Third Quarterly Progress Report: SR-1457
Aluminum Extrusion Optimization

Date: June 6th, 2008
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Overview

Work on SR-1457 is proceeding smoothly and is largely on schedule. Tasks 1, 2, 3, 4, and 6 have now been completed. The majority of Task 5 is also complete; although finite element investigations into panels with variable thickness across their width are still continuing and error analysis for the closed-form equations are still ongoing owing to slightly poorer performance of these methods than anticipated. These remaining areas of investigation on Task 5 are not expected to impact the overall project schedule or the issuing of the draft report (the next deliverable). The draft final report has also been started. 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. This task was complete when the December 20th progress report was issued, initial findings are summarized in the first quarterly progress report.

Task Three

Task three is now complete, and the final report sections that correspond to task three are now in preparation. The majority of the results for task three were presented in the first and second quarterly progress reports. Since the second quarterly progress report, the last area of investigation on task three has been the finite element investigation of plates of variable thickness. A series of variable thicknesses were investigated, covering both plates thickest at the edge and plate thickest in the middle. The plate thickness varied linearly from edge to middle. Five cases were investigated, as summarized below:

Table 1: Plate Thicknesses Investigated

Case	T_{EDGE}	T_{MIDDLE}
1	6.66mm	3.33mm
2	5.71mm	4.29mm
3	5.00mm	5.00mm
4	4.29mm	5.71mm
5	3.33mm	6.66mm

Three values of plate width were used, corresponding to plate slenderness values, β, of 2, 3, and 4, with β defined as:

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

In general, little increase in strength was seen for the heavier (β=2) plates, which tended to buckle in-elastically. For the more slender plates, where there was some post-buckling strength after initial elastic buckling, there was a clear tendency for the plates with the thicker edges to show higher ultimate strengths. This is shown for the β=2 and 3 plates in Figure 1 and Figure 2, note that the average plate thickness in all cases is equal to 5mm, and that the cases correspond to those listed in

Table 1 above. The theoretical elastic buckling stress is plotted on the Figure 2 as well as horizontal line, it can be seen that the differences in strength increase above the elastic buckling stress.

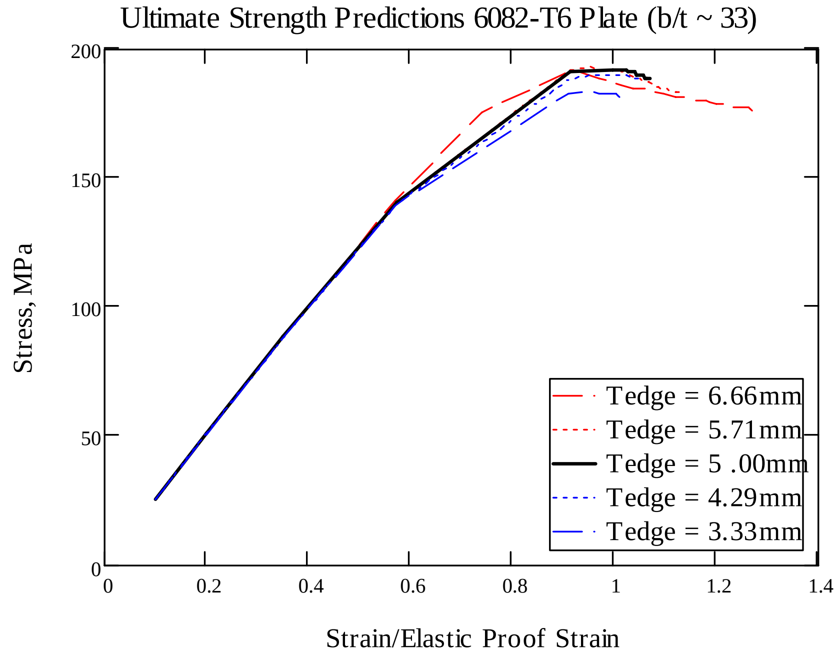


Figure 1: Strength Comparison for β=2 Plates of Various Edge Thickness (Note: elastic buckling stress higher than plot range)

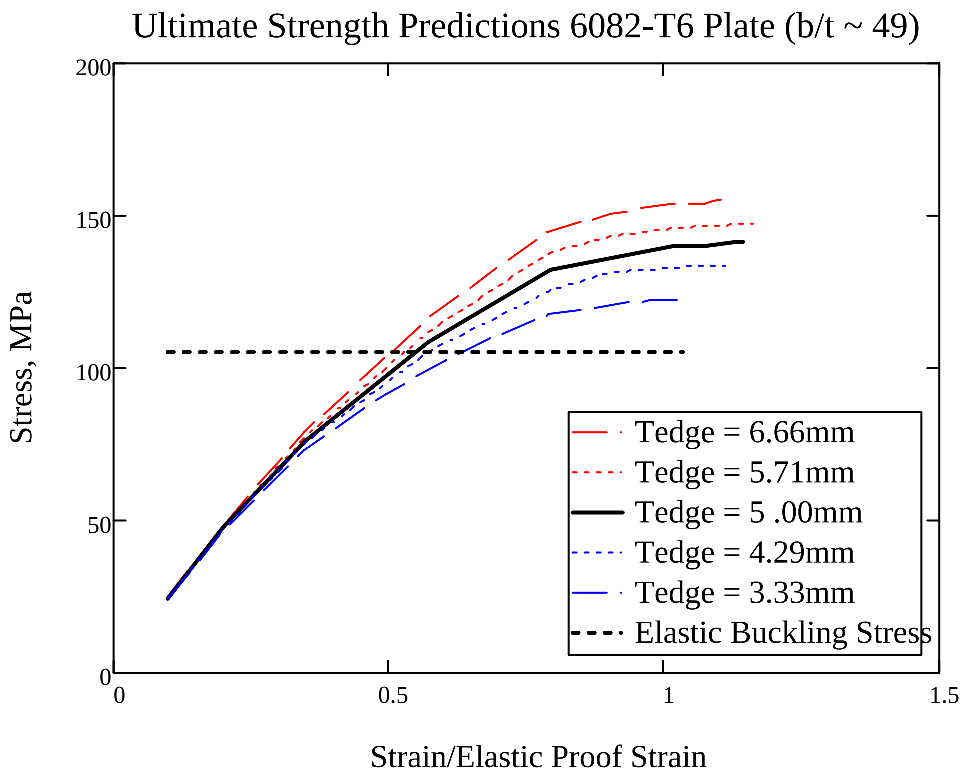


Figure 2: Strength Comparison for β=3 Plates of Various Edge Thickness

It is not clear how much of an advantage can be gained by varying the plate thickness in the extrusions, especially in cases where lateral loads are present as well. Many ship structures are designed not to buckle elastically, so it is not clear how much of this strength increase is obtainable in ship structures. Further investigation of variable plate thickness will be carried out in task five.

Task Four:

Task four covers the review of panel ultimate strength methods, with a proposed down-select to three methods for comparison with the experimental results. Based on our experience with task three, it will be possible to additionally study some simple regression formulas in addition to the three methods. The three methods that can handle both lateral load and compressive collapse that have been identified as promising are:

- **U.S. Aluminum Association Specification [9]**
- **Ultimate strength method proposed in Hughes [3]:** This method was developed for steel; however, it may be adaptable for aluminum alloys using some of the results from Task 3.
- **Linear and non-linear finite element analysis:** Mainly for the investigation of variable-thickness plates.

Additionally, three further methods that can primarily handle compressive collapse will be included in the analysis. These methods could be team up with simple elastic analysis or one of the three methods above to handle both lateral loading and compressive collapse. Several ABS formulations for combined buckling and lateral loading for steel structures will also be investigated as an option for extending the compressive collapse methods. The proposed methods are:

- **Wang et. al Formulation [10]**: Approach based on hybrid Johnsen-Ostenfeld/Faulkner formulation
- **Matsuoka Formulation [11]**: Mechanical model for conventional and hollow-core panels.
- **Paik, Duran, and Lee Formulation [12]**: Regression model based on non-linear finite element predictions for conventional aluminum panels.

Task Five:
Work on task five is underway. This task was slightly further delayed when the principle investigator became ill unexpectedly in April and early May. The following sources of data have been identified for comparison:

- **UK Panel Tests [13]**: A series of 5 panels of 4 different geometries tested by
- **Matsuoka Panel Tests [11]**: A small series of panel tests, including some hollow truss-type panels and variable-plate thickness panels.
- **Aalberg, Langseth, and Larsen Panel Tests [14]**: A series of extruded panel tests, only two geometries were studied, but two different panel lengths were used.
- **SSC-451 Panel Test [16]** : A large collection of aluminum panels recently tested by the SSC.

Implementation of the simplified methods is currently complete; however, some of the methods performance has not been promising to date, with large errors from the data sets. Further analysis, breaking down the experimental data by panel type is planned to try to shed some light on the causes of these errors. The Hughes and Aluminum Association methods are currently in testing. The non-linear finite element analysis of plates of variable thickness in larger panels is ongoing; however, the non-linear finite-element formulation is not suitable to be coupled to the genetic algorithm optimizer so either the Hughes method or the Aluminum Association method will be used for the final optimization in task seven.

Task Six:
Work on the formulation of the genetic algorithm optimizer is complete, and sample optimizations for single load directions have been made, using both the Paik, Duran and Lee[12] formulation and the Aluminum Association[9] formulation. The optimizer determines a Pareto frontier, along which lie the lightest structures for various levels of ultimate strength. Sample results are shown below for a case where the genetic algorithm has been run for 30 generations is shown in Figure 3.

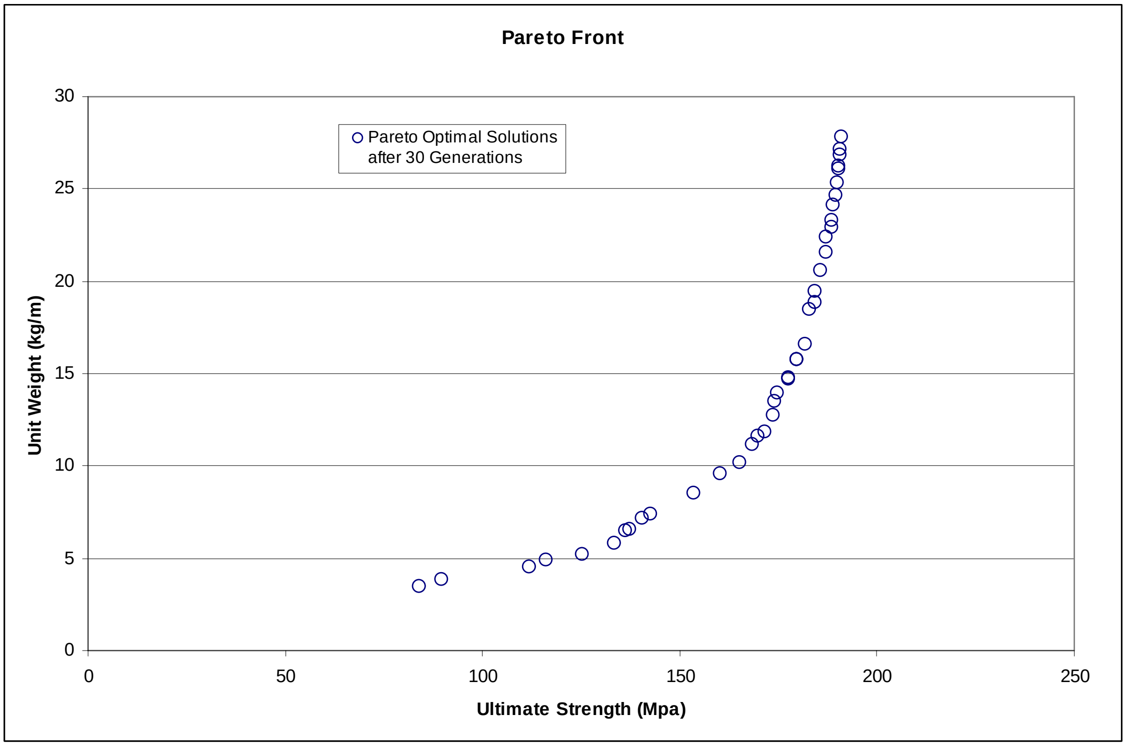
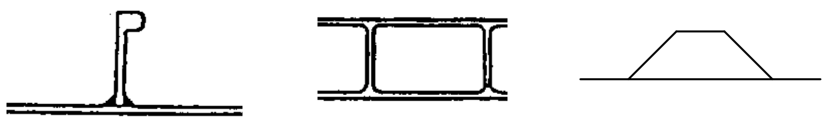


Figure 3: Sample Optimizer Output

Task Seven:

Sample panel for optimization are set to include:

- Cargo/Vehicle Deck: A small constant in-plane load will be applied to these panels, while the optimizer will produce a Pareto front linking panel weight to allowable out-of-plane load for the panel for the three types of panels shown in Figure 4. Limited investigations of variable-thickness panels will also be made by non-linear finite element formulation.
- Strength Deck: A small constant out-of-plate load and transverse compression will be applied to these panels, while the optimizer will produce a Pareto front linking panel weight to allowable longitudinal in-plane stress. Again, variable thickness panels will be investigated by limited non-linear finite element analysis.



Conventional & extrusion construction (after[11]) | **Sandwich-type extrusion (after[11])** | **Hat-type extrusion**

Figure 4: Panel Types for Optimizer

The panel size, height restrictions, and range of acceptable geometries will be based on the extrusions examined in the previous Ship Structure Committee study, SSC-438[15].

Task Eight:

The final report is under preparation, with the results from Task 2 and 3 currently be written up.

Schedule and Financial Progress

At the moment, with the exception of some small delays on Task 5, the project is largely on schedule. As the optimizer is now functionally complete and awaiting the final methods from Task 5 to complete Task 7, it is not anticipated that this delay will impact the overall project schedule. As of May 16th, the last SAIC financial reporting period before this status report, 63% of the total project budget had been spent, which is in line with expectations.

References

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