Development of Aluminum-Lithium 2195 Gores by the Stretch Forming Process

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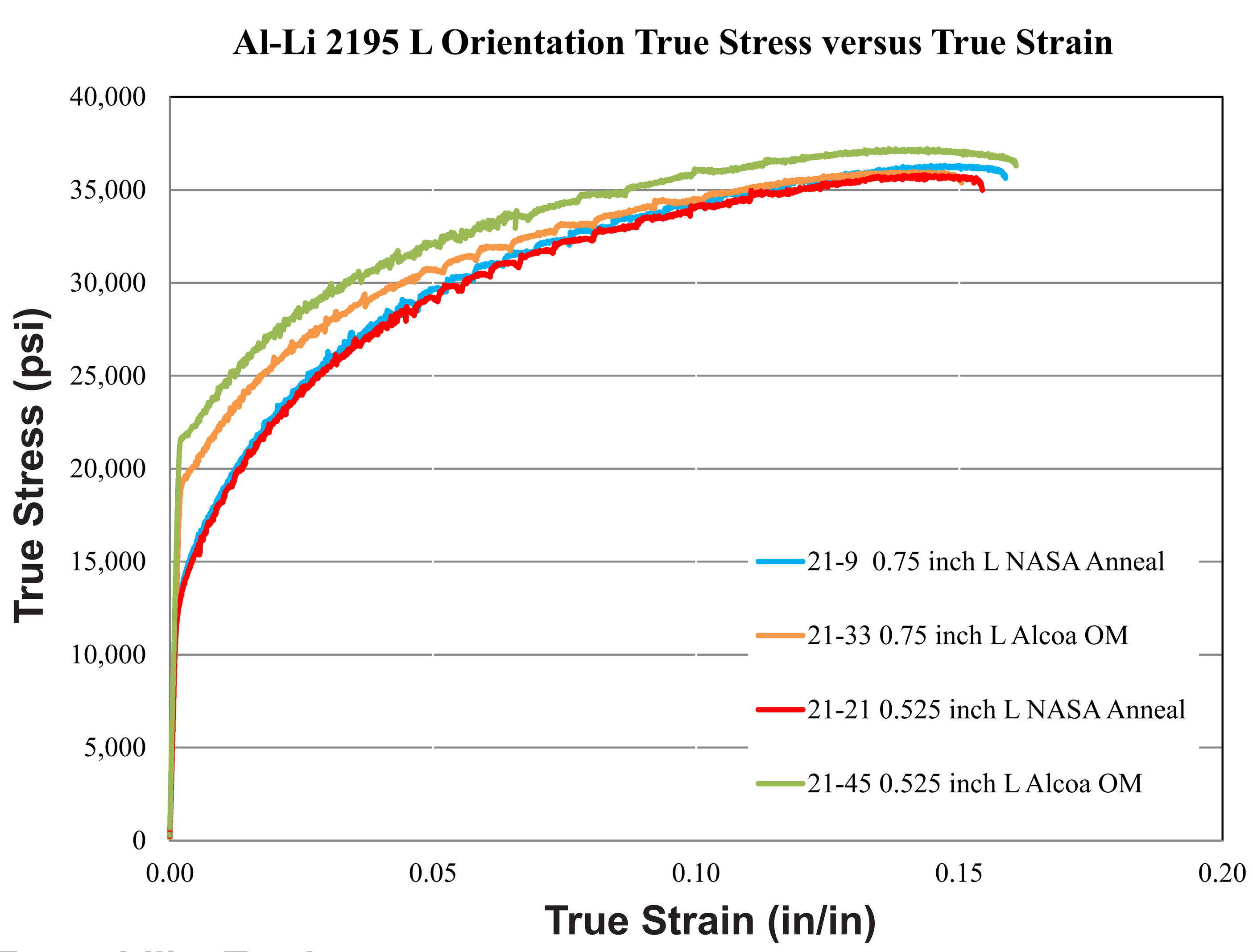
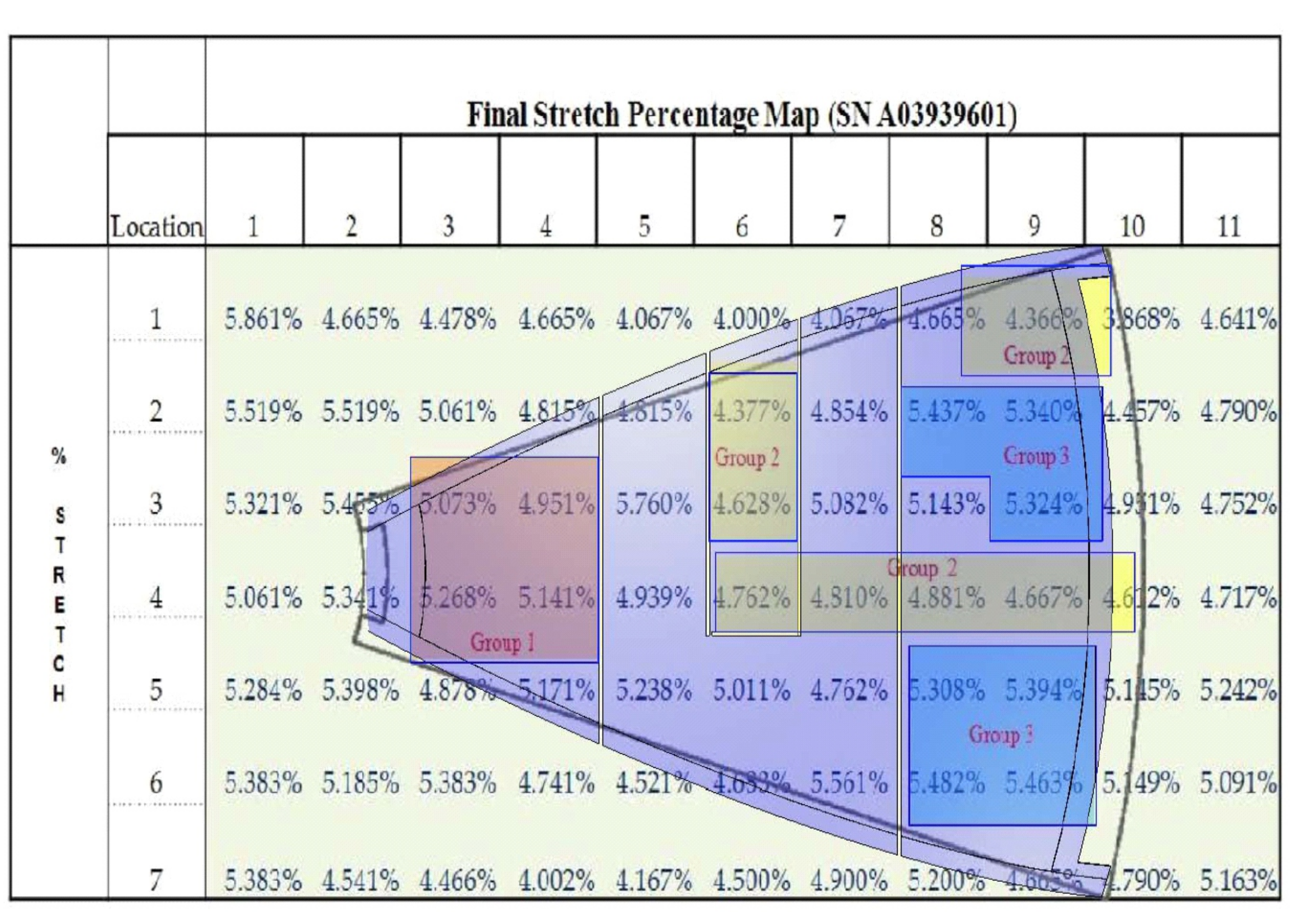
Abstract

Aluminum-Lithium alloy 2195 exhibits higher mechanical properties and lower density than aluminum alloy 2219, which is the current baseline material for Space Launch System (SLS) cryogenic tank components. Replacement of Al 2219 with Al-Li 2195 would result in substantial weight savings, as was the case when this replacement was made on the shuttle external tank. A key component of cryogenic tanks are the gores, which are welded together to make the rounded ends of the tanks. The required thicknesses of these gores depend on the specific SLS configuration and may exceed the current experience base in the manufacture of such gores by the stretch forming process. Here we describe the steps taken to enhance the formability of Al-Li 2195 by optimizing the heat treatment and stretch forming processes for gore thicknesses up to 0.75", which envelopes the maximum expected gore thicknesses for SLS tanks. An annealing treatment, developed at Marshall Space Flight Center, increased the forming range and strain hardening exponent of Al-Li 2195 plates. Using this annealing treatment, one 0.525" thick and two 0.75" thick gores were manufactured by the stretch forming process. The annealing treatment enabled the stretch forming of the largest ever cross sectional area (thickness x width) of an Al-Li 2195 plate achieved by the manufacturer. Mechanical testing of the gores showed greater than expected ultimate tensile strength, yield strength, modulus, and elongation values. The gores also exhibited acceptable fracture toughness at room and LN_2 temperatures. All of the measured data indicate that the stretch formed gores have sufficient material properties to be used in flight domes.



Formability Testing
The NASA anneal, when implemented prior to initial stretching, leads to a higher forming range and an improved strain hardening exponent.

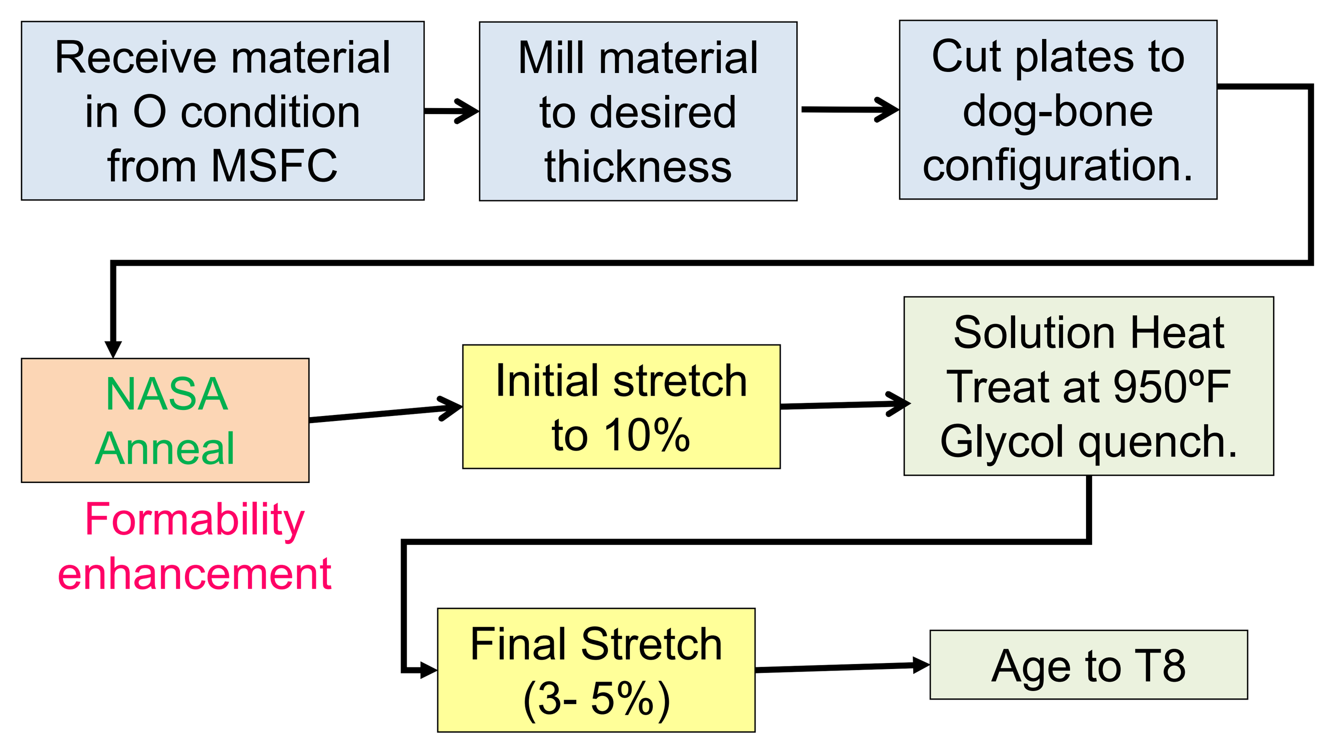


Final Stretch Percentage Map (SN A03939601)

% STRETCH Location	1	2	3	4	5	6	7	8	9	10	11
1	5.861%	4.665%	4.478%	4.665%	4.067%	4.000%	4.067%	4.665%	4.366%	3.868%	4.641%
2	5.519%	5.519%	5.061%	4.815%	4.815%	4.377%	4.854%	5.437%	5.340%	4.457%	4.790%
3	5.321%	5.455%	5.073%	4.951%	5.760%	4.628%	5.082%	5.143%	5.324%	4.951%	4.752%
4	5.061%	5.341%	5.268%	5.141%	4.939%	4.762%	4.810%	4.881%	4.667%	4.612%	4.717%
5	5.284%	5.398%	4.878%	5.171%	5.238%	5.011%	4.762%	5.308%	5.394%	5.145%	5.242%
6	5.383%	5.185%	5.383%	4.741%	4.521%	4.693%	5.561%	5.482%	5.463%	5.149%	5.091%
7	5.383%	4.541%	4.466%	4.002%	4.167%	4.500%	4.900%	5.200%	4.665%	4.790%	5.163%

Cut Plan and Mechanical Testing
Test samples were cut from the completed gores. Tensile testing and fracture toughness testing was completed for the 0.325", 0.525", and 0.75" gores at both room temperature and LN_2 temperatures.

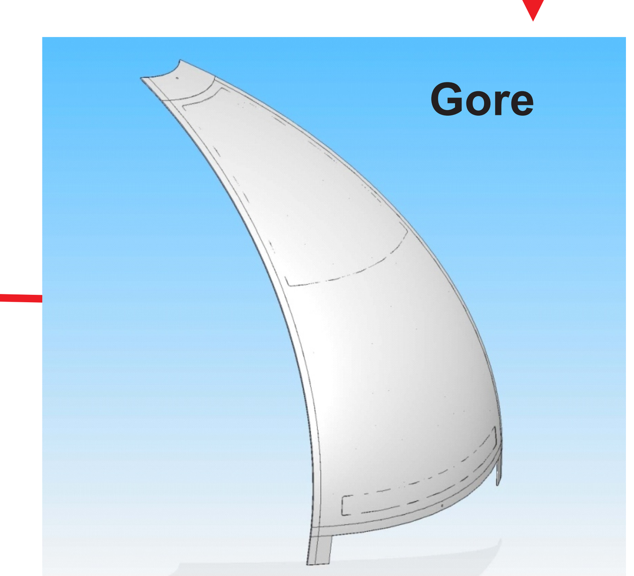
Machining of panel into dogbone shape

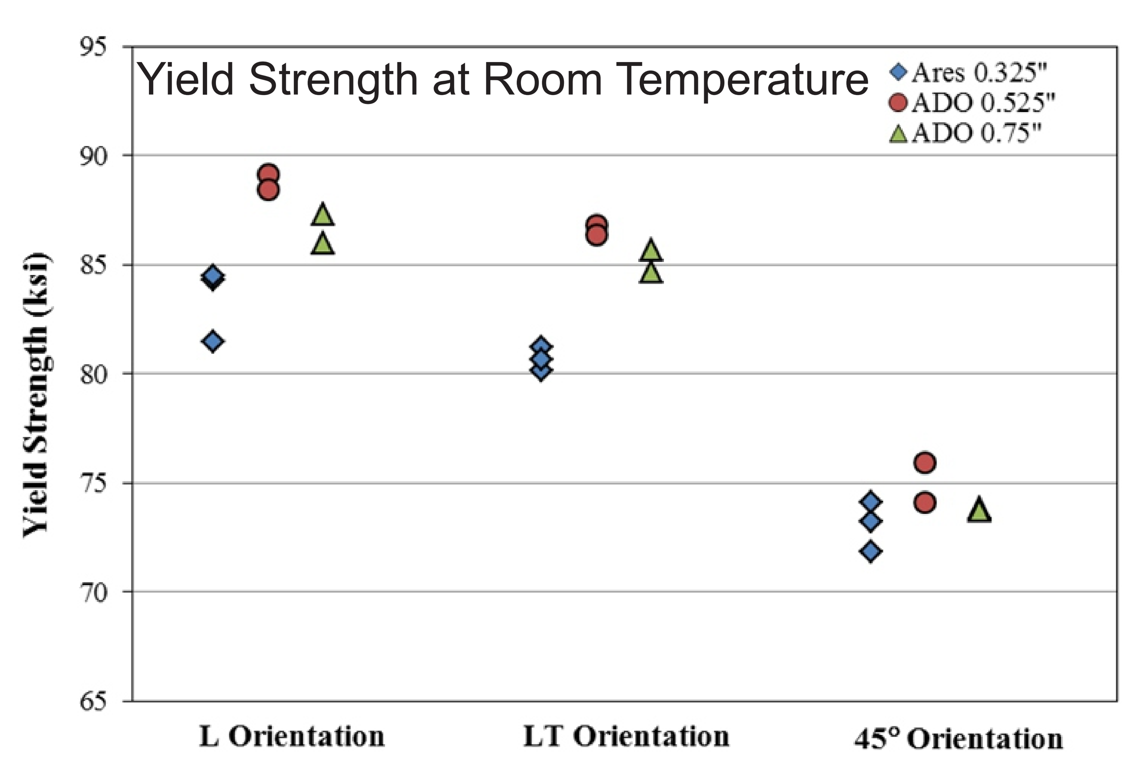


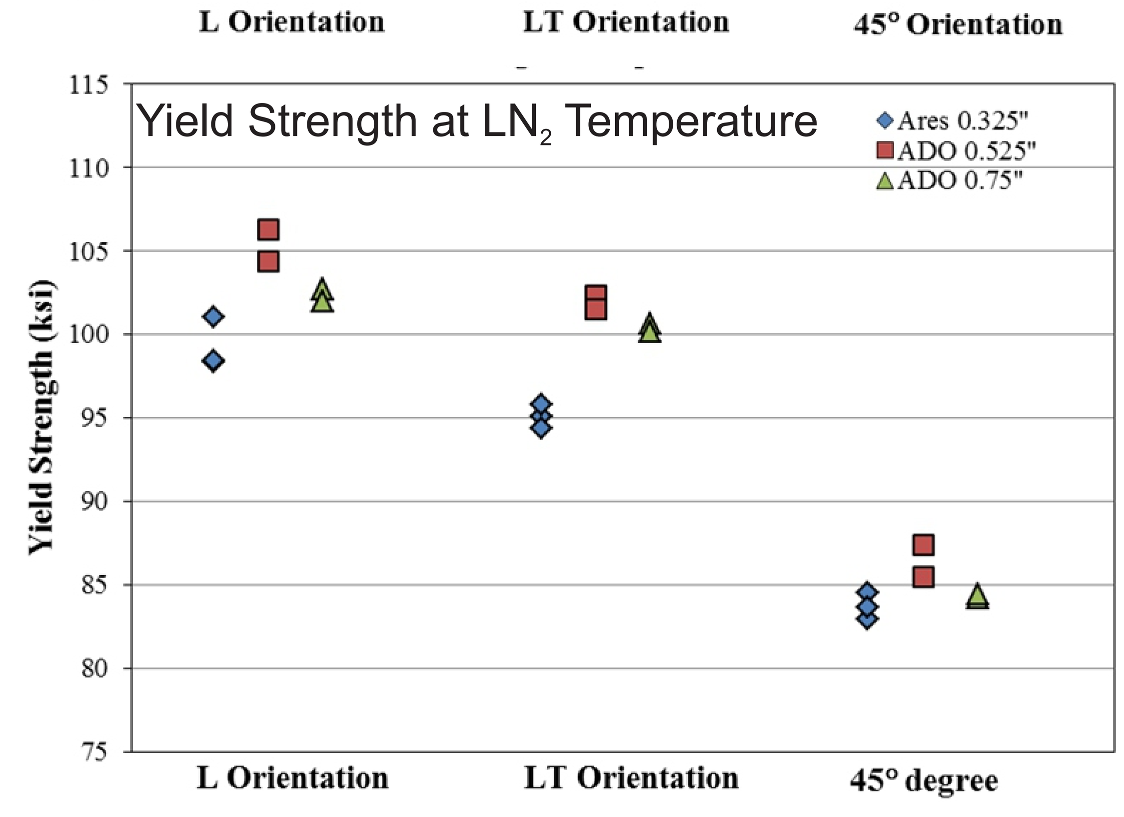
Loading of the panel into the jaw

Completion of stretch forming

Manufacture of Dome Gores
Al 2195 panels are first cut to a dogbone shape. They are stretch-formed to the desired contour and then machined into gore shapes. The gores are then welded together to create domes for cryogenic tanks for the SLS.







Summary

- Formability testing demonstrated that the NASA anneal led to a higher forming range and an improved strain hardening exponent.
- The increased formability resulting from the NASA anneal will permit large scale rocket domes to be reliably manufactured by stretch forming lightweight thicker plate Al 2195 alloy.
- Three Al 2195 gores were successfully manufactured by stretch forming (one 0.525" thick and two 0.75" thick)
- Mechanical testing of all gores showed greater than expected average UTS, YS, modulus, and elongation values.
- Compared to RT, at LN_2 temperature the UTS and YS increase by 15%- 25%, depending on orientation.
- The mechanical properties of the gores exceeded the specifications for Al 2195, STM 11-A1-LM, for all orientations, temperatures, and average stretch percentages.
- All gores tested exhibited acceptable fracture toughness at RT and at LN_2 temperature.
- Fracture data were characteristic of brittle fracture at RT and ductile tearing at LN_2 temperature.