SSC Project Recommendation for FY 2007

Ultimate Strength and Optimization of Aluminum Extrusions

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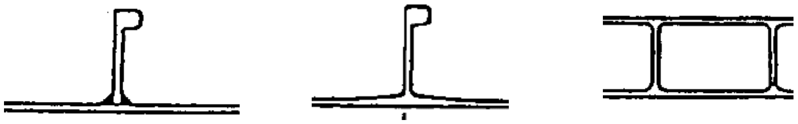
1.0 OBJECTIVE

The objective of this study is to develop and document ultimate strength methods for panels composed of complex extruded aluminum profiles, and to demonstrate potential weight-savings gained by using these profiles in place of conventional stiffened panel through an optimization procedure applied to representative stiffened panels.

2.0 BACKGROUND

The current commercial and military interest in large high-speed vessels has resulted in the development of monohulls, catamarans, and trimarans designs between 70m and 130m in length for transportation and combat roles. Minimization of lightship weight, and hence structural weight, is of great significance in the design of the vessels. Most of the vessels in this category have been constructed out of aluminum to reduce structural weight. In addition to being a lighter material than steel, aluminum is marked by its ability to be extruded into custom profiles very economically (Kissell and Ferry 2002). This ability gives the designer the freedom to replace convention plate and welded-stiffener panels with extrusion where the plate thickness may be varied, or where the plate and stiffener construction may be replaced by a sandwich-type structures (see Figure 1). Such extrusions can be used economically on large flat deck structures, such as cargo and passenger decks, cross-decks for multi-hull vessels, and the side shell above the waterline. Such extrusions offer the possibility of weight savings, along with easier welding and reduced complexity of the resulting structure.



Conventional construction **Variable plate thickness extrusion** **Sandwich-type extrusion**

Figure 1: Potential Extrusion Cross-Sections (after Matsuoka et al 1997)

To optimize the design of high-speed vessel structures, ultimate limit state design is the preferred approach. Using limit-state design to calculate the loads at which the structure will actually fail in service, a more rational risk assessment and comparisons of alternatives can be made in the optimization process. At the present time, ultimate strength methods are only available for conventional plate-and-welded stiffener panels in aluminum (Paik et. al 2004, Collette 2005, Wang et. al 2005), the more complex yet potentially more efficient designs possible by extruded aluminum cannot easily be considered. The goal of this project is to start to develop and document such procedures, and use an optimization approach to investigate if such extruded profiles do result in lighter structures.

3.0 REQUIREMENTS

3.1 Scope

3.1.1 The contractors shall document and apply ultimate strength methods to individual aluminum plate components of both constant and variable thickness under in-plane and lateral loads. Both simplified methods and numerical simulation procedures shall be considered. Loading shall consist of longitudinal and transverse compression, and uniformly-distributed lateral loads. The effect of heat affected zones from welding will be considered at the plate boundaries alone.

3.1.2 The contractors shall document and apply ultimate strength methods to assemblies of aluminum plates components, included the three categories of cross-sections show in Figure 1. A representative panel size between transverse frames and longitudinal girders shall be assumed, the modeling of this supporting structure will be excluded from the current study. Prediction method and applied loads shall be as the above task

3.1.3 The contractors shall develop an optimization procedure capable of optimizing panels of the types shown in Figure 1 considering achieved strength for in-plane and lateral loads and panel weight.

3.1.4 The contractors shall apply the ultimate strength and optimization procedures to two sample panels, one with in-plane loading dominant and one with lateral loading dominant. The performance of the three types of panels shown in Figure 1 will be compared.

3.2 Tasks

3.2.1 *Survey of existing plate components methodologies:* Existing ultimate strength prediction methods for individual aluminum plate components will be documented and reviewed, including simple formula and more advance numeric techniques such as finite element analysis. Emphasis will be placed on techniques which can predict strength to resist in-plane and lateral loads. Both linear methods and non-linear methods will be investigated. Information about the manufacturing producability of each type of extrusion will be reviewed. A section of the final report will be produced covering the methods reviewed. SAIC will research and compile the initial list of methods to be investigated, ABS will review this list and suggest any additional methods currently in use in classification or research for comparison.

3.2.2 *Comparison of plate component methodologies:* A comparison between the promising aluminum plate strength methodologies will be made for a group of sample plate components, of both constant and variable thickness. Where possible, methods will be verified against experimental results. Conclusion about the validity of the methods and the effect of variable thickness will be drawn. Special attention will be paid to the effect of transverse heat-affected zones at the plate boundaries. A section of the final report will be produced covering the results of the comparison. SAIC will be responsible for performing the majority of the analysis with the chosen methods and documenting the results, ABS will review the results and suggest improvements to the methods, and potentially apply existing methods used in-house for classification if these have been selected in 3.2.1.

3.2.3 *Survey of existing assembly of plate component methodologies:* Existing ultimate strength formula for assemblies of individual plate components will be documented and reviewed. The ability to handle the effects of local buckling, overall buckling, and interaction effects will be noted. Extrusion guidelines will be reviewed for producing complex hollow profiles. A section of the final report will be produced covering the methods reviewed. SAIC will research and compile the initial list of methods to be investigated, ABS will review this list and suggest methods currently in use in classification for comparison.

3.2.4 *Comparison of existing plate component methodologies:* A comparison between the existing methods for handling assemblies of aluminum plates will be made, using actual test data where possible (including the data from SR-1446 if available). The methods will be applied to each type of panel shown in Figure 1, and the validity and performance of each method will be assessed separately for each panel type. A section of the final report will be produced covering the methods reviewed. SAIC will be responsible for performing the majority of the analysis with the chosen methods and documenting the results, ABS will review the results and suggest improvements to the methods, and potentially apply existing methods used in-house for classification if these have been selected in 3.2.3.

3.2.5 *Design and implementation of optimization routine:* An optimization routine will be developed to optimize each type of panel shown in Figure 1. The corresponding problems will be formulated as multi-objective optimizations and appropriate design spaces, objectives and constraints will be identified. A genetic algorithm based optimization routine will be investigated and implemented that can be applied to a wide range of similar problems, including problems of increased complexity that may be required to look at the influence of extrusions on the overall structural design. Proper genetic coding strategy and genetic operators including selection, crossover and mutation will be developed. In addition, Design of Experiments (DoE) techniques will be investigated and utilized to create accurate response surface models to save computational efforts when necessary, such as in the case of using finite element methods for strength estimation. Pareto optimality will be provided for each type of panel as shown in Figure 1. SAIC will implement the optimization procedure using the methods developed in tasks 3.2.1-3.2.4 and link them with the optimizer via their in-house Envision integration software. ABS will help identify practical bounds on the optimization that may not be included in the strength model such as corrosion and stiffness requirements and review the optimization approach.

3.2.6 *Sample panel optimization:* The ultimate strength and optimization routine developed in the previous tasks will be applied to optimize two different types of panels. One will be a panel subjected primarily to in-plane loads with small applied lateral loads. The second will be a panel subjected primarily to lateral loads with smaller in-plane loads. For each panel, optimized designs for the three types of construction shown in Figure 1 will be determined, and the weight vs. structural performance compared. A section of the final report will be produced covering the optimization procedure. SAIC will be responsible for performing the sample panel analysis, ABS will help synthesize the hypothetical panel requirements including an acceptable range of panel dimensions and expected loading in service, based on their experience and rules for high-speed vessels.

3.2.7 *Report writing and review:* The report sections produced under the previous tasks will be integrated into a final report, which will be reviewed and revised as necessary. SAIC will write the report and provide it to ABS for review and comment, SAIC will revised the report and submit it to the SSC.

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.

6.0 PERIOD OF PERFORMANCE

6.1 Project Initiation Date: Date of contract award

6.2 Project Completion Date: Twelve months from date of contract award

7.0 TIME, COST, AND MAN-HOUR ESTIMATE

7.1 Project Duration: 12 months

7.2 Project effort: The total project effort is estimated at 900 hours.

7.3 Total cost: $ 114,800

8.0 REFERENCES

Collette, Matthew, 2005, Strength *and Reliability of Aluminium Stiffened Panels*, PhD Thesis, University of Newcastle, Department of Marine Science and Technology.

Kissell, J Randolph and Robert L Ferry, 2002, Aluminum Structures: A Guide to Their Specifications and Design, New York: John Wiley & Sons. Inc.

Matsuoka, K, et al., 1997, “Buckling Strength of A Lightened Aluminium Hull Structure”, *Welding International*, **11** (10), 765-773.

Paik, J.K, et al., 2004, "Considering aluminum welded panel structures for aerospace, marine and land-based applications: a comparison of ultimate compressive strength design methods", *Proceedings of PRADS'2004, 9th International Symposium on Practical Design of Ships and other Floating Structures*, Vol.2, 2004, pp.727-735.

Wang, Xiaozhi, et al., 2005, “Buckling and Ultimate Strength of Aluminum Plates and Stiffened Panels in Marine Structures”, *Proceedings of the Fifth International Forum on Aluminum Ships*, pp. 1-6.