JOINING
INNOVATION
AND EXPERTISE

Core Research Programme: New Projects Update February 2020

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Introduction

The Core Research Programme (CRP) invests half of TWI's Industrial Membership subscriptions, currently around £3.5m per annum, to develop new technology capabilities to be applied in industry in 3-5 years' time. These services include technical enquiries, expert advice, and research and consultancy via single client and joint industry projects, drawing on our world-leading laboratories. The CRP must therefore satisfy many requirements, which include addressing a range of technologies, meeting the needs of a range of industry sectors in a variety of countries, and achieving an appropriate balance between disruptive and incremental innovation.

The CRP is steered and monitored by Research Board, which comprises representatives of approximately 40 Industrial Members of TWI. The individuals are invited by the Director of Research and Technology to represent the interests of their industry sector and are from organisations that represent the broad cross-section of TWI's Industrial Membership. Programme monitoring is via three Research Committees drawn from Research Board, each of which oversees two suites of projects. These are the Engineering Committee (Integrity and Inspection Suites), the Materials Committee (Metals & Weldability Suite and the Polymers, Adhesives, Composites & Electronics (PACE) Suite), and the Joining & Fabrication Committee (Friction & Electron Beam Suite, and Arcs, Lasers & Sheet Suite).

TWI's R&D investment includes contributions to public funded, collaborative research in addition to the CRP. This R&D is focussed around a number of themes, which are developed with input from Industrial Members and TWI staff, and agreed with Research Board. The CRP represents approximately £3.5m per annum of investment, focussed on Industrial Members, whilst collaborative research provides approximately £12m per annum, aligned with UK and EU public funding priorities, and Industrial Member priorities where possible.

The CRP is a rolling programme of approximately 60 projects, with 10-15 new projects starting every year. Selection of new projects is via a process that ensures the needs of Industrial Members are addressed, in addition to considering wider industry needs and TWI's capabilities. TWI identifies potential topics for R&D through several routes, including feedback from Industry Panel meetings, conferences, technology roadmaps and theme maps, standardisation activities, and day-to-day interactions with industry, other research and technology organisations, and academia. The topics are prioritised by Research Board, who also rank project proposals prepared by TWI. Taking account of this ranking and the need for a balanced programme, as well as considering the budget available for new activity, TWI recommends a programme of new projects to Research Board.

This publication includes a summary of the new projects that started in January 2020, following the consultation process. A full list of the active projects within the CRP is also included. Three of the current research themes attracted particular interest from stakeholders during the selection of new projects, steering investment into these new areas, in addition to TWI's more traditional fields of activity:

- Additive manufacturing.
- Data processing and artificial intelligence.
- Electrification.

We hope that you find this overview useful, and that it will encourage you to learn more about the R&D activities being carried out in the CRP for TWI's Industrial Members. Additionally, suggestions are very welcome about new areas of research that will help to underpin our future products and services for Industrial Members.

REACH Compliant Aluminium Pre-treatments

Project 33541

Industry Sectors

- Aerospace
- Construction and Engineering
- Electronics and Sensors
- Medical
- Oil and Gas
- Power
- Surface Transport (Automotive, Marine, Rail)

Materials Committee

Objectives

- Review available chromium-free conversion coating technologies for aluminium alloys and select suitable candidate processes.
- Procurement and corrosion testing of current chromium-free conversion coating technologies, ranking them using industrially relevant key performance indicators.
- Develop decision support tool to inform and guide industry to suitable REACH compliant surface treatments for selected applications.
- Perform laboratory-based trials to develop innovative treatments for self-healing, chromium-free, anodised coatings.

Ben Robinson

Project Outline

This project seeks to address the current need for chromium-free aluminium alloy conversion coatings for improved corrosion resistance. There are several chromium-free conversion coatings commercially available; however, there is little impartial information comparing their corrosion performance. The majority of testing that has been carried out has been performed in either an academic environment, not using commercial products, or comparing coating performance solely with Cr(VI) analogues, either chromating or anodising.

This project seeks to provide a clear understanding of the performance of alternative chromium-free conversion coatings with regards to both their corrosion resistance and self-healing capability. Technologies are expected to include phosphating, plasma electrolytic oxidation, zirconium/titanium conversion coatings, cerium conversion coatings, and chromium-free anodising. Results will be used to develop a decision support tool to guide industry in replacing chromium-based technologies.

Benefits to Industry

The project will provide industry with a clear direction as to the most promising chromium-free conversion coating methods, in order to avoid the increasingly restrictive and costly Cr(VI) based approaches.

A decision support tool will be available online to recommend the most appropriate coating technologies as replacements for chromating and chromic acid anodising in different use cases.

Assessment of the Durability of Abhesive Surfaces

Project 33552

Industry Sectors

- Aerospace
- Electronics and Sensors
- Medical
- Power
- Plastics and Composites
- Surface Transport (Automotive, Marine, Rail)

Materials Committee

Objectives

- Further development of a rapid coating assessment methodology.
- Utilise the new assessment criteria for durability evaluation of repellent surfaces to compare commercial non-stick coatings on aluminium alloy, titanium alloy and glass.
- Identify the modes of failure of the repellent surfaces as a function of substrate.
- Extend the assessment criteria methodology to include erosion and photochemical damage.

Project Outline

Previous work has developed a new approach to the assessment of the durability of repellent surfaces. This approach used a multi-variate analysis method to define a figure of merit based on considerations of surface roughness, surface energy and retention of these key characteristics under abrasive and aggressive chemical conditions. The properties of candidate coatings and surface treatments are measured using standard methods and protocols under this approach. The retention of the key performance indicator, i.e. repellence, as a function of exposure to a range of harsh mechanical and chemical conditions can then be determined. The normalised performance data are plotted in the form of a radar diagram.

This approach bridges the gap that currently exists between measurement of individual properties (repellence, abrasion resistance etc) and long-term functional assessment. It also enables a more rapid comparative assessment between candidate coatings and surface treatments and so can be used to screen candidate coatings for longer term field trials.

Previous work focussed on coating formulations developed at TWI on aluminium Q-panels. This project will expand and extend this approach. In addition to candidate TWI coatings, commercial hydrophobic (fluorocarbon and hydrocarbon) coatings and silanes will be applied to Ti-6Al-4V, 2XXX series aluminium, and glass. These substrates are representative of the materials used in the aerospace and solar photovoltaic industries.

Alan Taylor

Benefits to Industry

The project will establish a more holistic and accelerated test methodology than conventional functional assessment.

This will enable industry to make better selection decisions and to validate these more rapidly than at present.

Performance of Sweet-Rated Steel in Souring Environment

Project 33553

Industry Sector

- Oil and Gas

Objectives

- Define the transition point from CO_2 to CO_2/H_2S conditions based on scaling properties.
- Define transition (CO_2 to CO_2/H_2S) severity domains as tool of risk assessment for H_2S-related degradation mechanisms on sweet rated material.
- Investigate the effect of transition from CO_2 to CO_2/H_2S on the surface of sweet-rated carbon steel and indicate the degree in risk for H_2S-related degradation mechanisms.

Maria Eleni Mitzithra

Project Outline

When existing sweet wells turn into sour, the risk of sweet-rated material suffering degradation (i.e. cracking) may increase, depending on the established pre-sour, the sour transition and post-sour conditions.

Previous work examined the behaviour of carbon steel upon transition from pure sweet (60 days) to sour (1% H_2S in CO_2 for 120 days) conditions at 40°C. It was shown that no steady-state conditions were achieved during the pure sweet exposure (no protective carbonate scales were formed), which did not counteract the upset in the test environment or inhibit the aggressive action of the H_2S on the material. In the event of souring, especially where non–sour rated material is used, the risk of introducing hydrogen and inducing hydrogen-based cracking in the material could be significantly increased.

This project will constitute a first step for an eventual setting of more realistic transition criteria from sweet to sour, adapted for each different situation. In particular, it involves the continuous long-term corrosion monitoring of small-scale samples of parent carbon steel material, using advanced electrochemical equipment. Long-term testing is highly desirable for industry. TWI has an extended history of undertaking very long term testing of materials in aggressive environments while maintaining excellent monitoring and control of environmental variables. This specific testing includes the variation in only two factors: the exposure period for each condition (i.e. 'sweet period' and 'sour period') and the test pressure.

Benefits to Industry

Transition severity domains will be set as a tool of risk assessment for H_2S-related degradation mechanisms on sweet rated material.

New capabilities and expertise in performing in situ corrosion monitoring at high partial pressure of H_2S will allow efficient and reliable assistance to industry in ensuring the safe operation of pipelines.

Ecostir – Single Use High-Temperature Friction Stir Weld Tooling

Project 33555

Industry Sectors

- Aerospace
- Electronics and Sensors
- Medical
- Power
- Surface Transport (Automotive, Marine, Rail)

Objectives

- Minimise tool contamination through improved welding procedures including pilot hole geometry.
- Understand the weld microstructure, effect of tool contamination and effect on mechanical properties.
- Assess tool performance when welding a range of plate thicknesses.
- Evaluate tool designs, candidate materials and backing bars against the criteria established for technical and economic performance.
- Produce data on tool life and cost to augment the business case for their use.

Jonathan Martin

Project Outline

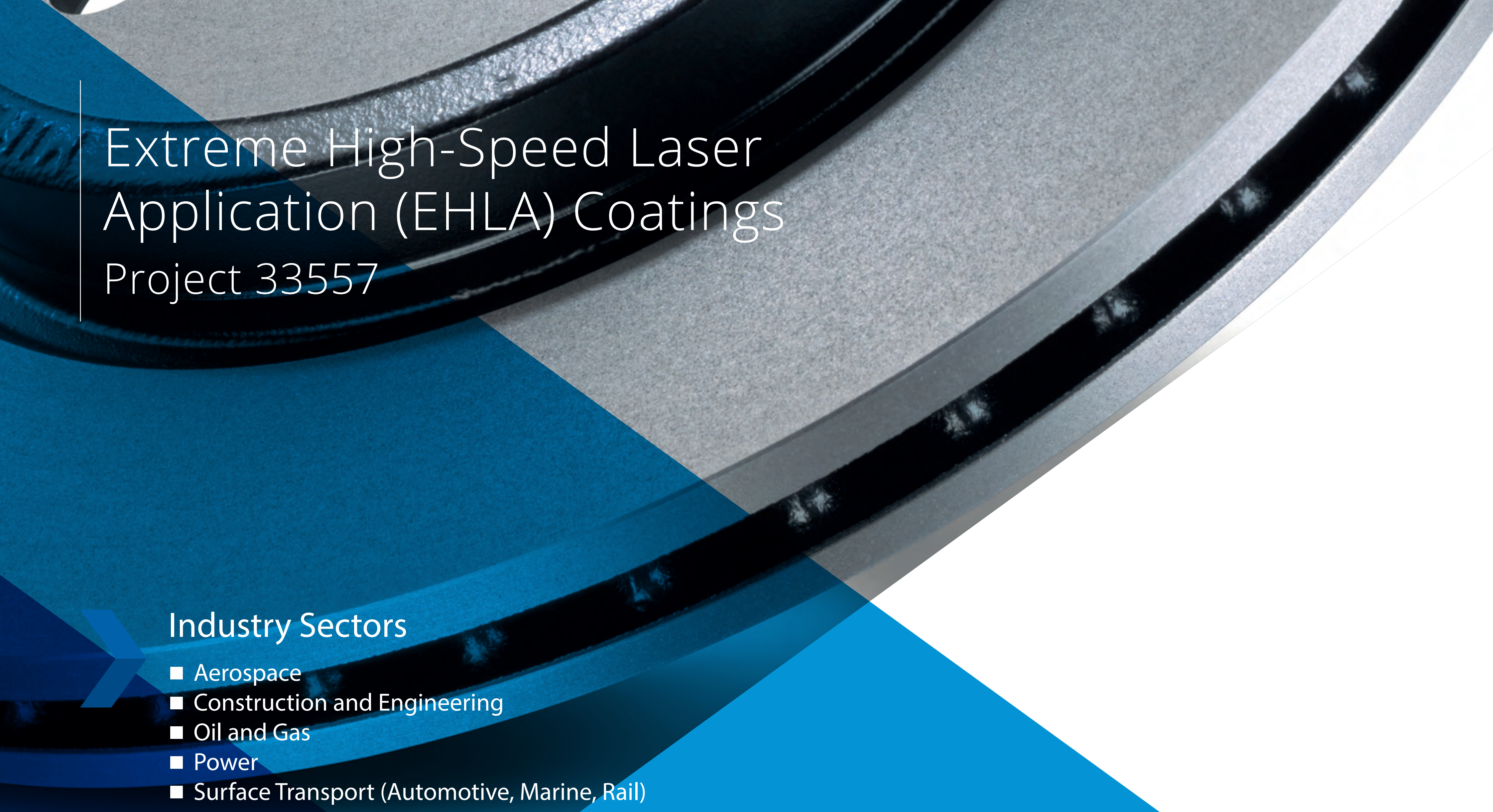
TWI has previously assessed a range of candidate friction stir weld (FSW) tool materials for welding Ti-6Al-4V. A ceramic material and tool design were identified which produced several metres of weld, with the potential to do so at a price considerably below that currently achievable with existing tool materials and designs.

The basic concept of this project is to build upon this work, assess different tool designs plate thicknesses, and backing bar materials, identify the process window, characterise the weld microstructure and tool weld contamination and then finally assess the mechanical properties. Data will be collated on weld quality, tool life and tool cost in order to assess the economic advantages of this new generation of FSW tools.

Whilst low cost tooling is attractive to all potential users, it is especially so to those in market sectors where the end products are of lower intrinsic value than in, for example, the aerospace sector. These sectors may also be able to tolerate a lower weld quality if, for example, the titanium component is required primarily for corrosion resistance rather than structural strength.

Benefits to Industry

The ability to undertake lower cost welding in titanium will be attractive across many industry sectors.



Extreme High-Speed Laser Application (EHLA) Coatings

Project 33557

Industry Sectors

- Aerospace
- Construction and Engineering
- Oil and Gas
- Power
- Surface Transport (Automotive, Marine, Rail)

Objectives

- Develop fundamental understanding of the EHLA process.
- Build expertise with the UK's first EHLA system.
- Developed knowhow in thin-coating capability to state-of-the-art levels.
- Benchmark EHLA coatings against end-use quality and performance requirements, and conventional manufacturing methods.

Charlotte Blake

Project Outline

The extreme high-speed laser application (EHLA) is capable of applying fully fused metallic coatings with a maximum coverage rate greater than 250cm²/min (i.e. more than ten times faster than conventional laser cladding). This is achieved by melting powder prior to reaching the substrate, thereby reducing the time/energy that would otherwise be needed to achieve melting of the substrate. EHLA is also capable of producing thinner coatings than conventional laser metal deposition (LMD) due to very little dilution between substrate and deposited material (10µm-300µm against more than 500µm). Low dilution also offers the potential for dissimilar materials coatings. EHLA is being developed as a direct replacement for chrome plating and thermal spray coating techniques.

EHLA-produced coatings will be characterised and tested. Detailed characterisation and analysis will ensure that process parameters are optimised in a systematic way, focusing on integrity and application requirements. In order to give a fair comparison between EHLA and conventional coatings, the quality of the coatings will be assessed through several iterations of development and study in both cases. Coated samples will be characterised by optical and SEM microscopy, and tested. As there is limited literature about EHLA material characteristics it is particularly important to build up knowledge in this area and make comparisons with conventional laser metal deposition and other competitive coating processes. We will compare characterisation and test results with literature on other coating processes.

The final demonstration phase of the project will include:

- Producing at least two different demonstrators to show application of components (on shafts up to 900mm long, or discs up to 450mm in diameter).
- Testing of demonstrator performance and integrity. This will depend on application but is expected to include both mechanical and environmental performance testing.
- Analyses of quality, performance, costs, wastage, and production rates.

Benefits to Industry

Industry will use the knowledge gained through fundamental development of the EHLA process, including metallurgical investigations, to inform decisions about coating materials and processes. Industry will have access to state-of-the-art EHLA capabilities, for the first time in the UK. This will facilitate technology transfer, and accelerate qualification of coated parts.

Joining and Recycling for Electric Vehicle Battery Pack Manufacture

Project 33559

Industry Sectors

- Aerospace
- Electronics and Sensors
- Surface Transport (Automotive, Marine, Rail)

Materials Committee

Objectives

- Benchmark different technologies suitable for battery cell to bus bar joining and joining of other features (e.g. wires) to bus bars.
- Undertake characterisation and mechanical testing of joints manufactured by different techniques – primarily tensile strength and fatigue performance.
- Develop a capability for electrical testing of 'live' battery cell packs.
- Develop suitable approaches for battery pack disassembly and recycling/reuse.

Project Outline

The overall project concept is two-fold. One priority will be to focus on research related to battery pack joining and joint performance using techniques suitable to connect cells and other features to bus bars. The second focus will be around developing new capability in terms of design, testing, recycling and other knowledge relevant to electrification.

Limited data exist in the public domain related to mechanical and electrical performance as a function of the different joining techniques, which makes the design of battery modules a more empirical process. Recent literature typically provides a top level review rather than process specific data. A suitable design for a cell to bus bar assembly will be developed in order to standardise a test methodology. This design will address the challenge of the variety of joint geometries created by the different joining processes.

Design concepts and opportunities for disassembly and recycling will be investigated. Opportunities based on the concept of design for disassembly will be developed that may facilitate better reuse/recycling of battery packs. A key aspect of this activity will be engagement with industry to identify future trends in pack design.

The final activity will focus on identifying gaps in current standards and identifying areas where the application of a standard could be beneficial. This could range from control and qualification of a joining procedure and associated inspection through to minimum levels of mechanical or electrical performance. TWI will work with other R&D organisations as well as industry, industry bodies and other stakeholders e.g. HSE, to identify and contribute to new standards as required.

Nick Ludford

Benefits to Industry

- Ability to reliably manufacture battery packs with reduced failure rates.
- Mechanical and electrical joint properties to allow for optimised designs.
- Understanding of requirements related to design for disassembly and second use/recycling.
- Validated mechanical testing methodology for QA.
- Non-destructive testing protocols for QA.

Effect of Material and Geometry on SurFlow™

Project 33567

Industry Sectors

- Aerospace
- Electronics and Sensors
- Medical
- Oil and Gas
- Power
- Plastics and Composites
- Surface Transport (Automotive, Marine, Rail)

Objectives

- Achieve a reliable, qualitative method of assessing SurFlow™, through the development of a test bench.
- Understand the effect of material on SurFlow™ by changing the fibre type, weave type, stacking sequence and the matrix of the composite, and measuring the signal propagation in simple laminates.
- Understand the effect of geometry on SurFlow™ by introducing a variety of geometrical features to composite structures and measuring the signal propagation.
- Understand the effect of transducer design on SurFlow™ by varying transducer design, performing electromagnetic (EM) simulation and measuring signal propagation.
- Establish SurFlow™ reliability by measuring data propagation speed, signal leakage and electromagnetic interference (EMI).

Project Outline

SurFlow™ technology allows signal propagation from one end to the other of a composite surface without the use of wiring harnesses or fibre optics. The signal travels over the composite surface in the form of an electromagnetic surface wave (EMSW). The signal is bound to the composite structure. There are three requirements for EMSW to function:

- The wave must be launched with the correct incident angle.
- A medium compatible with EMSW propagation.
- The waveform must be acquired and translated at the receiving end.

The following challenges related to SurFlow™ will be investigated in this project:

Material
Although demonstrations have been performed on different composites (glass, carbon etc) it has not been quantitatively established how the material affects the signal propagation. That means the effect of fibre type, weave type, stacking sequence, resin type etc are yet to be quantified.

Geometries
The effect of geometric features such as joints and curvatures is not fully understood. Depending on the location of the interface in which the signal propagates and the location of the feature (joint, curve) in the structure, the effect on the signal could be different.

Transducers
The transducers developed for SurFlow™ have not been characterised in an anechoic chamber. Although the aim was to optimise the transducer for EMSW propagation, they also emit an electromagnetic airwave (EMAW). The intensity of the EMAW increases when higher power levels are used to launch the wave. The transducer design, signal power level and control, and transducer shielding will be investigated in order to tailor the EMSW to EMAW ratio. Furthermore, the effect of EMI has not been assessed. This work will be carried out in an anechoic chamber.

Electronics
Off-the-shelf electronics have been used for transmitting and receiving the EMSW signals. However, these are not optimised for SurFlow™. Quantitative data measurements of the coefficient of signal transmission have been carried out using a vector network analyser. This work now needs to be repeated in an anechoic chamber.

Test reliability and repeatability
The test set-up for testing SurFlow™ is laboratory-based and currently has not been standardised. In order to compare different materials, structures and frequencies, the test set-up has to be standardised, in the form of a test bench, for repeatability and reliability.

Materials Committee

Jasmin Stein

Benefits to Industry

Industry can use the SurFlow™ test bench to assess whether composite structures are compatible with SurFlow™. Findings will provide industry with improved understanding of the technology and an indication of the reliability of SurFlow™ for specific applications.

Artificial Intelligence for NDT of Unknown Geometries using a Cooperative Robot

Project 33568

Industry Sectors

- Aerospace
- Construction and Engineering
- Electronics and Sensors
- Oil and Gas
- Power
- Plastics and Composites
- Surface Transport (Automotive, Marine, Rail)

Objectives

- Review current artificial intelligence (AI) techniques for goal-oriented action planning and their fields of applications. This will include self-driving car and mobile robot applications using deep-learning networks. The suitability of these approaches to be used with cobots will be determined.
- Integrate a highly sensitive force/torque sensor and phased array probe as the cobot tool.
- Develop algorithms that can correct the motion and orientation of a cobot based on force and ultrasonic feedback.
- Implement search algorithms to ensure full surface coverage as needed by the application with the cobot control software.
- Demonstrate the benefits and drawbacks of the developed system through a parametric study based on samples provided by industry.

Project Outline

This project will look at how artificial intelligence can be used in conjunction with ultrasonic sensors and cooperative robots (cobots) to perform NDT of unknown complex geometries. The use of force/torque sensors means that the robot can detect when a probe touches a surface. The feedback from these sensors can measure forces and torque in three dimensions, which allows the robot to control both position and orientation. These data can be utilised to follow a surface, alleviating the need to know the full surface geometry. NDT inspections often require a probe to cover a certain area, such as the heat-affected zone around a weld. Deciding how to cover this area is a task that is well suited for artificial intelligence (AI) as it becomes an exploration problem.

Ultrasonic phased array probes have been accepted as state-of-the-art in industry due to their enhanced imaging capabilities. By using a phased array probe (with a wedge) on a cobot, it is possible to incorporate this additional sensory information to align the cobot with the surface, in order to ensure that adequate data are captured. Combining force/torque sensing with ultrasonic feedback will lead to an automated scanning system that is optimised for NDT of complex surfaces.

The project will investigate an aspect of AI known as goal-oriented action planning. Goal oriented AIs have been used for a number of years in computer games and have recently been implemented in self-driving cars. The goal(s) are typically defined at a high level, such as "reach point B from point A", allowing the AI to make a number of decisions about how to reach that state autonomously. The project will incorporate this type of AI approach to ultrasonic inspection of complex geometries using cobots.

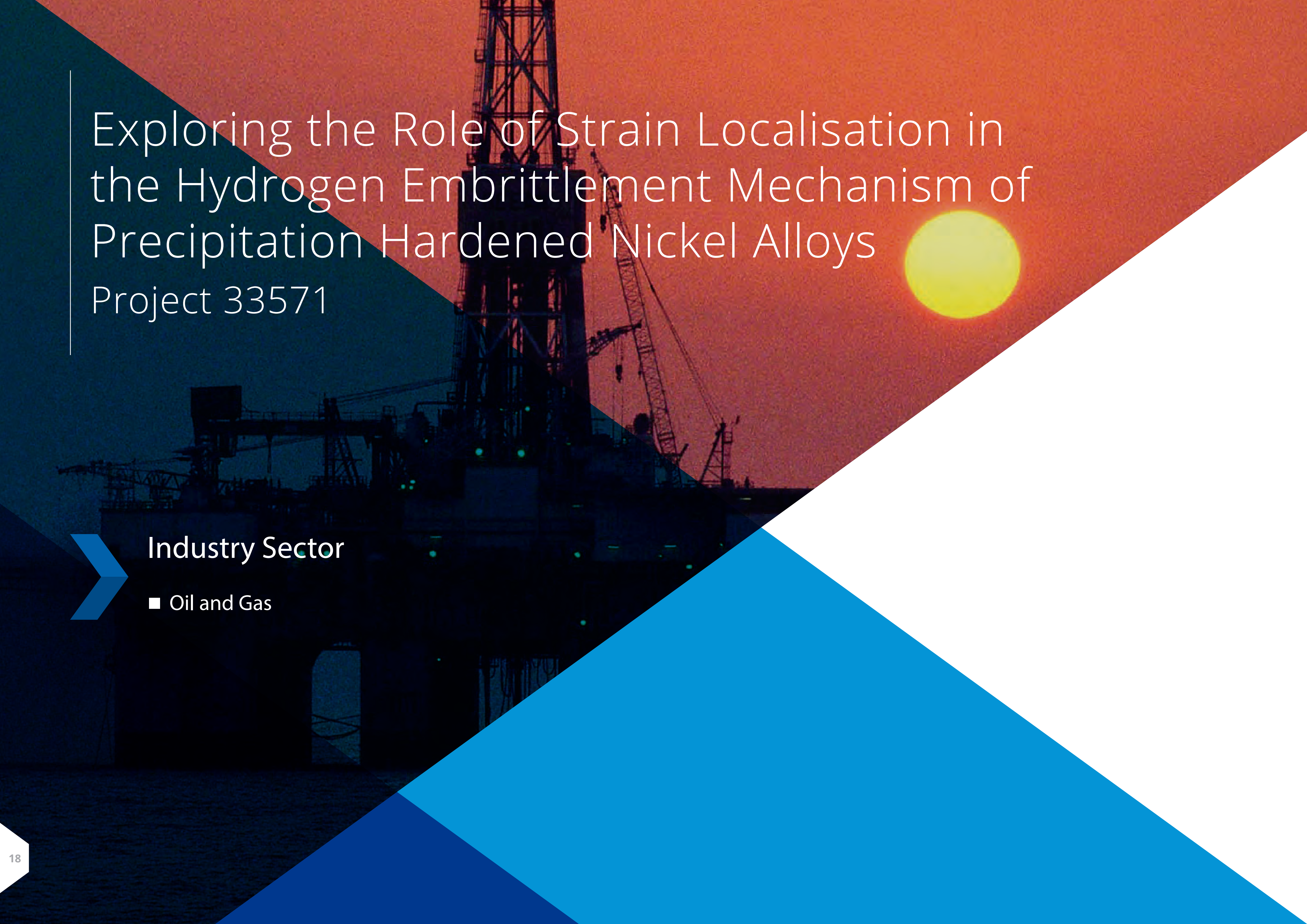
To ensure a well-defined problem space, the project will be limited to the inspection of complex weld geometries, supplied by industry partners, using a cobot with a phased array probe. This will ensure that the number of parameters is kept at a reasonable level while algorithms and AI approaches are developed. It is envisaged that the project will result in actual, on-site trials to determine the applicability of the developed system in real-world scenarios.

Jonathan Riise

Benefits to Industry

Deployable automated techniques are required for in-service inspections as well as at the manufacture and assembly stages. The drive toward industry 4.0 requires that digital automated systems are developed to provide feedback to design and manufacture and to enable the creation of digital twins. In addition, industry needs to leverage the power of AI to decrease set up times and ensure good data quality.

The capability developed in this project will enable industry to employ cooperating robots to undertake NDT and other tasks at manufacture and in-service without the need for a dedicated safety cell.



Exploring the Role of Strain Localisation in the Hydrogen Embrittlement Mechanism of Precipitation Hardened Nickel Alloys

Project 33571

Industry Sector

- Oil and Gas

Objectives

- Develop a test method capable of assessing the fitness-for-purpose of precipitation-hardened nickel alloys (PHNAs) with respect to hydrogen embrittlement (HE).
- Develop a technique that reliably captures crack initiation during slow strain rate tensile and incremental step load testing and which can later be used to define strain-based failure criteria.

Project Outline

Recent observation of slip bands on the brittle fracture surfaces of slow strain rate tensile (SSRT) test specimens has suggested that plastic strain is required in order to initiate HE cracking. Interrupted SSRT tests have suggested that more than 1.8% plastic strain is required to initiate HE cracking at the root of notched specimens. Further work using fracture toughness based testing methodologies on fatigue pre-cracked specimens has also shown the resistance of PHNAs to crack propagation is very low under environmental conditions known to embrittle the material in SSRT tests. This has led to the hypothesis that crack initiation may be the dominant factor controlling resistance to HE and a critical strain may be required for crack initiation to occur. If correct and measurable, the resistance of PHNAs could be quantitatively defined by this critical strain. Critical strain could also be used to develop a design criterion to increase the resistance of components to HE.

In order to measure the critical strain at which cracking occurs a method of detecting crack initiation is required. Previous work has investigated incremental step load (ISL) testing combined with direct current potential drop (DCPD) measurements as a means of detecting crack initiation. ISL testing has proved more sensitive to the effects of strain localisation on specimens with different notch acuities but it has not been possible to identify crack initiation using either mechanical test or DCPD data.

This project will investigate techniques for detecting crack initiation in notched specimens, including: DCPD, acoustic emission, ultrasonic techniques and strain gauges across the notched area. These approaches will be validated using interrupted testing at loads before and after the detection of cracking. Previous work will be extended using the ISL test method to investigate the influence of strain localisation on resistance to HE in high strength nickel alloys.

Previous work has focused on Alloy 718, the 'workhorse' alloy widely considered to be relatively resistant to HE; however, newer higher strength alloys are thought to be more susceptible to HE and the effects of strain localisation. This project will investigate whether the notch sensitivity of higher strength alloys is greater than Alloy 718 when tested using the ISL test method developed.

David Griffiths

Benefits to Industry

The acceptance/design criteria could be developed to prevent future failures of PHNAs due to hydrogen embrittlement. The expertise developed in this project will enable industry to understand, approve and adopt the testing techniques as part of their current materials approval processes.

Based on the outcomes, further work will allow industry to develop failure criteria for the materials currently given in API Standard 6ACRA.

Characterisation of Discontinuities with Advanced Ultrasonic Testing

Project 33578

Industry Sectors

- Aerospace
- Construction and Engineering
- Oil and Gas
- Power
- Surface Transport (Automotive, Marine, Rail)

Harry Atherton

Objectives

- Assess the sizing capabilities of phased array ultrasonic testing (PAUT) and full matrix capture (FMC) using current characterisation and sizing methods from ISO 16827.
- Compare the various sizing methods for both advanced ultrasonic testing (AUT) methods.
- Develop best practice methods for characterisation and sizing of discontinuities for AUT applications.

Project Outline

The project will assess the current sizing capabilities of AUT applications with reference to ISO 16827:2012 ("Non-destructive testing — Ultrasonic testing — Characterization and sizing of discontinuities") and investigate best practice for a variety of AUT techniques for sizing in butt-welded joints. The current methods for sizing with AUT are taken from manual ultrasonic testing (MUT) standards. During this project, these techniques adopted from ISO 16827:2012 will be reviewed and assessed to see how applicable they are for AUT techniques and whether different characterisation and sizing techniques may be more appropriate.

Probe manipulation for AUT is more rigid than for MUT. Standard AUT inspections involve the probe having a constant index offset from the weld; the probe moves along the length of the weld at a set rate. Flaw analysis in AUT is typically completed after inspection. The data collected during the inspection are recorded, allowing the operator to characterise and size indications later. The physical methods of collecting and analysing data for MUT and AUT, are different, but they currently still adopt the same techniques for characterising and sizing defects. An investigation into the characterisation and sizing capabilities and methods for AUT will develop new knowledge and expertise in the field for on-site sizing of defects in newly manufactured structures and ageing assets.

Trialling the variety of sizing methods (maximum amplitude, 6dB drop, 12dB drop, 20dB drop, etc) will provide a greater understanding to how these methods perform in different applications and inspections. Testing these methods on a range of sample thicknesses and defect types and sizes will build a far greater understanding of their capabilities and limitations.

Benefits to Industry

The assessment of the characterisation and sizing capabilities of AUT methods adopting the techniques from ISO 16827:2012 will allow a greater level of confidence in sizing defects for lab and site purposes. The work on defect critical sizing with PAUT and FMC will increase the level of confidence in sizing for new and ageing assets, and reduce the conservatism for defects for engineering critical assessment (ECA). New expertise and knowledge in the field of FMC will assist with development of upcoming standards on the method.

Additively Manufactured Metal Lattices

Project 33582

Industry Sectors

- Aerospace
- Construction and Engineering
- Medical
- Oil and Gas
- Power
- Surface Transport (Automotive, Marine, Rail)

Engineering Committee

Objectives

- Produce preliminary design guidelines and assessment approaches for the use of additively manufactured (AM) lattices in structural parts based on a combined modelling and experimental approach.
- Characterise and quantify the statistical deviations of the as-built lattices from their ideal representations using microfocus X-ray computed tomography (XCT) scanning.
- Develop a robust modelling and analytical approach that captures the inherent statistical deviations and allows for determination of design factors for static and fatigue performance.
- Undertake a design-of-experiments (DoE) study for the static properties and fatigue behaviour of lattices.
- Validate the design rules on representative demonstrator part.

Project Outline

A metal AM lattice is typically comprised of a periodic array or spatial tiling of a unit cell. A typical unit cell contains an oriented array of struts connecting the corners or faces of a geometric cell such as a body centred cubic (BCC) array. However, unit cells can be designed to exhibit unique features such as negative Poisson's ratios (auxetic materials); high surface area to volume ratios; and excellent energy absorption due to the combined effects of plasticity, self-contact, and compaction. However, it has been shown that the performance of as-built AM lattices is inferior to analytical calculations or finite element (FE) simulations. In order to address the gap between simulations and real mechanical performance, and to provide a reliable design tool for the use of lattice in mechanical applications, the project will implement the following four activities:

Modelling
Following a review of the state-of-the-art of models and typical geometric imperfections in AM lattices, the most appropriate models for the prediction of the mechanical performance will be implemented. The effect of the geometric imperfections will be incorporated in the model by means of statistics in order to predict the performance of the material accurately. The models will be calibrated and validated using test data from the project, and will be used for the development of design guidelines and models for the use of lattice structures in mechanical components.

Production of Samples
Hundreds of samples will be manufactured based on a DoE plan in order to guarantee a robust characterisation of the mechanical performance. The samples will consider different lattice types, sizes and densities, and will be produced using at least two different laser powder bed fusion machines.

Characterisation and Testing
XCT scanning will be undertaken to quantify the geometric imperfections, including struts off-axis measurement, strut waviness, strut diameter and material accumulation at nodes. The XCT measurements will be used to provide probability distributions of non-ideal geometric features as a function of not just the unit cell design, but also the orientation of the struts. DoEs will be undertaken to design the mechanical tests. The mechanical tests will include at least compression to failure to generate their effective stress-strain curves, and fatigue loading conditions (cyclic compression or tension).

Demonstrator Part Validation
The combined numerical modelling and test programmes will be used to generate design guidelines, including safety factors, for the use of lattices in parts. These will be validated on a representative component, including a curved region with different lattice structures and densities to test the ability of the modelling guidelines to predict and accurately capture realistic-parts, not just flat arrays.

Valerio Carollo

Benefits to Industry

The project will develop state-of-the-art modelling and model validation capabilities for use by industry. This will enable technology transfer, and more rapid qualification of novel components. The knowledge gained through a fundamental statistical examination of different components will help inform material and process selection for industry enabling robust and confident design.

The project will provide a methodology for application to other unit cell designs and materials; the lessons-learned through the DoE will enable more highly-optimised and efficient studies to be undertaken.

Transition Behaviour of Corrosion Pit to Fatigue Crack

Project 33593

Industry Sectors

- Oil and Gas
- Power

Objectives

- Determine stress/strain fields around corrosion pits of different geometries.
- Perform fatigue tests to determine the conditions at which a corrosion pit will develop into a fatigue crack and to compare fatigue performance between pitted and welded specimens.
- Develop a fracture mechanics parameter to characterise this transition.

Project Outline

There is a global push towards the use of renewable energy, and the offshore wind industry is growing rapidly. Offshore structures are subject to environmental loading. For example, offshore wind substructures (OWSs) are subjected to severe cyclic loads caused by wind, waves and dynamic structural response. Although most of these structures are protected by coating and/or cathodic protection against corrosion, some parts of the structures may be subject to free corrosion in seawater. The current fatigue design of offshore structures is based on data principally from welds in tubular steel jacket structures for the oil and gas sector. This project will investigate the pit to crack transition in steels for OWSs and mooring chains, and the results can be used for other offshore structures.

The project will be composed of three parts: experimental testing, numerical modelling to determine the stress/strain concentration surrounding corrosion pits, and constitutional modelling of the corrosion pit to crack transition. Two types of steels will be investigated: structural steels commonly used in OWSs and high strength steels commonly used for mooring chains. For each type of steel, corrosion pits of various sizes will be introduced artificially. Fatigue testing of pitted plate or strip specimens, some containing a girth weld, will be carried out in both air and free corrosion seawater to establish the critical pit size and pit aspect ratio corresponding to the transition. The test specimens will be sufficiently large to be as closely as possible representative of the actual components. Linear elastic finite element analysis (FEA) will be performed to determine the local stress and stress concentration factor (SCF) for various pit aspect ratio or shapes.

Corrosion pit transition to crack can be influenced by many factors. This project will mainly investigate the following three key factors: (1) effect of corrosion pit geometries on crack initiation; (2) weld profile; (3) effect of small stresses. For (1), specimens with different pit geometries will be tested to determine the threshold stress range for crack initiation. For (2), specimens with different weld profiles, representing that typically seen in OWS, will be tested to determine the conditions at which the fatigue strength of the weld is comparable with that of pitted specimen. For (3), the study will focus on the effect of small stresses on crack initiation from corrosion pits.

Eduardo Hippert

Benefits to Industry

The new data and fatigue design guidance generated from the project will allow offshore wind energy companies to design OWSs more efficiently and safely. The results are expected to be included in future revisions of BS 7608 "Guide to Fatigue Design and Assessment of Steel Products".

Novel Ultrasonic Testing Inspection Capability for Sizing of Rough Cracks

Project 33596

Industry Sectors

- Aerospace
- Construction and Engineering
- Electronics and Sensors
- Medical
- Oil and Gas
- Power
- Plastics and Composites
- Surface Transport (Automotive, Marine, Rail)

Objectives

- Develop a number of novel features/techniques to enhance the sizing capability of full matrix capture (FMC) for the inspection of rough cracks (Ra = 50µm or greater) in austenitic or ferritic steel components.
- Manufacture/procure a number of realistic rough crack samples, including at least one stress corrosion crack sample.
- Perform simulations and experimental trials as appropriate to develop suitable FMC inspection setup/technique for sizing of rough crack flaws.
- Using the European Network for Inspection and Qualification (ENIQ) methodology for guidance, develop a capability statement demonstrating the sizing capability for FMC for inspection of rough cracks.

Miles Weston

Project Outline

FMC ultrasonic inspection offers a number of benefits over existing ultrasonic inspection techniques, to support fitness for service assessments, including amongst others: detection and sizing of near-vertical and off-specular planar flaws; fully focussed inspection through complex-geometry; and ability to interrogate the inspection volume using a range of wave modes from a single scan.

This project will develop a number of novel techniques and apply these to TWI's FMC inspection software package, Crystal, in order to demonstrate sizing accuracy of FMC for rough cracks (Ra = 50µm or greater) in austenitic or ferritic steel. Novel FMC features/techniques to be developed within this proposed scope of work include:

- Development of a novel technique to differentiate corner trap signals when masked by geometric reflections. The intended approach will use differences in ultrasonic interaction between a corner trap signal and that from a geometric reflection to enable corner trap signals to be detected and used along with the tip response for flaw sizing.
- Development of an innovative crack tip enhancement feature to increase sensitivity to crack tip response from the major face of a rough crack. Tip and facet responses from a rough crack are typically an order of magnitude (or more) weaker than those of the corner trap, geometric reflection, or specular response from the major face of the flaw. This algorithm will exploit differences in the ultrasonic interaction between a tip/facet and that from material grain structure, corner trap or geometric reflections to enhance the signal to noise ratio of a crack tip/facet.

Benefits to Industry

The project outcomes will improve confidence in flaw detection and sizing accuracy, and provide documented evidence of capability for use by industry during inspection procedure qualification to reduce the time and cost for qualification using advanced ultrasonic testing.

Integrated Additive Manufacturing

Project 33631

Industry Sectors

- Aerospace
- Construction and Engineering
- Equipment, Consumables and Materials
- Medical
- Oil and Gas
- Power
- Surface Transport (Automotive, Marine, Rail)

Objectives

- Identify critical deposition parameters and control methods for wire arc additive manufacturing (WAAM) to ensure consistent bead cross sections and feature geometries under complex and varying thermal fields, through the generation of physical samples and their associated measurement data.
- Identify relationships between weld metal alloying additions and reheated microstructure in order to develop optimised feedstock compositions for WAAM applications.
- Identify and monitor the WAAM process parameters during deposition.
- Assess inspection techniques and factors which influence the inspectability of the part build as it takes place (i.e. online), with a view to providing an inspection capability envelope for the WAAM process.

Amina Salman

Project Outline

The aim for any additive manufacturing (AM) route is for it to be a digital process with (semi-) automated design, modelling and simulation, and manufacturing procedure generation all taking place to define an optimised process. Operation of the AM process should result in a part with known properties, and in-process monitoring should then ensure the physical part meets that expectation, without the need for further inspection. This multidisciplinary project will support this for WAAM and move AM for large structures closer to the vision of high quality design, simulation and right first time every time digital manufacturing.

TWI's expertise in processing, metallurgy, numerical simulation and inspection will be combined to develop the deposition process in order to:

- Make thermal history more regular.
- Understand microstructure as a function of feedstock composition and thermal history.
- Enable the build of complex parts with more consistent geometry and mechanical properties than is currently possible.
- Include on-line non-destructive evaluation to further understand and quantify the process and correlate this with the microstructures generated.

Benefits to Industry

The outcomes of the project will improve the quality and potential range of applications for WAAM components. The ability to create parts with consistent and predictable qualities and properties, and to monitor the manufacturing process online, reducing the post-process inspection burden, will make WAAM more cost-effective and therefore more attractive to industry. The process will therefore be available as an option for applications that are not currently considered suitable for AM.

Additively Manufactured Transition Pieces for Dissimilar Welding Applications

Project 33632

Industry Sectors

- Aerospace
- Construction and Engineering
- Oil and Gas
- Power
- Surface Transport (Automotive, Marine, Rail)

Joining and Fabrication Committee

Objectives

- Review the current state-of-the-art of additively manufacturing functionally graded materials.
- Arrive at an alloy design concept, from a metallurgical point of view, in particular identifying the chemical composition necessary in each built layer and the materials, using conventional wire or powder consumables, to achieve this concept.
- Investigate and develop the processing parameters for each of the selected additive manufacturing processes.
- Develop and conduct destructive and non-destructive evaluation (NDE) in order to assess the subsequent quality of the different builds.

Anibal Di Luch

Project Outline

A range of industry sectors face applications where transitions between dissimilar metals are required. Significant plant outage and repair costs are often encountered due to failures or degradation associated with joining strategies, processes or manufacturing methodologies for such transitions. A relatively common example is a joint between ferritic steel and stainless steel. Such joints typically include multiple dissimilar metal welds, leading to abrupt discontinuities in physical properties. The proposed solution consists of designing and then additively manufacturing a single engineering transition piece, with a suitable gradual change in chemical composition along its axial direction (i.e. a "functionally-graded material"). The composition of the transition piece will be produced to match, approximately, the chemical compositions of the ferritic steel at one side and the stainless steel at the other.

Candidate processes include wire arc additive manufacture (WAAM) and laser beam additive manufacture, using either two powders or two wires. In order to transform the typical coarse and columnar as-deposited microstructure into a more homogenous and finer one, the transition piece will then require additional thermomechanical processing. The project will develop a process to include hot forging and appropriate heat-treatment. Finally, machining to the desired shape and dimensions will be carried out.

Benefits to Industry

- Only one engineering transition piece would be required to link both structures, minimising the amount of on-site welding, thus reducing costs.
- Only two similar welds, i.e. ferritic steel to the ferritic end of the transition piece, and stainless steel to the stainless steel end of the transition piece, will be required.
- The final result would be a forged and heat treated component with a homogeneous, fine equiaxed grained microstructure, more likely to be acceptable in conservative end-use applications.
- A smooth material transition (free of abrupt discontinuities in composition and properties) from one end to the other will result in a more even distribution of thermal stresses, reducing the likelihood of thermal shock cracking occurring.
- Overall improved in-service performance, reducing repair costs.
- If required, internal cladding could potentially be built-up during manufacture of the transition piece.

Current Core Research Programme Projects

Additive Manufacturing

- Laser Metal Deposition for Large Net Shape Manufacturing
- Laser Metal Deposition Surface Coating and In-Line NDT Inspection for Wear and Corrosion Applications
- Advancement of Wire-Fed Electron Beam Additive Manufacture
- Comprehensive Evaluation of Fatigue Performance Enhancement through Elimination of Porosity in Selective Laser Melting
- Microstructure Models for Open Architecture Additive Manufacture
- Deposition and Repair of High-Temperature Materials Using Additive Manufacture
- Optimisation of Heat Treatment for Additive Manufacturing
- Extreme High-Speed Laser Application (EHLA) Coatings
- Modelling and Characterisation of Additively Manufactured Lattices
- Investigation of Integrated Additive Manufacturing from Feedstock to Part Quality
- Additively Manufactured Functionally-Graded Transition Piece

Coatings and Surface Engineering

- Damage Tolerance of Thermally Sprayed Aluminium Coatings
- Corrosion Behaviour of Wear Resistant and Corrosion Resistant Coatings in Seawater Including the Galvanic Effect of Cathode Protection
- Development of Ultrashort Laser Micromachining and Surface Modification Database
- Cold Atmospheric Plasma Treatment to Enhance Joining Processes
- Development of Laser Assisted Cold Spray
- REACH Compliant Coatings (Cadmium Replacement)
- Coatings of Fasteners for Dissimilar Materials Joining
- Influence of Roughness on Non-Wetting Behaviour
- REACH Compliant Aluminium Pre-treatments (Cr(VI)) Replacement
- Assessment of the Durability of Abhesive Surfaces
- Effect of Material and Geometry on SurFlow™

Joining and Materials Processing

- Perforated Composites
- Monitoring of Arc Welding
- Effect of Insufficient Homogenisation of Pigmented Resin During the Extrusion of Polyethylene Pipes on the Mechanical Performance of Butt Fusion Joints
- Laser Welding of Crack Susceptible Materials Using Tailored Energy Distributions
- Controlling Exposure to Hexavalent Chromium in Welding Fume
- Automated Process Parameter Optimisation for Robotic Arc Welding and Additive Manufacturing
- The Properties of Similar and Dissimilar Refill Friction Stir Spot Welds
- Composite to Metals Joining
- Electron Gun Development
- Intelligent Arc Welding Robots
- Managing CTE Mismatch in Dissimilar Material Joining
- Ecostir - Friction Stir Welding of Titanium
- Joining and Recycling for Electric Vehicle Battery Pack Manufacture

Materials Characterisation

- Hydrogen Embrittlement Behaviour of High Strength Steels
- Determination of Waisted Tensile Test Energy-to-Break Factors for Different Polyethylene Pipe Resins
- Hydrogen-Assisted Cracking Susceptibility of High Strength Nickel Alloys
- Development of a Mechanised Thermal Cycling Test Facility
- Annular Corrosion in Flexible Pipes
- Environmental Fracture Mechanics Testing of Dissimilar Metal Welds
- Performance of Sweet Rated Steel in Souring Environment
- Exploring the Role of Strain Localisation in the Hydrogen Embrittlement Mechanism of Precipitation Hardened Nickel Alloys

Non-Destructive Evaluation

- Quantitative Metal Loss Measurement at Contact Points using Ultrasonic Guided Waves
- Development of Offset X-ray and Panel Shift Computer Tomography Inspection
- Feasibility of Full Matrix Capture for Inspection of Pipeline Girth Welds
- Influencing Parameters for the Ultrasonic Inspection of Austenitic Welds
- Advanced Signal Processing Techniques for Guided Wave Inspection of Buried Pipelines
- Development of Tomosynthesis X-ray Inspection Techniques
- Automated Real Time Inspection of Reduced-Pressure Electron Beam Welding
- Damage Evolution at Corrosion Pits
- Development of Non-Destructive Ultrasonic Residual Stress Measurement Method for On-Site Industrial Measurements
- Automatic Defect Classification Using Machine Learning and Computer Vision Techniques for Ultrasonically Acquired Data
- Artificial Intelligence for NDT Scanning of Unknown Geometries using Collaborative Robots
- Characterisation of Discontinuities with Advanced Ultrasonic Testing
- Development of Novel Ultrasonic Inspection Capability for Sizing of Rough Cracks

Structural Assessment

- Integrity in Aggressive Environments: Fatigue Crack Growth Behaviour of Steel in H_2S-Containing Environments
- Development of Advanced ECA Techniques for Engineering Structures
- Fracture Resistance Behaviour of Carbon Manganese Steel in Sour Environments
- Development of ECA Methodology for Polyethylene Using µCT to Assess Suitability of Accelerated Test Methods that Generate Slow Cracks
- Fatigue Strength of Large Bolts
- Integrating Diverse Approaches to Reliability of Engineering Structures
- Investigation of Corrosion Fatigue of Offshore Wind Substructures