**SSC Project Recommendation for FY 2021**

# Strength of Welded Aluminum in Tension

## 1.0 OBJECTIVE.

1.1 This project will develop a more rational method for designing aluminum ship structures using the material characteristics of base metal, the heat-affected zone of welds, and weld metal.

## 2.0 BACKGROUND.

2.1 Aluminum structures offer potential structural weight-savings of up to 50% for many marine vehicles, thereby reducing fuel consumption and improving economics in many time-sensitive or draft-limited applications.

2.2 A key challenge in designing aluminum structures is dealing with the under-matched fusion welds used to assemble the structure. Unlike most steels, marine aluminum alloys suffer a reduction in strength in the heat affected zone (HAZ) of welds reaching as much as 50 percent of the strength of the prime material. Ship Structure Committee project SR-1476, Experimental Quantification of the Tensile Strength and Ductility of Under-Matched Aluminum Welds, has made an initial look at this problem by looking at non-load carrying fillet welds. This work needs to be expanded to experimentally determine the strength of larger structures, comparing the measured strength with analysis that includes the material characteristics of base metal, the heat-affected zone of welds, and weld metal.

2.3 The traditional approach to design has been to use the minimum strength of the HAZ as the design strength and treat the structure as monolithic. This approach may seriously underestimate the strength of welded structure while overestimating its ductility and energy absorption capabilities. Marine structures have many unique topologies of under-matched weld regions under tension, including stiffener to transverse frame joints, watertight bulkhead connections, and load-carrying fillet welds at the end of complex hollow-core extrusions. These complex topologies significantly exceed what was explored by simplified methods in previous work (Collette 2007; Collette 2011) .

2.4 While the marine industry has extensively explored compressive strength design methods for aluminum (Benson, Downes, and Dow 2011; J. Paik et al. 2005; J. Paik 2009; J. Paik et al. 2007; Rigo et al. 2003), tensile design methods have been comparatively ignored. The inability to efficiently predict the strength and ductility of tensile connections has serious implications to using modern limit-state design to develop lightweight aluminum structures. Progressive collapse methods such as the Smith method require the prediction of both the load-shortening and load-extension curves of structural elements, yet we lack any realistic way of predicting the load-extension curve for welded aluminum structures. Direct application of finite element methods has proven to be a difficult approach requiring mesh discretization much smaller than the plate thickness (Wang et al. 2007; Dørum et al. 2010). Furthermore, custom element enrichment is required if shell elements are going to be used in the model. Such techniques are not yet practical outside of academic research groups or specialized consultancies. The techniques developed to date have only been validated on the types of details common to civil engineering structures. Thus, the marine structural engineer currently lacks practical tools and experimental data to design structures with the impact of under-matched welds fully accounted for.

2.5 The current methods used for design of aluminum structures are based on the strength of welded tension specimens. Formerly, specimens with a 250-mm (10-inch) gauge length were used to define the tensile strength of various welded aluminum alloys, generally resulting in a 25 to 30 percent reduction in yield strength from the base metal. Structural design practice and specifications evolved around these properties. In recent years, welded yield strength of new alloys has been measured using 50-mm (2 inch) gauge length specimens, which show yield strength to be as low as

50 percent of the strength of base metal. Design codes and standards have not evolved to reflect these differences.

2.6 This project addresses the focus area of Novel Materials and Manufacturing.

## 3.0 <u>REQUIREMENTS</u>.

3.1 Scope.

3.1.1 The Contractor shall conduct a literature review of existing experiments and modeling techniques for the strength of under-matched aluminum welds.

3.1.2 The Contractor shall examine simplified finite element analysis modeling procedures for such welded aluminum joints, including relations between weld parameters and the material properties. Simplified models such as cohesive zones should also be explored. To be able to predict the response of such joints during design, a database of likely material properties throughout the heat-affected zone with different weld parameters shall also be developed.

3.1.3 The Contractor shall explore other types of tensile limit states for welded aluminum structures. While direct tension of the heat affected zone was shown in the work of SR-1476 to be critical, there are other types of connections that are also worth investigating. Load-carry fillet welds for double-sided extrusions are one example, and more complex stiffener-frame intersections shall also be explored.

3.1.4 Parametric studies of the performance of such joints with validated numerical models to help validate existing design approaches shall be made. A careful relation between the response of the joint and the assumed material parameters is essential. This would help remove the confusion arising from the use of different gauge lengths for setting heat-affected zone material properties in existing regulations.

3.1.5 The Contractor shall design and fabricate a test specimen representative of the joints analyzed. The specimen may be loaded either laterally or in direct tension, but with the critical areas in tension. The geometry and loading of the specimen shall be approved by the SSC Project Technical Committee for this project. A minimum of three specimens shall be fabricated.

3.1.6 The Contractor shall test these specimens until failure, recording relevant strains, stresses, and the evolution of failure for validating future modeling approaches.

3.1.7 The Contractor shall document the results of the project in a report.

3.2 Tasks.

3.2.1 The Contractor shall review the literature to determine previous studies on aluminum welds in tension for marine-grade alloys, typical marine structural connection details, and experimental procedures for conducting tests on assemblies with under-matched welds.

3.2.2 The Contractor shall examine simplified finite element analysis modeling procedures for such welded aluminum joints, including relations between weld parameters and the material properties. Simplified models such as cohesive zones should also be explored. To be able to predict the response of such joints during design, a database of likely material properties throughout the heat-affected zone with different weld parameters shall also be developed. In this task, the Contractor shall also explore other types of tensile limit states for welded aluminum structures. While direct tension of the heat affected zone was shown in the work of SR-1476 to be critical, there are other types of connections that are also worth investigating. Load-carry fillet welds for double-sided extrusions are one example, and more complex stiffener-frame intersections shall also be explored.

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3.2.6 The Contractor shall prepare a final report to discuss and analyze the results and their implications for current and future marine design standards and limit state approaches.

3.3 Project Timeline.

*Table 1. Proposed project timeline*

| Task | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Task 1: Literature review | X | X | X | X | | | | | | | | |
| Task 2: FE analysis | | X | X | X | X | X | | | | | | |
| Task 3: Parametric studies | | | X | X | X | X | | | | | | |
| Task 4: Specimen design | | | X | X | | | | | | | | |
| Task 5: Fabrication and testing | | | | | X | X | X | X | X | X | | |
| Task 6: Analysis and report preparation | | | | | | | | | | X | X | X |

## 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.

5.3 The Contractor shall provide validation data from the experiments in digital form for archiving on the Ship Structure Committee website

## 6.0 PERIOD OF PERFORMANCE.

6.1 Project Initiation Date: date of award.

6.2 Project Completion Date: 12 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: 12 months.

7.2 Total Estimate: $100,000.

## 8.0 REFERENCES.


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Chan, T., and R. Porter Goff. 2000. "Welded Aluminium Alloy Connections: a Simplified Plastic Model." *Proceedings of the Institution of Civil Engineers. Structures and Buildings* 140 (May): 161–168.

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Wang, T., O.S. Hopperstad, O.-G. Lademo, and P.K. Larsen. 2007. "Finite Element Modelling of Welded Aluminium Members Subjected to Four-point Bending." *Thin-Walled Structures* 45 (3): 307–320.