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Aluminum 2195 T8 Gore Development for Space Launch System Core and Upper Stage

Project Manager(s)/Lead(s)

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Sponsoring Program(s)

Human Exploration and Operations Mission Directorate
Space Launch System Advanced Development

Project Description

Gores are pie-shaped panels that are welded together to form the dome ends of rocket fuel tanks as shown in figure 1. Replacing aluminum alloy 2219 with aluminum (Al)-lithium (Li) alloy 2195 as the Space Launch System (SLS) cryogenic tank material would save enormous amounts of weight. In fact, it has been calculated that simply replacing Al 2219 gores with Al 2195 gores on the SLS core stage domes could save ~3,800 lbm. This is because the Al-Li 2195 alloy exhibits both higher mechanical properties and lower density than the SLS baseline Al 2219 alloy. Indeed, the known advantages of Al 2195 led to its use as a replacement for Al 2219 in the shuttle external tank program. The required thicknesses of Al 2195 gores for either SLS core stage tanks or upper stage tanks will depend on the specific design configurations. The required thicknesses or widths may exceed the current experience base in the manufacture of such gores by the stretch-forming process. Accordingly, the primary objective of this project was to enhance the formability of Al 2195 by optimizing the heat treatment and stretch-forming process for gore thicknesses up to 0.75 inch, which envelop the maximum expected gore thicknesses for SLS tank configurations.

Formability data and heat-treating parameters were determined prior to stretch forming the 0.525- and 0.75-inch-thick plates. The data were used in the finite element model that was developed to help guide the stretch-forming operations and to help interpret the

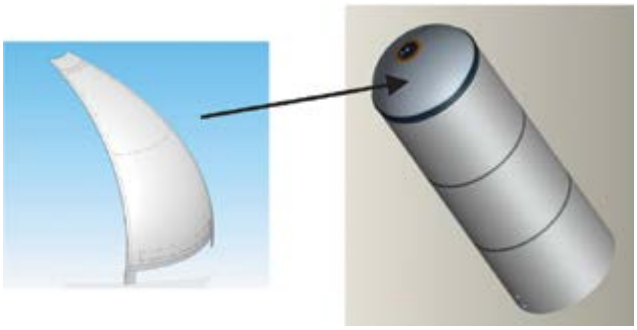

Figure 1: Gore panels are welded together to form the dome ends of SLS cryogenic tanks.

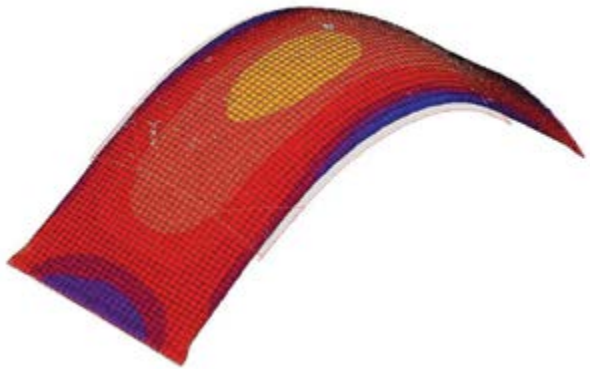

Figure 2: A finite element analysis model was used to determine the magnitude and variation of strain induced during the stretch-forming operation.

results (fig. 2). One 0.525-inch-thick and two 0.75-inch-thick Al 2195 plates were successfully stretch formed into gores using an existing die of the Ares I contour (fig. 3). Use of the Ares I die was a significant cost savings, as an SLS die did not have to be developed and constructed. Also, the Ares I contour is more severe than the SLS contour and therefore successful stretch-forming operations demonstrated with the Ares I die can also be expected to be successful with a die of the SLS contour.

Figure 3: An aluminum panel is stretch formed into the desired contour using a die.

Mechanical testing of the 0.525- and 0.75-inch Al 2195 gores showed greater than expected tensile properties when compared to the Lockheed Martin Engineering Materials Specifications for Al 2195, STM 11-A1-LM, which was developed for the external tank program. The fracture toughness is also satisfactory and can be improved further with an optimization in the aging treatment parameters. The results of this study were very promising. All of the formability and mechanical test data gained from this program indicate that the stretch-formed 2195 gores have sufficient material properties to replace the existing Al 2219 alloy that is the current baseline for SLS flight domes.

Anticipated Benefits

Prior to this study, Al 2195 plates thicker than 0.325 inch had never been stretch formed. Therefore, it was necessary to perform formability studies on Alcoa 0.525- and 0.75-inch-thick plates to ensure that the prescribed annealing treatment indeed improved their formability. Tensile tests were performed for 0.525- and 0.75-inch-thick Al 2195 plates to compare the effects of annealing treatment on the forming range and strain hardening exponent. The annealing treatment that led to a higher forming range and strain hardening exponents was selected to anneal 0.525- and 0.75-inch Al 2195 plates prior to gore stretch forming. This annealing process was developed at NASA Marshall Space Flight Center (MSFC) and is being patented (MFS-32954-1). The NASA annealing process led to a higher strain hardening exponent and higher formability, and demonstrated that large-scale rocket domes can be reliably manufactured by the stretch-forming process with the lightweight Al-Li 2195 alloy.

Potential Applications

The intended primary applications for this technology development were SLS core and upper stage cryogenic fuel tanks. This project demonstrated that relatively thick (up to 0.75 inch) Al 2195 plates can be processed by stretch forming. Thus, any aerospace application where increased strength and weight savings are desired can take advantage of this technology.

Notable Accomplishments

All of the planned tasks for this project were successfully completed.[1] An annealing treatment that led to a higher forming range and strain hardening exponent was utilized to anneal 0.525- and 0.75-inch Al 2195 plates prior to gore stretch forming. One 0.525- and two 0.75-inch-thick plates were successfully stretch formed into gore contours and heat treated to the T8 temper (fig. 4). Mechanical testing of the gores resulted in tensile properties that exceeded the specifications for Al 2195. Finally, a detailed plan was developed for future work to enable the incorporation of Al 2195 gores into the SLS program.

Figure 4: The three completed gore panels after delivery to MSFC. Test specimens were cut from the ends of two of the gore panels for mechanical and fracture toughness testing.

References

1. Volz, M.P.; Chen, P.S.; Gorti, S.; and Salvail, P.: "Development of Aluminum-Lithium 2195 Gores by the Stretch Forming Process," National Space and Missile Materials Symposium, Huntsville, AL, June 23–26, 2014.