group and the creation of a new NDT team. New equipment has also been installed, in partnership with Teesside University, to support tribology and coatings testing.

Looking forward, we are targeting future investment to support growing polymer activities within TWI, specifically in materials testing. TWI-NE is also involved in a number of national proposals relating to the development of the hydrogen economy, and the transition to a low carbon industrial base. Supporting the UK's transition to a low carbon future will continue to be a significant focus for TWI-NE going forward.

TWI Technology Centre Wales

Our activities in Port Talbot continue to grow, in association with the delivery of the Advanced Engineering Materials Research Institute (AEMRI) programme. The AEMRI programme has now attracted more than €2m of new collaborative research funding to TWI Wales, accelerating innovation and developing new products towards commercial readiness. In addition, the programme has stimulated engagement with a wide range of TWI Member companies, leading to more than £1.5m in direct industrial funding to date. To accommodate this growth, TWI has expanded to two sites in Port Talbot, with our new Baglan facility coming on stream during 2018.

This sustained growth is thanks to a number of important, and ongoing, technical developments at TWI Wales, including:

- Creation of a new industrial-scale robotic inspection cell with built in metrology and advanced UT systems
- Ongoing software development and multi-platform exploitation for FMC (Full Matrix Capture) technology
- Validation of FMC technology for girth welds, boiler tube, and a range of complex customer welded structures
- Advanced CT/laminography development including development of in-situ computed tomography

Looking to the future, and in response to increasing industrial demand for large product/full-scale NDT, our ambition is to build a dedicated new home for our Wales activities. Plans are being drawn up for a new 30,000 foot technology centre in South Wales, which will bring together our full activities in the region into one advanced engineering facility. TWI remains deeply grateful for the ongoing support and encouragement of our business from the Welsh Government and the Welsh European Funding Office (WEFO).

TWI Technology Centre Yorkshire

TWI Yorkshire continues to prosper, focusing on laser additive manufacturing and friction stir welding technologies.

Noteworthy developments include:

- Our advanced supply chain initiative (AMSCI) project is approaching completion. This successful programme has funded a new state-of-the-art laser additive manufacturing lab at TWI Yorkshire, including a range of processing and support equipment. This project has also supported an extensive technology transfer programme, which has resulted in a number of interesting new applications for AM technology
- Our new open architecture additive manufacturing programme has allowed us to invest in a new laser metal deposition system to replace the equipment originally purchased as part of the start-up of the facility. The system, due Q3 2019, will be one of the largest AM R&D machines available, with a 4m long gantry in a 5.5m housing. The equipment has advanced digital functionality, which has been specified to allow TWI to progress into larger AM structures
- Robotic friction stir welding (FSW) is being developed at TWI Yorkshire with particular success reported recently on industrial scale aerospace components. Future plans for investment to update and expand upon our capabilities in this area are being reviewed
- As part of our ongoing equipment developments, there will also be a rearrangement of the TWI Yorkshire engineering hall to be completed during Q3 2019

Outcome from Technology Transfer

21
REGIONAL DEVELOPMENT PROGRAMMES ACROSS THE UK

6879
JOBS CREATED OR SAFEGUARDED

£369
MILLION IN ADDITIONAL OR SAFEGUARDED TURNOVER

Regional and International Impact

Dr Shervin Maleki
Global Development Director

International Impact

The primary focus of TWI's international operations is split between training engineers in field-based certification and undertaking engineering work and providing services and support for Industrial Members through our overseas subsidiaries.

Training and examination continues to be strong in Asia and the Pacific, India, Central Asia and the Middle East, which has allowed us to continue our support for upskilling disadvantaged people across the world as well as developing a skilled workforce of employees operating in industries across Europe, North America, Southeast Asia, China, Japan, and elsewhere.

TWI's support for the Access India campaign has also provided confidence for UK SMEs looking to expand into India.

Over half of TWI's new Industrial Members came from abroad in 2018, with most of them hailing from China, Germany, Japan, Libya, and the USA.

Innovation and R&D also continues to be of importance to TWI on an international level. This has, for example, seen the launch of the Non-Metallic Innovation Centre alongside world-leading oil and gas company Saudi Aramco to conduct a research programme covering Technology Readiness Levels (TRL) 1-9.

We have also been promoting innovation in other global industries, including batteries, robotics and automation, additive manufacture, high-speed train manufacture, and the use of new technologies for applications across industry around the world.

With the extensive training and certification operation, the various collaborative working agreements with global businesses, and the ongoing expansion of Industrial Members overseas, TWI's international reach and impact was robust through 2018.

Training and Examinations

Overview

2018 has been a productive year for the global TWI Training and Examinations Services (TES), and candidate numbers have remained steady but solid, despite challenging market conditions.

Oil and gas companies have restructured due to depressed oil prices in the last five years, which has had an impact on the sector. However, in the last year, we have seen training numbers hold firm across the globe, which is in part due to our strong and trusted brand, our strength and depth of courses, and our innovation.

We are pleased to have continued demand for our blended learning products, which reduces the amount of classroom time and allows greater flexibility for the learner. This is in conjunction with our e-learning products, which are market-leading.

Innovation is our strength – we listen to industry demands, and match training and certification to real world situations.

The IIW/EWE Welding Diploma is still a popular course with industry-wide recognition. Taking the lead from the NDT blended learning, some of the modules now have digital e-learning segments.

The standard offering of CSWIP welding inspection and NDT courses are still very strong across the globe, and these courses and exams are constantly being updated and revised to reflect any industry changes. Constant market analysis and customer feedback contributes to our success, together with production innovation strategies.

TWI, in collaboration with the Lloyd's Register Foundation, has launched an international skill enhancement programme to train underrepresented communities in countries in South East Asia to upskill at least 10,000 people over 5 years. This intervention is expected to enhance safety standards through technical training. To date, over 500 candidates have been trained.

The technical services provided by GTS are primarily the provision of services relating to welding and joining consultancy, asset integrity (AI) and process safety management (PSM). AI services include materials selection and corrosion risk studies at engineering design phase, and welding consultancy including procedure development, qualification and construction code advisory services during construction phase, inspection planning, fitness for service, engineering critical assessments, failure investigation and life extension studies during the operations phase. PSM services include process hazards analysis, pre-start-up safety reviews, hazid, hazop, and development of operating, maintenance and inspection strategies for operational readiness at design and operating phases.

Regional and International Impact

Training and Examinations

Highlights

Innovation is key to staying ahead of the market, and improving the customer experience.

Together with the investments made into our e-learning platforms, we have globally rolled out our Surpass exam systems, which ensures a speedier and robust exam turnaround. These offerings will be further expanded during 2019. There has been a significant investment in new hardware to support this.

Furthermore, we have embarked on a virtual reality platform for some of our CSWIP underwater exams. This is both a significant investment, and a step change for further engagement with transformational technologies. TWI is proud to be a market leader with this high level of innovation.

Major client business has been secured with JLR, Rolls-Royce, Babcock International, and a large welder training programme in Oman, to name but a few.

Significant contracts were secured in SE Asia and Middle East, and these included risk based inspection planning for Pertamina Hulu Energi, preparation of asset integrity manuals and procedures for ADNOC Onshore, preparation of PSM related guidelines for Kuwait Oil Company, and updating of operations, maintenance and inspection manuals for PETCO Sudan.

Personnel and Company Certification

Whether you are purchasing welded products or subcontracting welding and associated tasks into your supply chain, TWI Certification Ltd supports confident decision-making. CSWIP certification of personnel supports your selection in recruitment and your confidence in supply chain competence assurance. Welding Fabricator Certification Scheme (WFCS) certification of compliance with ISO 3834 provides confidence in your suppliers' control of quality of welded production (CAESAS for structural steel and aluminium products, CWRVC for railway vehicles and components and CMSM for manufacture of special materials). Competence of welder training is assured by the Certification Scheme for Welder Training Organisations (CSWTO), which includes CSWIP Welding Instructor and CSWIP Welding Examiner requirements.

TWI Certification Ltd is a UKAS-accredited certification body, a Notified Body for the Construction Products Regulation, a Recognised Third Party Organisation for the Pressure Equipment Regulation, and is the Authorised Body in the UK for EWF and IIW qualifications and certification.

TWI INTERNATIONAL TRAINING PRESENCE

Corporate Social Responsibility

Business and Technology

TWI is dedicated to creating good outcomes for its Members and customers, and building the positive contribution of its business to a sustainable society. We have a strategic approach to the technology impact of our work, and integrate social, environmental, ethical, human rights and consumer concerns within our business operations and core strategy:

- Helping to prevent plant and equipment failure, and setting international standards
- Training skilled workers for employment or new working environments
- Assuring the competence of personnel and organisations
- Guiding professional development and registration of technicians and engineers and overseeing commitments to rules of professional conduct and continual learning

In 2018, we continued to develop our corporate impact assessment management model to review and report activities across five pillars: Business and technology; health; safety and environment; community; and employment.

Educational Outreach and Community

2018 was a strong year of involvement in education outreach and promoting engineering careers for women. TWI apprentices, The Welding Institute's Younger Members, the Tipper Group and our postgraduates at the National Structural Integrity Research Centre came together to deliver an exciting programme of technology workshops, as well as activities focused on careers and employability skills. Highlights across company regions included a LEGO Mindstorms® robotic inspection challenge for Year 5 pupils, a series of materials joining and engineering work experience weeks for Year 10s in Cambridge, a friction stir welding challenge project at the University of Sheffield, and helping to judge STEM designs at a Big Bang Science Fair competition in Llanelli. TWI works closely with STEM learning and national programmes such as Tomorrow's Engineers and Arkwright Engineering Scholarships, together with regional enterprises linking schools with businesses. Our outreach and laboratory tour programmes address all ages of education and a variety of community groups.

TWI's UK community contributions included sponsorship of a village beacon lighting celebration, annual Christmas donations to local causes, and fundraising by its sports and social team.

Overseas, TWI Training teamed up with the Zakat Selangor organisation in Malaysia on a charitable programme to upskill 22 young candidates from underprivileged backgrounds with a three-month practical course across an 'A to Z' of welding techniques. As a result, the candidates achieved an internationally recognised certificate and moved straight into a job placement to kickstart their careers. A new batch of students will undergo training in 2019.

Year 5 pupils from Fulbourn Primary School programme LEGO Mindstorms® robots for an inspection challenge

Corporate Social Responsibility

TWI People

TWI is committed to creating a great working and learning environment that enables our people to perform to their best to achieve TWI's goals. We offer a range of learning opportunities, including coaching and knowledge sharing, as well as internal and external development courses covering a range of topics from leadership development to business and soft skills. In addition, we sponsor our employees to obtain professional qualifications to help with career development, and encourage young people into engineering with our modern advanced apprenticeships.

Welding upskilling initiative, Malaysia

Environment

TWI has been demonstrating a commitment to reducing its impact on the environment since 2005 through the external verification of its Environmental Management System. This is now certified to the latest version of the standard: ISO 14001:2015.

Over 160 countries have implemented ISO 14001, which is designed to provide organisations with a standard model for protecting the environment by offering a systematic approach for their activities, processes, products and services. ISO 14001 certification requires TWI to:

- Identify its impact on the environment, both positive and negative
- Put controls in place to reduce negative impacts, such as pollution prevention measures
- Identify compliance obligations, including water discharge consents, waste management legislation and energy reduction
- Drive continual improvement through internal auditing and incident reporting
- Measure and monitor utility usage, waste and carbon footprint
- Promote environmental awareness amongst staff, which is being achieved through the new Environmental Champions Committee

During 2019, preparation will begin to ensure compliance to the new Streamlined Energy and Carbon Reporting Framework (SECR), which will replace the Carbon Reduction Commitment (CRC) from 2020.

International Women in Engineering Day (INWED), June 2018

Corporate Social Responsibility

The Tipper Group: Supporting Diversity and Inclusion in Engineering

Created in 2016, The Tipper Group has added great value to TWI business over the past three years by supporting and encouraging female talent in the scientific disciplines. Recently, the group has expanded its mission to improve employee experience and employer perception in an environment that understands and promotes diversity and inclusion at all levels. The purpose of this change is to bring everybody together under one umbrella in order to create an inclusive and diverse environment within TWI, to allow us to recruit the best staff regardless of gender, ethnicity, age, sexuality, beliefs, (dis) abilities and socio-economic background in order to develop our people to achieve their maximum potential.

The new objectives of The Tipper Group include, but are not limited to:

- Creating the awareness of unconscious bias
- Improving work/life balance
- Supporting/developing confidence
- Mentoring and peer support
- Working with HR and senior management to support implementing the diversity and inclusion policy, and aligning policies and procedures
- Improving representation across all levels of business, addressing structural barriers to progression, and tackling gender pay

These objectives are supported by lunchtime events and a strong social media presence.

Tipper Group Committee and founder members left to right: Marion Bourebrab, Catherine Condie, Marta Alvarez, Farnoosh Farhad, Kamer Tuncbilek (Chair) and Philippa Moore

TWI Capabilities

How TWI Can Help You

TWI prides itself on helping people and organisations around the world to maximise the performance of welding, joining and allied processes, as well as helping improve the resulting products and assets.

We can help you to implement and optimise your processes and product performance so you can provide maximum value to your customers. In addition, TWI can assist with matters of product integrity and performance as well as establishing the cause and mitigate the effect of any product or asset failures. As an independent organisation, you can be assured that TWI will deliver impartial and confidential advice.

Our support can be broken down into four over-arching areas:

Design and Engineering

- Optimised design for manufacture and inspection: Design review including optimum joint design for performance, productivity and inspection
- Behaviour of structures under loading: Review against operating requirements, as well as standard/bespoke testing, e.g. dynamic loading
- Material/consumable selection: Material properties and performance assistance extending to mechanical/corrosion testing and analysis
- Fitness-for-service: Including Engineering Critical Assessment (ECA) and Finite Element Analysis (FEA)
- Welding/joining/surfacing/additive manufacturing process review: Understand the process impact on material properties and product performance
- Prototyping: Production and testing of prototypes
- Heat treatment: Procedure guidance to optimise/improve product properties

Manufacture and Production

- Process selection for welding/joining/surfacing/additive manufacture: Process feasibility assessment, options and relative technical/economic performance
- Mechanisation and automation: Cost/quality/productivity assessment. Can and should you automate?
- Process/technology adoption and implementation: System specification, commissioning, training
- Qualification of procedures and welders/operators: Procedure review/development against relevant code/standards, as well as welding QA/QC software
- Commissioning and training: Site acceptance testing support, extending to bespoke/standard training for production staff
- Inspection and testing: Selection, qualification and verification of inspection processes
- Production challenges: Troubleshooting and solutions to production quality issues including weld/process defects

Operation and Failure

- Run-repair-replace decisions: Fitness for service assessments including ECA and life-extension of assets
- Life extension and inspection planning: Application of correct NDT techniques and inspection methodology including risk-based inspection (RBI)

- Predictive maintenance for operational reliability: Condition and structural health monitoring
- Decommissioning of assets: Development of processes and procedures for decommissioning activities
- Fabrication or in-service failure: Failure and root cause analysis
- Repair: Development of procedures, method statements and oversight
- Disputes and litigation: Expert, impartial advice, including expert witness support

Supporting Services

- Predicting performance of products and processes: Simulation of processes and operation of products/structures by numerical modelling
- Health and safety (including fume and EMF): Best practice and compliance with UK/International legislation
- Codes and standards: Understanding and complying with new/updated codes and standards. Creating in-house standards
- Quality assurance: QA for welding. Guidance, informal/formal auditing against best practice and relevant standards
- Training and professional development: Development of engineers/technicians - technical or professional (EWE, CSWIP, IEng, CEng, etc)
- Business development: New industry sectors/markets, accessing public funding, and relevant events/networks

We can visit you to assess your existing production processes, identifying and rectifying issues on-site. Our extensive range of in-house testing facilities means we can investigate and validate the performance of your materials, products or assets – including in-service inspection and monitoring, and lifetime extension.

Ben Neal conducting pipeline structural health monitoring using a permanently installed guided wave collar

Industrial Member Companies

Australia

Australian Nuclear Science & Technology Organisation (ANSTO)
BHP Billiton Petroleum Pty Ltd
Cooper Energy Limited
DST Group
MCA Australia Group
SPEE3D
Woodside Energy Ltd

Austria

PLANSEE SE

Belgium

ArcelorMittal Belgium NV
Laborelec C.V.B.A.
SABCA – Brussels
Tower Automotive Belgium BVBA
Toyota Motor Europe NV/SA

Brazil

Embraer
Petroleo Brasileiro SA – PETROBRAS

Canada

Canadian Nuclear Laboratories Ltd
CanmetMATERIALS Natural Resources Canada
Evraz Inc NA
NOVA Chemicals Corporation
Servo Robot
ShawCor Ltd

China

AECC Beijing Institute of Aeronautical Materials
Amet Welding Automation Technology (Beijing) Co Ltd
AVIC Manufacturing Technology Institute (MTI)
Baoshan Iron & Steel Co Ltd
Beijing Cisri Gaona Materials & Technology Co Ltd
Centre of Excellence for Advanced Materials
China Academy of Launch Vehicle Technology
China Offshore Oil Engineering Corporation
COMRI
CRRC Zhuzhou Locomotive Co Ltd
Dongfang Boiler Group Co Ltd
General Research Institute for Non Ferrous Metals Group Co Ltd
Harbin World Wide Welding Technology Co Ltd
Hefei General Machinery Research Institute
Huawei Marine Networks Co Ltd
Hunan Joinfront Welding Technology Co Ltd
Jiangsu Industrial Technology Research Institute
Nanjing Iron and Steel Co Ltd
National Institute Corporation of Additive Manufacturing Co Ltd Xi'an
Nuclear Power Institute of China (NPIC)
Shanghai Aerospace Equipment Manufacture
Shanghai Institute of Special Equipment Inspection and Technical Research
Shipbuilding Technology Research Institute of CSSC (STRI)
Southwest Institute of Technique and Engineering (SITE)
Suzhou Nuclear Power Research Institute Co Ltd
Tubular Goods Research Institute of China National Petroleum Corporation

Denmark

Danfoss Industrial Automation
National Oilwell Varco Denmark I/S
Ørsted Wind Power A/S

Egypt

Egyptian Refining Company
VTCO Petroleum Services

Finland

Huawei Technologies Oy (Finland) Co Ltd

France

ACB
Airbus Group (UK) Limited
APERAM Stainless Steel France R&D
Bureau Veritas Group
CNIM
Eddyfi UK LTD
EDF SA
Framatome
Garrett Motion
ITER Organization
Naval Group
Sofchem
Total
Vallourec Group - Pipe Line Projects (PLP) Division

Germany

Aleris Rolled Products Germany GmbH
Europipe GmbH
EWM AG
FOOKE GmbH
H Butting GmbH & Co KG
KAEFER Isoliertechnik GmbH & Co KG
Lilium GmbH
Linde AG (LEHQ) - Engineering Division
MT Aerospace AG
MTU Aero Engines AG
Oerlikon Metco WOKA Gmbh
Pro-beam AG & Co KGaA
Steigerwald Strahltechnik GmbH
Wolfram Industrie GmbH

Greece

Consolidated Contractors Group S.A.L (Offshore) (CCC)
Corinth Pipeworks Pipe Industry SA

Hong Kong

MTR Corporation Limited

India

Bharat Forge Ltd
Larsen & Toubro Limited - Heavy Engineering Independent Company
Mahindra & Mahindra Construction Equipment Design Division
Technocraft Industries (India) Ltd
TVS Motor Company

Ireland

Aughinish Alumina Ltd
BS&B Safety Systems Ltd
ESB Power Generation
Hollister ULC
Medtronic Vascular Galway Ltd
Mincon International Ltd
Timoney Technology Group

Italy

Ariston Thermo Group
Cescor Srl
Cooltech Srl
ENI SpA - Exploration & Production Division
ETS Sistemi Industriali Srl
Nooter/Eriksen Srl
Saipem Group
Thales Alenia Space SpA
Walter Tosto SpA

Japan

AeroEdge Co Ltd
Akahoshi Inc
Daicel Polymer Ltd
Daido Steel Co Ltd
Daihen Corporation
Furukawa Electric Co Ltd
Futaba Industrial Co Ltd
Hitachi Ltd - Rail Systems Business Unit (Kasado Works)
Hitachi Zosen Corporation
Honda Research & Development Co Ltd
IHI Corporation
INPEX Corporation
ISEL Co Ltd
JFE Steel Corporation
JGC Corp
Kawasaki Heavy Industries Ltd
Kobe Steel Ltd
Nippon Light Metal Co Ltd
Nippon POP Rivets and Fasteners
Nippon Sharyo Ltd
Nippon Steel & Sumitomo Metal Corporation (NSSMC) (Formally Sumitomo)
Nippon Steel Corporation (Nippon Steel)
Osaka Gas Co Ltd - Pipeline Business Unit
Sumitomo Heavy Industries Ltd
Sumitomo Precision Products Co Ltd
TADA Electric Co Industrial Apparatus Works
Teijin Limited
TLV Co Ltd
Toyo Kanetsu KK
Toyobo Co Ltd
Yamaha Motor Co Ltd

Republic of South Korea

ANSCO
KEPCO KPS - Pusan Decommissioning Centre and Naju Head R&D Centre
Samsung Heavy Industries Co Ltd - Shipbuilding Divn

Kuwait

Kuwait Oil Company (KOC)

Libya

Jabel Oilfield Services (JOS)
Ras Lanuf Oil & Gas Processing Co

Luxembourg

Molecular Plasma Group SA

Former Yugoslav Republic of Macedonia

ZAVAR Company

Malaysia

MFE Formwork Technology Sdn Bhd

Mexico

Petroexperts

Netherlands

Allseas Engineering BV
Bayards Aluminium Constructies BV
European Space Agency, Materials & Processes Divn – ESTEC
Huisman Equipment BV
SIF Group BV
WRS Cathodic Protection BV

New Zealand

Optimech International Ltd

Norway

Equinor ASA
Kvaerner Verdal AS
Metalock Industrier AS
Nexans Norway AS
Norsk Titanium
Petroleum Safety Authority Norway

Industrial Member Companies

Saint Jean Wheels AS
Scansense AS
Seram Coatings AS
Siemens AS
SINTEF Manufacturing AS
Teekay Petrojarl Production AS

Oman
Salalah Methanol Company LLC
TMK Gulf International Pipe Industry LLC

Qatar
Dolphin Energy Ltd
Qatar Liquefied Gas Co Ltd
Q-Chem

Saudi Arabia
KONE Areeco Ltd
SABIC
Saudi Aramco Technologies Company (AramcoTech)

Singapore
Cladtek Holdings Pty Ltd
Keppel FELS Ltd
Professional Testing Services Pte Ltd

South Africa
ESKOM Holdings SOC Ltd
PetroSA (Mossel Bay)

Spain
Equipos Nucleares SA, SME
Fusion for Energy
Grupo Nicolas Correa Laser SA
Navantia SA - Cartagena Shipyard
SENER Ingeniería y Sistemas SA
Siemens Gamesa Renewable Energy
Tecnicas Reunidas SA
Windar Offshore

Sweden
Arcam AB
ECAPS (Ecological Advanced Propulsion Systems)
ESAB AB
ETP Transmission AB
Freemelt AB
Hydro Extruded Solutions AB
Livbag SAS
NDE Offshore AB
Shiloh Industries - Europe (Gothenburg)
Sol Voltaics AB
Swedish Nuclear Fuel & Waste Management Co (SKB)
Westinghouse Electric Sweden AB

Switzerland
Georg Fischer Piping Systems Ltd
Nagra
Sulzer Management Ltd - Pumps Equipment

Thailand
CUEL Limited

Turkey
AKU Automation – Turkey
Arlentus Kontrol AS
Floteks AŞ
FNSS Defence Systems Inc
Integrity NDT Engineering
Nesne Elektronik
Sabanci University - SU-IMC (Integrated Manufacturing Technologies Research and Application Centre)
Yesilova Holding AR-GE Centre

United Arab Emirates
Abu Dhabi Co for Onshore Oil Operations (ADCO)
Abu Dhabi Oil Refining Co (TAKREER)
Acteon Middle East FZE
Archirodon Construction (Overseas) Co SA
Borouge PTE Ltd Abu Dhabi
Dolphin Manufacturing Ltd
Exterran Energy FZE
Lamprell Energy Ltd
Petrofac Engineering & Construction International Ltd
Proclad Group
Zakum Development Company (ZADCO)

United Kingdom
3T Additive Manufacturing Ltd
ABB Automation Ltd, Water & Industrial Business Unit
ABB Ltd
Air Products Plc
Airhead Design Ltd
AIXTRON Ltd
Allied Holdings and Consultants Ltd
AMG Al UK Ltd
AN Motorsport Ltd
Andritz Powerlase Ltd
Anne's Day
Ansaldo Nuclear Ltd
Apache North Sea Production Limited
API Microelectronics Limited
Applus RTD UK Ltd
Aquam Water Services
Aquasium Technology Ltd
Aquaterra Energy
Arc Energy Resources Ltd
Arc Machines Inc
Arcadis Consulting (UK) Limited
ATB Group UK Limited
Atkins Energy
Atlantic Acquisitions Holdings Ltd
Aubert & Duval

Avingtrans Plc
AWE Plc
Babcock Integrated Technology
Babcock Marine (Clyde)
Babcock Marine Rosyth
BAE Systems Plc
Baker Hughes - A GE Company
Balltec Ltd
BD Nuclear Ltd
Bechtel Ltd
Berkeley Modular Ltd
Biomet UK Healthcare Ltd
Boeing Company, The
Bombardier Aerospace Shorts
Bombardier Transportation (Derby)
Bosch Thermotechnology Ltd
BP Exploration Operating Company Limited
Braemar Technical Services (Engineering) Ltd
British Engineering Services Ltd
British Steel Ltd
Brose Ltd
Bruel & Kjaer VTS Ltd
BRUSH
BSP International Foundations Ltd
BWI UK Ltd
C4 Carbides Ltd
Cairnhill Structures Ltd
Calon Cardio-Technology Ltd
Calsonic Kansei UK Ltd
Carnival Corporate Shipbuilding
Caunton Engineering Ltd
CAV Advanced Technologies (CAVAT)
Cavendish Nuclear
Ceres Power Limited
Clayton Engineering Ltd
Clean Energy Partners CEP Services Ltd
CNR International (UK) Ltd
Cokebusters Ltd
Collins Aerospace (UK)
Comau UK Ltd
Component Recovery Solutions Ltd
Connect Plus M25 Ltd
Constellium UK Ltd
Corewire Ltd
Costain Ltd
COWI UK Ltd
Cox Powertrain Ltd
CRC-Evans Offshore Ltd
Cross Manufacturing Co (1938) Ltd
Cummins Electrified Power
CWT Ltd
Dage Precision Industries Ltd
Danecca Ltd
Darchem Engineering Ltd
Dashboard Ltd
Datapaq Ltd
Daventry Metal Products Ltd
Delta Motorsport Ltd
DePuy International Ltd
Devonport Royal Dockyard Ltd
Diamond Light Source Ltd
Domino UK Ltd
Doncasters Bramah
Dril-Quip (Europe) Ltd
Dunlop Oil & Marine Ltd (Grimsby)
Durr Ltd
Dynex Semiconductor Ltd
E.ON Climate and Renewables UK Ltd
EBTEC Corporation
EDF Energy Nuclear Generation Ltd
EDO MBM Technology Ltd
Electron Beam Processes Ltd
Elekta Ltd
Elektron Technology UK Ltd
Element Six Group
Encocam Ltd
Energy Power Resources Ltd
Erlson Precision Ltd
Esterline Advanced Sensors
Express Engineering Ltd
Fairlead Maritime
FAUN Trackway Ltd
Flakt Woods Ltd
Flint Engineering Ltd
Fronius UK Ltd
G4S Monitoring Technologies Ltd
GE Power Conversion UK Ltd
GE Power Services Ltd
GE Power, Gas Power Systems, Materials & Processes Engineering - Systems Materials
Gems Sensors Ltd
Gestamp Tallent Ltd
GHD Cambridge
GKN Plc
Goodwin Steel Castings Ltd
Gordon Murray Design Ltd
Graham Engineering Ltd
Gyrus Medical Ltd
Harland and Wolff Heavy Industries Ltd
Harris Pye UK Ltd
Hayter Ltd
Health & Safety Executive (HSE)
Heatric Ltd
Henrob Ltd
HiETA Technologies Ltd
Highways England Company Ltd
Hitachi Rail Ltd
Hollygate Fabrications Ltd
Holroyd Precision Ltd
Houlder Ltd
Howden Technology
HS Marston Aerospace Ltd
Huntingdon Fusion Techniques Ltd
IMRA Europe S.A.S.
INEOS Grangemouth
Integral Powertrain Ltd
International Oilfield Drilling Supplies Ltd
International Power - UK Power Generation Operations
Invibio Ltd
IPP Mardale Ltd
IPS Structural Adhesives Inc
J C Bamford Excavators Ltd
Jackweld Ltd
Jacobs UK
Jaguar Land Rover Ltd
James Fisher Nuclear Ltd
James Fisher Testing Services
James Purdey & Sons Ltd
JDR Cable Systems Ltd
John Reid and Sons (Strucsteel) Ltd T/A REIDsteel
Johnson & Starley Ltd
Johnson Matthey Davy Technologies Ltd
Jost UK Ltd

Industrial Member Companies

JRM Group Ltd
Kazakh Projects Joint Venture Ltd
KCC Ltd
Kellogg Brown & Root (UK) Ltd
Klinger UK Ltd
Komatsu Mining Corp (UK)
Krohne Ltd
Kuka Systems UK Ltd
Laing O'Rourke Plc
Lander Automotive Ltd
Leonardo MW Ltd
LICenergy UK Ltd
Liebherr-Aerospace Lindenberg GmbH
Lincoln Electric Europe SL
Linx Printing Technologies Ltd
Lion Engineering Services Ltd
Lloyd's Register
Lockheed Martin UK Ampthill Ltd
London Underground Ltd
LPA Niphan Systems
LTi Metaltech Ltd
Luvata Welwyn Garden Ltd
M.S.C.M. Ltd
MAATS Tech Ltd
MacGregor Welding Systems Ltd
MacTaggart Scott & Co Ltd
Magnox Ltd
Marshall of Cambridge Aerospace Ltd
MASHCo - Manchester Airport Hydrant Transformation
Master Filter Ltd
MBDA UK Ltd
Meggitt UK Ltd
Mercedes AMG High Performance Powertrains Ltd
Metaldyne International (UK) Ltd
Metalysis
Micromass UK Ltd
Micrometric Ltd
Ministry of Defence
Molecular Products Ltd
Moog Inc Aircraft Group
MTCe Ltd
National Nuclear Laboratory Ltd - Workington Laboratory
Neptune Offshore Services Ltd
Network Rail
NMB Minebea UK Ltd
Norma UK Ltd
Novanta Technologies UK Ltd
NquiringMinds Ltd
Office for Nuclear Regulation
Oil States Industries (UK) Ltd
Oliver Crispin Robotics Ltd
Olympus Keymed Ltd
Orchid Orthopedic Solutions Sheffield Ltd
Ove Arup & Partners Ltd
Oxford Instruments Nanoscience
Pall Manufacturing UK Ltd
Paradigm Precision - Burnley Ltd
Perenco UK Ltd
Peter J Douglas Engineering Ltd
Philips AVENT
Phillips 66 Limited
Pipeline Engineering & Supply Co Ltd
Pipeline Technique Ltd
Pipeline Technology Centre Ltd
Portsmouth Aviation Ltd
Primetals Technologies Ltd
Proserv UK Limited
Proxisense Ltd
PSI (Phoenix Scientific Industries) Ltd
Pure Fishing (UK) Ltd
PX Ltd
QinetiQ Additive Manufacturing Group
Qualfab Ltd
Radioactive Waste Management Ltd
RAL Space
Ransomes Jacobsen Ltd
Rapiscan Systems Ltd
Reaction Engines Ltd
Red Bull Technology Ltd
Redman Controls & Electronics Ltd
Renishaw Plc
Repsol Sinopec Resources UK Ltd
Responsive Engineering Ltd, Fabrication & Welding Division
Rheinmetall Defence UK Ltd
Rhyal Engineering Ltd
Ricardo Cambridge Technical Centre
Rolls-Royce Plc
Royal Enfield UK Technology Centre
Royal IHC Ltd
Royal National Lifeboat Institution
RTN Ltd
Rutherford Appleton Laboratory – ISIS
Sarclad Limited
SC Group-Global Limited – Supacat
Scottish & Southern Energy (Generation Divn)
Scottish Power – Generation and Renewables
Sellafield Ltd
Serious Engineering Ltd
Sheffield Forgemasters International Ltd
Shelbourne Reynolds
Shell Global Solutions International B.V.
Siemens Magnet Technology
Silverwell Energy Ltd
Skycraft Services Ltd
Spectus Window Systems
SPI Lasers UK Ltd
Spincraft ETG Ltd
Spiral Weld Ltd
Spirit AeroSystems (Europe) Ltd
Springfields Fuels Ltd
SPS Aerostructures
SPTS Technologies Ltd
SST Technology
STL Technology Ltd
Stork Technical Services (RBG) Ltd
Strix Ltd
Subsea 7
Subsea Components
T J Smith & Nephew Ltd - Trauma Division
Talga Technologies Ltd
TAQA Bratani Ltd
Tata Steel UK Ltd
Taylor Studwelding Systems Limited
Technetics Group
TechnipFMC Plc
TenCate Advanced Composites Ltd
Terex GB Ltd Dungannon
Terex Materials Processing – Omagh
Tesla Engineering Ltd
Test Company

Thales UK (Maritime Mission Systems)
The Validation Centre Ltd
The Welding Alloys Group Ltd
Thermal Engineering Ltd
Thomas Broadbent & Sons Ltd
Timet UK Ltd
Titan Steel Wheels Ltd
Tokamak Energy Ltd
TPS Weldtech Ltd
Transvac Systems Ltd
Tremco-Illbruck Ltd
Trinity House - Field Ops and Operations
Triton Electronics Ltd
Tullow Oil Plc
Turbo Power Systems Ltd
Ultra Electronics Controls Division
Ultra Electronics Ltd - Nuclear Control Systems (Wimborne)
Underwater Cutting Solutions
Unipart Powertrain Applications Ltd
Uniper Technologies Ltd
United Kingdom Atomic Energy Authority
URENCO Nuclear Stewardship Ltd
UTS Engineering Ltd
Vandewiele UK Ltd
Vantrunk Ltd
Veolia Nuclear Services Ltd
WD Close Ltd
Weir Engineering Services Ltd - Turbomachinery Engineering
Weir Valves & Controls UK Ltd
West Special Fasteners Ltd
WFEL Ltd
Whessoe Engineering Ltd
Whittaker Engineering
William Cook Cast Products - Leeds Plant
WSP UK Ltd
Wykes Engineering Co (Rushden) Ltd
ZF Lemforder UK Ltd
Zytek Automotive Ltd

United States

ABS Americas
Advanced Metal Products Inc
AFGlobal Corporation
American Engineering & Manufacturing Inc
Anadarko Petroleum Corporation
Arconic
Bayou Wasco Insulation LLC
Caterpillar Inc
Chevron Corporation
ConocoPhillips Company
Emerson Electric Company
ExxonMobil Upstream, ExxonMobil Midstream & ExxonMobil Corporate Strategic Research
Hess Corporation
Honeywell Aerospace
Kaiser Aluminum Fabricated Products LLC
Kosmos Energy LLC
LORD Corporation Aerospace and Defense
LPI Inc
Magnegas Corporation
Manufacturing Technology Inc
McDermott International Inc
MIC Group LLC
Microalloyed Steel Institute LP
Miller Electric / Hobart
MODEC Group
OneSubsea (A Schlumberger Company)
Orbital ATK UK
Relativity Space Inc
ROHR Inc, A Collins Aerospace Company
Siemens Energy Inc - Process Safety Consulting Business Unit
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