Corrosion of AM components – Dstl-funded PhD Projects

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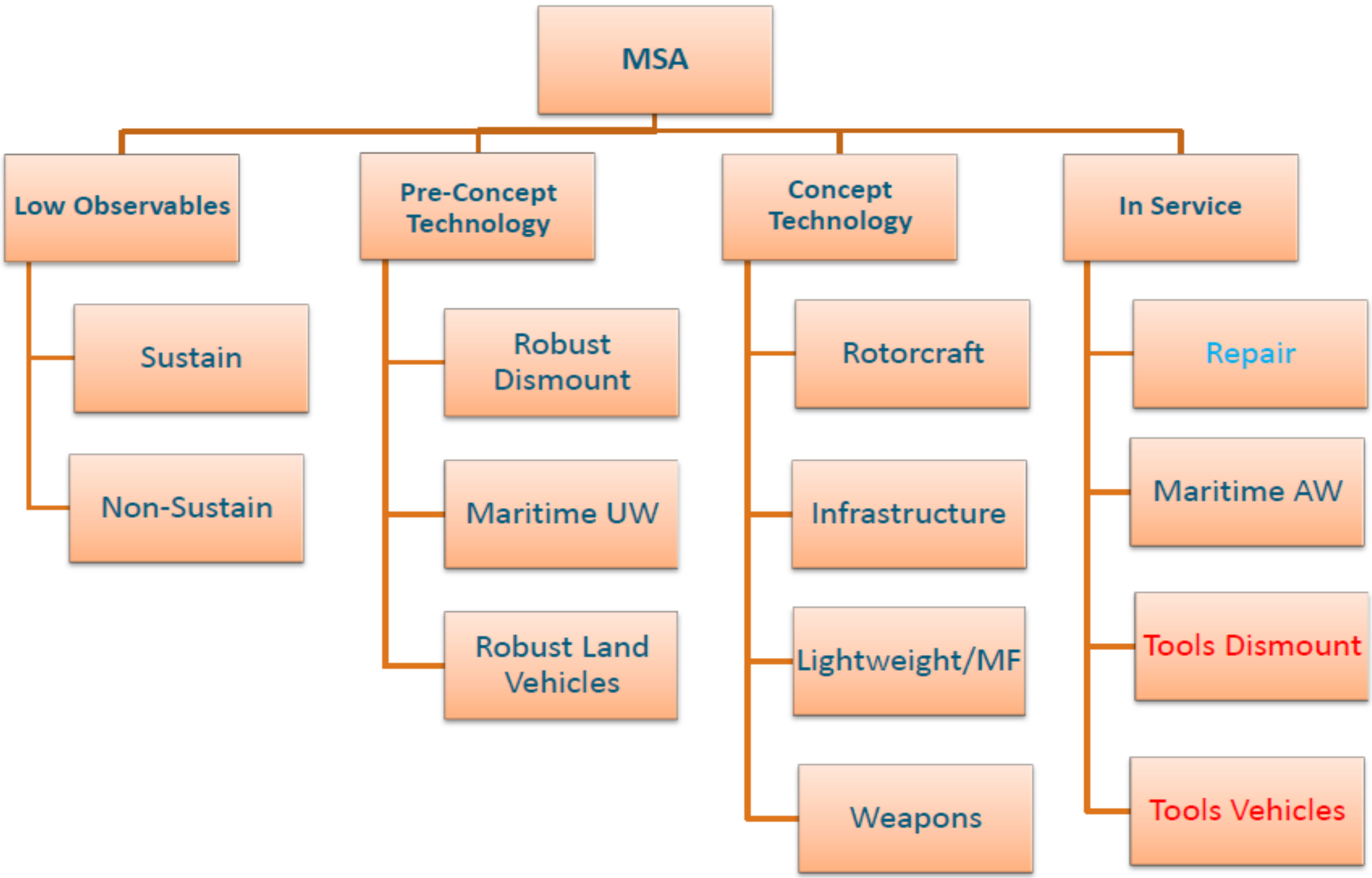
Dstl

Materials for Strategic Advantage Programme (MSA)

ARL MEDE

- One of 24 Dstl-led Programmes funded by the MOD Chief Scientific Adviser
- Aim: *'to exploit global developments and innovation in materials and structures science for UK defence and security'*
- Funds research in materials and structures across all operating environments, but focused on innovation
- 80% spent on Extra Mural Research through large supplier base.
- Seed the S&T pipeline for Materials and Structures for defence and security applications

MSA Programme Structure



Maritime Materials Requirements

Above Water	Below Water
Part of In-service Theme	Part of Pre-concept Theme
Materials S&T to address range of operational challenges	Materials S&T that will influence the design of Next-Gen Submarines
Cost of ownership and platform availability key drivers	Disruptive technology and new approaches are focuses of research

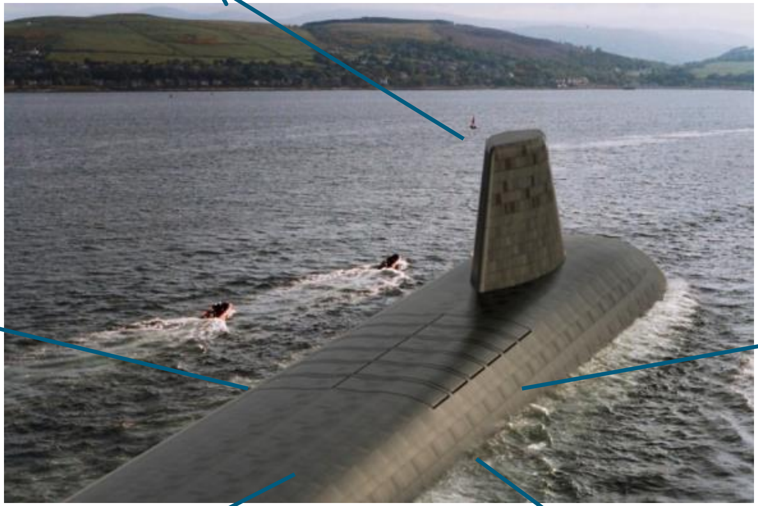
"Provide research into the design and invention of new materials and advances in structure design to support maritime survivability and availability. Solutions must consider the short, medium and long-term impact upon supply chains, manufacture and through life support (time and cost), systems and sub-system integration, and external drivers such as environmental legislation."

Above- and Below-Water Requirement Outline

Materials for Strategic Advantage - Below Water Requirement

Advanced Manufacturing

Affordable Ti



Advanced Hull Anti-Fouling

Managing Inaccessible Spaces

Marine Growth Prevention

Maritime Materials Priority Areas

- Overcoming blockers to material insertion to allow the Royal Navy (RN) to take advantage of the latest developments and opportunities
- Changing the way vessels are maintained, moving towards condition-based maintenance and extended forward-deployed periods
- Ensuring MOD has robust responses to external drivers (environmental regulations, operational changes, new standards)

MSA - Corrosion of AM Research

- Interested in understanding the response of AM metallic components to maritime environment
- PhDs funded with Surrey, Swansea and Birmingham Universities as first steps in investigations
- Engagement with other nations planned to utilise relevant work already carried out and identify potential for collaboration

Surrey PhD: WAAM of Submarine Steel

- Led by University of Surrey Metallic Materials team
  - Active in metallurgy of AM samples and development of titanium matrix composites
  - In partnership with wire feedstock supplier to create wires compositions for wider range of alloys
- Project will examine the suitability of Wire Arc AM to deposit submarine-grade steels
  - Initial focus will be corrosion susceptibility of deposited samples, but mechanical testing may also be considered in later work

University of Surrey

Ministry of Defence

WAAM Corrosion - Work Plan

Work Package 1: Production of WAAM Steel Samples

- Develop a powder composition (with Corewire Ltd) that produces WAAM samples matching conventional submarine steels
- Investigate the potential to introduce a compositionally graded surface to improve corrosion performance

Work Package 2: Microstructural Evaluation

- Compare microstructure of conventional, as-deposited and heat treated WAAM samples

Work Package 3: Corrosion Investigation

- Study localised corrosion due to the morphological and chemical variations of WAAM samples from wrought
- Assess the overall corrosion performance of the samples compared to conventional manufacture, including effect of heat treatment

WAAM Corrosion - Progress

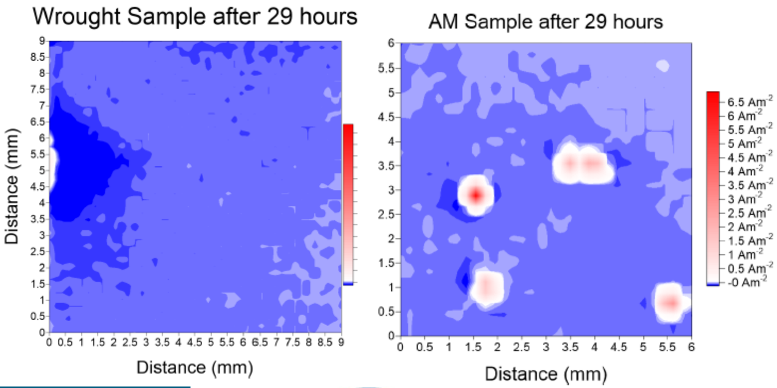
- Initial HY100 WAAM samples have been produced
  - Composition close to spec.
    Matching C, slightly higher Mn & Cr, lower Ni
- New powder composition being formulated to closer match wrought specification
- Microstructural analysis and SKEP being carried out
- Comparison to conventionally manufactured steels to be carried out

Swansea PhD: AM Impact on Corrosion Performance

- Led by Swansea University Corrosion and AM teams
  - Specialise in electrochemical and microstructural corrosion characterisation, and powder bed laser fusion of novel metal powders respectively
- Project aims to study the impact of LPBF build parameters on corrosion performance
  - Post-processing (inc. HIP) to also be examined
  - Initial build of Invar complete, future builds to examine alloys of increasing complexity

AM Impact on Corrosion Performance - Progress

- Utilising Scanning Vibration Electrode Technique (SVET) to map anodic regions and galvanic effects
- Time lapsed microscopy also being used to observe the formation of pits for immersed coupons
- Currently discussing alloys of most defence interest and corrosion mechanisms to study



Birmingham PhD: Improving Design of AM builds

- Led by the University of Birmingham Materials and Processes Modelling team
  - Interested in the relationship between manufacturing processes, microstructures and mechanical properties
- Two projects looking at improving the fatigue- and SCC-resistance of Ti64 produced by AM techniques
- SCC Project has recently secured student and commenced work

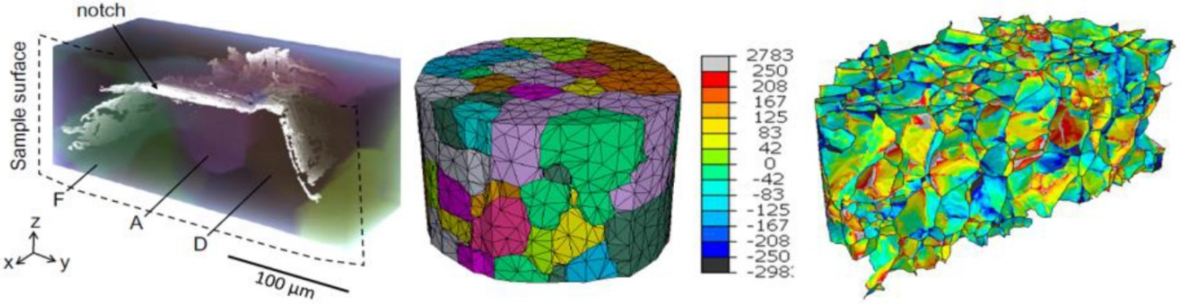
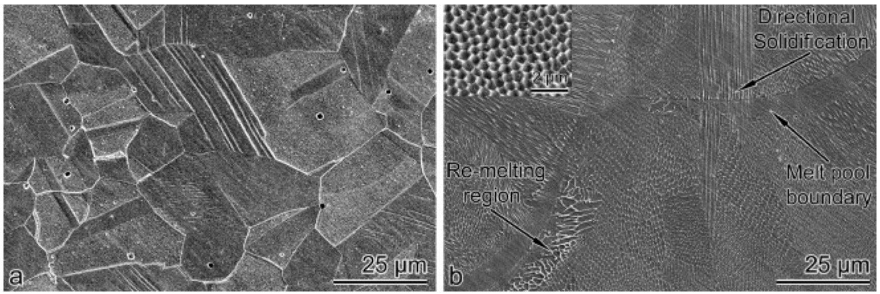


Figure 1. In-situ crack in a microstructure using synchrotron diffraction (left), image-based model of a reconstructed microstructure (centre) and predicted stresses at the grain boundaries (right) [6,7,10]

TTCP Study Assignment

Corrosion of Additively Manufactured Parts

TP-13 SA13.9



Micrographs of etched 316L from (a) wrought, (b) powder bed fusion AM (*Lodhi et al. (2018) Materialia, 2, 111-121)*

Objectives

- Summarise current understanding of how variance in AM build parameters will impact corrosion performance of relevant materials.
- Identify the failure mechanisms (e.g. SCC, corrosion fatigue, pitting) that are of greatest concern and their relationship to AM processes.
- Work with the AM COI to disseminate findings of interest to other TTCP panels.
- If significant gaps are identified in understanding, develop an activity plan for a Collaborative Project.

Defence Significance

When compared to studies of mechanical properties, the corrosion performance of metals produced using Additive Manufacture has yet to be studied in any great depth. Features linked to AM processes including porosity, residual stresses, grain structure variations, surface roughness will have a significant impact on a components performance when exposed to real-world operating conditions. Initial results seen thus far have shown showing a potential for both improved and diminished corrosion performance from AM techniques, therefore is it important for to understand how a given manufacture process will impact the corrosion performance of specific materials of interest. A review is necessary to:

- Identify the current understanding of how build parameters can be optimised with respect to corrosion performance.
- Consider the impact of post-processing on material properties and potential impact on corrosion performance.

Collaboration

W Neil (AUS), C Munroe (CAN), B Withy (NZ), J Plummer (UK), M Benedict (US)

Cross-TTCP links

AER TP13, MAT TP11, AM COI

Objectives

Review national AM approaches for additive manufacturing to agree techniques and materials of interest.
Review of relevant activities within TTCP community
Review current knowledge and understanding of corrosion performance for techniques and materials identified
Assessment of priorities for collaboration
CP Activity Plan