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Production of Aluminum-Lithium Near Net Shape Extruded Cylinders

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Production of Aluminum-Lithium Near Net Shape Extruded Cylinders

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1.0 INTRODUCTION

In the late 1980's, the Advanced Launch System (ALS) Program sponsored the development of near net forming technology under the Advanced Development Program #3106. The Lockheed Martin Company was responsible for utilizing their then recently developed Weldalite® 049 alloy for production of near net shape extrusions. The goal was to replace the External Tank (ET) tee-stiffened barrel panels that were machined from 2219-T87 thick plate (resulting in a 85-90% scrap) with near net shape extrusions that required minimal machining. This was to be accomplished by extruding large cylinders that would then be flattened, heat treated and formed into the ET radius. This concept offered a potential cost savings due to reduced raw material and machining costs. The ALS program successfully developed the technology to extrude and flatten near net shape extrusions [1]. The extrusions were produced by Wyman Gordon in Houston, TX and then solution heat treated and stretched at Ticorm and AHF Ducommun, both in Gardena, CA. Soon after the testing of these extrusions was complete the funding for the program was canceled. Fortunately, due to the potential cost savings of this technology, the Shuttle-C Program allocated additional funds to further its advancement.

2.0 OBJECTIVES

The objectives of this program were to:

- Produce one each near net shape extrusion out of the 2219, 2195, RX 818 and 2096 (formerly referred to as MD 345) alloys.
- Develop thermomechanical processing techniques to induce a nominal 3.5% cold work through the membrane and the tee-stiffeners.

3.0 MATERIAL

The nominal compositions of the ingots used in this program are presented in Table 1. In all cases, except for the 2096, these compositions were determined at the ingot level. The composition of the 2096 was taken from the wrought product and was determined by the Inductively Coupled Plasma (ICP) method. The 2219 was supplied by Spectrulite Consortium Inc. as a 29.5 inch diameter x 59.5 inch long solid round scalped ingot. The 2195, RX 818 and 2096 were all supplied from Reynolds Metals Company (RMC) in McCook, IL, as rectangular scalped ingot. The 2195 was purchased under Lockheed Martin Astronautics Group/NASA Marshall Space Flight Center Joint IR&D and the RX 818 and 2096 were donated by RMC.

Table 1. Chemical Compositions (weight %)

Alloy	Drop #	Lot or Heat #	Ingot Size t x w x l (in)	Cu	Li	Mg	Mn	Zr	Fe	Ti	Ag
2219	GN 275		29 1/2 dia. x 59 1/2	6.4	-	<0.01	.28	.13	.12	-	-
2195	1140-27A	910Z009A	14 3/8 x 54 1/4 x 47 3/4	4.05	1.05	.46	-	.14	.05	.07	.44
RX818	13830-04	P21982	13 3/4 x 39 1/2 x 29	3.62	.91	.48	-	.15	.04	NC	.38
2096	13881-04	-	14 1/2 x 54 x 20	2.38	1.42	.73	-	.14	.05	NC	.31

4.0 INGOT CONVERSION

Due to the unavailability of large round 2195, RX 818 and 2096 ingot, rectangular ingot typically used for plate production was converted into round hollow blockers (sometimes referred to as billets) for this application. One advantage of this added step (although it has not been quantified) is that the grain structure receives further breakdown, above and beyond that induced during the extrusion operation, which ultimately refines the microstructure and improves properties. The author did not witness any of the ingot conversion but will convey the process steps as described in Reference 2. Although the exact sizes of each of the ingots varied, the conversion process, as illustrated in Figure 1, was generally the same for each. Table 2 describes the ingot and die temperatures and resulting reduction ratios for the 2195 blocker. The temperatures for the RX 818 and 2096 ingots were increased to ~850°F for the conversion process, however die temperatures were generally held constant. (The reduction ratios for these two alloys is not available.) The desired nominal blocker size for all alloys was 33 inch ID and 45 inch OD. All die surfaces were lubricated with cam lube prior to the forging operation.

Table 2. Ingot Conversion for the 2195 Blocker

Alloy	Step	Ingot Temp. (°F)	Time at Temp. (hrs)	Die Temp. (°F)	Reduction Ratio	Final Billet Height (in)
2195	1	750	4-7	500-800	1.4:1	
	2	N/A	N/A	N/A	N/A	
	3	750	1-2		2.05:1	
	4	750	1-2	800	1.4:1	33.24

The first breakdown, illustrated in Step 1, was conducted in a 55 inch diameter blocking pot. The ingot was placed with the width-height plane down and using flat faced dies was expanded to within 10-15% of round.

The second and third steps used flat faced dies and a 36 inch diameter blocking pot to further reduce the ingot. The ingot from the first step was rotated 90°, flat forged, reheated and then forged into the pot. Small laps were sometimes present as a result of this process. Although this is typical for such an operation, it does require smoothing of the metal before proceeding to the next step. This ultimately reduces the volume of metal available to produce the extrusion and as such the formation of any surface defects are carefully monitored.

The forth step, back extruding, converted the solid blocker into a hollow blocker. This process was accomplished using a 45 inch diameter blocking pot and a 33 inch diameter punch. As the punch came into contact with the Al blocker, the blocker expanded to fill the pot. Simultaneously, a hole was pierced and the metal back extruded to yield a hollow blocker as shown. As a result of the various ingot starting sizes the height of the final blockers varied. The hollow blockers were final machined on all surfaces to remove any small laps, defects or cracks. Approximately 1/16 to 1/2 inch of material was removed during this operation.

5.0 EXTRUSION PRODUCTION

The hollow blockers were extruded into the geometry illustrated in Figure 2. This configuration is similar to those extrusions produced under the ALS program with the exception of the wall thickness. The ALS extrusions had a wall thickness of approximately 0.472 inch, the extrusions produced for this program were thinned down to a nominal 0.320 inch. (This change increased the extrusion reduction ratio from ~14:1 to ~18:1.) This was considered a significant change for two reasons. The first was the potential instability of the extrusion as it exited the vertical press; the thinner the membrane the more likely the extrusion will be to fall to one side. Secondly, as the wall thickness decreases the reduction ratio increases. Consequently, the pressure required to break the blocker through the die increases to the point where it may exceed the press capacity. Neither of these conditions resulted from decreasing the membrane to 0.320 inch. In order to make the extrusions even more economical for future programs, wall thicknesses as low as 0.250 inch may be achieved with modified stiffener configurations.

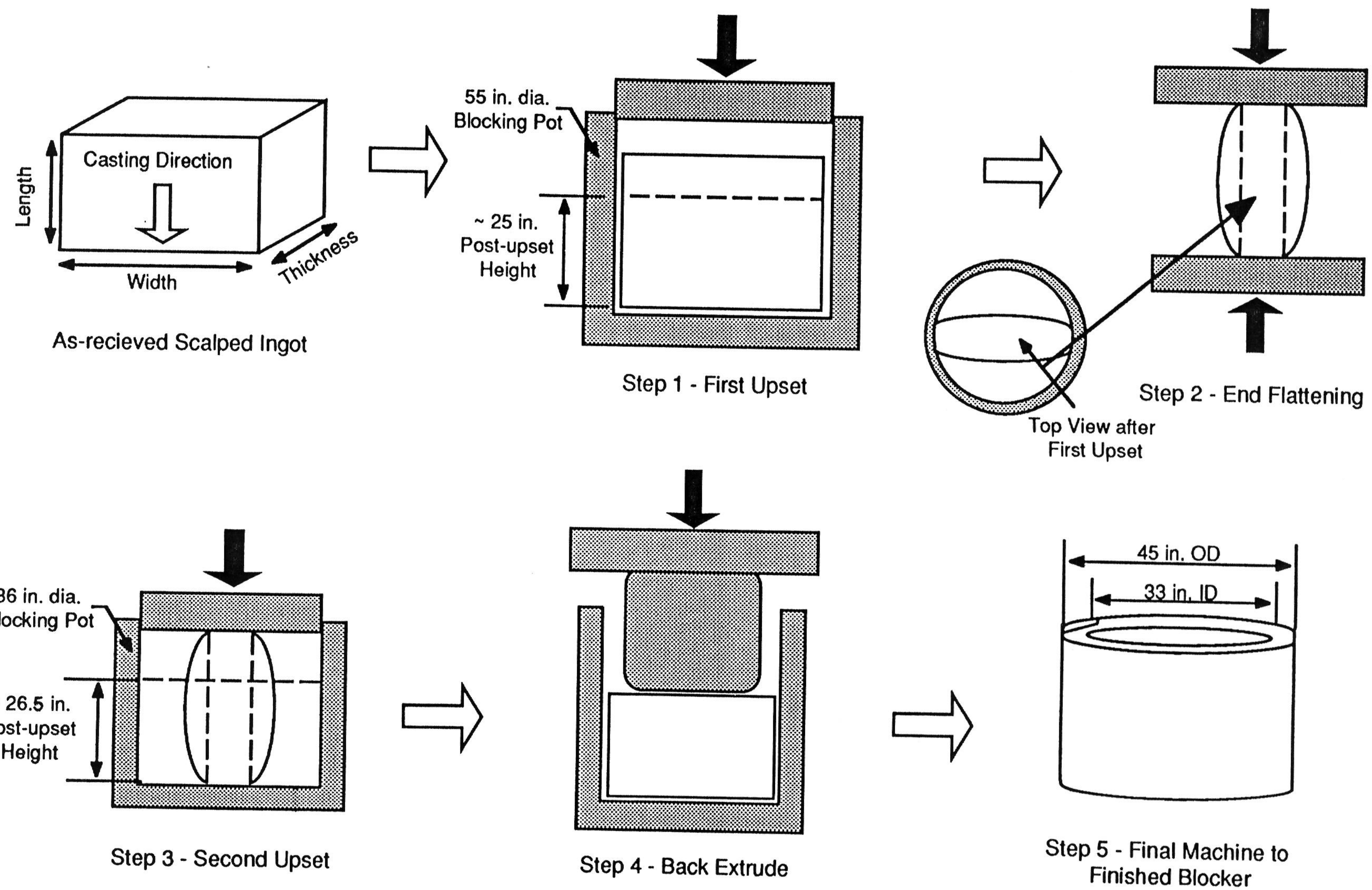

Figure 1. Ingot Conversion Manufacturing Sequence

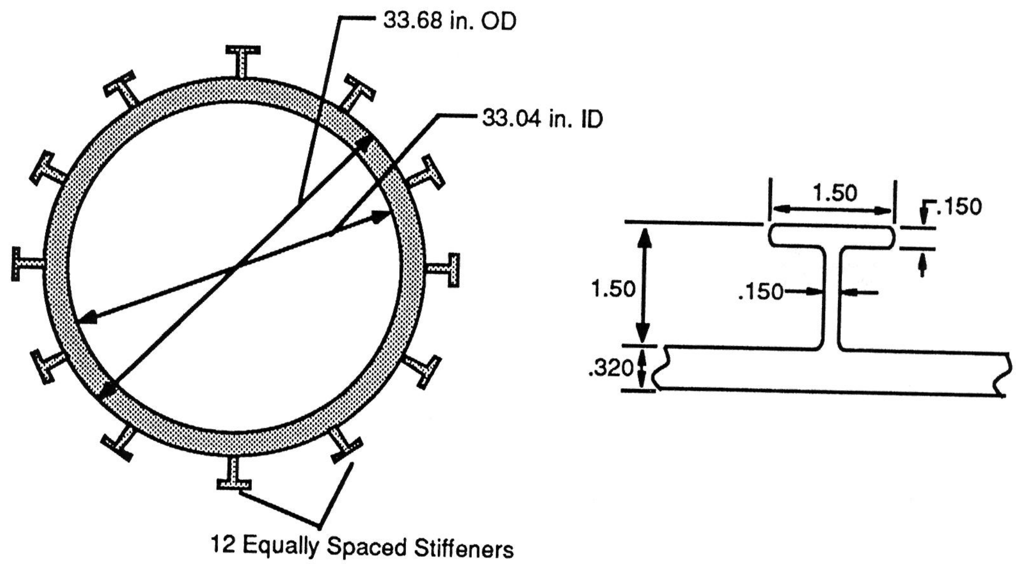

Figure 2. Nominal Geometry of the Near Net Shape Extrusion

All of the extrusions were produced in generally the same way, utilizing Wyman Gordon's 35,000 ton vertical-up extrusion press (see Figures 3 through 6) and flat-faced dies. The manufacturing flow of the extrusions were as follows.

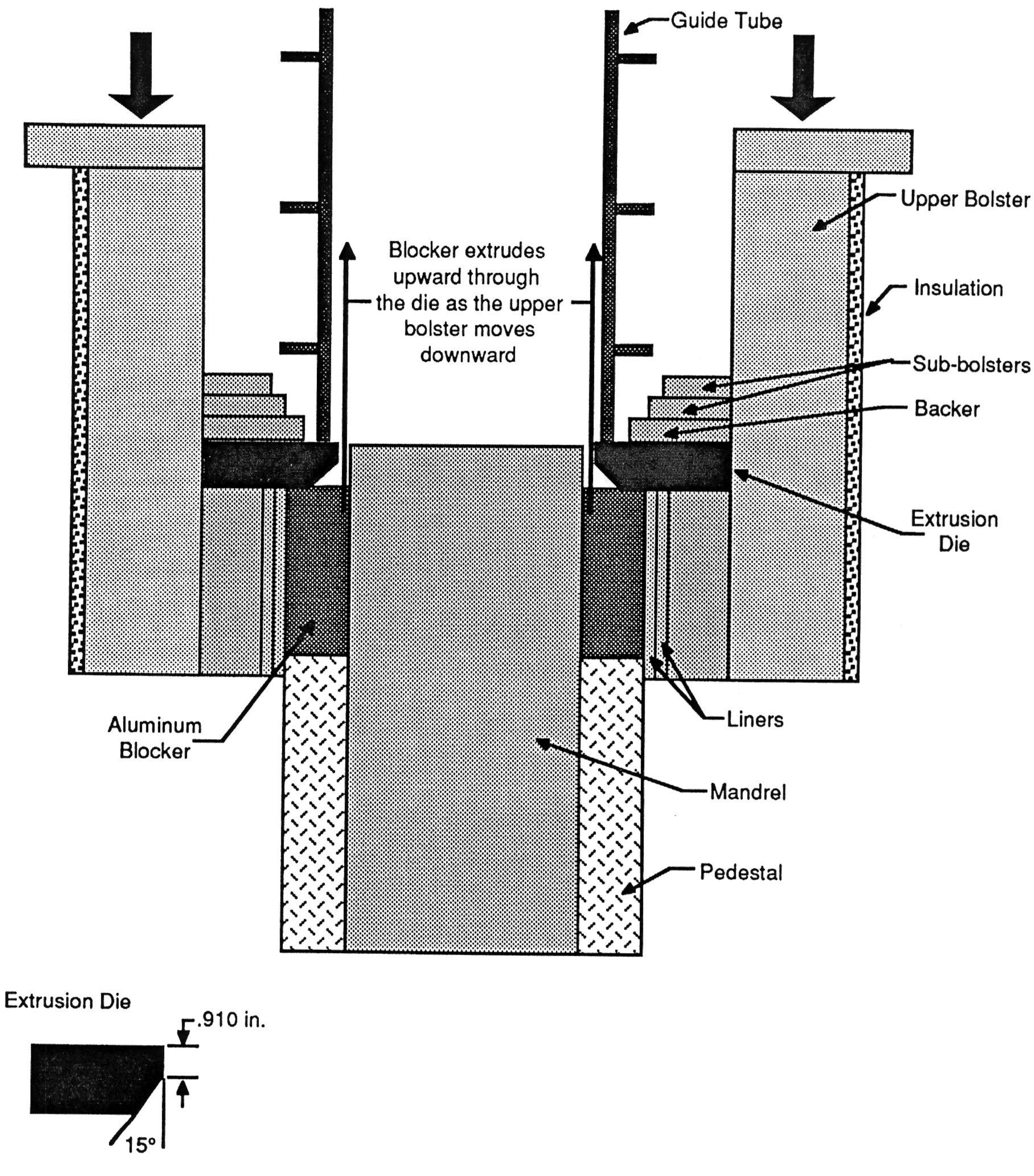

Figure 3. The Vertical Extrusion Process using Wyman Gordon's 35,000 Ton Press

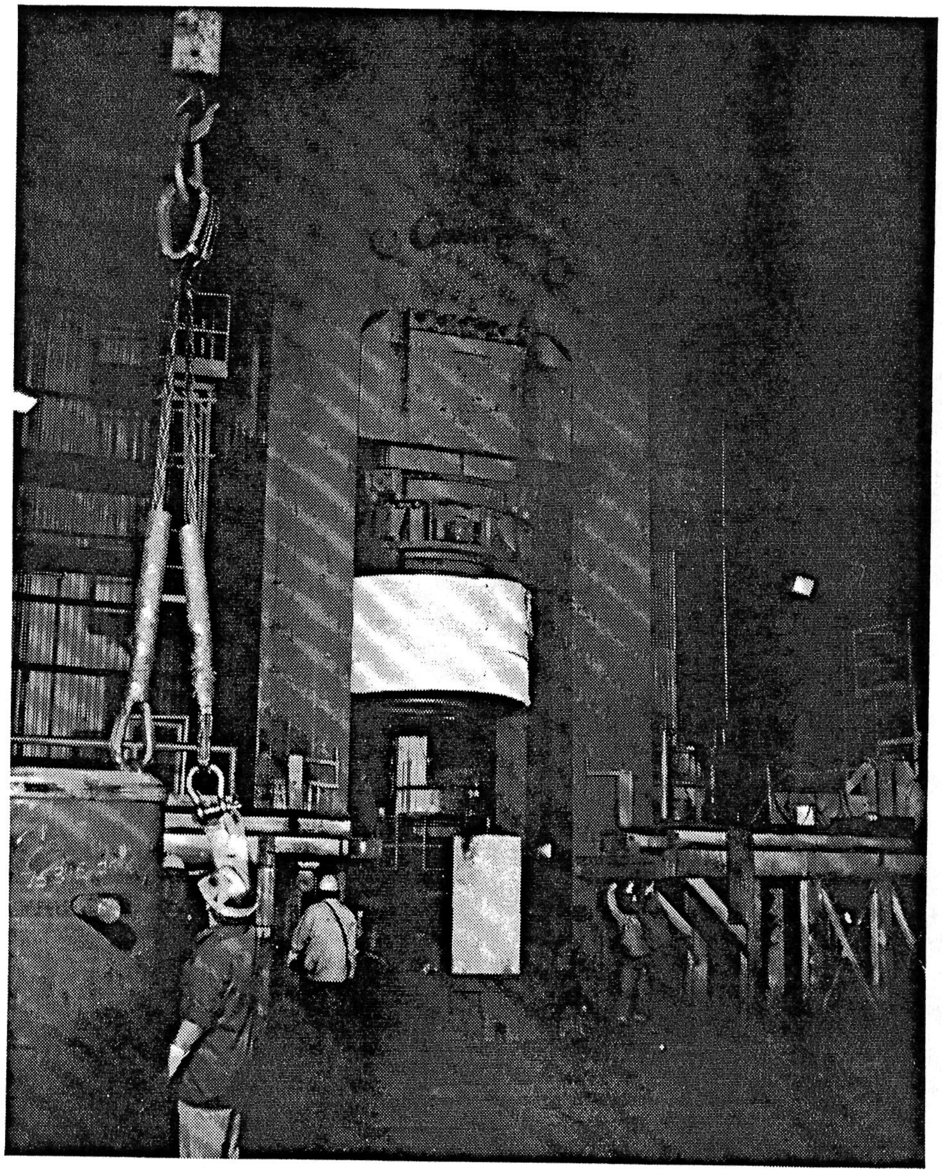

Figure 4. View of the Press with the Upper Bolster Raised and the Pedestal Ready for Insertion

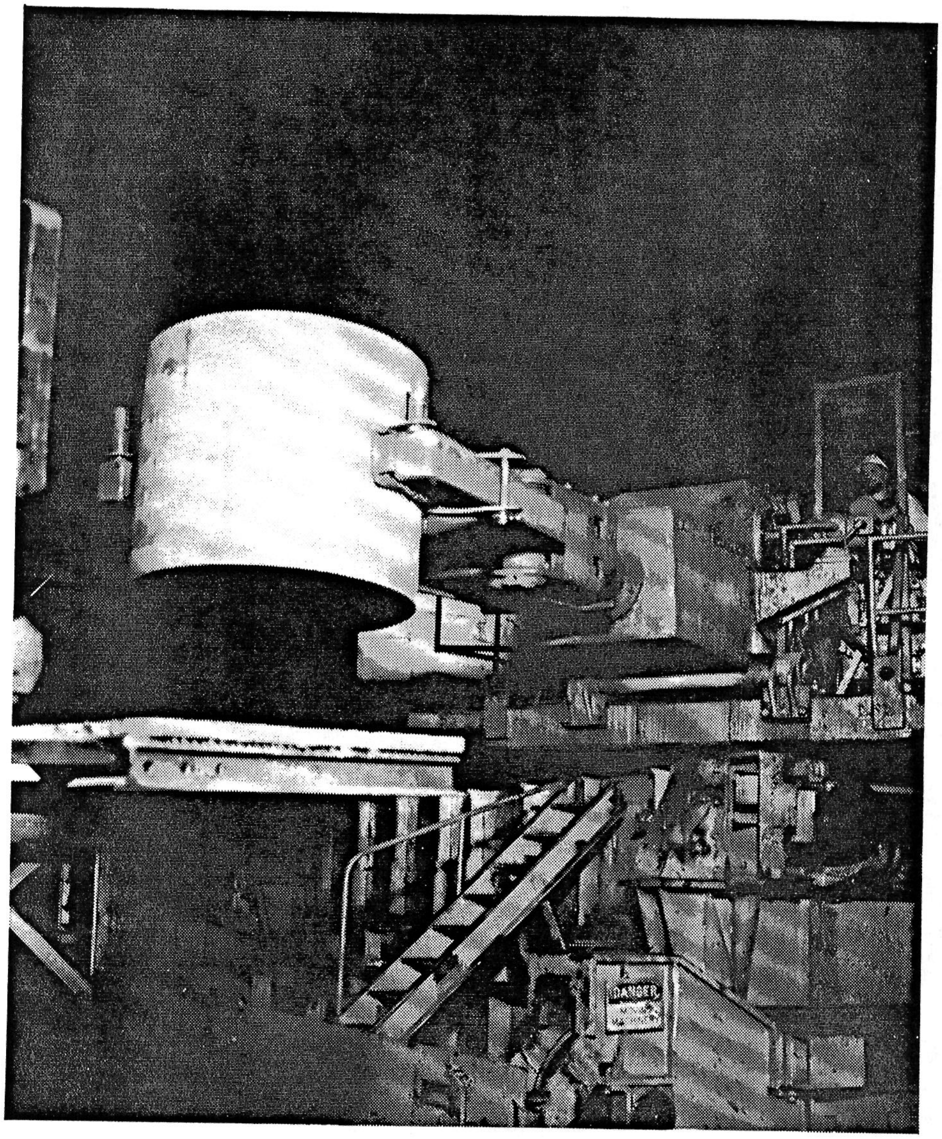

Figure 5. The 2219 Blocker Being Removed from the Furnace

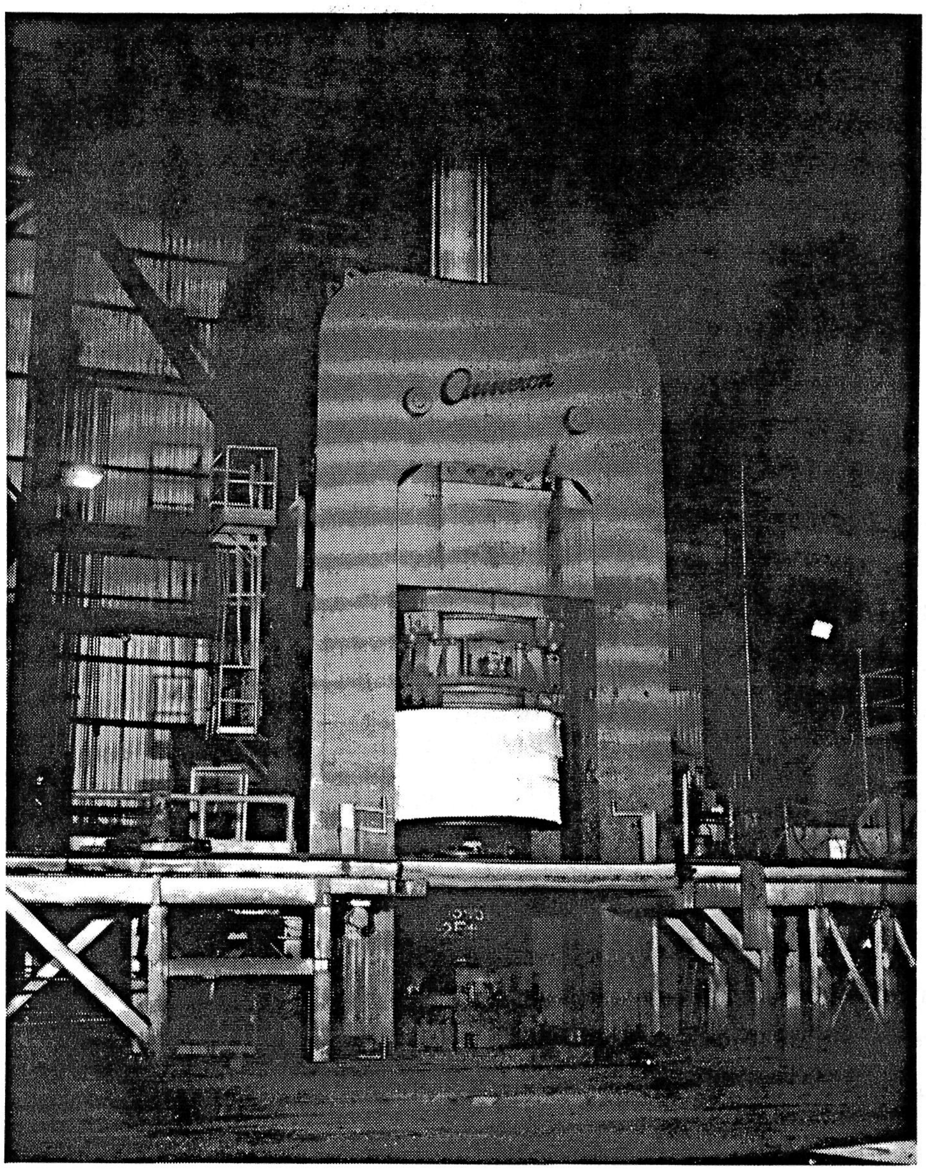

Figure 6. An Extrusion as it is Exiting the Press

1) The extrusion die, die backer and sub-bolsters were heated in a furnace to approximately 900°F. The mandrel was heated in a separate furnace to ~725°F while the pedestal was heated using an open flame to ~400°F. The upper bolster was heated to ~725°F using a specially designed heating element that fit inside the bolster. The blockers, heated to the temperatures in Table 3, were equipped with thermocouples to accurately monitor their surface temperature. The pedestal and upper bolster temperatures were verified with a pyrometer. The temperature of all other components were monitored by way of load thermocouples placed in the furnace (not in direct contact with the part).

2) All dies and associated tooling were removed from the furnaces and placed onto the press in a timely manner. Efficiency in placing the tooling is required in order to minimize heat loss. As the tooling temperature drops the probability of successfully extruding is also reduced. Tooling was aligned within the press as shown in Figure 4.

3) The blockers were removed from the furnace, as presented in Figure 5, and placed on the pedestal. The blockers were not lubricated.

4) The entire support frame of the press moved downward with a ram speed of 4-5 inches per minute, while the blocker extruded upward through the die. An extrusion, as it is exiting the top of the press, is illustrated in Figure 6. The tees and membrane were formed through the 0.910" bearing surface of the die. After the majority of the blocker was extruded, the press was opened and a 2219 lubricated slug (a few inches thick) was placed on the pedestal directly in contact with the blocker. The extrusion process resumed until all of the main blocker material (2219, 2195, RX 818 or 2096) was extruded. The purpose of this step is to enable all of the main blocker material to extrude through the die in order to maximize material yield. The lubricant on the 2219 slug acts as a parting plane such that when the extrusion is grabbed from the top of the press the two materials part cleanly (this did not always happen).

Table 3 summarizes the relevant data obtained for the extruded cylinders. This includes the finish length, breakthrough pressure and die and liner temperatures. Generally, eight to 12 feet of scrap were cut from the ends of the extrusions to yield the finish lengths (as shipped to Ticorm).

Table 3. Summary of Extrusion Information

Alloy	Serial Number	Extrusion Finish Length (in)	Breakthrough Pressure (lbs)	Blocker Temp (°F)	Liner Temp. (°F)	Date Extruded
2219		120	20,000	850	800	11/15/93
2195	56634-1 and -2	255	28,000	775	725	1/17/94
RX 818	57103	120	23,800	750	-	8/8/94
2096	57233	165	23,036	750	-	9/19/94

5.1 2219 Extrusion

The 2219 extrusion was successfully produced. This was the first time that the additional 2219 slug was used to part the extrusion from the die. Additionally, a mechanized overhead gripper was also employed to guide the extrusion out of the press and eventually lay it in a pit next to the press for visual inspection.

5.2 2195 Extrusion

While extruding the 2195 blocker, two problems arose. First, there was an unexplainable loss of pressure about 1/3 of the way into the push. Wyman Gordon claimed that this had not happened before but that the press was due for servicing in the next several weeks and that the problem would be identified and resolved. (This phenomenon has not been experienced since by Wyman Gordon.) As a result of the momentary press shutdown, there was a ring around the circumference of the extrusion approximately two inches wide. In this area, the thickness was slightly built-up and the tees were somewhat distorted. When pressure was restored, the remainder of the extrusion was successfully produced. The surface finish of the extrusion was exceptionally nice, as were all of the extrusions produced for this program. The finish is shiny and relatively defect free.

The second concern arose when the extrusion was gripped for removal from the press. The overhead gripper envelopes the outer periphery of the extrusion and an inward force is applied so that the extrusion can be lifted away from the press. The pressure was so great that the top 8-10 feet of the extrusion were completely destroyed.

5.3 RX 818

The RX 818 extrusion was successfully produced with only a minor glitch. After the 2219 slug was placed into the press and the final push was applied, the overhead gripper did not exert an upward force equivalent to the ram force. Consequently, the bottom section of the extrusion went into compression and was slightly rippled. Additionally, the bottom of the extrusion had a very jagged look indicative of a disproportionate flow of metal through the die as illustrated in Figure 7. Also visible in this figure is the parting plane between the 2219 slug and the RX 818.

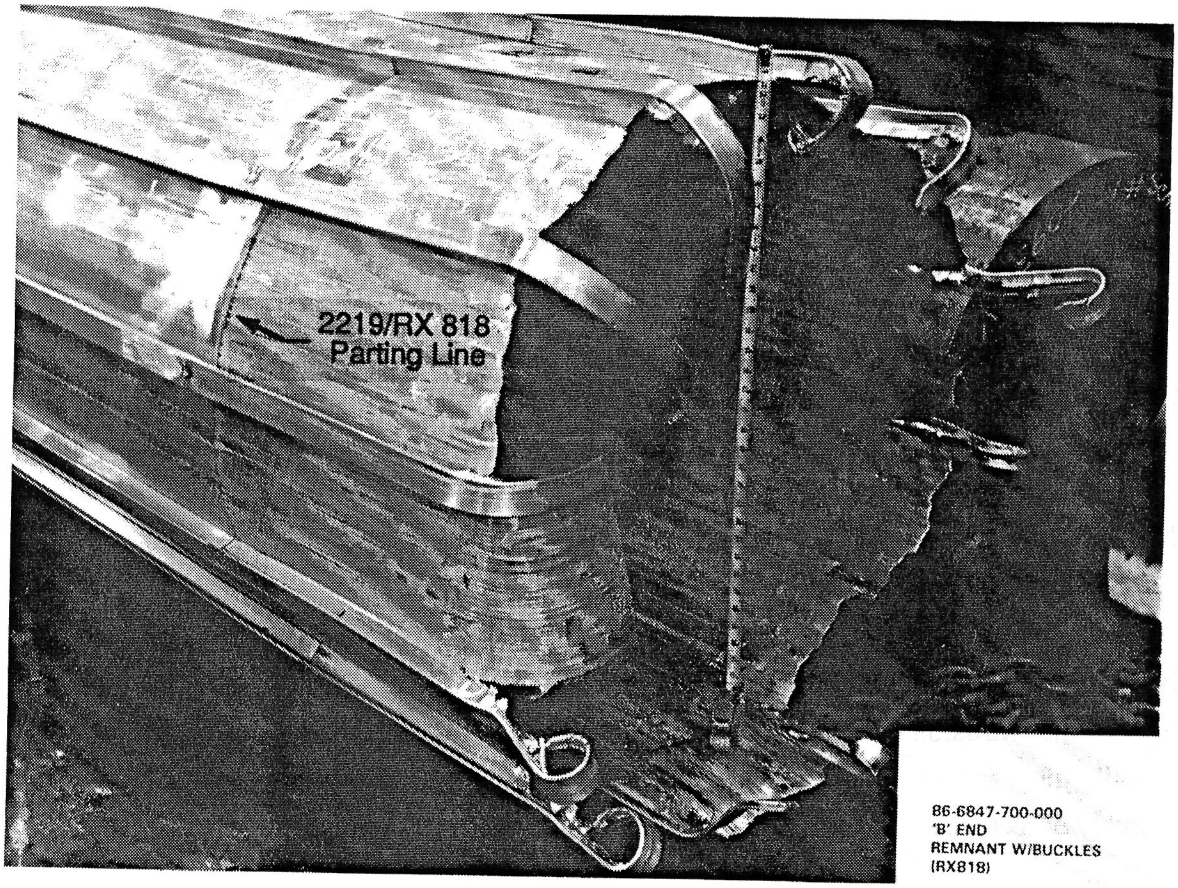

Figure 7. The Bottom of the RX 818 Extrusion Illustrating the Jagged Edges and Parting Line

5.4 2096

The 2096 was the final alloy extruded in this program. The extrusion process went very smoothly and again the breakthrough pressure was well below the capacity of the press. As with the RX 818 extrusion, some problems were encountered while gripping and removing the extrusion from the press. The grabber came in contact with the extrusion prematurely which resulted in dents and scratches on the top seven feet. Again, the top 7-8 feet were also crushed as a result of the grabber. There was also minor blistering on the top section as illustrated in Figure 8. This condition results from faster than optimal extrusion speed and is normally not a major concern. Blistering has been seen in many of the Al and Al-Li extrusions produced under the ALS program and Lockheed Martin internal research and development programs. Finally in Figure 9 is the final trimmed extrusion as it was shipped to Ticorm for further processing.

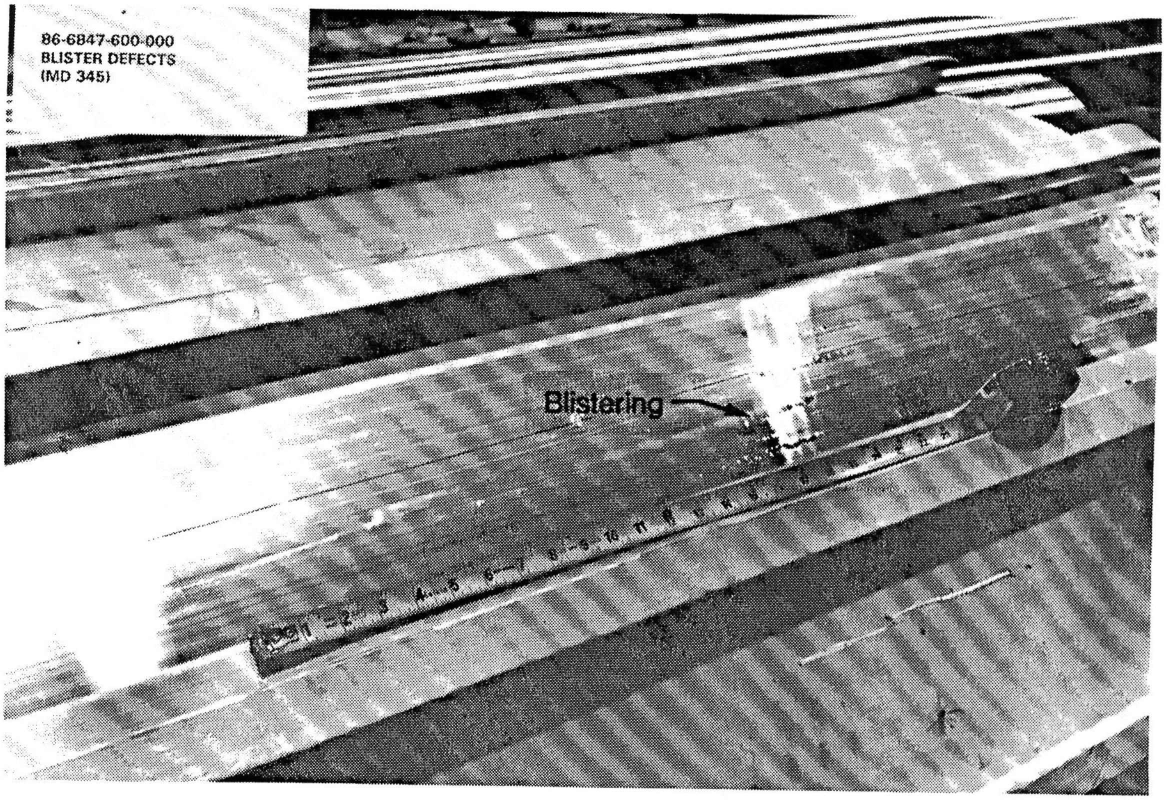

Figure 8. Blistered Surface of the 2096 Extrusion

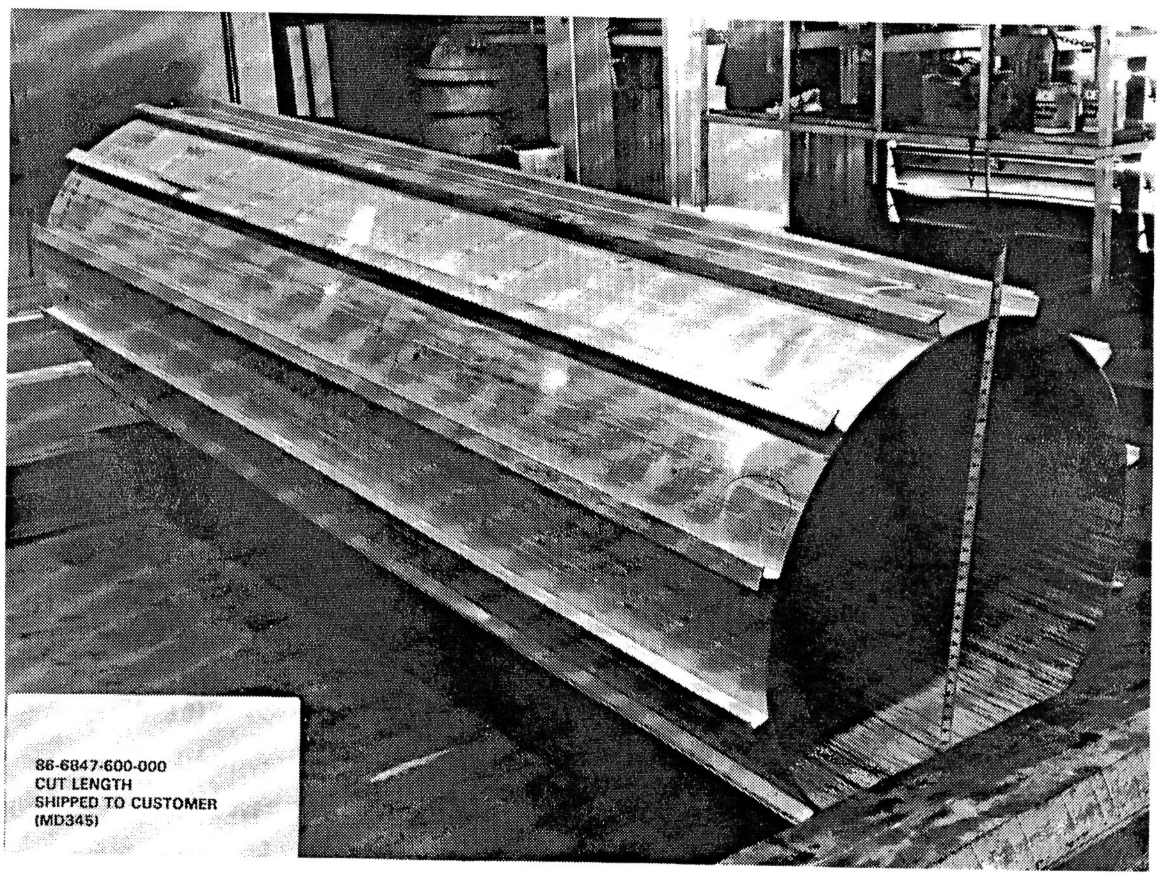

Figure 9. Final Trimmed 2096 Extrusion

5.5 RX 818 and 2096 Measurements

Extensive measurements were taken on the RX 818 and 2096 extrusions to determine inner and outer diameter, wall thickness and tee dimensions. These data are presented in Tables 4 and 5 with the measurement locations as illustrated in Figure 10. Clock orientation of the extrusions was maintained at all times and measurements were made with a ball tip micrometer. The tee's directly to the right of the membrane correspond to the same clock orientation.

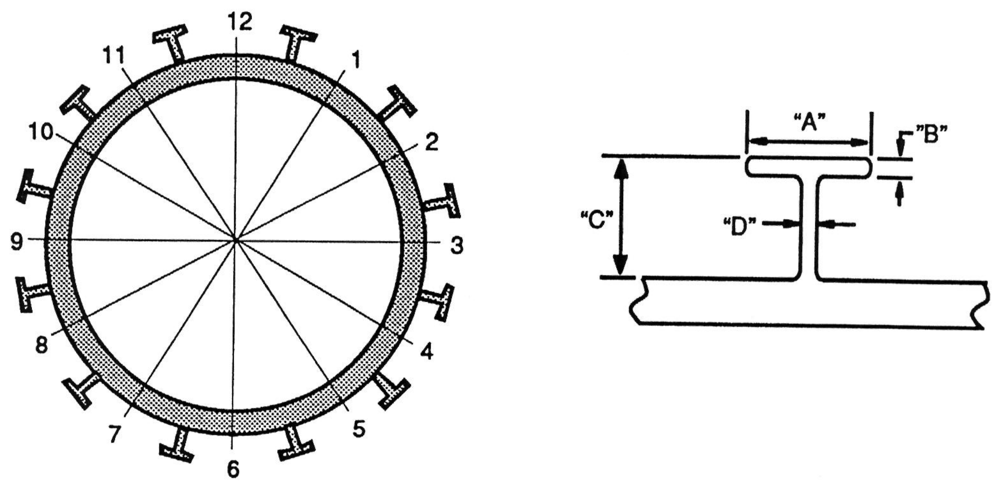

Figure 10. Location of Thickness and Diameter Measurements

The A and B ends (which are different from the "A" and "B" dimensions of the tee sketch in Figure 10) represents the top (exited the press first) and bottom of the extrusion, respectively. Measurements were averaged around the circumference of the extrusion and then the variation in measurements from the A to the B end were calculated (based on averages). Generally, the variability in the tee dimensions around the extrusion and from end to end was negligible. The thickness of the base and the height of the tee's deviated substantially from drawing dimensions and the height of the tee's for the RX 818 extrusion were significantly higher than those for the 2096. (1.524 vs. 1.506 inches)

Although complete dimensional check of the inner and outer diameter was not conducted for both alloys, the data presented for the RX 818 extrusion indicates that the variability around the A end was as much as 0.500 inch while on the B end the difference decreased to 0.138 inch. This may indicate that the extrusion became more uniform as the process stabilized. Wall thickness measurements for both extrusions indicate that the thickness decreases down the length of the extrusions, for the RX 818 it decreased from 0.296 to 0.287 inch and for the 2096 from 0.306 to 0.287 inch. The wall thickness variability around the circumference was minor. In all cases the measured membrane thickness was less than the drawing thickness of 0.320 inch.

Table 4. Measurements for the 2096 Extrusion

End	Location	"A" (in)	"B" (in)	"C" (in)	"D" (in)	Max OD (in)	Max ID (in)	Wall Thick. (in)
A	1	1.507	0.200	1.517	0.143	34.365	33.740	0.315
	2	1.500	0.198	1.500	0.143	33.690	33.084	0.300
	3	1.482	0.193	1.497	0.144	34.060	33.482	0.298
	4	1.486	0.191	1.498	0.136	34.000	33.378	0.305
	5	1.480	0.188	1.504	0.133	33.652	33.072	0.315
	6	1.490	0.190	1.514	0.133			0.323
	7	1.495	0.198	1.498	0.141			0.310
	8	1.500	0.195	1.501	0.139			0.302
	9	1.495	0.193	1.529	0.136			0.298
	10	1.498	0.200	1.496	0.136			0.294
	11	1.497	0.193	1.517	0.134			0.297
	12	1.501	0.202	1.512	0.143			0.311
	Average	**1.494**	**0.195**	**1.507**	**0.138**	**33.953**	**33.351**	**0.306**
	Std. Dev.	**0.008**	**0.004**	**0.011**	**0.004**	**0.293**	**0.282**	**0.009**
B	1	1.501	0.195	1.497	0.132	34.265	33.507	0.284
	2	1.500	0.194	1.518	0.130	34.025	33.387	0.281
	3	1.496	0.196	1.509	0.139	33.935	33.401	0.270
	4	1.494	0.195	1.496	0.136	34.031	33.462	0.275
	5	1.479	0.193	1.493	0.125	34.271	33.688	0.290
	6	1.467	0.188	1.509	0.123			0.312
	7	1.474	0.189	1.513	0.129			0.312
	8	1.490	0.196	1.494	0.140			0.293
	9	1.496	0.202	1.517	0.137			0.284
	10	1.505	0.202	1.528	0.136			0.280
	11	1.501	0.201	1.502	0.140			0.280
	12	1.498	0.195	1.487	0.130			0.281
	Average	**1.492**	**0.196**	**1.505**	**0.133**	**34.105**	**33.489**	**0.287**
	Std. Dev.	**0.012**	**0.005**	**0.012**	**0.006**	**0.153**	**0.121**	**0.013**
	Average of A-B	**0.002**	**0.000**	**0.002**	**0.005**	**-0.152**	**-0.150**	**0.019**

Table 5. Measurements for the RX 818 Extrusion

End	Location	"A" (In)	"B" (In)	"C" (In)	"D" (In)	Max OD (In)	Min OD (In)	Max ID (In)	Min ID (In)	Wall Thick (In).
A	1	1.483	0.201	1.526	0.141	33.950	33.667	33.371	33.095	0.274
	2	1.495	0.191	1.514	0.130	34.062	33.580	33.543	33.018	0.278
	3	1.490	0.197	1.538	0.137	34.950	34.370	34.312	33.802	0.283
	4	1.482	0.191	1.507	0.136	34.890	34.074	34.250	33.527	0.286
	5	1.483	0.187	1.505	0.130	33.705	33.530	33.180	32.947	0.292
	6	1.491	0.193	1.507	0.131	34.014	33.810	33.403	33.197	0.300
	7	1.497	0.194	1.518	0.138	33.950	33.667	33.371	33.095	0.308
	8	1.491	0.192	1.520	0.134	34.062	33.580	33.543	33.018	0.317
	9	1.489	0.192	1.525	0.129	34.950	34.370	34.312	33.802	0.313
	10	1.493	0.191	1.572	0.133	34.890	34.074	34.250	33.527	0.314
	11	1.493	0.192	1.537	0.132	33.705	33.530	33.180	32.947	0.297
	12	1.480	0.199		0.146	34.014	33.810	33.403	33.197	0.285
	Average	**1.489**	**0.193**	**1.524**	**0.135**	**34.262**	**33.839**	**33.677**	**33.264**	**0.296**
	Std. Dev.	**0.006**	**0.004**	**0.019**	**0.005**	**0.500**	**0.310**	**0.460**	**0.317**	**0.015**
B	1	1.500	0.200	1.522	0.137	34.150	34.042	33.587	33.467	0.284
	2	1.486	0.194	1.508	0.132	34.249	34.171	33.655	33.600	0.292
	3	1.472	0.189	1.505	0.131	34.260	34.165	33.702	33.617	0.302
	4	1.470	0.185	1.501	0.124	34.302	34.027	33.723	33.452	0.300
	5	1.476	0.186	1.535	0.127	33.956	33.890	33.376	33.334	0.294
	6	1.492	0.192	1.532	0.128	34.002	33.934	33.431	33.375	0.292
	7	1.507	0.196	1.525	0.136	34.150	34.042	33.587	33.467	0.279
	8	1.504	0.193	1.523	0.131	34.249	34.171	33.655	33.600	0.279
	9	1.500	0.194	1.531	0.128	34.260	34.165	33.702	33.617	0.277
	10	1.503	0.197	1.526	0.131	34.302	34.027	33.723	33.452	0.279
	11	1.506	0.193	1.545	0.133	33.956	33.890	33.376	33.334	0.279
	12	1.504	0.200	-	0.143	34.002	33.934	33.431	33.375	0.281
	Average	**1.493**	**0.193**	**1.523**	**0.132**	**34.153**	**34.038**	**33.579**	**33.474**	**0.287**
	Std. Dev.	**0.014**	**0.005**	**0.013**	**0.005**	**0.138**	**0.110**	**0.138**	**0.110**	**0.009**
	Average of A-B	**-0.004**	**0.000**	**0.001**	**0.003**	**0.109**	**-0.200**	**0.098**	**-0.210**	**0.009**

6.0 THE FLATTENING PROCESS

The extrusions were flattened at Ticorm in Gardena, CA. Ticorm developed this cold forming operation under the ALS program. The as-extruded tubes were first cut length-wise between two tees. Next, two holes were drilled along each outside-edge, approximately one inch from the edge and hooks were inserted. Using a crude pulley-type set-up, the extrusions were opened up into a U-shape. The extrusions were then placed in a large reverse-bump forming machine, as illustrated in Figure's 11 and 12, where they were incrementally flattened.

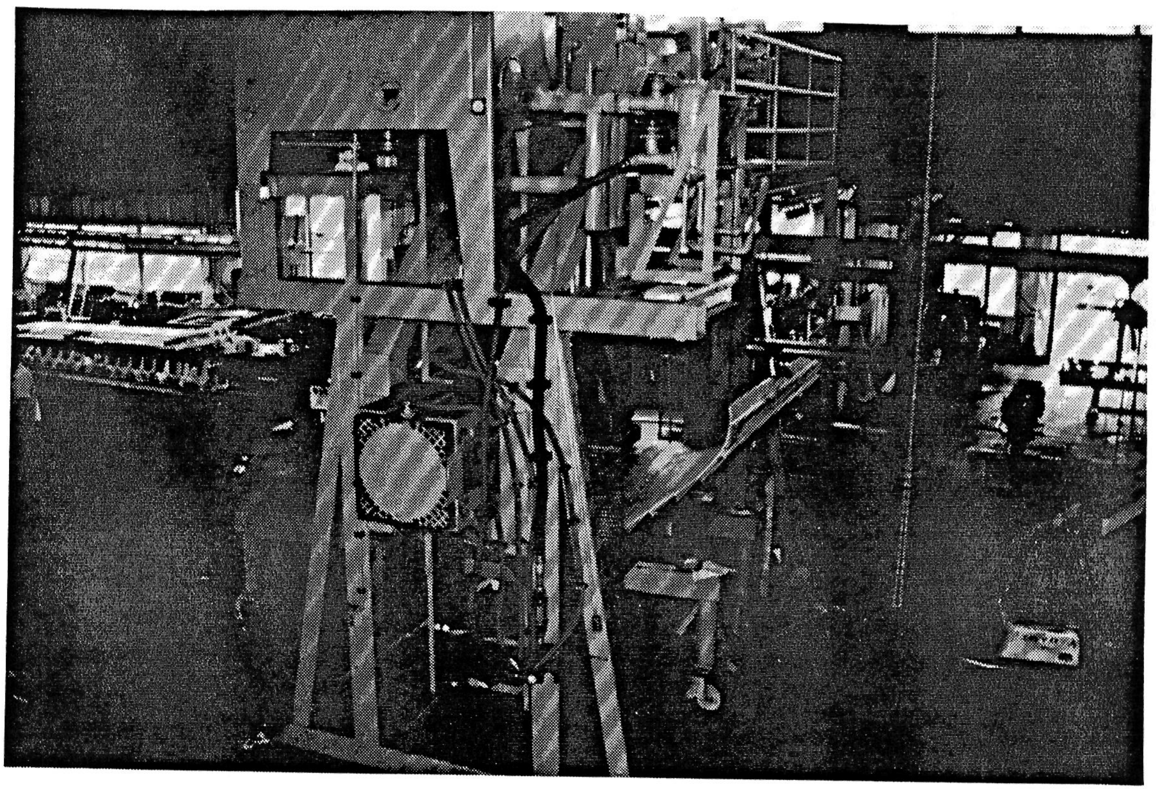

Figure 11. Bump Press used to Flatten the Cylindrical Extrusions

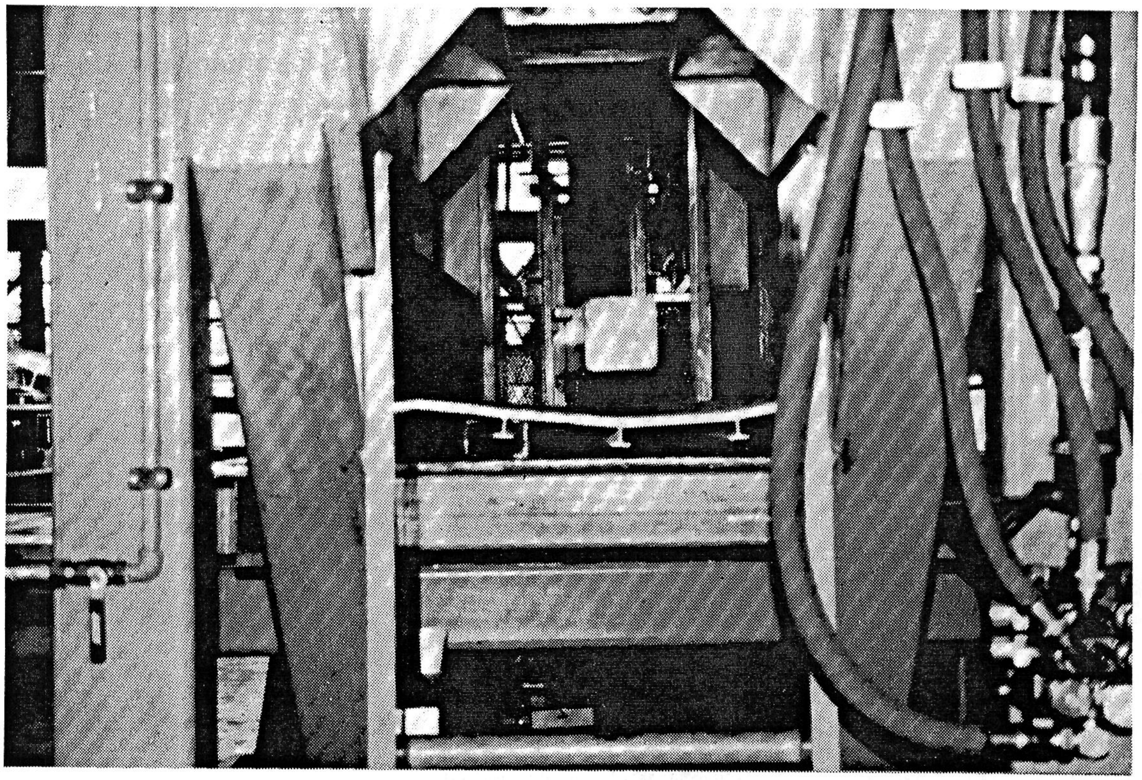

Figure 12. Close-up of Extrusion Tee Being Flattened

7.0 SOLUTION HEAT TREAT AND STRETCHING

The panels were solution heat treated and stretched a nominal 3.5 % at RMC in McCook, IL. (A section of each extrusion will be retained in the F temper for metallurgical evaluations.) The stretching process was conducted by inserting Al 7075 spacers between each of the tees before solution heat treat (SHT), as illustrated in Figure 13. This was done so that the stretcher jaws could grab not only the panel's membrane but also the tees themselves. This allows for a more uniform stretch throughout the length of the extrusion and as such, more consistent mechanical and toughness properties. Presented in Table 6 are recorded SHT parameters and the measured permanent stretch in various locations. Permanent stretch was measured by placing 10 inch fiduciary marks at the leading edge (LE), middle and trailing edge (TE) of the extrusion on both the tops of the tees and on the membrane. The fiduciary marks were equally placed across the width of the panels in three locations, the two outside edges and the middle; eighteen total locations were measured. The data in the table are presented for each alloy at either the LE, middle or TE with the values presented as edge, center, edge (in that order).

Each of the extrusions were solution heat treated and quenched in the horizontal position. The leading edge of the panels entered the furnace and spray quench medium first. As expected, the solution heat treat and quench process went very smooth. Some minor distortion did result from the quench operation. Although no photographs are available for the panels processed during this time, a videotape of the 2195-01, 2195-02 and the 2096 is available from the author.

It is necessary to make two general comments regarding the stretching operation. Two of the parts, the 2195-01 and the RX 818, had tooling holes at various locations along the length and near the edge that were used during the flattening process, small cracks propagated from these holes during stretching. The second problem encountered with this process was obtaining a good fit of the spacers in between the tees. Each of the extrusions exhibited some degree of twist and slight variations in the distance between the tees and the distance from the membrane to the under side of the tees. As a result, some of the spacers fit very loosely and some were quite tight. Consequently, stretcher "slippage" occurred which resulted in a variation of permanent set in the panel.

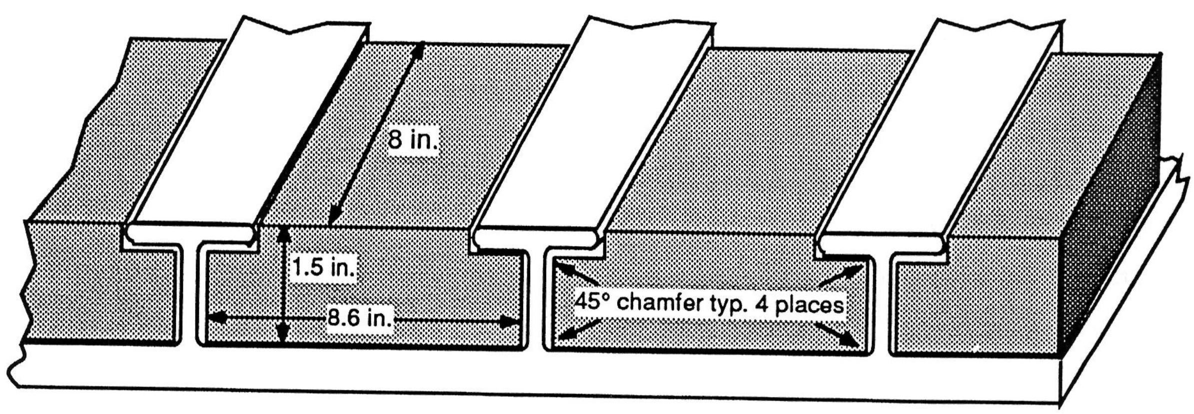

Figure 13. Location of Spacers in Extruded Panel for Stretching Operation

Table 6. Solution Heat Treat Parameters and Permanent Stretch Measurements

	Measure. Location	2219	2195-01	2195-02	RX 818	2096
Process Date		May 10, 1995	March 3, 1995	June 9, 1995	May 24, 1995	April 24 & June 9, 1995
SHT Temp (°F)		995	950	950	980	980
SHT Time (min.)		60	60	60	60	60
LE	Top of Tee	6.3, 8.1, -	2.25, 3.75, 1.75	3.35, 3.75, 3.30	1.5, 1.46, 1.58	2.00, 2.70, 3.60
	Membrane	6.3, 6.5, -	1.72, 3.38, 2.70	2.50, 3.70, 3.50	1.5, 1.01, 1.55	2.00, 2.92, 3.60
Middle	Top of Tee	6.4, 7.2, -	2.85, 3.72, 3.00	3.70, 3.45, 3.30	1.65, 1.82, 1.48	1.75, 3.10, 3.65
	Membrane	6.8, 7.2, -	3.15, 4.12, 3.35	3.30, 3.45, 3.50	1.94, 1.97, 1.57	1.75, 3.15, 3.65
TE	Top of Tee	6.8, 7.1, -	3.82, 3.35, 3.05	3.25, 3.20, 3.50	1.44, 1.38, 1.50	2.00, 2.70, 3.60
	Membrane	6.8, 7.4, -	3.40, 3.35, 3.05	3.25, 3.20, 3.30	1.49, 1.32, 1.85	1.48, 2.90, 4.25

7.1 2195-01

The first panel that was processed was the 2195-01. Measurements at the top of the tee and at the membrane for the middle of the panel and at the trailing edge were quite consistent. On average, the permanent stretch in the middle was $3.19 \pm 0.47\%$ and $3.54 \pm 0.51\%$ for the top of the tee and membrane, respectively, while at the trailing edge the top of the tee and membrane measured $3.4 \pm 0.38\%$ and $3.26 \pm 0.19\%$, respectively. In contrast the average values for the leading edge on the top of the tee and membrane were $2.58 \pm 1.04\%$ and $2.6 \pm 0.83\%$, respectively. Not only was the permanent strain significantly less in the leading edge, but the variation from tee to membrane and across the width was also substantial. Generally, the cold work induced into the membrane was relatively close to that induced into the tee. There was again however, a large variance across the leading edge. A small crack propagated from one of the tooling holes and ran to the outside edge of the panel, approximately one inch in length. Since this happened at the end of the process, it did not prevent RMC from achieving the required stretch level.

7.2 2195-02

Processing of the 2195-02 panel was quite successful. This, in part, is attributed to the learning curve associated with this process. The average permanent set in the overall part was 3.36 ± 0.28%. The average stretch in the tee and membrane was 3.4 ± 0.19% and 3.3 ± 0.34 %, respectively.

7.3 RX 818

Due to a crack propagating early in the stretch process, the RX 818 did not receive the desired stretch. As in the 2195-02 panel, the measured cold work was quite consistent in the panel. The average stretch in the tees and membrane was 1.53 ± 0.13% and 1.57 ± 0.31 %, respectively, with the average stretch throughout being 1.56 ± 0.23%. If this panel had been longer, it would have been reprocessed as was the 2096.

7.4 2096

The 2096 extrusion posed the most problems while stretching. In a large portion of the panel, the Al 7075 inserts extended slightly above the tops of the tees and as a result, the stretcher jaws were unable to adequately grab the panel. Consequently, stretcher "slippage" occurred and only about 25% of the panel received the required stretch. Additionally, the parting line between the area that received no stretch and that which received approximately 3.5% developed a small tear. The stretching processes was terminated as soon as this tear was identified. As a result of this, the panel was re-solution heat treated and restretched and those are the values that are presented in Table 6. The consistency of stretch throughout this extrusion was disappointing. As is evident in the data, the two outside edges of the extrusion had quite different stretch levels, approximately 1.83% on one side and 3.73% on the other. There was however agreement between the tops of the tees and the membrane for most of the extrusion.

7.5 2219

The 2219 panel was stretched to ultimately achieve the T87 temper. This was done so that direct comparisons between the Al-Li alloys and the baselined cryogenic tank material, 2219-T87, can be made during the testing. As shown in the table, measurements were only made on one side and in the center of the 2219 panel. The permanent stretch did meet the requirements of 6 to 8 %

cold work. Except for the measurements in the middle of the panel at the leading edge, the measurements for the tops of the tees and at the membrane were quite consistent.

8.0 CONCLUSIONS

1) All alloys were amenable to the forging and extrusion processes.

2) The dimensional data gathered for the RX 818 and 2096 extrusions indicate that a) the variability of the tees around the circumference and along the length were consistent, b) the measured thickness of the base and the height of the tees was substantially less than the drawing dimensions and varied considerably between the two alloys, c) the wall thickness decreased down the length of the extrusion but remained relatively constant around the periphery and d) the inner and outer diameters of the extrusions became more consistent near the "B" end of the extrusions.

3) The stretching technique employed in this program, although successful, was too sensitive to final extrusion condition.

9.0 RECOMMENDATIONS

1) Conduct mechanical, fracture toughness, corrosion and microstructural evaluation of the extrusions.

2) Determine the chemical composition of the wrought products.

3) Conduct dimension checks on each of the extrusions to determine flatness, tee parallelism, general warpage and membrane thickness.

10.0 REFERENCES

(1) Final Report - Development & Manufacture of Advanced Cryogenic Tank, NLS ADP #3106, May 28, 1993.

(2) Sisk, Dave, Contact Report # CTTP-LIB-1339, January 21, 1994.

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13. ABSTRACT *(Maximum 200 words)*

In the late 1980's, under funding from the Advanced Launch System Program, numerous near net shape technologies were investigated as a means for producing high quality, low cost Aluminum-Lithium (Al-Li) hardware. Once such option was to extrude near net shape barrel panels instead of producing panels by machining thick plate into a final tee-stiffened configuration (which produced up to 90% scrap). This method offers a reduction in the volume of scrap and consequently reduces the buy-to-fly cost. Investigation into this technology continued under Shuttle-C funding where four Al alloys 2219, 2195, 2096, and RX 818 were extruded. Presented herein are the results of that program. Each alloy was successfully extruded at Wyman Gordon, opened and flattened at Ticorm, and solution heat treated and stretched at Reynolds Metals Company. The first two processes were quite successful while the stretching process did offer some challenges. Due to the configuration of the panels and the stretch press set-up, it was difficult to induce a consistent percentage of cold work throughout the length and width of each panel. The effects of this variation will be assessed in the test program to be conducted at a future date.

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