

## SSC Project Recommendation for FY 2021

### **Localized Weld Repair of Fatigue-Cracked and/or Corrosion-Damaged Aluminum Structures**

#### **1.0 OBJECTIVE.**

- 1.1 This project is designed to develop localized low-heat-input weld repair techniques for aluminum vessel structures, where fatigue-cracked and corrosion-damaged aluminum components are repaired by employing a weld cladding process. Preliminary performance evaluation will be accomplished to demonstrate the effectiveness of the weld repair technique.

#### **2.0 BACKGROUND.**

- 2.1 Ship and vessel light weighting has been an important issue for meeting the design goals and reaching high performance. Aluminum has been used for the deckhouse structures of US Navy combatant and amphibious ships for decades, and it is estimated that about fifty percent of new-build U.S. Navy ships will be either all aluminum or with aluminum deckhouse [8.1].
- 2.2 The aluminum alloys used for these kinds of marine applications are often limited to 5xxx- and 6xxx-series aluminum alloys in principal product forms of plates and extrusions [8.2]. While 6xxx-series alloys are easier to be extruded, less expensive, more versatile, and heat-treatable, their application is limited to structures not in direct contact with seawater due to the concerns about their corrosion resistance. As to 5xxx-series alloys, solid solution strengthening and work hardening are the main strengthening mechanisms, and the alloys are not heat-treatable.
- 2.3 These aluminum alloys are prone to fatigue degradation; serious cracking has been observed in the aluminum structures [8.3, 8.4], which will be further aggravated in seawater due to corrosion fatigue. 5xxx-series alloys are noted for their good resistance to general corrosion, and unpainted structures of them have been deployed at locations exposed to seawater; nevertheless, these alloys are prone to sensitization under elevated temperature above 65°C for extended periods of time. Under such conditions,  $Mg_3Al_2$  precipitates may form along the grain boundaries, and acts anodically as compared to the aluminum matrix [8.5]; this can lead to stress corrosion cracking (SCC), intergranular corrosion, and/or exfoliation.
- 2.4 For aluminum structures subjected to fatigue cracking or SCC, temporary or permanent repair is needed [8.3, 8.4]. As far as permanent repair is concerned, weld repair after localized crack removal and/or welding of small and large insert plate after removal of cracked base material are reported. Recently, a localized thermal process was introduced to reverse a sensitized plate back to its stable state [8.6, 8.7].
- 2.5 In the cases where local fatigue surface crack clusters exist or where local sensitization has resulted in serious intergranular corrosion or SCC, plate removal and insert welding may be a choice for repair, but may not always be economically competitive; furthermore, local thermal desensitization is insufficient to reconcile these surface damages.
- 2.6 One further issue is the high heat-input normally associated with the traditional arc welding, which can cause some serious negative effects on the aluminum vessel structures. This problem can be addressed by employing low-heat-input GMAW techniques that has been developed recently. Cold metal transfer (CMT) technique is such a process enabling an extremely low heat input during welding/cladding.
- 2.7 That being said, this project is proposed to develop localized low-heat-input processes for weld repair of fatigue-cracked and corrosion-damaged aluminum structures by employing a weld cladding process, and to conduct preliminary performance evaluation of weld-repaired aluminum components.

### **3.0 REQUIREMENTS.**

#### 3.1 Scope.

- 3.1.1 The Contractor shall conduct a brief assessment of repair techniques with a focus on welding-related repair methods.
- 3.1.2 The contractor shall develop techniques for localized repair of fatigue surface-cracked and corrosion-damaged aluminum plates/components.
- 3.1.3 The contractor shall perform metallographic characterization and initial performance evaluation to demonstrate the effectiveness of the localized weld repair techniques developed.

#### 3.2 Tasks.

- 3.2.1 The Contractor shall conduct a brief literature review and assessment of various repair techniques, with a focus on welding-related repair methodologies.
- 3.2.2 The Contractor shall develop a concept for localized repair of fatigue surface-cracked and/or corrosion-damaged aluminum plates/components based on a weld cladding process.
- 3.2.3 The contractor shall develop single and/or multi-layer weld cladding processes on non-sensitized and sensitized aluminum alloys.
- 3.2.4 The contractor shall perform metallographic characterization of non-sensitized and sensitized aluminum alloys before and after weld cladding as well as of the claddings themselves.
- 3.2.5 The Contractor shall perform preliminary electrochemical corrosion evaluations in seawater on non-sensitized and sensitized specimens of selected Al-alloy plates before and after weld cladding, respectively.
- 3.2.6 The Contractor shall produce test specimens, which can represent the localized weld repair by weld cladding, for preliminary evaluations of their respective fatigue, corrosion fatigue, and SCC behavior.
- 3.2.7 The Contractor shall develop an experimental scheme for S-N fatigue testing in air and in sea water, and generate initial fatigue and corrosion fatigue data using specimens representing the base metal and the weld repaired areas.
- 3.2.8 The Contractor shall perform slow strain rate testing in seawater on specimens of base metal and with weld cladding, respectively, enabling an initial assessment of their respective SCC behavior.
- 3.2.9 The Contractor shall analyze the resultant results and outcomes, and provide quarterly progress reports and a print ready master final report as detailed in Section 5.0.

#### 3.3 Project Timeline.

The project will be started once the contract is awarded, and the execution will follow the timeline below:

Task	Month from Project Initiation																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18				
3.2.1	█																					
3.2.2		█																				
3.2.3			█																			
3.2.4				█																		
3.2.5					█																	
3.2.6						█																
3.2.7								█														
3.2.8										█												
3.2.9			◆			◆			◆			◆			◆	█						

**4.0 GOVERNMENT FURNISHED INFORMATION.**

4.1 Standards for the Preparation and Publication of SSC Technical Reports.

**5.0 DELIVERY REQUIREMENTS.**

5.1 The Contractor shall provide quarterly progress reports to the Project Technical Committee, the Ship Structure Committee Executive Director, and the Contract Specialist.

5.2 The Contractor shall provide a print ready master final report and an electronic copy, including the above deliverables, formatted as per the SSC Report Style Manual as posted on the website <http://www.shipstructure.org>.

**6.0 PERIOD OF PERFORMANCE.**

6.1 Project Initiation Date: date of award.

6.2 Project Completion Date: 18 months from the date of award.

**7.0 GOVERNMENT ESTIMATE.** These contractor direct costs are based on previous project participation expenses.

7.1 Project Duration: 18 months.

7.2 Total Estimate: US\$125,000.00

7.3 The Independent Government Cost Estimate is not attached to this document; detailed cost estimation can be submitted upon request if the project proposal could be endorsed.

**8.0 REFERENCES.**

8.1 R. A. Sielski, K. Nahshon, L. W. Salvino, K. Anderson, and R. Dow, “The ONR Ship Structural Reliability Program”, Naval Engineers Journal, 125 (2013) 61-84.

8.2 R. A. Sielski, “Review of Structural Design of Aluminum Ships and Craft”, 2007 (<http://www.sname.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=cd63b47b-b4e0-41d5-84f0-f2d879a1596e>).

- 8.3 R. A. Sielski, "Research Needs in Aluminum Structures", 10<sup>th</sup> International Symposium on Practical Design of Ships and Other Floating Structures, Houston, Texas, © 2007 American Bureau of Shipping.
- 8.4 R. Schwarting, G. Ebel, and T. J. Dorsch, "Manufacturing Techniques and Process Challenges with CG47 Class Ship Aluminum Superstructure Modernization and Repairs", 2011 (<https://admin.navalengineers.org/SiteCollectionDocuments/2011%20Proceedings%20Documents/FMMS2011/Papers/Schwarting.pdf>).
- 8.5 R. H. Jones, J. S. Vetrano, and C. F. Windisch Jr, "Stress Corrosion Cracking of Al-Mg and Mg-Al Alloys", Corrosion, 60 (2004) 1144-1154.
- 8.6 L Kramer, M Phillippi, WT Tack, and C Wong, "Locally reversing sensitization in 5xxx aluminum plate", Journal of Materials Engineering and Performance, 21 (2012) 1025-1029
- 8.7 R.-Y. Chen and C.-C. Lai, Reversing Sensitization of Naturally Exfoliated 5456-H116 Aluminum Alloys", Journal of Marine Science and Technology, 22 (2014) 450-454

## **9.0 SUGGESTED CONTRACTING STRATEGY.**

- 9.1 It is suggested that the project be executed by a research team at NRC-Vancouver, which is well equipped with welding/joining as well as materials testing and characterization facilities, including a robotic welding (or cladding) system with CMT capability; mechanical testing systems, such as a servo-hydraulic MTS mechanical testing system integrated with an environmental chamber and with corrosion cells; electrochemical corrosion evaluation cells and capacities; and metallographic/materials characterization capacities, such as a XRD and optical and scanning electron microscopes.