

First Quarterly Status Report: SR-1457 Aluminum Extrusion Optimization

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Overview

The initial phase of work on SR-1457 has been proceeding smoothly and is on schedule. Task one has now been completed and the associated deliverables (draft and final project plans) passed to the USCG. Task two is also finished, and results are summarized below. Task three is now underway, and intermediate results are presented in this progress report. The project schedule, labor and costs are in line with the final project plan.

Technical Progress

Task One

The objective of task one was to complete the draft and final project plans. This task was completed on schedule, with the final work plan delivered to the USCG on October 12th, 2007.

Task Two

The objective of task two was survey plate strength methods for analysis in task three. During the kickoff meeting, the initial method list was reviewed and the PTC suggested the addition of the Navy DDS 100-4 as a method. During subsequent review of the DDS 100-4 method, it was apparent that this method is very similar to Faulkner's classic steel plate strength method (which itself forms part of the basis of the Wang, et al.[1] formulation). This method has now been included into the method list:

- **Aluminum Association Specification for Aluminum Structures**
- **Eurocode 9**
- **Kristensen Formulation**
- **Paik, Duran and Lee Formulation**
- **Wang et. al Formulation**
- **US Navy DDS 100-4**
- **Linear and Non-Linear Finite Element Analysis**

Background on the methods has been gathered for inclusion in the final report. Most methods are either straight regression fits to experimental data, or modifications of classical elastic buckling theories, dividing the plate's initial response into elastic and inelastic regions based on slenderness and modifying the strength in the inelastic region.

Methods for lateral loading were also reviewed; the ABS High-Speed Naval Craft Rules and Dr. Sielski's SR-1448 project contain methods for assessing laterally-loaded plates. In most ship-type panels, it is normally the panel beam behavior that is limiting for lateral

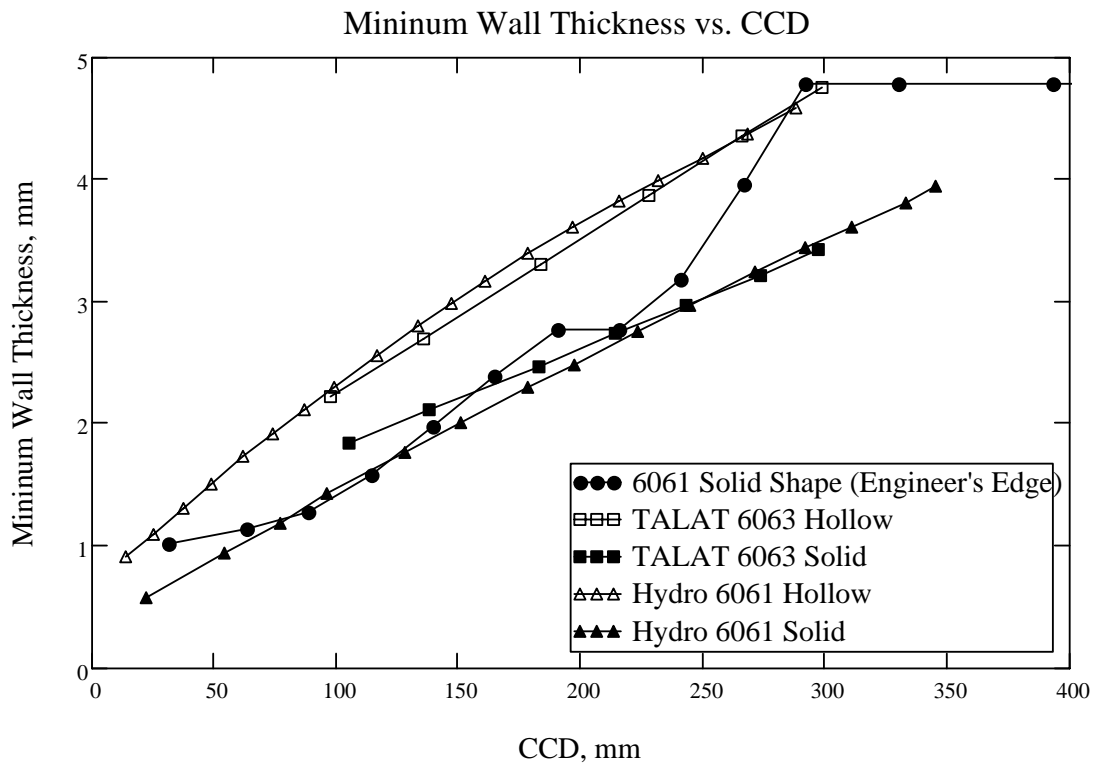
pressure loading, collapse or rupture of the individual plate elements from pure lateral loading rarely governing. The same is expected to be true for the aluminum panels investigated in this project.

Load interaction equations were also examined as part of task two, and will be compared in Task 3. Kristensen provided interaction equations based on his finite element results, while several “classical” interaction equations for metallic (not aluminum specific) structures have been found in marine literature and Galambos[2].

Limitations on extrusions dimensions were also explored as part of task two. These limitations will act as constraints on the optimizer in tasks six and seven. The following sources have been reviewed to date:

- Hydro Aluminum Extrusion Design Manual
- Aluminum Extruders Guide
- Dr. Sielski’s SSC Report
- Aluminum Extruders Council 2007-2008 buying guide
- EEA TALAT aluminum training material
- Internet search

It appears that the dominate restrictions that will need to be considered are a minimum thickness, based on the overall size of the die (circumscribing circle diameter or CCD). Several charts with minimum thicknesses have been found in the literature, and are plotted below on a single set of axis.



Reviewing the presses available in the U.S., it seems that 16"/406mm is a reasonable upper-bound on the extrusion circle, and hence the maximum stiffener spacing for the optimization in tasks six and seven. Many profiles will fit within a 12"/300mm circle, based on this, hollow shapes will be constricted to wall thickness of roughly 4mm-5mm, while solid shapes can have wall thickness of roughly 3mm. This data is higher than that reported in SR-1448, which noted that hollow deck panels may only have 2mm wall thickness in 6xxx-alloys, which seems to be supported by commercial experience. Some extruders can use special presses for these rectangular-shaped sections, which may be one of the reasons they can get thinner metal than a purely circular die. Further investigation into the extruding limitations will be made for the 6xxx series alloys. 5xxx series alloys are universally regarded as hard to extrude, with thin hollow shapes rarely attempted. SR-1448 suggests a lower limit of 4.6mm for 5083 extrusions; ALCAN can produce small profiles (50mm total height) with 3mm thickness in 5383, according to their extrusion dimension sheets.

An additional recommendation from the Aluminum Extruders Council (AEC) is to keep the ratio of the wall thickness of adjacent members of the cross section less than or equal to 2:1.

Task Three

The objective of task three is to compare the plate component methods performance to experimental data. At the current time, experimental data is limited to uniaxial compression test, though numerical simulation data for biaxial and lateral loading is being reviewed. The available experimental data has been digitized, and the comparison of promising methods to experimental data has begun.

Experimental data

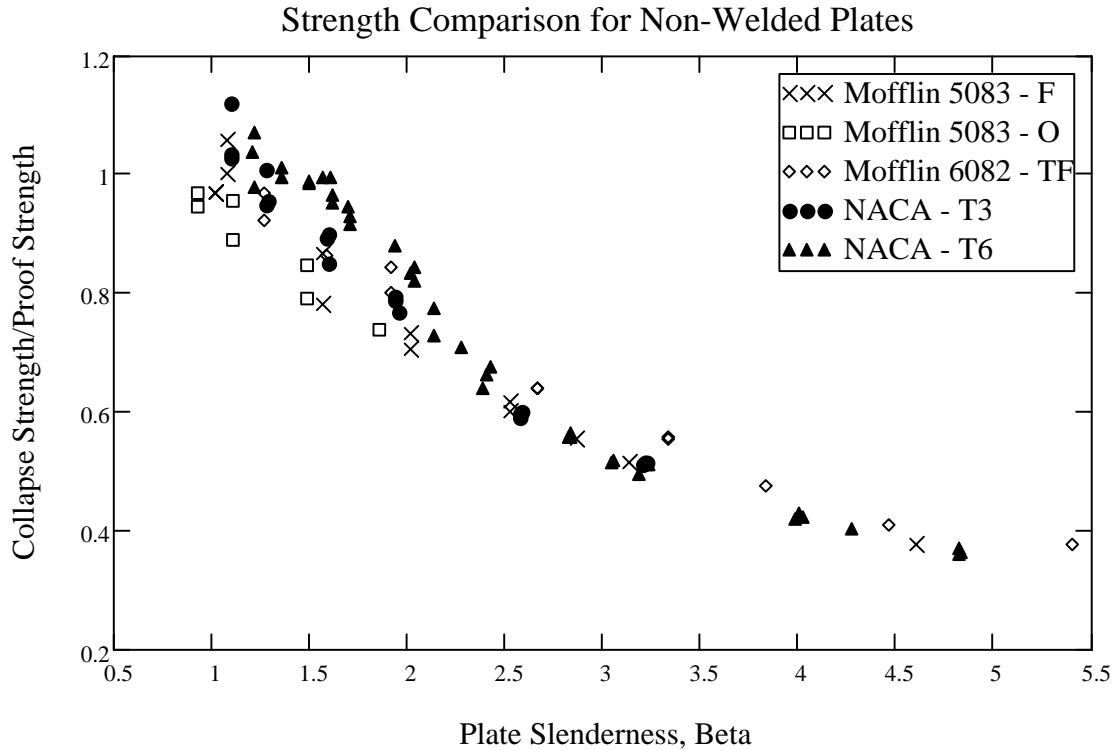
Experimental aluminum plate collapse data has been collected from the open literature. At the moment, 124 uni-axial compression results have been located, covering a wide range of alloys, including 5083, 6082, 2024, 2014, and 7075. The first two alloys come from a series of tests carried out by Mofflin[3], while later three aerospace alloys (2024, 2014, 7075) come from a series of tests from NACA[4]. These plates cover a mix of welded (long unloaded edges) and un-welded specimens. Tests under biaxial compression and lateral loading are being investigated.

To better visualize the available data set, several plots have been prepared showing the non-dimensional ultimate strength, defined as the ratio of average axial compressive stress at collapse to proof stress, to the plate slenderness ratio, beta. Formulas for both of these quantities are given below

$$\sigma_{NOM} = \frac{\sigma_{AVE_FAIL}}{\sigma_{02}}$$

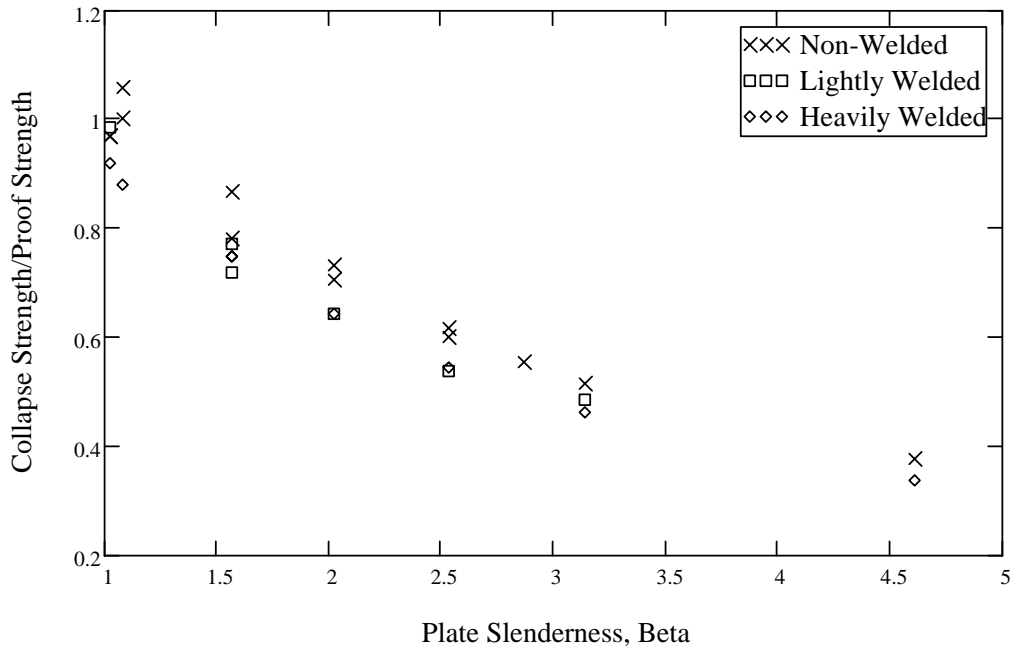
$$\beta = \frac{b}{t} \sqrt{\frac{\sigma_{02}}{E}}$$

Where b is the plate breadth, t is the plate thickness, $\sigma_{0.2}$ is the 0.2% offset proof stress, E is the elastic modulus of the material, and σ_{AVE_FAIL} is the average end stress at failure recorded in the experiment. The data is plotted below, with the Mofflin data broken down by alloy and temper, and the NACA data broken down by heat-treatment temper.

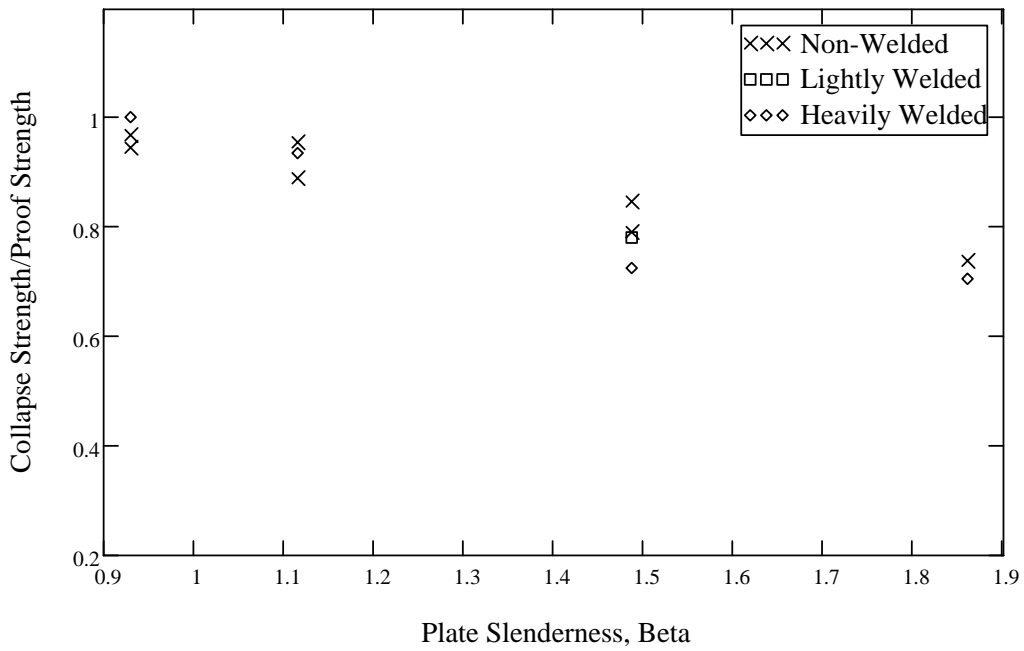


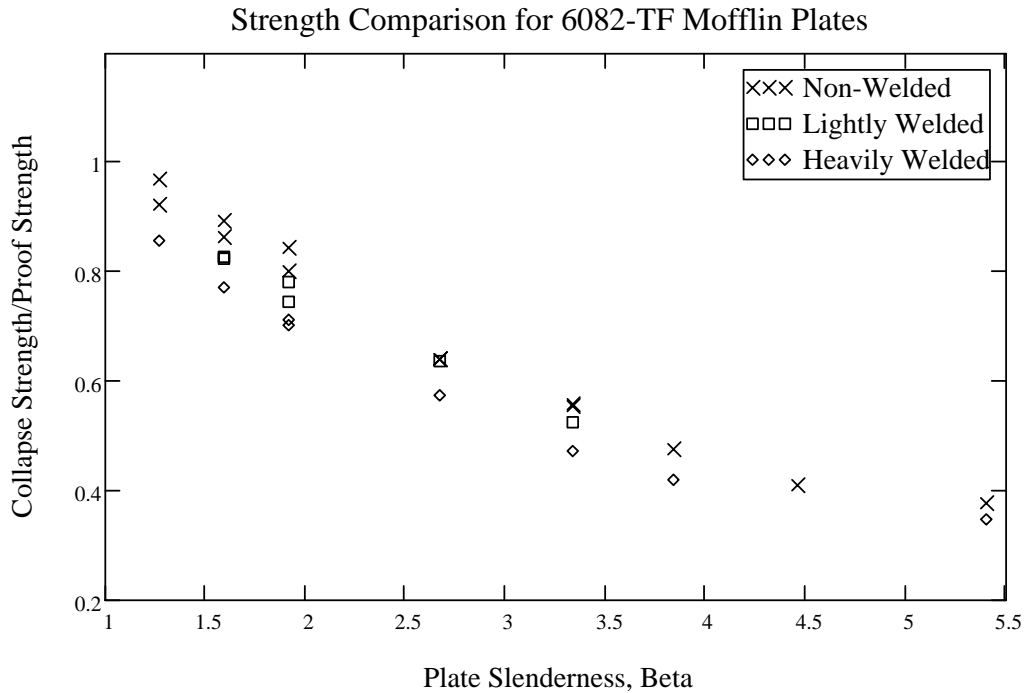
The plate strength plot shows a difference between the 5083 alloys, and the higher-strength heat-treated 6xxx/2xxx/7xxx alloys, particularly in the inelastic buckling region where the plate strength is over ~70% of the proof strength. Also worth noting is the trend for the T6 temper to outperform the T3 temper in this region. This behavior is expected, and reflected in several aluminum design codes. As the plates become more slender, this difference appears to diminish, which is also expected. For the Mofflin experimental data sets, each alloy was tested without welds, with light welds, and with heavy welds. For the welded plates, the welds were run along the unloaded, long edges only. The performance of these plates is summarized in the following three graphs. The NACA plates were only tested in the un-welded condition, and are not included.

Strength Comparison for 5083-F Mofflin Plates



Strength Comparison for 5083-O Mofflin Plates





The welded plates show a fairly smooth reduction in strength compared to the un-welded plates, as expected. The annealed 5083-O material shows a much smaller welding impact, this material is expected to have no HAZ near the weld, but welding residual stresses will still be present.

Work has started on the comparison of the methods to the simplified data. For uniaxial compression, many of the simplified methods are quick enough that it seems to make more sense to compare all of them to the data, then to try to down-select to the three most promising as outlined in the proposal. The simplified methods are being implemented in MathCAD, to allow easy comparison and plotting of the results of the methods against the experimental data. The current status of this work is summarized in the table below.

Method Implementation Status

Method	Status
Aluminum Association Specification	Calculations started
Eurocode 9	Calculations started
Kristensen Formulation	Draft calculation completed
Paik, Duran, and Lee Formulation	Draft calculation completed
Wang et. al Formulation	Draft calculation completed
U.S. Navy DDS 100-4	Draft calculation completed
Linear/Non-Linear Finite Element Analysis	Calculations started

Schedule and Financial Progress

The project at the current time is running in line with the schedule contained in the final workplan. Financial progress is also in-line with expectations, with completed tasks one and tasks two consuming 4.4% of the total planned budget as of November 30th, 2007 which was the last SAIC internal financial reporting point before this progress report. These tasks were originally budgeted to consume 4% of the total project budget. The progress against schedule is summarized below:

Project Schedule Overview (Active tasks only)

Event	Date	Status
Draft Contractor Project Plan and Kick-Off Meeting	October 9 th 2007	Complete
TPP 1: Final project plan complete	October 12 th , 2007	Complete
TPP 2: Review of plate methods complete	November 9 th , 2007	Complete
1 st Quarter Progress Report	December 21 st , 2007	Complete
TPP 3: Plate method comparison complete	February 1 st , 2008	In Progress

References

1. Wang, X., Sun, H., Akiyama, A., and Du, A. *Buckling and Ultimate Strength of Aluminum Plates and Stiffened Panels in Marine Structures*, In 5th International Forum on Aluminum Ships, Tokyo, Japan, 11-13 October 2005. \
2. Galambos, Theodore. Guide To Stability Design Criteria for Metal Structures. 5th ed. New York: John Wiley and Sons, 1998.
3. Mofflin, D.S. *Plate Buckling in Steel and Aluminum*, PhD Thesis, Trinity College, University of Cambridge, 1983.
4. Anderson, R.A., and Anderson, M.S., *Correlation of Crippling Strength of Plate Structures with Material Properties*, NACA Technical Note 3600, January 1956.