TR21522 Corrosion Testing for Additive Manufacturing

AMPP™

Background

A gap was identified in global specifications; existing specifications did not address corrosion related issues with respect to Additive Manufacturing.

A decision was made at AMPP to address the gap and form a work group that was to prepare a report that describes the AM attributes that have strong effects on performance as related to corrosion associated failure degradation mechanisms and ways to measure this performance that were specific to AM.

Goals

Will identify corrosion failure mechanisms that are affected by AM.

Will identify the AM attributes that affect the corrosion mechanism.

Will identify tests that measure performance by corrosion mechanism.

Will provide guidance on test details/examinations to better assess performance.

Will identify gaps in where current test/examination details are not suitable for AM.

Scope

Create a technical report that presents current state of knowledge and gap analysis on corrosion testing of metallic materials relevant for oil and gas applications for additive manufacturing via primarily laser powder bed fusion (LPBF) and wire arc additive manufacturing (WAAM). Many variables may not be sufficiently detailed at this time for the assessment of performance of AM products; some variables such as microstructure, post build processing, surface condition, residual stress, physical defects and selection of representative test specimens (size and/or geometry) for a finished product are addressed. This report contains recommendations for an approach for corrosion and environmental cracking assessment of AM material, including test details that are relevant to the AM processes for some specific cases. The technical report provides the foundation for the preparation of test standard(s) that apply to AM products.

Subteams

- Leaders and corrosion mechanism
  - Elizabeth Trillo (SwRI) – Corrosion
  - Liu Cao (DNV) - Corrosion Fatigue
  - Mark Yunovich (Shell) – Environmental cracking SSC/SCC
  - Bill Kovacs (DNV) - Hydrogen related HISC, HIC, SWC
  - Luciana Intiso (RINA CSM) – High temperature oxidation
- Report components
  - Access to literature sources among members
  - Noted important links between AM process variables & corrosion related mechanism
  - Testing performed related to AM details & mechanism

Report index (preliminary)

INDEX

Scope

Introduction (description of processes covered and mechanisms considered?)

Current knowledge of AM variables that effect corrosion and testing results

- Corrosion (general & localized)
- Corrosion fatigue (applying what we know of fatigue with respect to AM to corrosion fatigue)
- Environmental cracking (SSC & SCC)
- Hydrogen associated (HISC, SWC, HIC)
- High temperature oxidation

Links between AM variables and performance

Corrosion Threat Assessment for AM Products

Guidance on applying existing standards to assess performance

Gap analysis; need for more variable cause effect data and test methods

Progress

Where are we?

Identified about 250 literature sources that were relevant to our charge. Started the review process and categorized by mechanism, material and relevance.

We have determined some of the key factors that relate to the corrosion mechanisms and have listed them in our Scope.

Test – Inspection details (preliminary)

- Selection and condition of test specimens used to assess resistance to the associated corrosion mechanisms
- Relevance of test specimen to component
- Surface inspection including residual stress (non-destructive)
- Process & component inspection/test relationship
- NDE versus destructive tests

Progress

A	B	C	D	E	F	G	H	I
Subgroup	**relevance**	**corrosion mechanisms**	**material class**	**AM process**	**AM variables investigated**	**corrosion tests**	**paper access**	**link to paper or abstract**
Corrosion	3	corrosion	CoCr	laser powder bed fusion	microstructure	boiling acids	AMPP/NACE	
Corrosion	2	corrosion	Austenitic SS	DED - wire arc	surface condition, microstructure	echem FeCl3	AMPP/NACE	
Corrosion	2	corrosion & SSC-SCC-HISC	Ni base	laser powder bed fusion		SSRT & echem	AMPP/NACE	
Corrosion	2	corros & fatigue & SCC-HISC	Ni base	laser powder bed fusion		SCC, echem, fatigue	AMPP/NACE	
Corrosion	not read	corrosion	Al base	laser powder bed fusion	surface roughness	fatigue	Science Direct	Effect of surface roughr
Corrosion	not read	corrosion	stainless steels	PBF & DED	microstructure	echem	Science Direct	Corrosion performance
Fatigue	not read	corrosion & fatigue	other multiples	laser powder bed fusion	surface roughness, microstructure, defects		TMS Journal	
HISC-SWC	not read	corrosion & SSC-SCC-HISC	Ti base	laser powder bed fusion	strain rate, wrought vs. AM	SSRT, Corrosion, microstructure	Science Direct	https://doi.org/10.1016/
Oxidation	not read	oxidation	Ni base	laser powder bed fusion	microstructure	oxidation	Science Direct	https://doi.org/10.1016/
Oxidation	not read	oxidation	Ni base	laser powder bed fusion	microstructure	oxidation	Science Direct	https://doi.org/10.1016/
SCC/SSC	not read	corrosion & SSC-SCC-HISC	Precip hard SS	laser powder bed fusion	orientation	SSC method A	AMPP/NACE	

Progress

A comparative study of microstructure and hydrogen embrittlement of selective laser melted and wrought 17-4PH stainless steel
Michella Alnaijar et al, Mat Sci & Engin A, 785 (2020) 139363

- Material - UNS S17400
- Process - Power Bed Fusion (PBF) via SLM (Selective Laser Melting)
- Condition - HT - SA 1050°C 1h then ageing 580°C 4h
- Corrosion testing – SSRT charging, echem H permeation
- Other testing – tensile, SEM/EDS, metallography
- Relevant AM attributes related to performance – grain size, microstructure
- Gap AM vs wrought – relevant AM attributes above
- Key takeaway(s) – lower ferrite in AM; lower SSC resist in AM; H perm 3X greater in AM – due to Cu rich ppts

Investigation of Additive Manufacturing of Components for the Oil & Gas Industry
Felix Hiebler Master's Thesis Montan Universität Leoben June 2020

- Material - UNS S17400
- Process - Power Bed Fusion (PBF) via SLM (Selective Laser Melting)
- Condition - HT - SA 1040°C 45min then PH 480°C 1h
- Corrosion testing - sulfide stress cracking, HIC

  Other testing – tensile, Charpy V-notch, hardness, metallography

  Relevant AM attributes related to performance – residual stress, porosity, heat treat condition

  Gap AM vs wrought – relevant AM attributes above

  Key takeaway(s) – characterization of porosity via several methods

Timeline

- January 2022 – completion of ranking (relevance) of literature and assignments for review
- March 2022 – completion of literature review
- May 2022 - analysis of literature, compilation of gems relevant to our report. Finalization of index and scope.
- June 2022 – draft teams assembled and assignments defined for drafting text.
- September 2022 – compilation and review of text sections
- October 2022 – circulation of initial draft report in Committee
- November 2022 – final review and preparation of final draft report.
- December 2022 - circulation and vote of final draft report to AMPP SC08.