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Evaluation of the Dissolution Behavior of L-Bundle End Caps and HFIR Fuel Carriers

W. E. Daniel

T. S. Rudisill

J. I. Mickalonis

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REVIEWS AND APPROVALS

AUTHORS:

____

W. E. Daniel, Chemical Flowsheet Development Date

____

T. S. Rudisill, Separations Science and Technology Date

____

J. I. Mickalonis, Applied Materials Research Date

TECHNICAL REVIEW:

____

E. E. Perez, Actinide Materials Science and Technology, Reviewed per E7 2.60 Date

____

W. H. Clifton Jr., H-Canyon Outside Facilities & Technical Support Date

APPROVAL:

____

J. M. Duffey, Manager Date
Separations Science and Technology

____

S. D. Fink, Director Date
Chemical Processing Sciences

____

T. L. Tice, Manager Date
H-Canyon Outside Facilities & Engineering

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EXECUTIVE SUMMARY

The H-Canyon facility is currently using the 6.1D dissolver for the dissolution of Material Test Reactor (MTR) fuel and the 6.4D dissolver for the dissolution of High Flux Isotope Reactor (HFIR) fuel using mercury-catalyzed HNO_3 dissolution flowsheets. The processing strategy for both dissolvers involves the dissolution of multiple charges of fuel per batch. After the designated heating cycle, the dissolvers are opened, and the charging wells are probed to determine if the MTR or HFIR fuel has dissolved. If undissolved fuel fragments are beyond a certain height, the dissolver must be closed and heated for an additional amount of time to dissolve the remaining material.

In recent MTR fuel dissolutions, "high probes" (i.e., excessive undissolved material) were frequently observed, which resulted in extended dissolution times. The suspected cause of the high probes was the incomplete dissolution of the L-Bundle End Cap, rather than the fuel or fuel bundles. The End Cap is hypothesized to be binding in the insert well and not dropping into the acid as the L-Bundle and fuel dissolve. Once the End Cap is dislodged by the probe and drops into the acid, the dissolution rate of the End Cap appears to be significantly reduced compared to the dissolution rate of the fuel and other parts of the L-Bundle. A similar issue has also been observed with the lifting bail on the HFIR fuel carriers. During HFIR fuel dissolutions, the lifting bail on the outer carrier has resulted in high probes due to incomplete dissolution. In one case, a partially dissolved bail was caught in one of the insert well holes which prevented the probe from going to the bottom of the well.

To address these issues, the Savannah River National Laboratory was requested to evaluate the dissolution behavior of the various components of the L-Bundle End Cap and the HFIR fuel outer carrier and correlate the component's metallurgical properties (i.e., grain size, hardness, etc.) with dissolution rate. An understanding of this relationship between the dissolution rate and the metallurgical properties of the materials may provide an approach to decrease fuel dissolution cycle times by changing the materials of construction or specifications used to fabricate the L-Bundle and HFIR fuel carriers.

Laboratory-scale experiments were performed to measure the dissolution rate of L-Bundle End Caps and a HFIR fuel outer carrier. Small coupons were cut from various components of the End Cap and the outer carrier. In previous work, the dissolution of Al alloys containing a lower percentage of Al (e.g., Al-6061-T6) proceeded at a slower rate than (commercially pure) Al-1100. The current work showed that the HFIR fuel outer carrier components (sidewall, lifting bail, lifting bail support bar, and lifting bail support band) fabricated from Al-6061 dissolved at a rate approximately two orders of magnitude slower (-3.9E-04 $g/cm^2/min$) than the Al-1100 alloy. The L-Bundle End Cap components (lifting bail and top plate) fabricated from Al-6061 also dissolved at a rate approximately two orders of magnitude slower (-3.4E-04 $g/cm^2/min$) than Al-1100. However, the End Cap sidewall fabricated from Al-6063 dissolved at a rate which was of the same order of magnitude (-3.9E-02 $g/cm^2/min$) as the Al-1100 alloy. An Al-6063 coupon had a similar dissolution rate to that of the End Cap sidewall and Al-1100.

The metallurgical analyses did not show any quantifiable dependence of the dissolution rate on the hardness or grain size of the different components of the L-Bundle End Cap and the HFIR fuel outer carrier. An investigation of the second-phase or intermetallic particles that are part of the Al alloy microstructures showed that the L-Bundle End Cap sidewall had the least particles. This observation was not consistent with observations for the Al-1100 and Al-6063 alloys which had a much higher particle count. The deposition of Hg, which was the catalyst for dissolution, onto the surfaces of the components was also investigated with the L-Bundle End Cap sidewall showing qualitatively the highest number of Hg particles. The deposition of Hg onto Al-1100 and Al-6063 coupons did not show similar results.

The results of this study show that higher dissolution rates are associated with Al alloys containing smaller quantities of alloying elements. This result is consistent with previous observations; however, data from this study extend this conclusion to include another major Al alloy, Al-6063, the material of construction for the End Cap sidewall. Several hypotheses are suggested for the variable rates observed during the dissolution of the End Cap and outer carrier components and Al alloy coupons, including changes to the solution reduction/oxidation potential during dissolution and the changes in the intermetallic particle characteristics as a function of Al alloy. Recommended testing for future studies includes electrochemical measurements of changes in the solution potential as well as more thorough surface analysis of partially dissolved coupons.

The results from this and previous studies demonstrate that Al alloys containing smaller amounts of alloying elements (e.g., Fe, Mg, Si, etc.) dissolve at a faster rate. Therefore, one option recommended for potentially increasing the dissolution rate of L-Bundle End Caps and HFIR fuel outer carrier components is the fabrication of these items from an Al alloy with lower impurities and alloy element concentrations. However, prior to selection of one of the Al alloys containing a higher percentage of Al, an engineering evaluation must be performed to determine if the mechanical properties (e.g., yield strength, tensile strength, elongation, etc.) are acceptable for fabrication of the End Cap and carriers.

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LIST OF ABBREVIATIONS

CMTR	Certified Material Test Report
EBS	Expanded Basin Storage
EDS	Energy Dispersive Spectroscopy
HFIR	High Flux Isotope Reactor
ID	Identification
LCM	Laser Confocal Microscope
MTR	Material Test Reactor
NIST	National Institute of Standards and Technology
Redox	Reduction/Oxidation
SCE	Saturated Calomel Electrode
SEM	Scanning Electron Microscope
S/N	Serial Number
SNF	Spent Nuclear Fuel
SRNL	Savannah River National Laboratory
XRD	X-ray Diffraction
XRF	X-ray Fluorescence

1.0 Introduction

The flowsheets currently used by the H-Canyon facility for the dissolution of Material Test Reactor (MTR) and High Flux Isotope Reactor (HFIR) fuels were developed by the Savannah River National Laboratory (SRNL) using an Al alloy (Al-1100) which provided a bounding estimate for H_2 generation.[1,2] Other Al alloys (Al-6061) and U-Al (30 wt % and 68.8 wt % U) alloys were also dissolved in laboratory experiments to confirm that Al-1100 provided the bounding H_2 gas generation rate. The observed dissolution rates of the Al and U-Al alloys vary based on the alloy composition and potentially the metallurgical properties. The Al-1100 alloy which contains the highest percentage of Al or the least amounts of alloying elements and impurities, dissolves at the highest rate. The other alloys which contain lower concentrations of Al (including the U-Al alloys) dissolve at much reduced rates. The slower dissolution rates may be correlated to metallurgical factors, such as grain size, secondary-phase or intermetallic particle characteristics (e.g., composition, size, distribution, etc.), the types of metal forming processes (e.g., rolling, extrusion, etc.) or the temper conditions (e.g., temperature, time, etc.).

Material Test Reactor fuels are stored in Al containers referred to as L-Bundles or Expanded Basin Storage (EBS) Bundles which are also used to transport the fuel from the L-Area storage basin to H-Canyon for reprocessing. L-Bundle carriers consist of a bottom Al tube and an End Cap that attaches to the tube using bendable tabs, which are secured once the fuel is loaded (Figure 1-1 (A)).[3,4] Figure 1-1 (B) shows a photograph of an L-Bundle carrier with MTR fuels being moved by crane using the lifting bail on the End Cap. Figure 1-2 shows photographs of the bottom of an L-Bundle carrier and an End Cap. The MTR fuels are fabricated as a flat or curved plate or other similarly formed fuel (a nested cylindrical configuration).

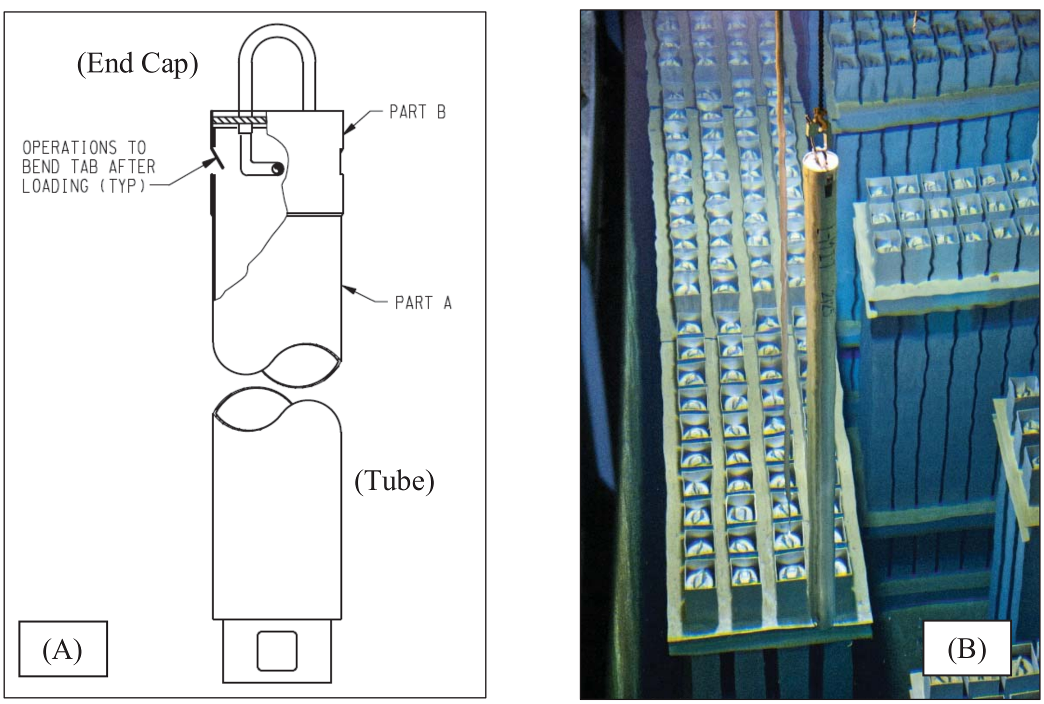

Figure 1-1. L-Bundle carrier for MTR fuels: (A) schematic of bundle and (B) view of carrier in storage basin

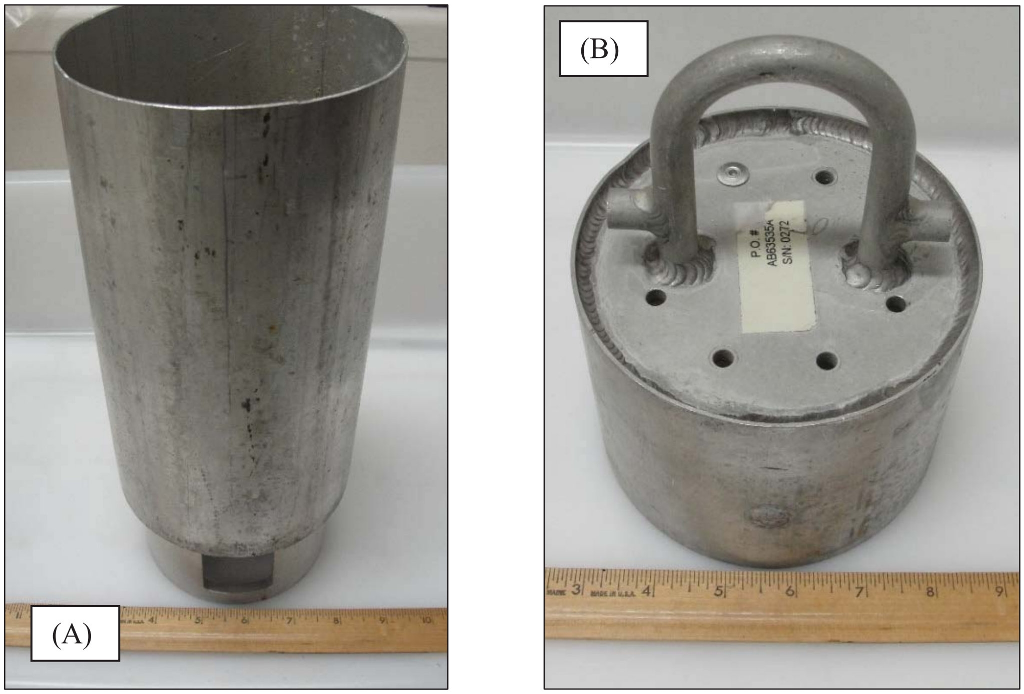

Figure 1-2. L-Bundle bottom (A) and End Cap (B) for MTR fuels

High Flux Isotope Reactor cores contain inner and outer fuel elements (Figure 1-3 (A)) which are positioned on inner and outer carriers once the fuel is received at the L-Area storage basin (Figure 1-3 (B)).[5,6] The HFIR fuel cores are fabricated as concentric cylinders with the fuel plates located in the annulus between the inner and outer cylinders. The HFIR fuel cores rest on their respective carriers and are moved using the lifting bails.

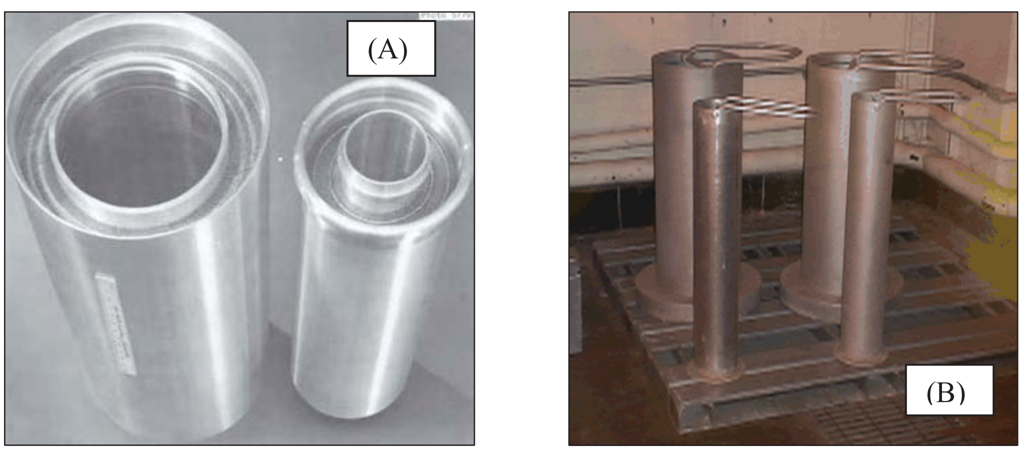

Figure 1-3. Inner and outer HFIR fuel elements (A) and their associated carriers (B)

During the dissolution of a HFIR or MTR fuel batch, complete dissolution of fuel/bundle material is assessed by probing the dissolver insert. When undissolved material is present, the probe will not travel all the way to the bottom of the insert which results in a “high” probe. The cause of high probes during the dissolution of MTR fuel is suspected to be that the L-Bundle End Cap is not dropping into the acid solution. In addition, once the End Cap is dislodged by the probe and falls into the solution, the dissolution rate is slower than other parts of the L-Bundle and fuel. This behavior is consistent with laboratory experiments performed to evaluate the impact of purchase order labels on L-Bundles and L-Bundle End Caps. During this work, it was noted that certain areas of the End Caps were more difficult to dissolve.[7] A similar issue has been observed with the lifting bail on the HFIR fuel carriers. During HFIR fuel dissolutions, the lifting bail on the outer carrier has resulted in high probes due to incomplete dissolution. In one case, a partially dissolved bail was caught in one of the insert well holes which prevented the probe from going to the bottom of the well.

1.1 Objective

The objective of this study was to evaluate the relationship between the dissolution rate and metallurgical properties of L-Bundle End Caps and HFIR fuel outer carriers. To examine how different alloys impact dissolution rates, experiments were performed using samples from two End Caps, samples from an outer carrier, and Al alloy corrosion coupons. The dissolution rates were measured in a nitric acid solution containing a Hg catalyst using conditions consistent with the flowsheets used for MTR and HFIR fuel dissolutions.[1,2] The metallurgical properties of samples of the same materials were measured to assess whether a correlation exists between the properties and dissolution rates. The metallurgical properties measured include hardness, grain size, alloy composition, and intermetallic particle types, distribution, and size. By developing an understanding of the relationship between the dissolution rate and the metallurgical properties of the materials used to fabricate the End Cap and HFIR fuel outer carrier, the information may provide an approach to decrease fuel dissolution cycle times by changing the materials of construction or specifications used to fabricate the L-Bundle and HFIR fuel carriers.

2.0 Experimental Procedure

2.1 L-Bundle End Cap and HFIR Fuel Outer Carrier Test Coupons

Samples of an L-Bundle End Cap (Figure 2-1 (A)) and a HFIR fuel outer carrier (Figure 2-1 (B)) were provided to SRNL by H-Canyon Engineering. Sample coupons of the End Cap and carrier were cut from various locations by electrical discharge machining to minimize the impact on metallurgical properties of the Al alloys. Several coupons of each type were cut since the dissolution testing and metallurgical characterization occurred concurrently.

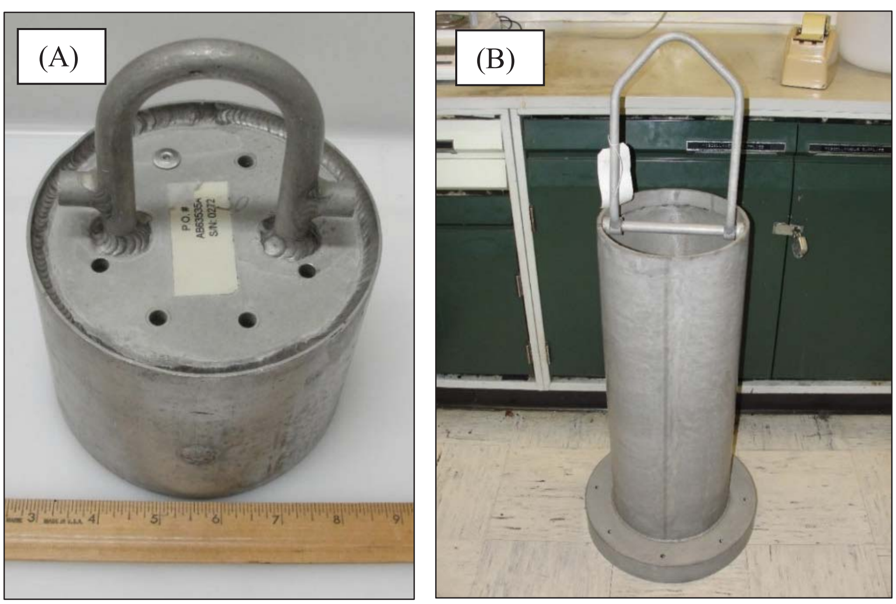

Figure 2-1. L-Bundle End Cap for MTR fuels (A) HFIR fuel outer carrier (B)

The cut locations and sample labeling for the L-Bundle End Cap coupon are shown in Figure 2-2. The End Cap coupons were labeled C for the straight sections of the lifting bail, D for the top plate, E for the sidewall, and F for the curved section of the lifting bail (Figure 2-2 (A)). Other descriptors (i.e., 1, 2, etc.) were added to identify the subsample from the various End Cap locations as shown in Figure 2-2 (B).

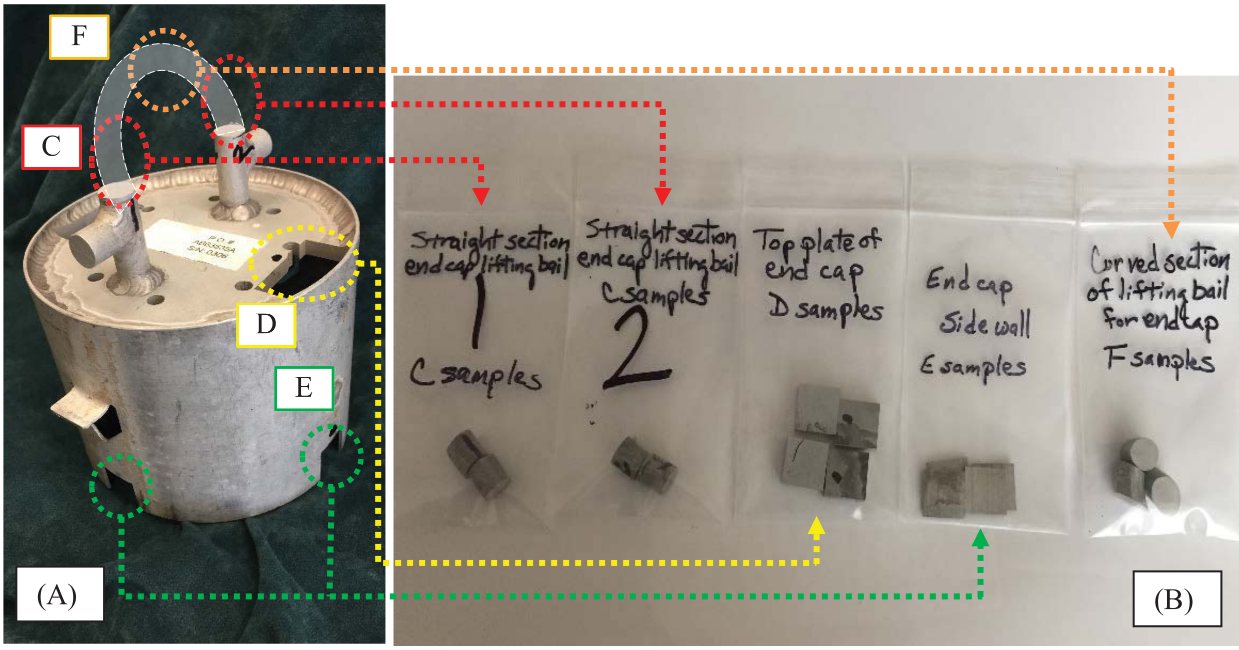

Figure 2-2. L-Bundle End Cap (A) and coupon cuts (B)

The HFIR fuel outer carrier coupon cut locations and labelling are shown in Figure 2-3. The sectioned HFIR fuel outer carrier shown in Figure 2-3(A) identifies where coupons were removed. The HFIR fuel outer carrier cut coupons (Figure 2-3 (B)) were labeled 1 for the straight portion of the lifting bail, 2 for the bent portion of the lifting bail, 3 for the straight horizontal support bar for the lifting bail, 4 for the Al band around the top of the carrier to support the lifting bail, and 5 for the sidewall just below the Al band.

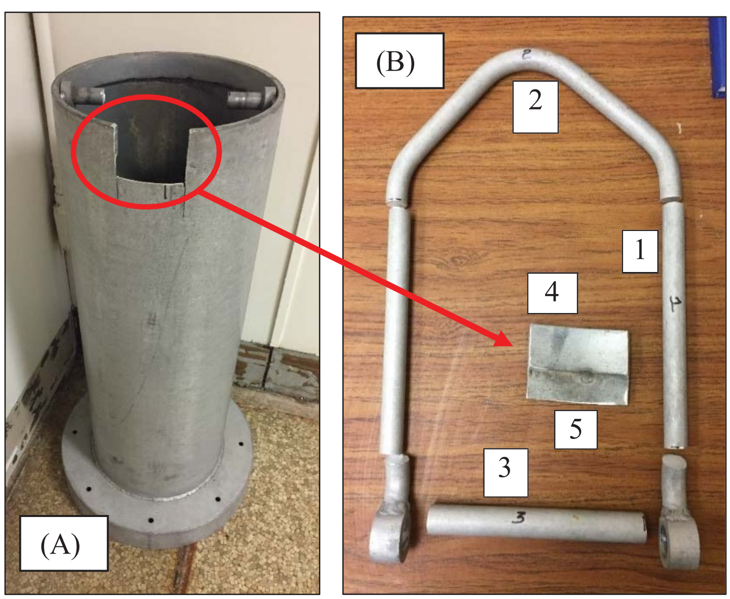

Figure 2-3. HFIR fuel outer carrier (A) and coupon cuts (B)

A summary of the test coupons removed from the L-Bundle End Cap and HFIR fuel outer carrier is given in Table 2-1. For each coupon, the identification (ID) and location information are provided. Additionally, the orientation for the microstructural analysis is also given and discussed in further detail in the next section.

Table 2-1. Test Coupon Summary

Sample	Location	ID	Orientation*
L Bundle End Cap	Straight section of lifting bail	EC - C	Cross section
	Welded upper plate	EC - D	Longitudinal without weld
	Sidewall	EC - E	Planar
	Bent section of lifting bail	EC - F	Cross section
HFIR Carrier	Straight section of lifting bail	HF-1	Longitudinal
	Bent section of lifting bail	HF-2	Cross section
	Support bar for lifting bail	HF-3	Longitudinal
	Support band	HF-4	Longitudinal
	Sidewall	HF-5	Planar

*Orientation was for microstructural analysis

2.2 Characterization of L-Bundle End Cap and HFIR Fuel Outer Carrier Test Coupons

Two sets of the L-Bundle End Cap and HFIR fuel outer carrier coupons were cut; one set was used for dissolution rate determination and another set was used for metallurgical property analyses. The general size and shape of the coupons were chosen to fit the experimental dissolution equipment described in Section 2.3.

2.2.1 Metallurgical Characteristics of Coupons

The metallurgical characterization for the Al material used in each carrier's components consisted of a review of certified material test reports (CMTRs) obtained from vendors during procurements of L-Bundle and HFIR fuel carriers, hardness measurements, and microstructural analysis including grain size measurements and intermetallic particle analysis.

Compositional data provided by CMTRs from the procurement of L-Bundles (procured according to procurement specification C-SPP-L-00024, dated 7/10/2012) and HFIR fuel carriers (dated 2017) are given in Appendix A along with the ASTM specification for composition. From a review of these data, the L-Bundle End Cap sidewall was found to be fabricated from Al-6063-T6 (The L-Bundle drawing (C-CS-L-0962, Rev 9[4]) specifies either Al-6061 or Al-6063 may be used for fabrication). All the other components of the L-Bundle carrier as well as all those of the HFIR carriers were fabricated from Al-6061 of various tempers (T6, T651, and T6511). A review of the ASTM specification for Al-6061 and Al-6063 shows that Al-6063 has lower concentrations of the major alloying elements and impurities including Si, Fe, and Mg, the principal components of the intermetallic particles that form in these 6-xxx series Al alloys.[8]

Hardness measurements were performed on the Rockwell B and 15t (superficial) scales following the guidance in ASTM International test method E18-17.[9] Hardness measurement involves an indent of a specified sized object (i.e., sphere, pyramid, etc.) with a specified force. The size of the indent is measured which corresponds to a hardness number. For the Rockwell B and 15t scales, a 1/16-in steel ball is the indenter with a force of 100 kgf and 15 kgf, respectively. Hardness measurements were made on a standard sample prior to measuring hardness of the coupons. The hardness value presented in this report are an average of three measurements. The hardness measurements were made on the carrier coupons without further surface preparation. Measurements were made on two orthogonal surfaces, either cross section, which lies on a surface plane that cuts across the direction of deformation, (i.e. the extrusion direction) or longitudinal, which lies on a surface plane that parallels the direction of deformation (see Appendix B for description).

For microstructural analysis of the coupons, the coupons were mounted in an epoxy resin, ground through a series of silicon carbide papers of decreasing grit size, and polished with 1-µm diamond paste to produce a flat, non-deformed surface. The orientations of the coupons (i.e. surface of examination) are given in Table 2-1. Mounted coupons were examined both etched and unetched to measure the grain size and to characterize the intermetallic particles, respectively. A Keller's reagent (a mixture of distilled water, and nitric, hydrochloric and hydrofluoric acids) was used as the etchant to highlight the grain boundaries. A Keyence laser confocal microscope (LCM) and Keyence digital optical microscopy were used for these examinations. The average grain size was determined using the guidelines of ASTM International test method E112-13.[10] Intermetallic particle count and sizing were determined using analysis software associated with the LCM and micrographs of a coupon prepared surface.

Samples were selected to verify the Al alloy compositions using X-ray fluorescence (XRF) and the intermetallic particle chemistry using a Scanning Electron Microscope (SEM) with Energy Dispersive Spectroscopy (EDS).

In addition to the coupons from the L-Bundle End Cap and HFIR fuel outer carrier, a small plate that was stamped Al-6061-T6 was also evaluated. This plate was used as a confirmed Al-6061-T6 material. Coupons cut from this plate were given the designation "G". A series of partial dissolution tests were performed in which Al-1100, Al-6061, and Al-6063 coupons were used. These coupons were previously procured from Metal Samples (Munford AL). The Al-1100 and Al-6061 coupons were 2-in x 1-in x 0.125-in and the Al-6063 coupon was 2-in x 0.75-in x 0.125-in.

2.2.2 Surface Area and Mass of End Cap and Carrier Coupons

For the dissolution experiments the coupons were weighed and measured. No other pretreatment of the coupons (i.e., sanding or washing) was performed for the dissolution experiments so the coupons would represent the same condition as the initial source materials. Some of the coupons had uniform shapes and others did not. Therefore, formulas for the surface area of the coupons varied. The L-Bundle End Cap Coupon C (EC-C) and HFIR fuel outer carrier Coupons 1 and 3 (HF-1, HF-3) were treated as right cylinders using the length (L) and middle (average) diameter (D) to calculate a surface area (SA) as shown in equation (1).

$$\mathrm{SA}_{RC}(\mathrm{cm}^2) = \left[\pi\bullet \mathrm{D}(mm)\bullet L(mm) + 2\bullet\pi\bullet\left(\frac{\mathrm{D}(mm)}{2}\right)^2\right]\bullet\frac{1cm^2}{100mm^2} \tag{1}$$

The L-Bundle End Cap Coupon F (EC-F) and HFIR fuel outer carrier Coupon 2 (HF-2) were treated as right cylinders with an elliptical end. For this shape the surface area was calculated as the sum of the area for the circular end, the curved length, and the elliptical end. The surface area for the circular end (SA_C) of diameter (D_C) is given by equation (2).

$$\mathrm{SA}_{C}(\mathrm{cm}^2) = \left[\pi\bullet\left(\frac{\mathrm{D}_C(mm)}{2}\right)^2\right]\bullet\frac{1cm^2}{100mm^2} \tag{2}$$

The elliptical end has a small diameter which is the same as the circular end diameter (D_C) and a large diameter (D_L) as shown in Figure 2-4.

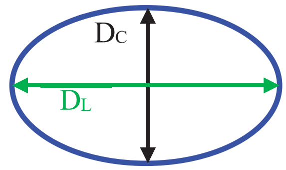

Figure 2-4. Dimensions of elliptical end

The surface area for the elliptical end (SA_E) is calculated by equation (3).

$$SA_E(\text{cm}^2) = \left[\pi \bullet \frac{D_C(mm)}{2} \bullet \frac{D_L(mm)}{2}\right] \bullet \frac{1cm^2}{100mm^2} \tag{3}$$

The surface area of the curved length was approximated by fitting a quadratic equation over the length (L) of the coupon. Using x to represent the distance along the length of the coupon, points on the curve were defined at x=0 equal to the circular end diameter (D_C), at x=L/2 equal to the middle diameter (D_M), and at x=L equal to the large diameter (D_L) of the elliptical end. The three diameters were subsequently used to define a quadratic equation for the diameter as a function of the coupon length (equation 4).

$$D_x(\text{mm}) = a \bullet x^2 + b \bullet x + c \tag{4}$$

The surface area of the curved length (SA_{CL}) was calculated using the integral represented by equation (5).

$$SA_{CL}(\text{cm}^2) = \frac{1cm^2}{100mm^2} \bullet \pi \bullet \int_0^L D_x(mm) \bullet dx \tag{5}$$

Substituting equation (4) into equation (5), the formula for the surface area of the curved length is shown as equation (6).

$$SA_{CL}(\text{cm}^2) = \frac{1cm^2}{100mm^2} \bullet \pi \bullet \int_0^L \left(a \bullet x^2 + b \bullet x + c\right) \bullet dx = \frac{1cm^2}{100mm^2} \bullet \pi \bullet \left(\frac{a}{3} \bullet L^3 + \frac{b}{2} \bullet L^2 + c \bullet L\right) \tag{6}$$

The total surface area for the cylinder with a circular and an elliptical end (SA_{CE}) is the sum of the surface areas of the circular and elliptical ends and the surface area of the curve length (equation 7).

$$SA_{CE}(\text{cm}^2) = SA_C + SA_E + SA_{CL} \tag{7}$$

The L-Bundle End Cap plate with a weld on one edge (EC-D) was treated like a quadrilateral slab with widths measured along each edge (W_1, W_2, W_3, and W_4), depths measured at the rectangular end (DD_1, DD_2, DD_3), and depths measured at the triangular or weld end (D_1, D_2, and D_3) (Figure 2-5).

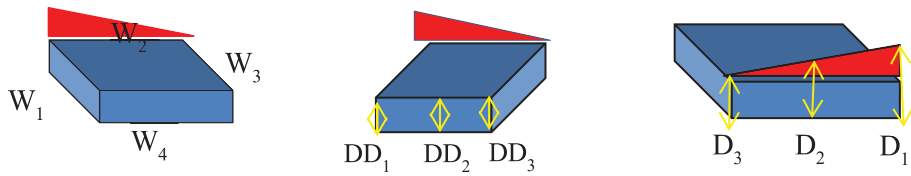

Figure 2-5. Dimensions of End Cap plate with a weld on one edge

The surface area for the End Cap plate with a weld (SA_{PW}) was calculated using equation (8).

$$SA_{PW}(\mathrm{cm}^2) = \frac{1cm^2}{100mm^2} \bullet \left[2 \bullet \left(\frac{W_1 + W_3}{2} \right) \bullet \left(\frac{W_2 + W_4}{2} \right) + \left(\frac{DD_1 + DD_2 + DD_3}{3} \right) \bullet \left(W_1 + W_2 + W_3 + W_4 \right) + 0.5 \bullet \left(D_1 - DD_1 \right) \bullet W_2 \right] \quad (8)$$

The L-Bundle End Cap sidewall (EC-E), the HFIR fuel outer carrier support band for the lifting bail (HF-4), the HFIR fuel outer carrier sidewall near the support band (HF-5), and an Al-6063 coupon were treated as rectangular slabs of average length L, average width W, and average depth D (Figure 2-6).

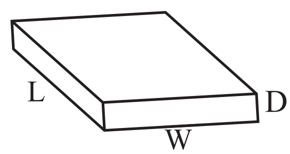

Figure 2-6. Dimensions of rectangular slab

The surface area for a rectangular slab was calculated using equation (9).

$$SA_R(\mathrm{cm}^2) = \frac{1cm^2}{100mm^2} \bullet \left[2 \bullet \left(L \bullet W + W \bullet D + L \bullet D \right) \right] \quad (9)$$

As a comparison to the HFIR fuel outer carrier and L-Bundle End Cap coupons, a coupon was cut from a stamped Al-6061-T6 plate (Coupon G). This coupon was rectangular but multiple depth measurements were taken to try to capture any uneven dissolution along the largest faces (Figure 2-7).

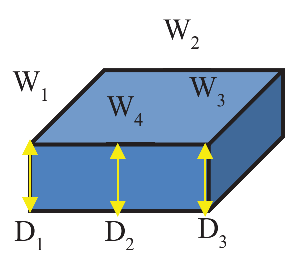

Figure 2-7. Dimensions of rectangular slab with multiple depths

The surface area for the rectangular slab with multiple depths (SA_{R*}) was calculated using equation (10).

$$SA_{R*}(\mathrm{cm}^2) = \frac{1cm^2}{100mm^2} \bullet \left[2 \bullet \left(\frac{W_1 + W_3}{2} \right) \bullet \left(\frac{W_2 + W_4}{2} \right) + \left(\frac{D_1 + D_2 + D_3}{3} \right) \bullet \left(W_1 + W_2 + W_3 + W_4 \right) \right] \quad (10)$$

The initial masses, dimensions, and surface areas of the coupons used in the experiments are provided in Table 2-2 through Table 2-5.

Table 2-2. L-Bundle End Cap and HFIR Fuel Outer Carrier Cylindrical Coupon Characteristics

Exp. No.	Coupon ID	Mass	Length	Diameter	Surface Area
---	---	(g)	(mm)	(mm)	(cm^2)
141	EC-C1 Bottom	4.218	12.36	12.67	7.44
149	HF-1	9.011	16.93	15.88	12.40
151	HF-3	12.422	16.16	19.08	15.40

Table 2-3. L-Bundle End Cap and HFIR Fuel Outer Carrier Cylindrical with Elliptical End Coupon Characteristics

Exp. No.	Coupon ID	Mass	Length	Circular Diameter (D_C)	Middle Diameter (D_M)	Large Elliptical Diameter (D_L)	Parameters of Quadratic Fit of D_x			Surface Area
							a	b	c	
---	---	(g)	(mm)	(mm)	(mm)	(mm)	---	---	---	(cm^2)
142	EC-F	4.618	12.36	12.68	12.77	16.40	4.63E-02	-2.72E-01	12.68	8.08
150	HF-2	8.696	16.36	15.71	15.72	16.12	2.91E-03	-2.26E-02	15.71	12.04

Table 2-4. Rectangular Shaped Coupon Characteristics

Exp. No.	Coupon ID	Mass	L	W	D	Surface Area
---	---	(g)	(mm)	(mm)	(mm)	(cm^2)
144	EC-E	1.434	18.72	18.85	1.58	8.24
152	HF-4	3.282	19.98	9.81	6.30	7.67
153	HF-5	0.847	20.19	9.92	1.61	4.97
154	Al-6061-007	7.481	50.74*	18.84	2.97	4.92
154	Al-6061-008	7.536	50.64*	18.87	2.98	4.93
154	Al-1100-101	7.299	50.73*	18.77	2.90	4.88
154	Al-1100-102	7.403	50.71*	18.78	2.94	4.90
154	EC-E-0306	1.439	18.72	18.75	1.56	8.19
154	EC-E-113	1.409	18.79	18.53	1.57	8.14
155	Al-6063-015	2.298	16.00	19.03	2.89	8.11

*Full length but only 10 mm immersed into solution. Surface area is only for immersed section.

Table 2-5. L-Bundle End Cap Top Plate with Weld Coupon Characteristics

Exp. No.	Coupon ID	Mass	W_1	W_2	W_3	W_4	D_1	D_2	D_3	DD_1	DD_2	DD_3	Surface Area
---	---	(g)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(cm^2)
143	EC-D2 Right	6.189	18.41	18.69	18.44	18.69	9.39	7.22	7.18	6.6	6.6	6.6	12.05
145	Al-6061 G-2	3.524	11.41	18.22	11.41	18.17	6.38	6.38	6.38	---	---	---	7.93

2.3 Dissolving System

The vessel and offgas condenser used to perform the Al alloy dissolution experiments were fabricated from borosilicate glass by the SRNL Glass Shop. The dissolving vessel was made from a 300-mL round-bottom flask. Penetrations were added for a condenser, (internal) thermocouple, vessel purge, and a syringe pump for Hg addition. The bottom of the flask was flattened slightly to facilitate heating and agitation using a hot plate/stirrer with a magnetic stir bar. The solution temperature was controlled using an external thermocouple monitoring the hot plate. During dissolutions, the Al coupon was charged to the dissolver in a glass basket suspended by a glass rod which was held in place by a compression fitting. The compression fitting allowed adjustment of the basket height during dissolution. A photograph of the equipment is shown in Figure 2-8.

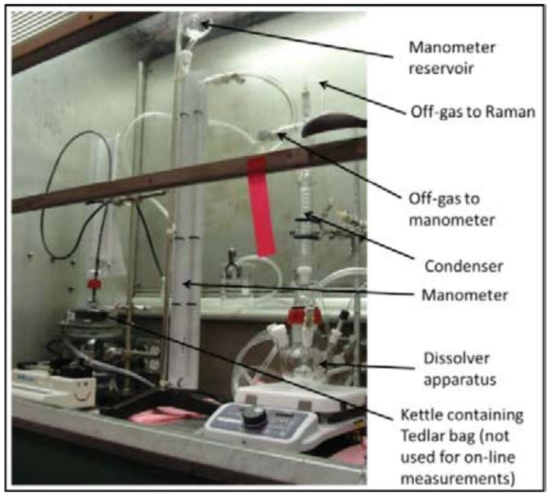

Figure 2-8. Dissolver setup with online Raman offgas analyzer

2.4 <u>Dissolution Experiments</u>

To perform a dissolution experiment, the Al alloy sample was initially placed in the perforated glass basket and suspended above the solution. The solution was heated to the desired temperature (e.g., boiling). Chilled water (at 3 ˚C) was circulated through the condenser during the dissolution to remove water vapor from the offgas stream. Once the solution reached the desired temperature, the basket containing the sample was lowered until it was completely immersed. A timer was started to record the time the sample went into the solution. At the desired interval, the basket was raised out of solution, the timer stopped, and the basket removed from the dissolving vessel. The sample was then removed from the basket, rinsed, dried, and weighed and the dimensions (e.g., length, width, and thickness) measured. The sample was then returned to the basket and the basket lowered back into the solution. The timer was started again. This process was repeated until sufficient data was acquired to accurately calculate the dissolution rate. The experiments used 150 mL of 7 M HNO_3 with 1.8 mL of a 0.169 M Hg to achieve a target concentration of 0.002 M Hg.

A sequential partial dissolution of three types of coupons (Al-6061, Al-6063, and Al-1100) was also conducted to assess Hg deposition during the dissolution process. The six coupons were dissolved in the same solution sequentially so only one coupon was dissolved at a time. The initial composition of the solution was the same as described above. The six coupons were pairs of Al-1100 and Al-6061 corrosion coupons and the End Cap sidewall.

2.5 <u>Quality Assurance</u>

A Functional Classification of Safety Significant was applied to this work. Analytical measurement systems with a General Service functional classification were used to collect data during evaluation of the dissolution behavior of the L-Bundle End Caps, HFIR fuel outer carrier, and Al alloy corrosion coupons. Chemical reagents used in experiments and sample preparation were purchased at levels 2 or 3. Standards used for analytical measurements were traceable to NIST or equivalent per manual 1Q, 2-7 section 5.2.3.

To match the requested functional classification, this report received technical review by design verification. Requirements for performing reviews of technical reports and the extent of review are established in manual

E7, 2.60. SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2.

3.0 Results and Discussion

3.1 Dissolution Rates of L-Bundle End Cap and HFIR Fuel Outer Carrier Coupons

The dissolution rates for the L-Bundle End Cap, HFIR fuel outer carrier and Al-6061-T6 plate coupons were calculated from the slopes of linear fits of the mass to surface area ratio versus dissolution time data. These data are discussed in this section for each of the materials and the various coupons sectioned from the L-Bundle End Cap and HFIR fuel outer carrier. The data are grouped by the coupon shapes since similarly shaped coupons of the same material are most likely exposed to the same metallurgical stresses during fabrication. The plots of the mass to surface area ratio versus dissolution time are shown below, while the tabularized data are given in Appendix C.

Dissolution data (Experiment 141) for the straight section of the L-Bundle End Cap lifting bail (EC-C) are shown in Appendix C Table C-1. The mass to surface area ratio versus dissolution time data are linear as shown in Figure 3-1. A linear fit of these data gives a slope or dissolution rate of -2.33E-04 g/cm^2/min with a standard deviation of 7.04E-06 and an R^2 equal to 0.994.

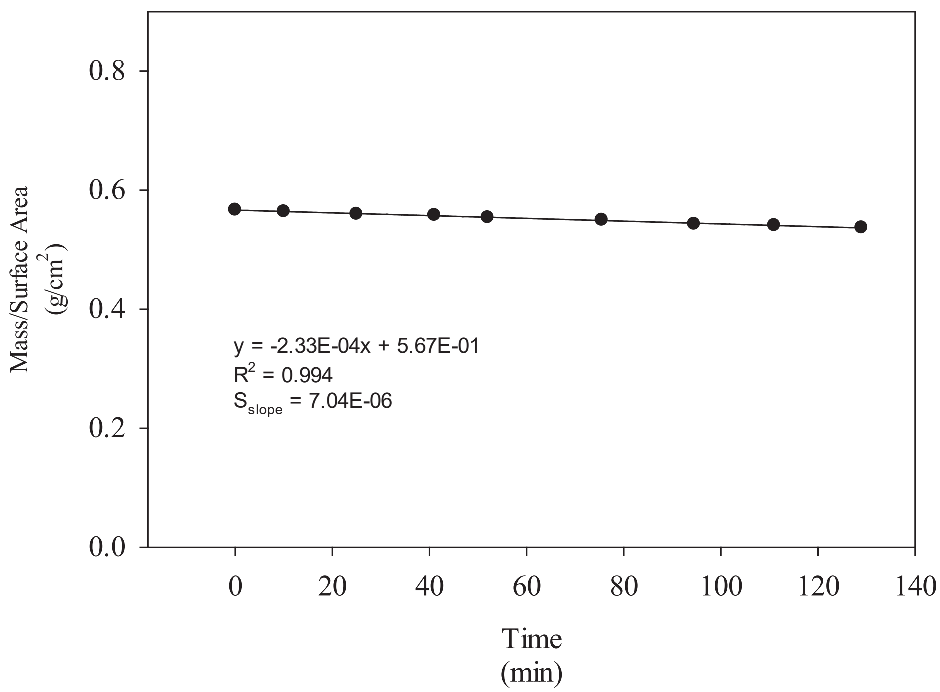

Figure 3-1. Experiment 141 – End Cap lifting bail straight section (EC-C) dissolution data

Dissolution data (Experiment 149) for the straight section of the HFIR fuel outer carrier lifting bail (HF-1) are shown in Appendix C Table C-2. The mass to surface area ratio versus dissolution time data are linear as shown in Figure 3-2. A linear fit of these data gives a slope or dissolution rate of -2.74E-04 g/cm^2/min with a standard deviation of 7.00E-06 and an R^2 equal to 0.995.

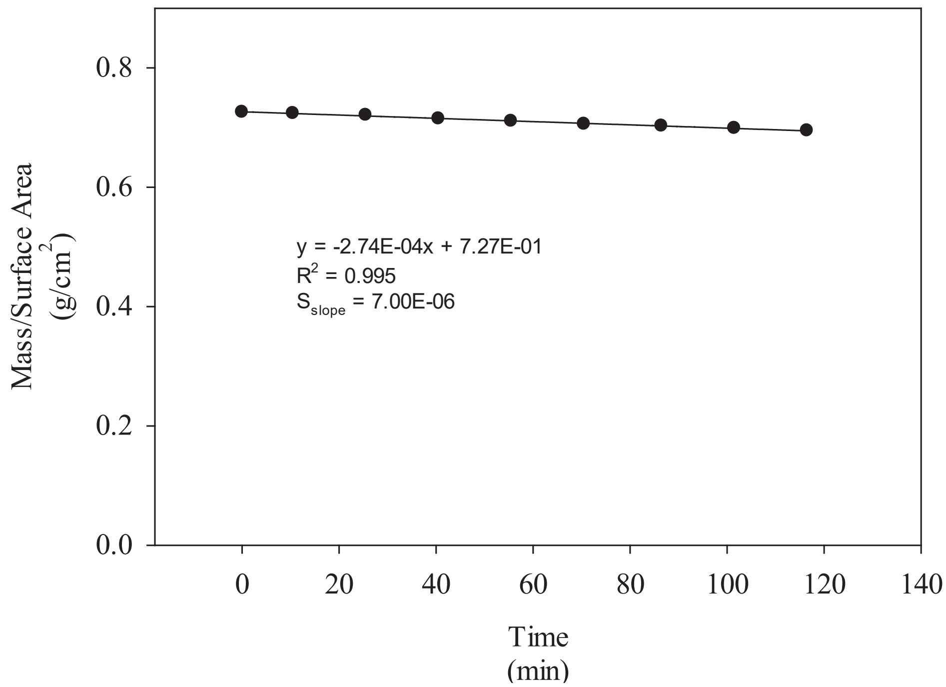

Figure 3-2. Experiment 149 – HFIR fuel outer carrier lifting bail straight section (HF-1) dissolution data

Dissolution data (Experiment 151) for the HFIR fuel outer carrier lifting bail support bar (HF-3) are shown in Appendix C Table C-3. The mass to surface area ratio versus dissolution time data are linear as shown in Figure 3-3. A linear fit of these data gives a slope or dissolution rate of -2.48E-04 g/cm^2/min with a standard deviation of 7.14E-06 and an R^2 equal to 0.994.

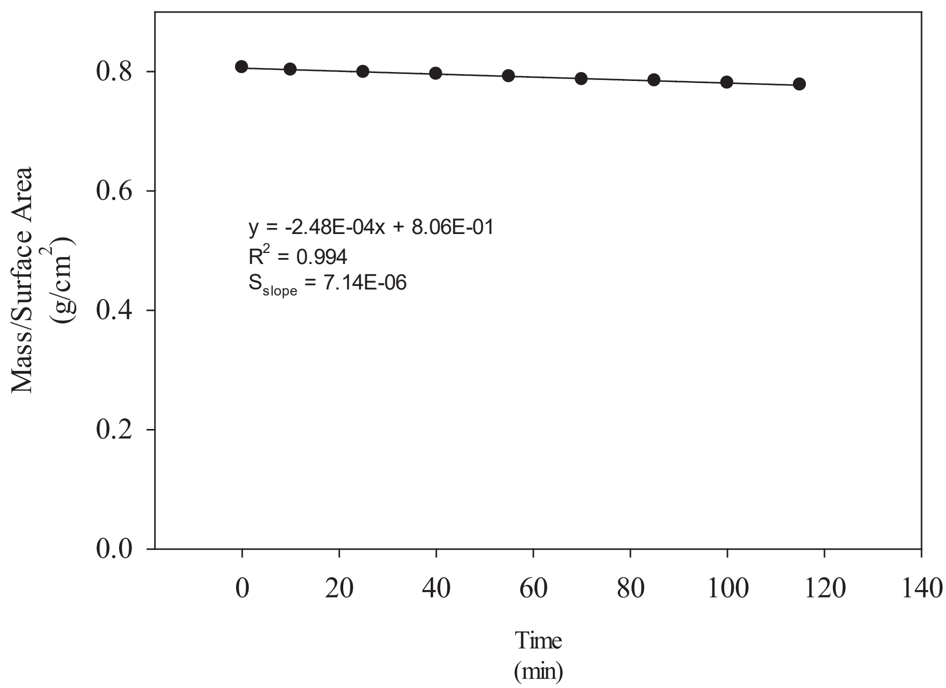

Figure 3-3. Experiment 151 – HFIR fuel outer carrier lifting bail support bar (HF-3) dissolution data

Dissolution data (Experiment 142) for the bent section of the L-Bundle End Cap lifting bail (EC-F) are shown in Appendix C Table C-4**.** The mass to surface area ratio versus dissolution time data are plotted in Figure 3-4. The data show some scatter which could be attributed to the difficulty in measuring the dimensions of the bent sample during the dissolution and accurately calculating the surface area. However, the dissolution rate obtained from the regression line is acceptable for comparison with the dissolution rates of other samples from the End Cap and HFIR fuel carrier. A linear fit of these data gives a slope or dissolution rate of -2.97E-04 g/cm^2/min with a standard deviation of 4.78E-05 and an R^2 equal to 0.811.

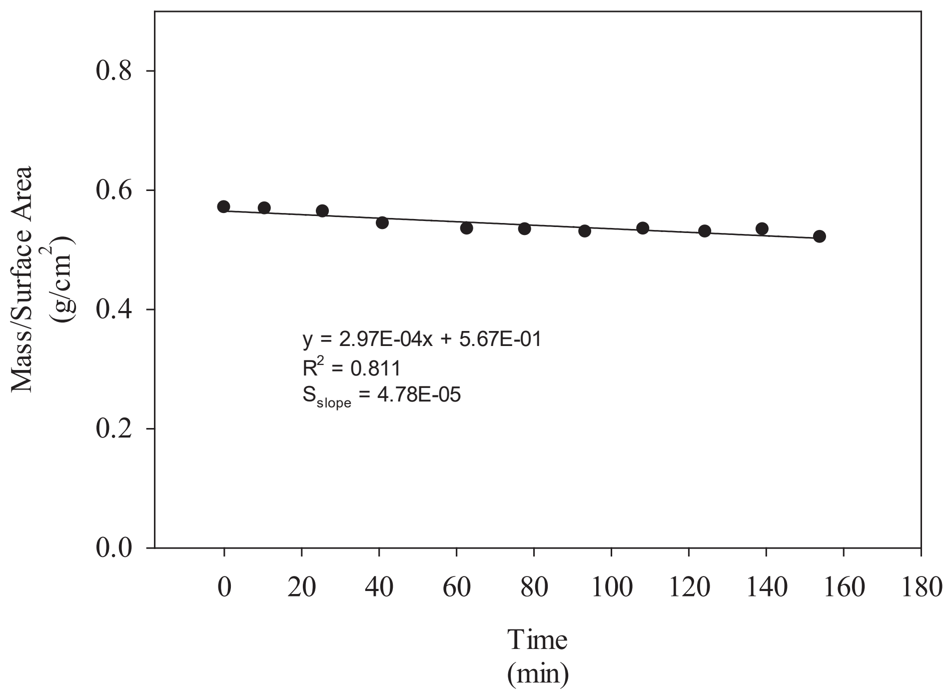

Figure 3-4. Experiment 142 – L-Bundle End Cap lifting bail bent section (EC-F) dissolution data

Dissolution data (Experiment 150) for the bent section of the HFIR fuel outer carrier lifting bail (HF-2) are shown in Appendix C Table C-5. The mass to surface area ratio versus dissolution time data are plotted in Figure 3-5. The data show some scatter which may again be attributed to the difficulty in measuring the dimensions of the bent sample during the dissolution and accurately calculating the surface area. However, the dissolution rate obtained from the regression line is acceptable for comparison with the dissolution rates of other samples from the End Cap and HFIR fuel carrier. A linear fit of these data gives a slope or dissolution rate of -6.80E-04 g/cm^2/min with a standard deviation of 8.85E-05 and an R^2 equal to 0.881.

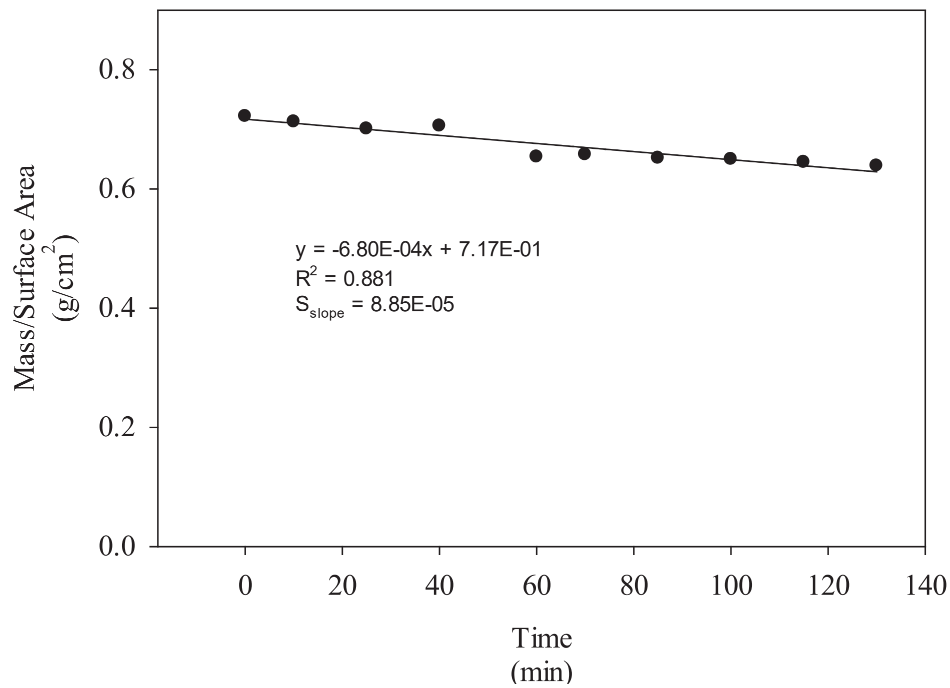

Figure 3-5. Experiment 150 – HFIR fuel outer carrier lifting bail bent section (HF-2) dissolution data

Dissolution data (Experiment 143) for the welded top plate of the L-Bundle End Cap (EC-D) are shown in Appendix C Table C-6. The mass to surface area ratio versus dissolution time data as shown in Figure 3-6 indicate a constant dissolution rate. A linear fit of these data gives a slope or dissolution rate of -4.84E-04 g/cm^2/min with a standard deviation of 1.09E-05 and an R^2 equal to 0.996. The small section of weld and the surrounding heat-affected zone does not appear to influence the dissolution rate of the whole sample based on the consistent slope. The rate of change of the measured individual coupon depths with no weld (D1, D2, D3) and depths with weld (DD1, DD2, DD3) over time are shown in Appendix C Table C-7 and plotted in Figure 3-7. The figure shows the rate of change of each dimension during the dissolution (calculated by linear regression) and two times the uncertainty (i.e., 2 standard deviations) which is approximately equivalent to a 95% confidence interval. Comparison of the data for each measurement shows that within measurement uncertainty, the rate of change between the weld locations and the non-weld locations were statistically the same. The weld locations have less variability than the non-weld locations, but different experiments with more precise surface mapping would have to be performed to identify any differences.

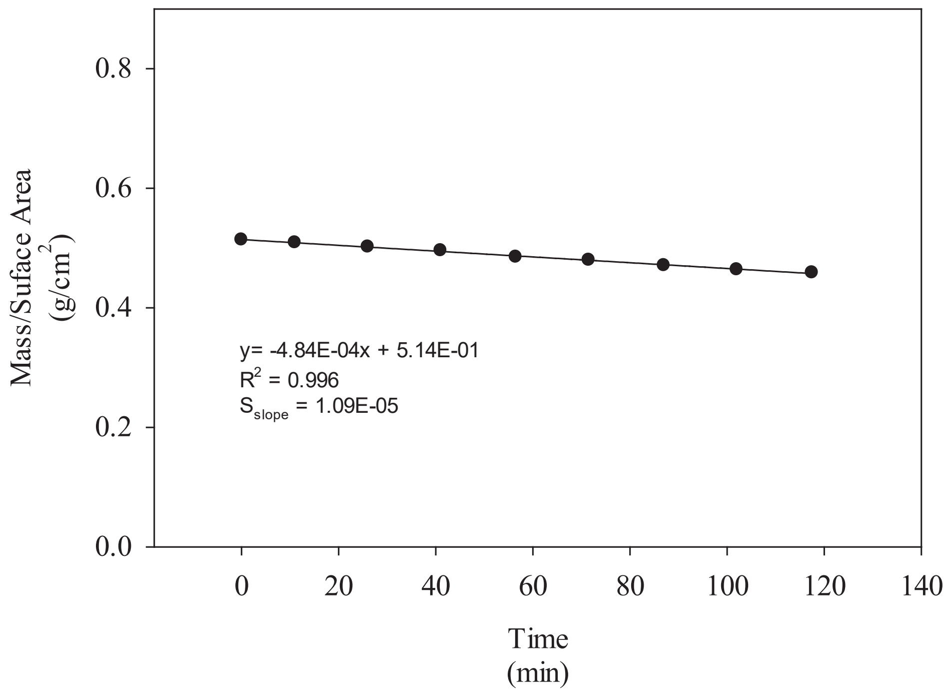

Figure 3-6. Experiment 143 – L-Bundle End Cap top plate with weld (EC-D) dissolution data

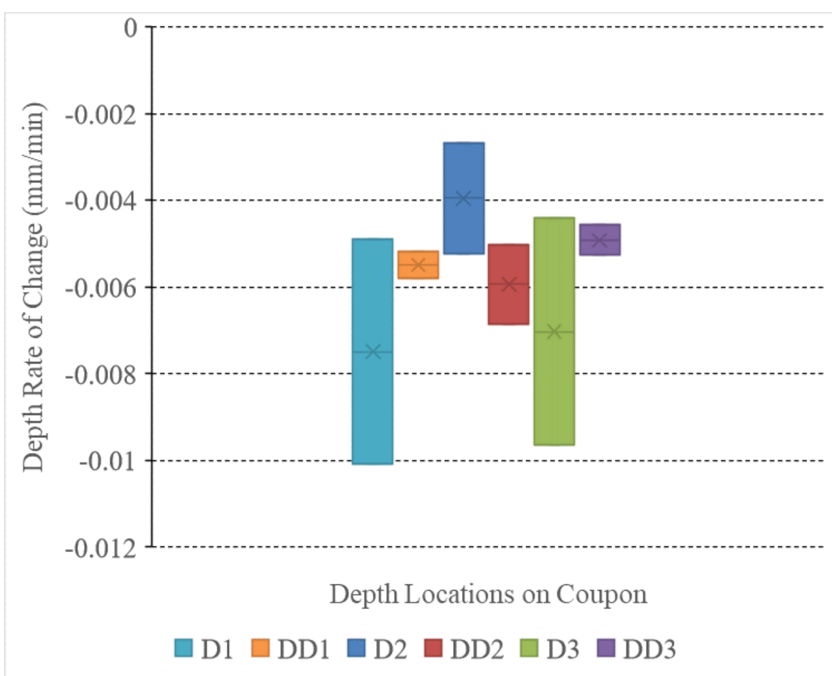

Figure 3-7. Experiment 143 L-Bundle End Cap Top Plate with Weld – Depth Change Rates

Dissolution data (Experiment 145) for the Al-6061-T6 plate (Coupon G) are shown in Appendix C Table C-8. The mass to surface area ratio versus dissolution time data are plotted in Figure 3-8. The data show some scatter which may be attributed to measuring the coupon dimensions during the dissolution. Non-uniform variations in the multiple depth measurements taken along the largest faces may be responsible for the small step changes observed in the mass to surface area ratios. However, the dissolution rate obtained from the regression line is acceptable for comparison with the dissolution rates of the samples from the End Cap and HFIR fuel carrier. A linear fit of these data gives a slope or dissolution rate of -1.27E-03 g/cm^2/min with a standard deviation of 9.58E-05 and an R^2 equal to 0.941.

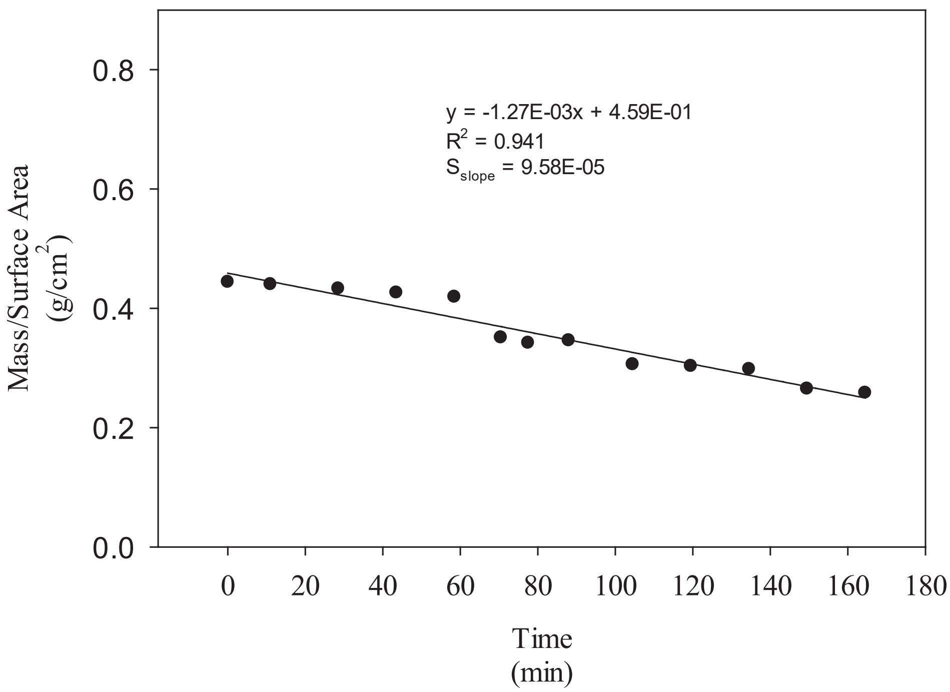

Figure 3-8. Experiment 145 – Al-6061-T6 plate (Coupon G) dissolution data

Dissolution data (Experiment 144) for the L-Bundle End Cap sidewall (EC-E) are shown in Appendix C Table C-9. The mass to surface area ratio versus dissolution time data are plotted in Figure 3-9. The dissolution rate was so fast after immersing the coupon in the nitric acid solution that it was not recovered for additional measurements. A linear fit of the available data gives a slope or dissolution rate of -3.87E-02 g/cm^2/min which is two orders of magnitude faster than the dissolution rates measured for the End Cap and HFIR carrier coupons. The L-Bundle End Cap sidewall was fabricated from an Al-6063 alloy. The higher dissolution rate observed for the coupon is more consistent with the dissolution rate of an Al-1100 alloy (-6.41E-02 g/cm^2/min) estimated from previous work[1,2] (see Section 3.2). Since the dissolution rate for the End Cap sidewall is much faster than the other components of the End Cap, the sidewall could separate from the rest of the L-Bundle causing the remaining end cap material to tilt, and get lodged in the charging well.

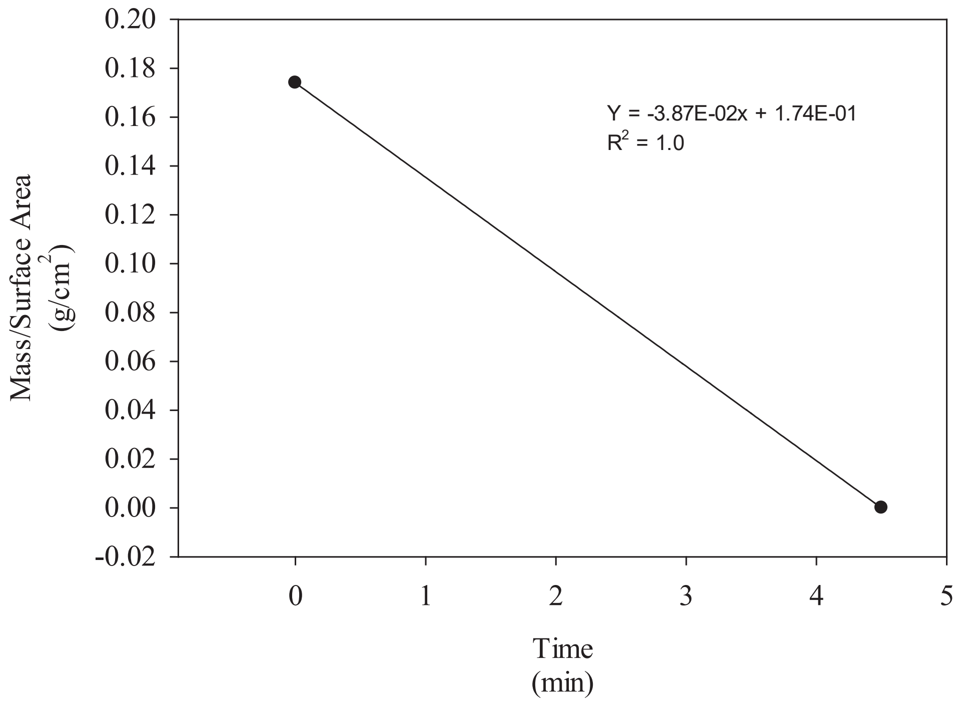

Figure 3-9. Experiment 144 – L-Bundle End Cap sidewall (EC-E) dissolution data

Dissolution data (Experiment 152) for the HFIR fuel outer carrier lifting bail support band (HF-4) are shown in Appendix C Table C-10. The mass to surface area ratio versus dissolution time data are plotted in Figure 3-10. The break which occurs in the data between 10 and 20 minutes is not understood; although, it may be an artifact of measuring the coupon dimension during dissolution. The initial dissolution rate is bounded by two times the uncertainty in the second dissolution rate (an approximate 95% confidence interval) and is not statistically different. A linear fit of the data beyond the break gives a slope or dissolution rate of -2.49E-04 g/cm^2/min with a standard deviation of 2.58E-05 and an R^2 equal to 0.949.

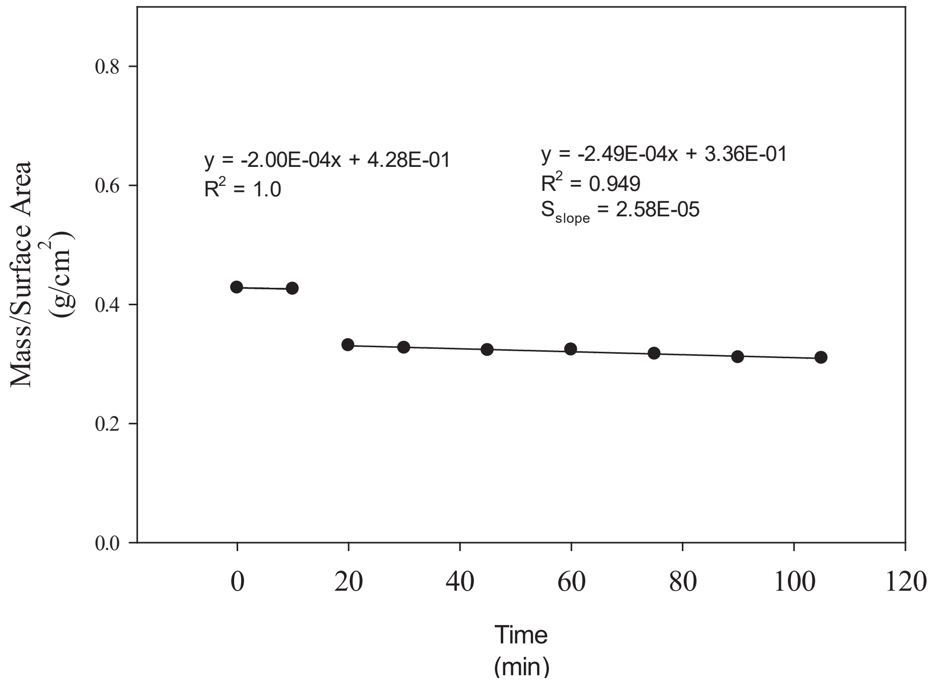

Figure 3-10. Experiment 152 – HFIR fuel outer carrier lifting bail support band (HF-4) dissolution data

Dissolution data (Experiment 153) for the HFIR fuel outer carrier sidewall near the support band (HF-5) are shown in Appendix C Table C-11. The mass to surface area ratio versus dissolution time data are plotted in Figure 3-11 and show a constant dissolution rate. A linear fit of the data gives a slope or dissolution rate of -4.75E-04 g/cm^2/min with a standard deviation of 4.89E-06 and an R^2 equal to 0.999. The dissolution rate for the outer carrier side wall is comparable to the other measured dissolution rates for coupons removed from the HFIR fuel outer carrier associated with the lifting bail.

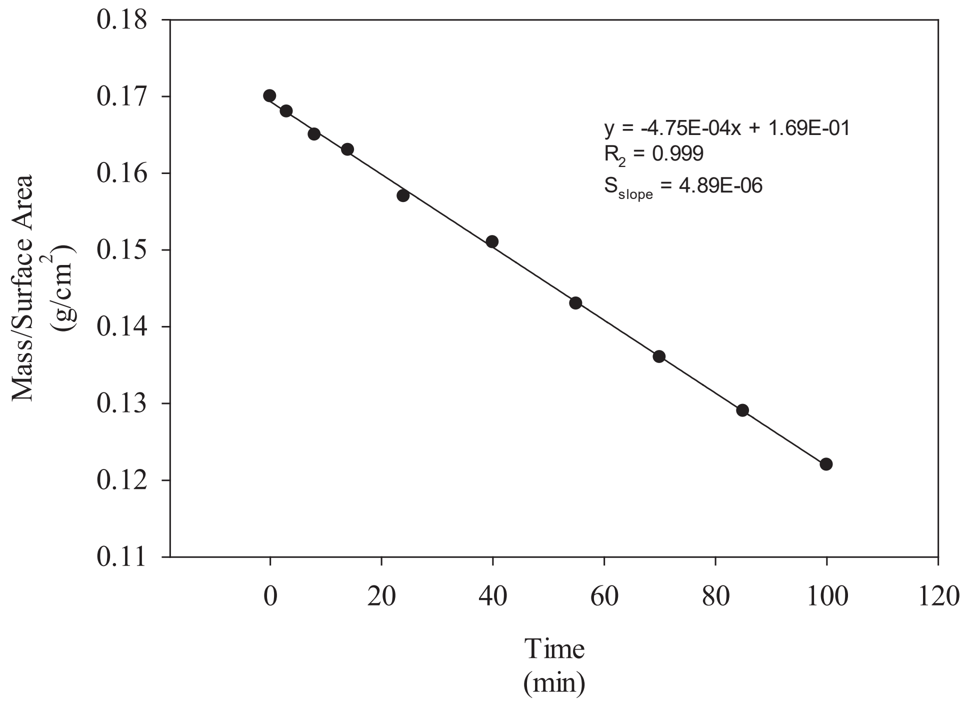

Figure 3-11. Experiment 153 – HFIR fuel outer carrier sidewall near support band (HF-5) dissolution data

The dissolution rates for the End Cap and HFIR fuel outer carrier coupons fabricated from Al-6061 are compared in Figure 3-12. Data from the dissolution of the coupon prepared from the Al-6061-T6 plate (Coupon G) are also included. The dissolution rates of the End Cap and HFIR fuel outer carrier coupons are quite similar but show a significant difference when compared to the dissolution rate of the Al-6061 coupon. The average dissolution rate of the End Cap and HFIR carrier coupons was -3.68E-04 g/cm^2/min with a pooled standard deviation of 3.91E-05. Even at a 95% confidence level (i.e., approximately two times the standard deviation), the average dissolution rate of the End Cap and HFIR coupons are statistically different from the dissolution rate of the coupon cut from the Al-6061-T6 plate (-1.27E-03 g/cm^2/min). The more rapid dissolution of the Al-6061-T6 plate compared to the End Cap and HFIR coupons is not understood and was not pursued further in this study. However, the data does show that the components of the L-Bundle End Cap and HFIR fuel outer carrier fabricated from Al-6061 alloy dissolve at approximately the same rate using conditions representative of the MTR and HFIR fuel dissolution flowsheets.[1,2]

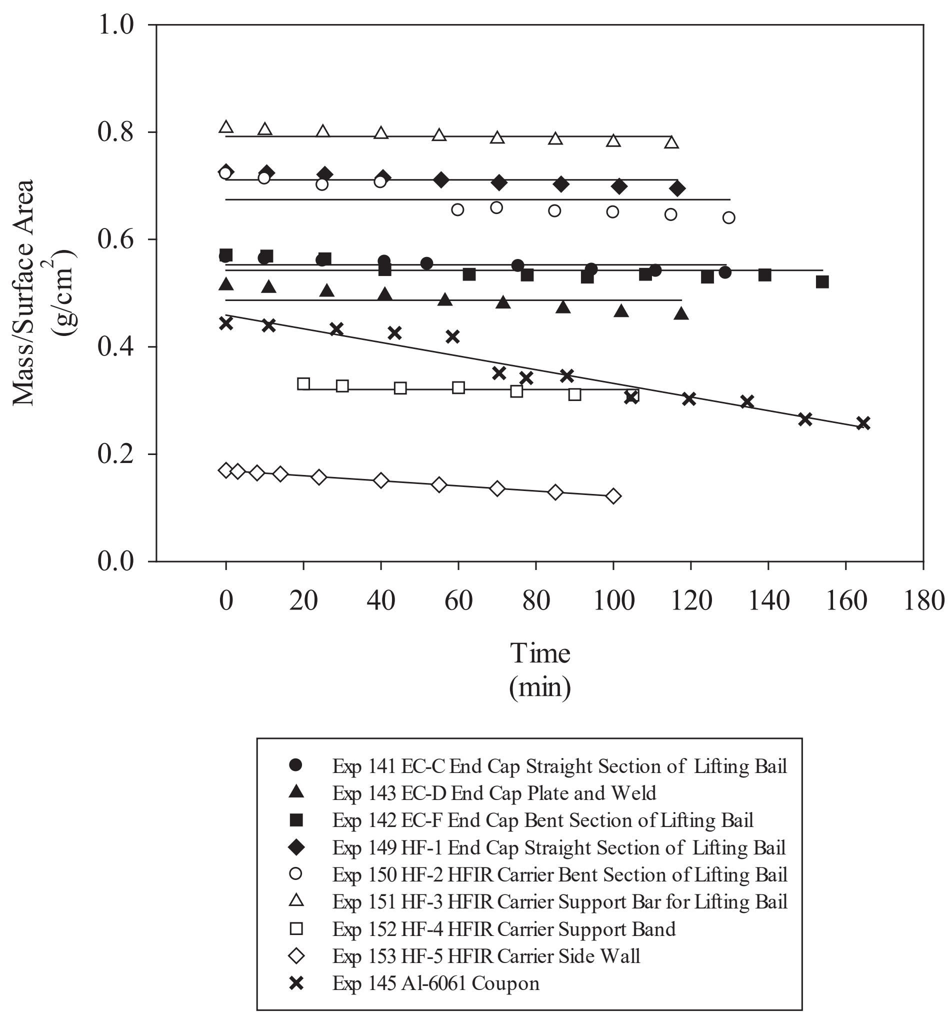

Figure 3-12. Dissolution data for the L-Bundle End Cap and HFIR fuel outer carrier coupons fabricated from Al-6061

3.2 Comparison of the End Cap Sidewall with the Dissolution of Other Al Alloys

Dissolution of Al-1100 has been used to define the dissolution flowsheets for MTR and HFIR fuels based on flammable offgas generation.[1,2] Using the offgas data from a prior dissolution of an Al-1100 coupon (Experiment 97) in boiling 7 M HNO_3 with 0.002 M Hg as a point of comparison, the mass to surface area ratio versus dissolution time data were calculated as shown in Appendix C Table C-12. For these calculations, the surface area was assumed to be constant at 4.94 cm^2 based on a 10 mm immersion of a 40.90 mm (long) x 19.05 mm (wide) x 2.90 mm (thick) Al-1100 coupon.[1] The mass to surface area ratios versus dissolution time data show that the dissolution rate was constant (Figure 3-13). A linear fit of the data gives a slope or dissolution rate of -6.41E-02 g/cm^2/min with a standard deviation of 8.93E-04 and an R^2 equal to 0.994. The dissolution rate of the L-Bundle End Cap sidewall (which was fabricated from Al-6063) is about 2/3 the dissolution rate of Al-1100 or of the same order of magnitude compared to the dissolution rates of the Al-6061 coupons from the End Cap and HFIR carrier, which are 2 orders of magnitude less.

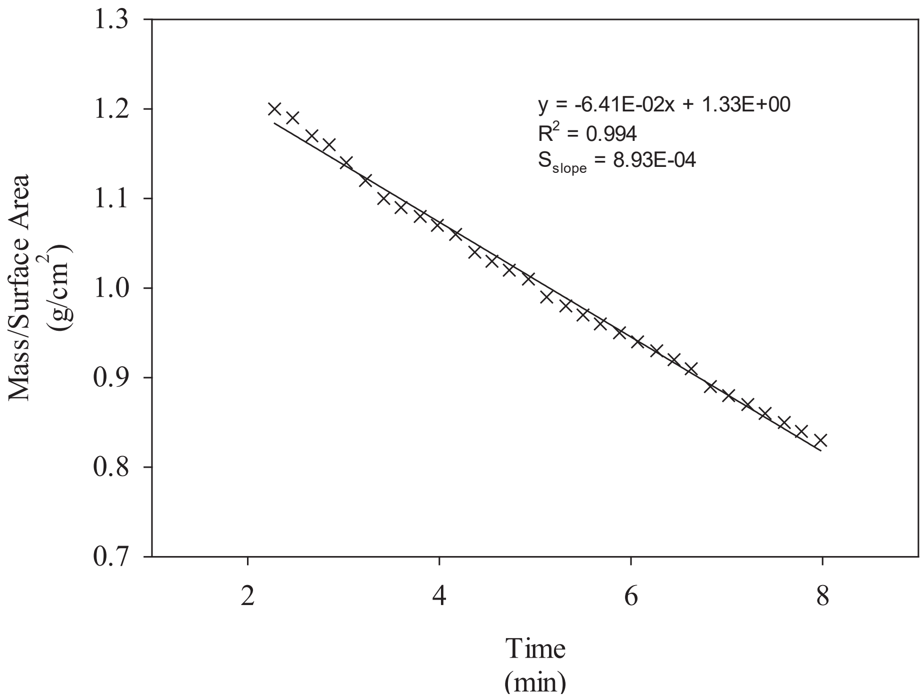

Figure 3-13. Experiment 97 – Calculated Al-1100 coupon dissolution data from offgas generation measurements

The dissolution of an Al-6063 alloy coupon was performed to obtain dissolution rate data for comparison to the rate measured for the End Cap sidewall (EC-2) which was fabricated from Al-6063. The mass to surface area ratio versus dissolution time data are shown in Appendix C Table C-13 and are plotted in Figure 3-14. The data plotted in the figure were used to calculate a dissolution rate of -2.13E-02 g/cm^2/min with a standard deviation of 2.78E-03 with an R^2 equal to 0.936. The dissolution data for the End Cap sidewall (EC-2) were also plotted in Figure 3-14. The dissolution rate (-3.87E-02 g/cm^2/min) of the End Cap sidewall is statistically different than the dissolution rate measured for the Al-6063 coupon at an approximate 95% confidence limit (i.e., two times the standard deviation); however, the dissolution rates differ by less than a factor of two demonstrating that the Al-6063 coupons dissolve at similar rates.

Both Al-6063 and Al-1100 alloys contain a higher percentage of Al than Al-6061 (see Appendix A). During the development of the dissolution flowsheets for HFIR fuel, Al-1100 and Al-6061-T6 alloys were evaluated to select a surrogate material which was bounding for offgas generation.[2] The results from the dissolution studies demonstrated that the offgas generation rate for the Al-1100 alloy was bounding. More rapid dissolution rates are also consistent with higher offgas generation rates which leads to the conclusion that dissolution rate generally increases with the purity of the Al alloy. Therefore, the observation that the End Cap sidewall (which was fabricated from an Al-6063 alloy) dissolved at a faster rate than the components of the End Cap and HFIR fuel carrier fabricated from an Al-6061 alloy is consistent with the previous flowsheet development for HFIR fuels.

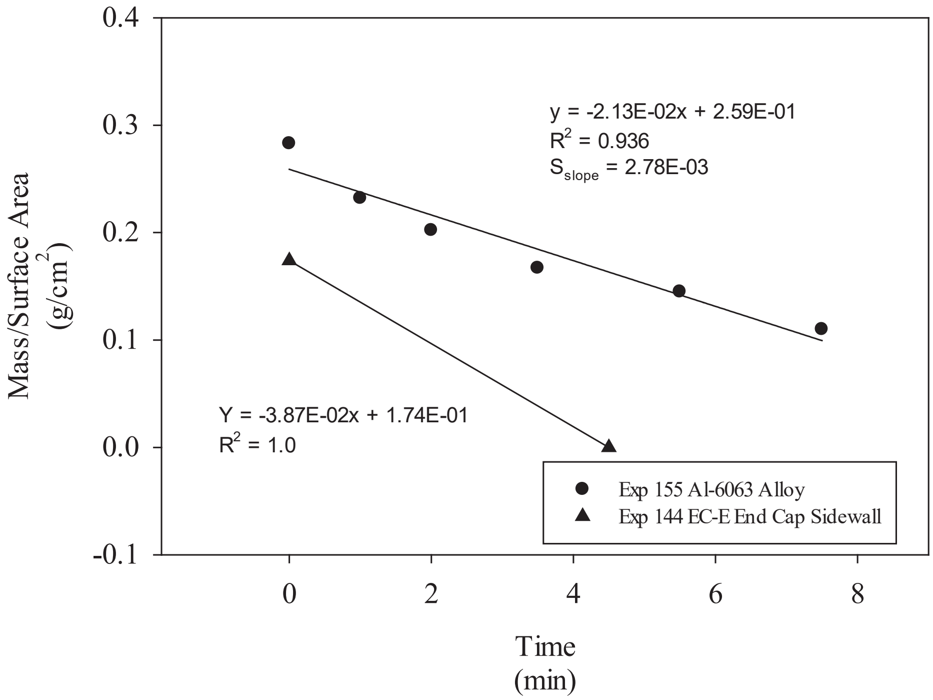

Figure 3-14. Experiment 155 – Al-6063 coupon dissolution data

3.3 <u>Sequential Partial Dissolution of Al-1100, Al-6061, and L-Bundle End Cap Coupons</u>

Partial dissolutions were conducted to examine the deposition of Hg onto the Al surfaces, especially the relative quantity and the location of deposition, as this could affect the surface catalyzed dissolution rate. These coupons were examined by a SEM and a digital microscope. The test coupons included Al-1100 and Al-6061 corrosion coupons of the same thickness and L-Bundle End Cap sidewall coupons. All coupons were partially dissolved sequentially in Experiment 154. The initial and final masses, dimensions, and surface areas for the partially dissolved coupons are shown in Appendix C Table C-14. As shown by a comparison of the initial and final masses and dimensions of the coupons, a portion of each coupon was dissolved. Dissolution rates were not calculated since the initial solution condition (i.e., Al concentration) for each coupon differed. Examination of the surfaces of the coupons are discussed in Section 3.4.

3.4 <u>Metallurgical Analyses of L-Bundle End Cap and HFIR Fuel Outer Carrier Test Coupons</u>

The composition, microstructure and material property differences for components of the L-Bundle and HFIR fuel carriers are potential factors for the observed difference in dissolution rates. Initially, the scope of this study included a characterization of grain size and hardness as parameters for establishing a link to the dissolution rate variability. Other factors were identified during this study that may be contributing factors including the density, type, and dissolution rate of intermetallic particles as well as the material composition (Al-6061 and Al-6063). Since the dissolution is a multi-step process, the variation in component dissolution rate may be associated with one of these steps. The deposition of Hg on the Al surface, which is hypothesized to be an electrochemical process,[11] was assessed by looking for the presence of Hg on partially dissolved test samples.

In Al alloys, the composition, fabrication process, and aging conditions affect the microstructure, which impacts hardness, grain size, intermetallic particle formation, and mechanical and physical properties of the material. Alloy compositions must meet specified requirements for composition in ASTM International standards, which differ for the various material processes (i.e., extrusion or rolling). The governing ASTM standards for Al-6061 and Al-6063 include B221-14 for extruded products,[8] B209-14 for sheet and plate products (Al-6063 is not included in this standard),[12] and B241/B241M-16 for seamless pipe.[13] Certified material test reports for the L-Bundle assembly and the HFIR fuel outer carrier, which include the compositional data for the specific material used in a carrier, are shown in Appendix A along with ASTM B221 compositions. As stated earlier, the End Cap sidewall was fabricated from an extruded Al-6063 tube and not Al-6061.

Aluminum-6061 and Al-6063 have slightly different ranges for the alloying elements as shown in Table 3-1 and Appendix A, which was also observed in the available CMTRs for the End Cap sidewall and the other components of the fuel carriers. The End Cap sidewall had the lowest concentration of alloying and impurity elements, especially Mg, Si, and Fe, which agrees with the lower concentration of these elements in Al-6063 alloys. The End Cap sidewall also had a smaller number of Mg_2Si particles, similar to the Al-6063 coupon used in this testing. The amount and location of the Mg_2Si particles, a prevalent intermetallic in Al-6061, are a function of the type and degree of thermal treatment applied to the product;[14] although, this aspect was not investigated during this study.

The compositions of several components were examined by XRF since CMTRs for the specific test samples of the L-Bundle End Cap and the HFIR fuel outer carrier were not available. These data are presented in Table 3-1 along with the ASTM B209 and B221 compositions for Al-6061 and Al-6063.[12,8] The L-Bundle End Cap sidewall composition falls in line with the standard composition for Al-6063, while the other components match well the standard composition for Al-6061, which correlates with the measured dissolution rates during this study. Overall, Al-6063 appears to have lower elemental concentrations (Si, Fe, Cu, Mn, Mg, Cr, and Zn) than Al-6061. The data uncertainty here is taken from the Al-1100 standard used for the XRF measurements. Aluminum-1100 has lower concentrations of non-aluminum elements like Si, Fe and Mg. The Al-1100 standard deviations for these elements were 0.005 (Si), 0.0185 (Fe), 0.0028 (Mg) and 0.0055 (Cu).

Table 3-1. Dissolution Test Coupon and ASTM Standard Compositions

Coupon/ Standard	**Composition (wt. %)**						
	Si	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**
6061-B209/B221	*0.4-0.8*	*<0.7*	*0.15-0.4*	*<0.15*	*0.8-1.2*	*0.04-0.35*	*<0.25*
End cap F	0.65	0.31	0.29	0.058	0.87	0.07	0.029
HFIR 1	0.61	0.15	0.2	0.12	0.96	0.091	0.013
HFIR 5	0.73	0.51	0.19	0.13	0.94	0.16	0.066
6063-B209	*0.2-0.6*	*<0.35*	*<0.1*	*<0.1*	*0.45-0.9*	*<0.1*	*<0.1*
End cap E	0.39	0.15	0.051	0.011	0.5	0.018	0.005

A standard temper for Al-6061, which was used abundantly in these carriers, was T6. For the T6 temper, Al is heated to ~ 950˚ F as a solution anneal, followed by a water quench and aging at ~350˚ F for up to 8 hours. The solution anneal dissolves the alloying elements into solid solutions and the quench holds these elements in solution. The aging conditions allow for a controlled formation of the intermetallic particles to obtain the desired mechanical properties. The tempers for the materials used in the carriers were T6, T651 and T6511. The T651, which was used on the 0.25-in plate (Coupon G in this study), involves a 1-3% stretching for removal of residual stresses so the product can maintain shape. The extruded components, which were primarily used for the lifting bail, had a T6511 temper which indicates a straightening after the aging process to maintain tolerances. The additional steps for stretching and straightening may affect the microstructure and cold work of the material.

The metallurgical characterization of the coupons consisted of four measurements: hardness, grain size and second-phase particle count and sizing. The hardness measurements were made on the coupons prior to mounting. The other measurements were made on the mounted and prepared coupons. The hardness is a measure of the physical metallurgy of the sample and is impacted by the alloy composition and material processing. The grain size and second-phase particles characterize the microstructure and are also impacted by the alloy composition and material processing. The intermetallic particle parameters, count and total surface area of particles, are an average of four measurements, two from the center of the sample and two from the edge of the mounted sample. Table 3-2 provides a summary of these measurements for each coupon.

The first measurements made were for hardness. Two different indenters or scales were used: Rockwell B (100 kgf, 1/16-in ball) and a superficial Rockwell 15t (15 kgf 1/16-in ball). Reliable Rockwell B measurements could not be obtained on all components so superficial Rockwell 15t measurements were made. The hardness results are presented in Table 3-2 for each component of the L-Bundle End Cap and HFIR fuel outer carrier. A nominal value for Al-6061-T6 on the Rockwell B is 60.[15] For wrought Al products, Rockwell B hardness can range between 91-28.[16] The few Rockwell B measurements made on three HFIR fuel outer carrier components were approximately 46-57, so they are within the typical range.

The Rockwell 15t measurements for the HFIR components ranged from approximately 62 to 79, while those for the L-Bundle End Cap ranged from approximately 56 to 76. The stamped Al-6061-T6 plate had an average hardness of 80.1, the highest of all components measured. These hardness values did not show a correlation with the dissolution rates. The End Cap sidewall which had the highest dissolution rate had a hardness value (75.5) in the upper end of the measured hardness values but not the highest (third highest value). All the other L-Bundle End Cap and HFIR fuel outer carrier components had dissolution rates two orders of magnitude slower with average superficial 15t hardness ranging between approximately 62 to 80.

The hardness variability depends in part on grain size, degree of cold work, and density of intermetallic particles. These factors are impacted by the material processing and specific aging conditions for strengthening the component.[17,18] For example, the surface of a piece of metal will be slightly harder than the interior due to cold work from the process method (i.e., rolling, machining, etc.). These factors may have influenced the range measured in this study for the different components.

Grain size measurements were made on the mounted, polished and etched samples taken from the components of the L-Bundle End Cap and HFIR fuel outer carrier. Due to the ease of oxide formation on Al, the etching can be difficult.[19] The differences in the etched microstructure of various components can be seen in Figure 3-15 after etching with a Keller's reagent, which did not highlight the grain boundaries for all the components. Different reagents were tried but without success. Etching of grain boundaries is impacted by the specific heat treatments and fabrication processing of an Al component. The coupon ID's in Table 3-2 are shown in the caption for Figure 3-15. Grain sizes were measurable for micrographs shown in Figure 3-15 (A), (D) and (F). For Figure 3-15 (B), the grains were insufficiently highlighted for the entire sample to perform a measurement. The grain size measured for the L-Bundle End Cap components (3.3, 5.4) overlap the range for the HFIR fuel outer carrier components (2.7, 4.9), which does not explain the difference in dissolution rates. The End Cap sidewall with the highest dissolution rate had a grain size of 3.3 falling within the grain size range for the HFIR outer carrier components.

Table 3-2. Metallurgical Characteristics of Test Samples from L-Bundle End Cap and HFIR Fuel Carrier

Coupon	Section*	Average Hardness**		Grain Size∞	Second-Phase Particles		
		RB	*R15t*		*Count (#)*	*Area (μm^2)*	*Area/Particle (μm^2/#)*
G	L	ND	80.1 ± 0.5	7	335 ± 44	462 ± 62	1.4 ± 0.1
EC – C	C	ND	56.2 ± 3.6	ND	822 ± 128	559 ± 55	0.7 ± 0.1
	L		55.9 ± 0.4				
EC – D	L	ND	57.1 ± 0.3	5.4	599 ± 39	568 ± 81	0.9 ± 0.1
EC – E	L	ND	75.5 ± 0.3	3.3	92 ± 18	225 ± 28	2.5 ± 0.4
EC – F	C		65.7 ± 4.5				
	L	ND	59 ± 4.1	ND	832 ± 64	526 ± 58	0.6 ± 0.1
HF-1	L	56.5 ± 0.8	77.9 ± 0.3	ND	265 ± 44	493 ± 45	1.9 ± 0.2
	C	46.6 ± 3.5	75.8 ± 1.1				
HF-2	L	52.3 ± 0.6	76.5 ± 0.2	4.9	422 ± 53	386 ± 111	0.9 ± 0.3
	C	53.3 ± 2.6	78 ± 0.9				
HF-3	L	52.8 ± 0.1	76.6 ± 0.1	2.7	163 ± 45	370 ± 49	2.3 ± 0.6
	C	55.5 ± 1.9	78.7 ± 0.6				
HF-4	L	ND	65.9 ± 2.8	ND	380 ± 12	659 ± 101	1.7 ± 0.3
	C		61.6 ± 2.6				
HF-5	L	ND	70.3 ± 1.4	ND	672 ± 120	1066 ± 81	1.6 ± 0.2

*Cross section of component (C), Longitudinal section of component (L)
** Average Rockwell hardness ± Standard deviation
∞ For only one person making the measurements, the relative accuracy of these measured values is within ± 0.1
× Grain Size per ASTM Standard Test Method E-112[10]

Once grain size and hardness were found to not correlate with the measured dissolution rates, the intermetallic particle size, density and distribution were investigated because the End Cap sidewall intermetallic particles were notably different than all the other components. The intermetallic particles were observed in mounted and polished samples of the different components; etching was not required. Several LCM micrographs are shown in Figure 3-16 for comparison of the different materials of construction of the L-Bundle End Cap and HFIR fuel outer carrier components. The components include the outer carrier lifting bail support bar, upper support ring, and sidewall and the L-Bundle bent section of lifting bail, upper plate and sidewall. While the size of the particles at 500x appear similar, the density of particles was clearly different with the End Cap sidewall showing the lowest density of particles.

In Al-6061, the primary intermetallic particles are Al_3Fe (several variants exist including those with Si or one of the other minor constituents such as Cu and Cr) and Mg_2Si. In the End Cap sidewall, which had the highest dissolution rate, the particles were mostly variants of Al_3Fe, while all the other End Cap and HFIR fuel carrier components contained both types of particles. In Figure 3-16, the two particles are noted by the difference in color and somewhat by shape. Although a little difficult to differentiate, the grayer and lighter particles are Al_3Fe and the darker particles are Mg_2Si (Arrows identify particles in Figure 3-16 (B) and (C)). Since the LCM does not have chemical characterization capabilities, particles were chemically evaluated using SEM/EDS to identify elemental make up. A comparison of the LCM and SEM images were used to identify likely compositions in the LCM images, which showed the particles with different gray coloring.

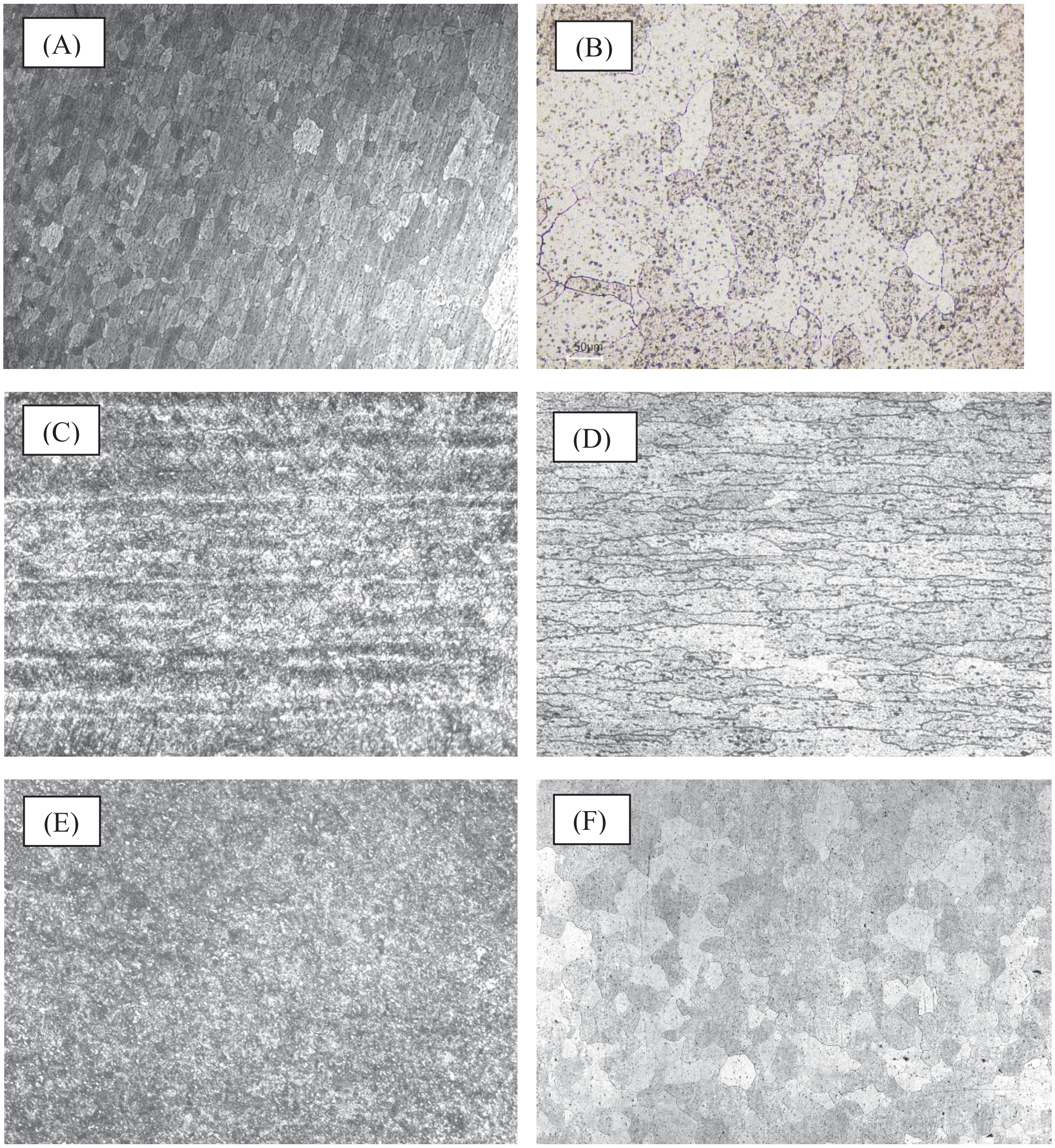

Figure 3-15. Etched microstructures of L-Bundle End Cap and HFIR fuel outer carrier components: (A) HFIR lifting bail support rod (HF-3), 50x; (B) L-Bundle bent section of lifting bail (EC-F), 200x; (C) HFIR support band (HF-4), 500x; (D) L-Bundle top plate (EC-D), 100x; (E) HFIR fuel outer carrier sidewall (HF-5), 500x; and (F) End Cap sidewall (EC-E), 50x (etched with Keller's reagent)

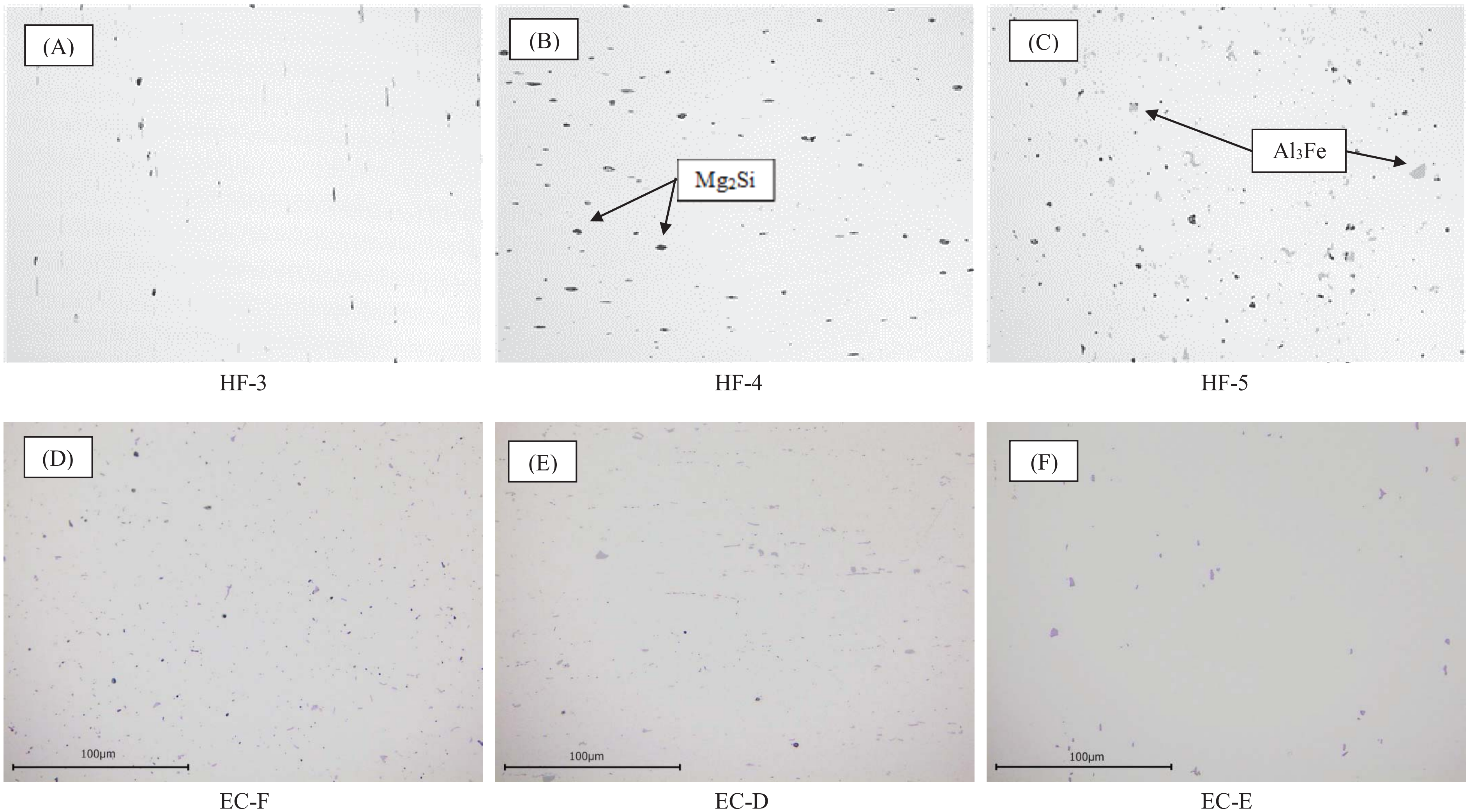

Figure 3-16. Unetched LCM micrographs (500x) of the L-Bundle End Cap and HFIR fuel outer carrier components: (A) HFIR fuel outer carrier lifting bail support bar; (B) HFIR fuel outer carrier support band; (C) HFIR fuel outer carrier sidewall; (D) L-Bundle bent section of lifting bail; (E) L-Bundle top plate; and (F) End Cap sidewall

The microstructure of the Al-1100, Al-6061, and Al-6063 coupons were also examined for the intermetallic characterization. In Figure 3-17, the unetched LCM micrographs show similar characteristics to those observed for the carrier components presented in Figure 3-16. The intermetallic particles show a generally linear alignment as indicated by arrow direction, which is typical of the longitudinal view of rolled plates.

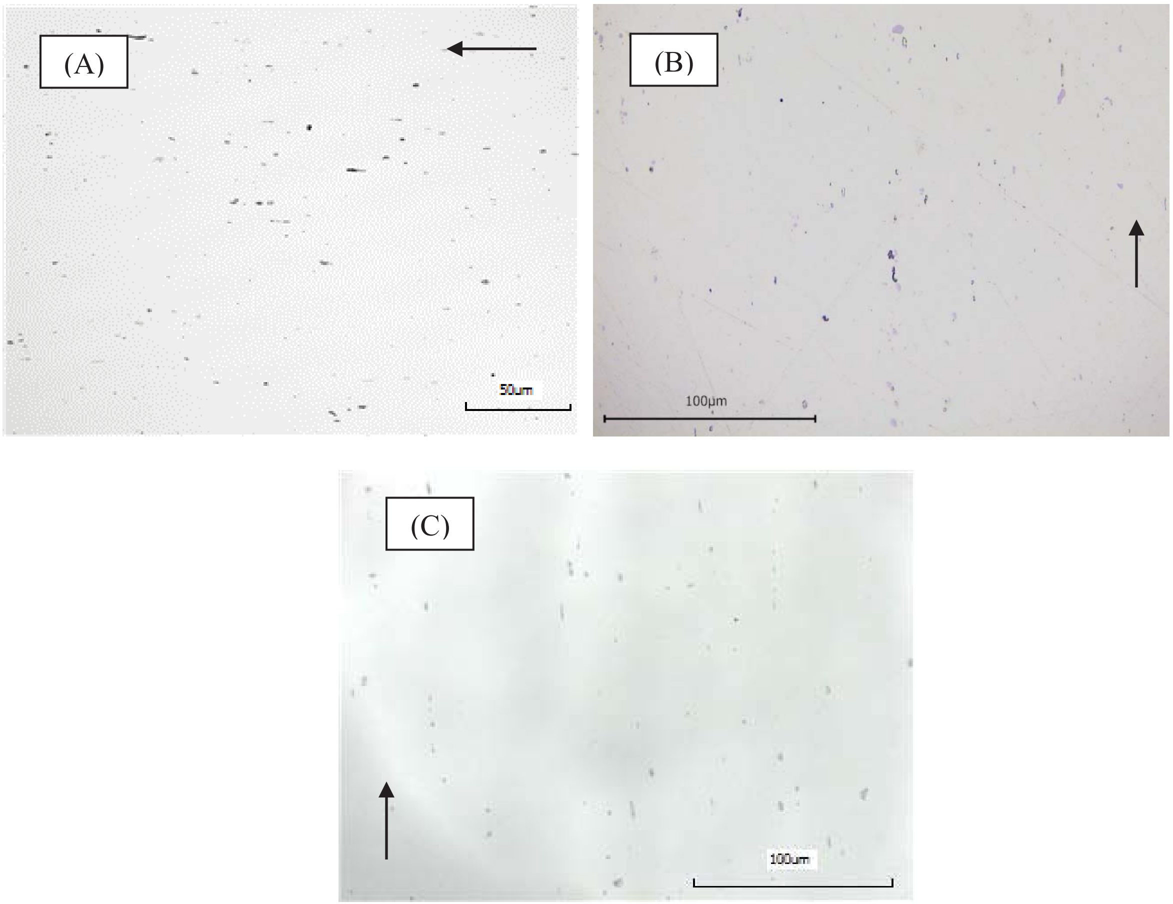

Figure 3-17. Unetched LCM micrographs (500x) of Al-1100 (A), Al-6063 (B) and Al-6063 (C) coupons

A particle count was performed using representative digital LCM micrographs and a particle analysis routine. Particle counts were made on two micrographs from the sample center and two from the edge. The particles included both Al_3Fe and its variants as well as Mg_2Si. In the particle analysis routine, the total areas of the particles are also estimated. The results were presented in Table 3-3. Although the data are not shown separated for the edge and center measurements, the edge counts in some cases were greater (0.1-0.2 µm/# particles) for samples in which the edge was the outer surface of the formed part (i.e., an extruded rod or rolled plate). One exception was the End Cap welded top plate where the edge and center counts were similar. The HFIR and End Cap sidewalls, where samples were not taken from the edge of the rolled sheets, the edge and center counts were similar. This difference between edge and center particle counts may be an indication that the cold work and recrystallization that can occur near these outer surfaces may impact the solubility of the alloy elements, such as Fe, Mg, and Si, causing a change in intermetallic formation and density.

The End Cap sidewall (coupon EC-E) had the lowest particle count (<100) with the lowest total particle area (225 μm^2). An area/particle ratio was also calculated based on these values. The End Cap sidewall also had the highest area/particle ratio (2.5 μm^2/particle) of all the measured components. These data indicate that the fast dissolving End Cap sidewall has the fewest, largest intermetallic particles. The intermetallic particles in the End Cap sidewall appeared to be dominated by Al_3Fe and its variants with few Mg_2Si as based on a qualitative assessment of the microstructure.

Several different samples of the End Cap sidewall were examined including one from another L-Bundle End Cap (the serial numbers (S/N) of the L Bundle End Caps examined during this investigation include 0306 and 113, although both were procured at the same time and probably from the same heat of material). The individual data for all the End Cap coupons are shown in Table 3-3. In general, the End Cap sidewalls had lower particle counts and higher area/particle values, although one sample had a large edge count similar to the count averages for the other components shown in Table 3-2, indicating some significant variability might exist in the particle distribution.

Table 3-3. Average Intermetallic Particle Parameters and Standard Deviations for L-Bundle End Cap Sidewall Coupons

Sample (S/N, location)	Particle Count (#)	Total Particle Area(μm^2)	Area/Particle (μm^2/#)
113 #1 Center	105 ± 18	242.5 ± 29	2.4 ± 0.7
113 #1 Edge	79.5 ± 0.7	206.5 ± 14.8	2.6 ± 0.2
113 #2 Center	92.5 ± 7.8	346± 51	3.7 ± 0.2
113 #2 Edge	255.5 ± 119.5	650 ± 202	2.6 ± 0.4
0306 Center	72 ± 7.1	274 ± 23	3.8 ± 0.1
0306 Edge	70.5 ± 9.2	324 ± 78	4.6 ± 0.5

The particle count for the other components given in Table 3-2 ranged from 163 to 832 with both intermetallic particles (i.e., Al_3Fe and Mg_2Si) apparent in the micrographs. Some overlap existed due to the high particle count for the edge of one End Cap sidewall sample. The area/particle ratios for these other components ranged between 0.6 to 2.3 μm^2/#. The HFIR fuel outer carrier lifting bail support bar had values closest to that of the End Cap sidewall samples with a count of 163, a total area of 370 μm^2, and an area/particle ratio of 2.3 μm^2/#. This similarity can be seen visually by comparing Figure 3-16 (A) and (F). The difference between these two components was the larger presence of Mg_2Si particles in the HFIR component. Attempts were made to isolate and count these particles separately from Al_3Fe, but sufficient differentiation could not be made without including other features.

Particle analysis was also conducted on the Al-1100 and Al-6063 coupons, which had dissolution rates similar to the L-Bundle End Cap sidewall. Particle counts and total area were approximately 350 and 460 μm^2 for Al-1100 and 210 and 390 μm^2 for Al-6063. The Al-6063 particle values are slightly higher than those for the sidewall samples as shown by a comparison with the data in Table 3-3. The Al-1100 particle values are in line with the other components of the L-Bundle assembly, the HFIR fuel outer carrier and Coupon G, which is an Al-6061-T6 coupon. Taken collectively, the intermetallic particle density as indicated by a count from a 500x micrograph is only loosely correlated with the dissolution rate. Other aspects such as intermetallic chemistry or properties may also be a contributing factor.

Mounted and polished samples of two of the carrier components and an Al-1100 coupon were analyzed using the SEM/EDS for elemental characterization. The two components were the L-Bundle End Cap bent section of lifting bail (in cross section orientation) and the HFIR fuel outer carrier straight section of lifting bail (in longitudinal orientation). The identified particles for these Al-6061 components fell into four elemental groupings: Al-Si, Al-Si-Mg, Al-Fe(Cu)-Si, and Mg-Si-Al. Since most particles were small (<2 μm), the excitation volume for the analysis included the surrounding Al matrix. Only a few Mg-Si-Al particles were identified. For the Al-1100 coupon, the primary elemental groupings were Al-Si, Al-Fe(Cu)-Si, and Mg-Si. The measurements for the Al-1100 matrix did not show the presence of Si, but only Mg, which is not an alloying element for this alloy. The Al-6061 matrix measurements showed both Mg and Si, which are alloying elements as shown by the data in Table 3-1 and Appendix A. For all the samples, Cu was usually also found to be present in the Al-Fe-Si particles; Cu can be added in small amounts for improved strength in these alloys. While the Al-6063 coupon was not examined in cross section using the SEM, the intermetallic particles appear to be similar in shape to those of Al_3Fe identified in the Al-6061 fabricated components.

The 2-D shape of the particles was found to be characteristic of the intermetallic particles. If the intermetallic particles were sufficiently small, they tended to be circular in most cases. Many of the Al-Fe-Si particles were light gray and angular, although the shapes were usually irregular. The Al-Si and Mg-Si-Al particles were mostly black, irregular-shaped circular or ellipsoidal bodies. By shape characterization only for the L-Bundle and HFIR fuel outer carrier components, neither the End Cap sidewall nor the Al-6063 coupon showed a large preponderance of Mg-Si-Al particles.

The type of particle could affect the dissolution of the material since different intermetallic particles have different corrosion potentials from that of the Al matrix.[20] This difference in corrosion potential would impact the dissolution as well as the Hg deposition which is one of the steps in the dissolution process. In neutral-pH 0.01 M Cl^- solution, the corrosion potential for Al measured -0.679 V (SCE) while Al_3Fe and Mg_2Si had corrosion potentials of -0.493 and -1.355 V (SCE), respectively.[20] A saturated calomel electrode (SCE) was the reference electrode used for making the potential measurements. Potential values depend in part on the type of reference electrode used. The less negative potential for Al_3Fe indicates that these particles would be a cathode (reduction reactions occur) in an electrochemical reaction with Al being the anode (Al oxidation). Reduction reactions could include NO_3^- reduction, H^+ reduction, and Hg^{2+} reduction. The Mg_2Si particles with a more electronegative potential would be the anode with Al as the cathode (i.e., the particle would corrode preferentially). The lack of Mg_2Si particles on the surfaces of partially dissolved coupons supports the preferential dissolution hypothesis.

In a process described by Rice[11], reduction of Hg on the Al may be necessary for the amalgam formation with Al to occur, followed by amalgam dissolution in the acid. If the Al_3Fe particles in the Al-6061 alloy are the site for Hg reduction instead of on the Al matrix itself, the amalgam formation with Al could be hindered thereby slowing the dissolution process. The larger concentration of intermetallic particles in the HFIR fuel outer carrier components and most of the L-Bundle End Cap components would support such a hypothesis. For the End Cap sidewall with the faster dissolution rate, the low count for Al_3Fe particles could lead to higher dissolution rates over the other components. However, most Hg deposits were found on partially dissolved samples using the SEM at locations rich in Al with low concentrations of the other alloying elements.

Another possibility, however, may be associated with the dissolution of the Al_3Fe particles or the Fe concentration in the alloys. The addition of Fe ions to a dissolution solution was found to reduce the dissolution rate of Al alloys, although the mechanism has not been determined.[21] Based on this observation, another hypothesis associated with the Al_3Fe particles is that their dissolution would increase locally the Fe ion concentration potentially leading to local inhibition of the dissolution. The End Cap sidewall with fewer overall particles would have a lower ionic Fe concentration and may not be impacted by this inhibition. The other components with much lower dissolution rates may have sufficient Al_3Fe particles to be inhibited. The presence of ionic Fe may also impact the solution potential altering the Hg deposition process.

To ascertain if the difference in dissolution rates was significantly impacted by the type and number of intermetallic particles or if Fe dissolution/redeposition was playing a role, a series of partially dissolved samples were produced (See Section 3.3). These samples along with a set of partially dissolved samples from previous dissolution/offgas studies and the Al-6063 coupon were examined using the SEM/EDS. Of interest was the presence of electrodeposited Fe or Hg and the type of particles remaining on a dissolved surface.

Numerous Fe-rich particles were found on the surfaces of the partially dissolved coupons. The cross-sectional view of these coupons showed that many of these particles were acting as cathodes as indicated by the apparent dissolution of the Al matrix around the particle. Figure 3-18 shows this dissolution for a partially dissolved Al-1100 coupon and for a partially dissolved Al-6061 corrosion coupon. The Fe-rich particles have an angular appearance. The surrounding areas did not appear to have a layer of Fe on the surface as might be expected for an electrodeposit.

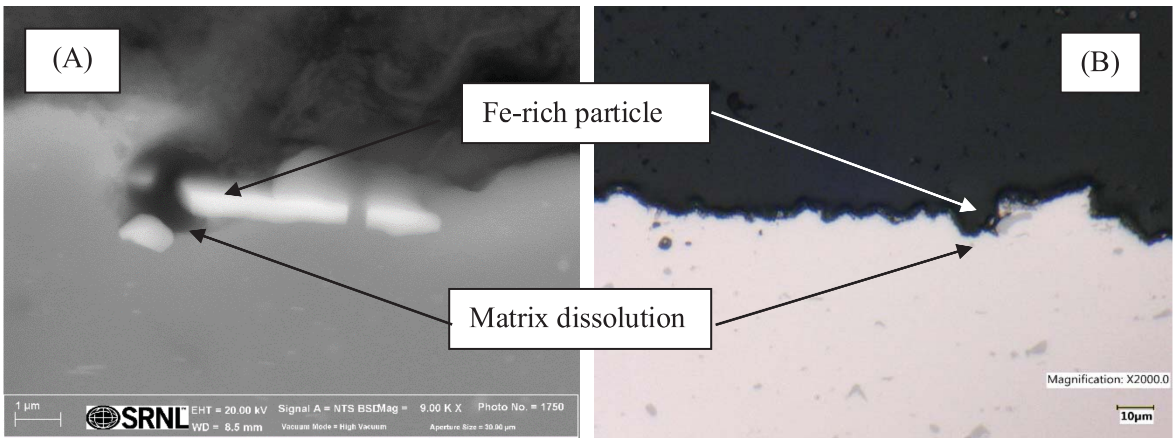

Figure 3-18. (A) SEM micrograph (9000x) of partially dissolved Al-1100 coupon, cross-sectional view; and (B) Digital micrograph (2000X) of partially dissolved Al-6061 coupon, cross-sectional view

During the SEM investigation of the surfaces of the partially dissolved samples, both Fe- and Hg-rich particles were found to have a spherical appearance as shown by the SEM micrographs in Figure 3-19. Two particles on each sample are highlighted by the dotted line circles indicating an Fe-rich particle and a Hg-rich particle. (Note: other particles on the surface were found to contain either Fe or Hg and all particles were not analyzed.) Since Hg was not part of the alloy composition, the similarity in shape of Fe- and Hg-rich particles may indicate a similar route of deposition. The shape of an electrodeposited metal can have numerous shapes depending on solution and surface, so shape alone is insufficient for characterization of deposition. Circular shaped Fe-rich particles were found in the microstructure of the various components, so a clear distinction cannot be made of their origin. No data were found in the literature on electrodeposition of these metals from a nitric acid-based solution.

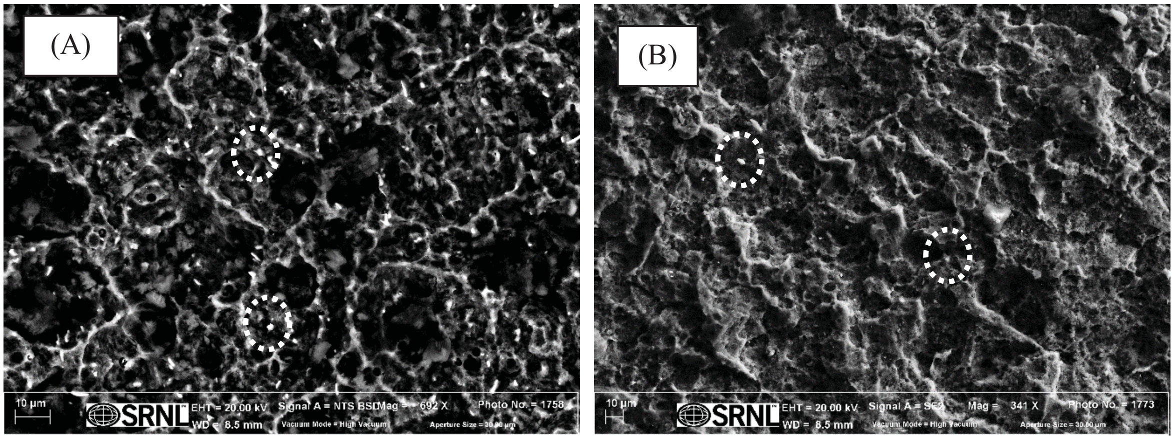

Figure 3-19. SEM micrographs showing the surface morphology of partially dissolved samples: (A) L-Bundle lifting bail – straight section (692x); and (B) HFIR fuel outer carrier sidewall (341x)

The Hg-rich particles, however, would only appear from a deposition process. Mercury was found on all the partially dissolved samples, but the End Cap sidewall coupon qualitatively appeared to have the most Hg-rich particles. In some locations on this sample, small Hg-rich particles appeared to be depositing along edges as shown by the SEM backscattered and secondary electron micrographs in Figure 3-20. The largest circular particle in the image (circled), which also contains Hg, clearly appears to be a sphere.

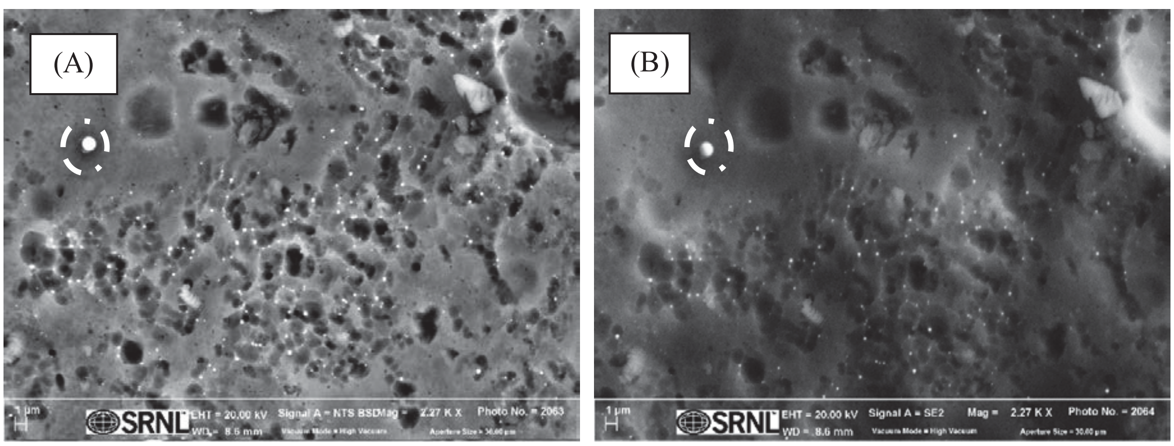

Figure 3-20. SEM micrographs (backscattered (A) and secondary electron (B)) of the partially dissolved End Cap sidewall (2270 x)

The Al-6063 coupon was not completely dissolved during the standard dissolution test similar to components from either carrier. The SEM/EDS examination of this coupon showed a similar surface morphology to that of the End Cap sidewall. Particles containing Al-Fe-Si were observed on the surface similar to the other components; and Mg_2Si particles were not found. Particles containing Fe, Cr and Ni were found on the surface, but were not apparent in the cross-section view. If these particles are not sample preparation contaminants and actually in the material, they would facilitate the dissolution of the Al matrix depending on whether surface oxides provide a sufficient barrier to electron flow. This difference indicates a possible surface contamination. Mercury was not found on the surface similar to some HFIR components.

An observed feature in the cross sections of the partially dissolved coupons was both an irregular surface that might indicate a morphology in a planar view as shown in Figure 3-20. In Figure 3-21, note the "hilliness" of the surface which may indicate selective dissolution of these areas. This hilliness was more prevalent for the End Cap sidewall and Al-6061 corrosion coupon samples. Three contributors might be: 1) the location of Fe-rich particles acting as cathodes causing localized dissolution to form a pit-like or trough-like feature, 2) the location of Mg_2Si particles acting as anodes and oxidizing to form a pit-like feature, and 3) the preferential deposition of Hg at a high-energy feature (such as a strained area resulting from cold work) or the edge of a pit-like feature resulting from one of the first two contributors. In Figure 3-21 (D), numerous "hilltops" are capped by Fe-rich particles (gray particles at peaks of hilltops, see arrows) which supports the hypothesis of the Fe-rich particles acting as cathodes. The complete lack of Mg_2Si particles at the surface circumstantially supports the anodic nature of these particles. Additionally, Mg_2Si particles were not noted on the surfaces of these partially dissolved samples during the SEM investigation. The cross-section views of these samples were not examined in the SEM, so Hg-rich particles were not specifically identified at the surfaces.

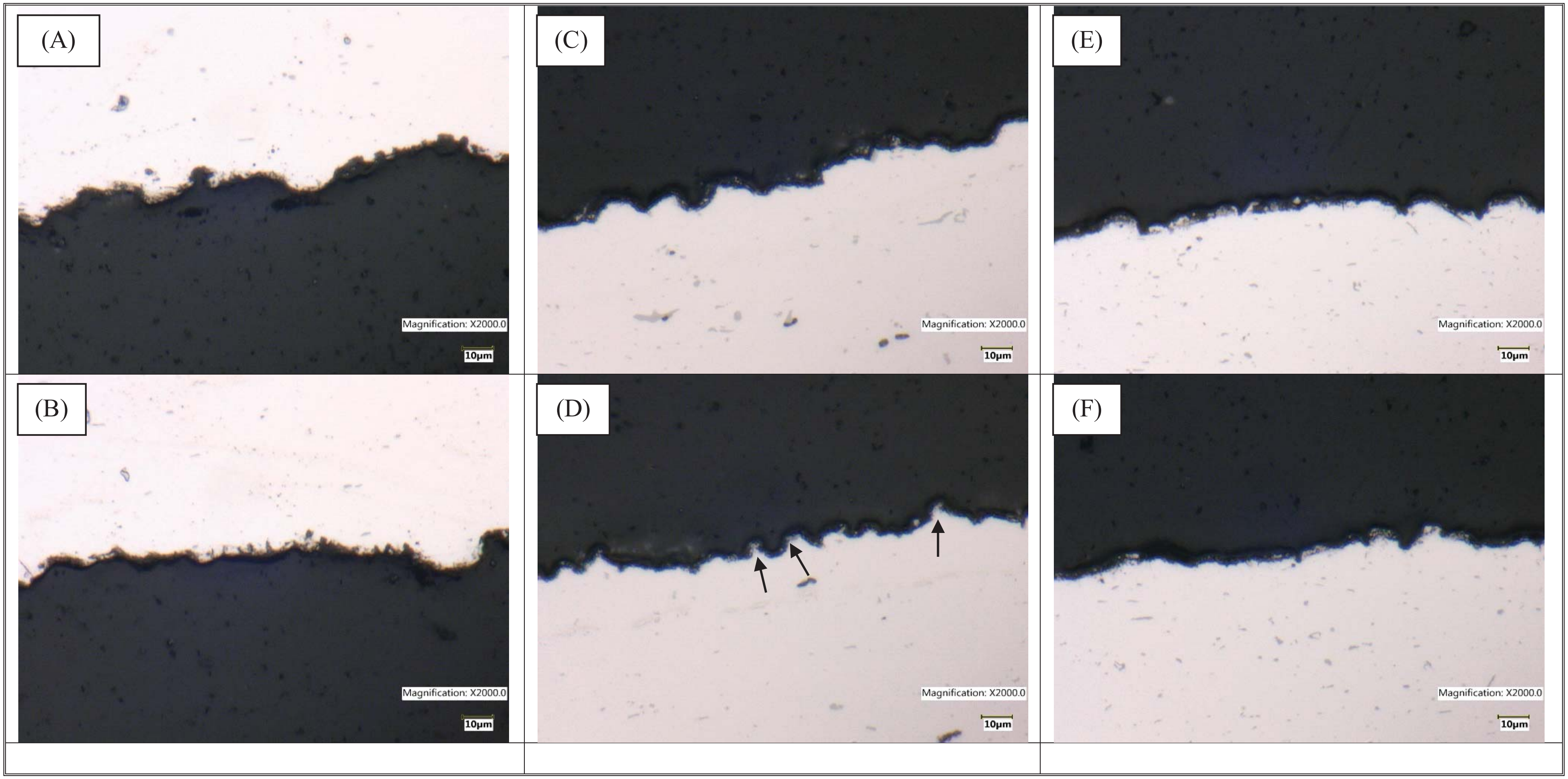

Figure 3-21. Digital cross-section micrographs of the partially dissolved samples showing surfaces "hilliness": (A, B) End Cap sidewall; (C, D) Al-6061 corrosion coupons and; (E, F) Al-1100 corrosion coupon (2000 x)

The second observed feature in the cross-section views for the End Cap sidewall and the Al-1100 corrosion coupon was a subsurface dissolution that appeared to be removing layers of the Al matrix as shown by the micrographs in Figure 3-22. This phenomenon was observed in greater number on the End Cap sidewall coupon than the Al-1100 corrosion coupon and was not observed on the Al-6061 corrosion coupon. This appearance is only in one plane of the cross section, so the apparent separated piece of the matrix may be attached to the surface at another point not within this planar view. This type of dissolution, however, may lead to a higher rate of dissolution if small layers of the Al matrix were removed from the surface at one time. This removal would open fresh surface for the dissolution to progress without the atomistic removal of metal. Aluminum alloys are susceptible to exfoliation or layer corrosion where corrosion occurs along pathways, generally grain boundaries, parallel to the surface. Mercury may or may not play a role in this process.

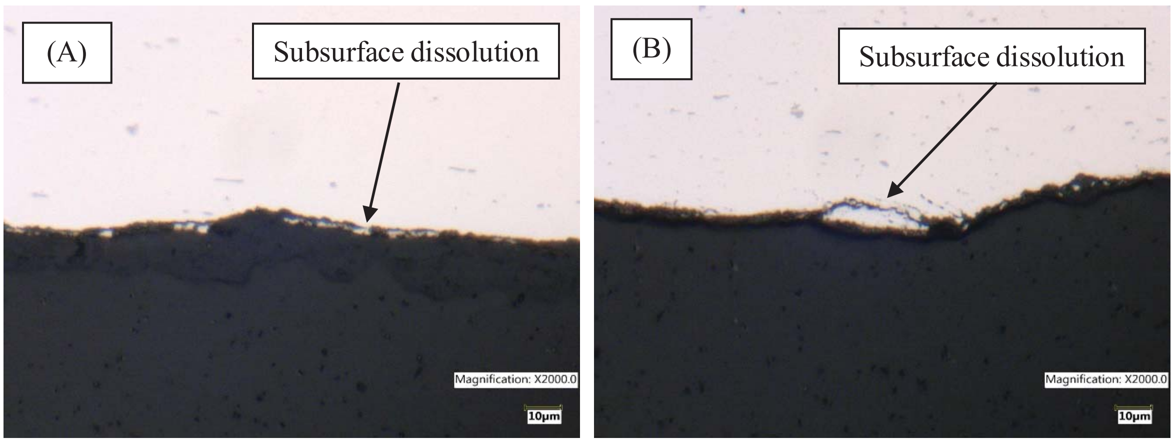

Figure 3-22. Digital cross-section micrographs of the partially dissolved samples showing layer removal of the Al matrix: (A) End Cap sidewall and; (B) Al-1100 corrosion coupon (2000 x)

3.5 Probable Contributors to H-Canyon Dissolution Rate Variability for L-Bundle and HFIR Carriers

Circumstantial evidence from the probing of H-Canyon dissolver insert wells to verify complete dissolution of fuel suggests that certain components of the L-Bundle and the HFIR fuel outer carrier dissolved slower than the remainder of the charge. Extended dissolution cycles for MTR fuels have been attributed to the failure of the L-Bundle End Cap to drop into the acid solution and its slow dissolution rate once dislodged from the well by the probe. Incomplete dissolution of an outer carrier lifting bail was also observed when the HFIR fuel insert was inspected by camera. The observations from this study and previous SRNL studies on the dissolution of Al alloys have identified several factors which are likely contributing to the slow dissolution of the End Cap and carrier components.

A consistent observation from these studies has been that increasing the elemental concentrations of Al alloy constituents (e.g., Fe) is associated with a decrease in the alloy dissolution rate. In prior dissolution studies, when Fe, Ni, Cr, and Mn were present in the nitric acid solution, the Al alloy dissolution rate slowed down or even stopped.[21] To overcome the impact of the impurities on dissolution, the Hg concentration had to be increased from 0.002 M to 0.012 M for specified concentrations of the impurities. The specific factors/mechanism of the reduction in rate is not completely understood; however, a working hypothesis is that the Reduction/Oxidation (Redox) chemistry of the solution at the alloy surface changes with the addition of Redox active species (such as Fe). As the material dissolves, the local concentration of the alloy constituents increases near the surface of the metal. This Redox change appears to alter the electrochemical deposition of Hg on the surface of the alloy thereby reducing (or even stopping) the dissolution process. Without sufficient Hg on the surface, the amalgamation and subsequent dissolution of Al is minimized.

Other factors impacting the dissolution rate (e.g., formation of an oxide barrier to dissolution on the surface of the metal) may become dominant as this occurs.

In this and in previous studies,[1,2,21,22] variations in the dissolution rates of different Al alloys were observed. Both Al-1100 and Al-6063, including the L-Bundle End Cap sidewall, had similar dissolution rates that were much greater than measured for Al-6061. Both Al-1100 and Al-6063 have smaller alloying additions than Al-6061, as shown by the data in Appendix A, indicating that a purer Al alloy has a faster dissolution rate. The specific mechanism coming into play cannot be defined by the available data, but potential hypotheses include the dissolution of more pure Al results in a smaller effect on the Redox chemistry at the alloy surface (as discussed above) and the effects of the intermetallic particle distribution, type, and/or size in less pure alloys has a deleterious effect on the Hg amalgamation, a key step in the Al dissolution process.

The intermetallic particles that formed in the different alloys or more specifically their relative quantity was found to be different for the different alloys. During this study, the End Cap side wall, with the greatest dissolution rate of the carrier components, had far fewer intermetallic particles that were primarily variants of Al_3Fe. These particles also tended to have a greater area per particle. While the Al-6063 coupon was less studied, the particles, although greater in number than those found in the End Cap sidewall, were far smaller (or the total surface of the intermetallic particles was smaller) and appeared to be principally Al_3Fe. In both cases the occurrence of Mg_2Si was intermittent. The components fabricated from Al-6061 have both Al_3Fe and Mg_2Si present as well as what appears to be Si, or more specifically Al-Si.

The difference in the electrochemical behavior of these intermetallic particles may also be a factor but was not investigated in this study. Literature data has shown that Al_3Fe is cathodic to the Al matrix, while Mg_2Si is anodic, so Mg_2Si particles would dissolve preferentially, while Al_3Fe would not.[17] All the partially dissolved coupons that were examined showed a minimal number or no Mg_2Si at the surface. The Al_3Fe particles were abundant on a partially dissolved surface. Cross-sectional analysis of these surfaces showed preferential dissolution of the Al matrix around these Al_3Fe particles.

While the data from this study continues to support the hypotheses of the variation of dissolution rate with increasing solution impurities, the impact on the dissolution mechanism has not been specifically investigated. Some key additional studies in this area would include:

1. Electrochemical studies of the solution Redox chemistry as a function of solution impurities resulting from dissolution.
2. Additional surface analysis from partial dissolutions to understand the preferred locations of Hg deposition.

4.0 Conclusions

The SRNL evaluated the dissolution behavior of the various components of the L-Bundle End Cap and the HFIR fuel outer carrier as well as representative coupons of Al-1100, Al-6061, and Al-6063 to understand the difference in dissolution rates which appears to exist in the H-Canyon dissolvers. Metallurgical properties of these components, including hardness, grain size and intermetallic particle characteristics, were analyzed to correlate with their dissolution rates.

Coupons were cut from two L-Bundle End Caps and a HFIR fuel outer carrier. The coupons were removed from various components of the End Cap and carrier. For the HFIR fuel outer carrier, the components fabricated from Al-6061, including the sidewall, lifting bail, lifting bail support bar, and lifting bail support band, dissolved about two orders of magnitude slower (-3.9E-04 $g/cm^2/min$ with a pooled standard deviation of 4.4E-05) than Al-1100 (-6.4E-02 $g/cm^2/min$ with a standard deviation of 8.9E-04) and Al-6063 (-2.1E-02 $g/cm^2/min$ with a standard deviation of 2.8E-03). The dissolution rates of the components from the L-Bundle End Cap fabricated from Al-6061 were similar to the HFIR fuel outer carrier (-3.4E-04 $g/cm^2/min$ with a pooled standard deviation of 3.1E-05), except for the Al-6063 sidewall (-3.9E-02 $g/cm^2/min$) which dissolved at the same rate as an Al-6063 coupon and at the same order of magnitude as Al-1100.

Hardness and grain size measurements of the various components did not show any correlation to the component dissolution rate. As part of the microstructural evaluation of these components, the second-phase or intermetallic particles that form during metal processing showed a slight correlation to the dissolution rate. The L-Bundle End Cap sidewall had the lowest counts of these particles while also having the highest dissolution rate. This correlation did not hold for the Al-1100 coupon that was previously dissolved and had a much higher particle count.

The deposition of Hg onto the surfaces of the components was also investigated using partially dissolved coupons. The L-Bundle End Cap sidewall showed qualitatively the highest number of Hg particles with Hg identified on intermetallic particles as well as at edges. The intermetallic particles and Hg deposition on the Al-1100 and Al-6063 coupons did not show similar results, although this result may be associated with the limited total surface area examined. An additional factor, although not fully quantified, is the degree of cold work a component has experienced. Since the End Cap sidewall was the thinnest component, the degree of cold work may affect Hg deposition on the metal surface so as to increase the dissolution rate.

The results of this study show that higher dissolution rates are associated with Al alloys containing smaller quantities of alloying elements. These results are consistent with those observed previously but have been extended to include another major Al alloy, Al-6063, the material of construction for the End Cap sidewall. Several hypotheses were suggested for the variable dissolution rate during dissolution of the End Cap and carrier components and Al alloy coupons, including changes to the solution Redox chemistry and the changes in the intermetallic particle characteristics as a function of Al alloy. Recommended testing for future studies includes electrochemical testing for investigating changes to the solution Redox chemistry as well as more thorough surface analysis of partially dissolved coupons.

5.0 Recommendations

The results from this study and previous studies[1,2,21,22] have demonstrated that Al alloys containing smaller amounts of alloying elements (e.g., Fe, Mg, Si, etc.) dissolve at a faster rate. Therefore, one option recommended for potentially increasing the dissolution rate of L-Bundle End Caps and HFIR fuel carrier components is the fabrication of these items from an Al alloy with less impurities. Measured dissolution rates for Al-1100 and Al-6063 were two orders of magnitude greater than the dissolution rate measured for Al-6061. Aluminum-6061 was used for the fabrication of most of the End Cap and carrier components, excluding the End Cap side wall which was fabricated from Al-6063. However, prior to selection of one of the Al alloys containing a higher percentage of Al, an engineering evaluation must be performed to determine if the mechanical properties (e.g., yield strength, tensile strength, elongation. etc.) are acceptable for fabrication of the End Cap and carriers.

6.0 References

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Appendix A. L-Bundle and HFIR Fuel Carrier Components and Al-6061 and Al-6063 Compositions

HFIR Carrier Component	Lot #*	Al Product Form and Temper	Composition (wt %)							
			Si	Fe	Cu	Mn	Mg	Si/Mg	Cr	Zn
Outer Bail	22839311	1.25" Extruded Rod, T6511	0.67	0.38	0.26	0.06	0.9	0.74	0.06	0.06
Outer Bail	22850550	5/8" Extruded Rod T6511	0.75	0.36	0.31	0.06	0.85	0.88	0.05	0.06
Outer Bail	22952144	5/8" Extruded Rod T6511	0.73	0.35	0.22	0.07	0.87	0.84	0.05	0.06
Outer Interior Can Stop	22822038	10" Extruded Sch 80 Seamless Pipe, T6	0.69	0.25	0.21	0.04	0.91	0.76	0.06	0.02
Outer Can shell, base, base skirt**	86040A4	0.063" Rolled Sheet T6	0.74	0.46	0.18	0.094	1.18	0.63	0.35	0.02
Outer Bail mount	22945258	0.75" Extruded Rod, T6511	0.74	0.35	0.23	0.06	0.85	0.87	0.06	0.05
Inner Bail	3049418	3/8" Extruded Rod, T6511								
Inner Int Can Stop	22830985	5" Extruded Pipe, T6511	0.74	0.46	0.33	0.11	0.86	0.86	0.15	0.08
Inner Base	535664	0.25" rolled plate T651	0.66	0.4	0.25	0.05	0.9	0.73	0.15	0.04

*Compositions obtained from certified material test reports associated with PO# 50887216.
**These components are referred to throughout the report as sidewall.

L-Bundle Assembly Component	Lot #	Al Product Form and Temper	Composition (wt %)							
			Si	Fe	Cu	Mn	Mg	Si/Mg	Cr	Zn
End cap sidewall	21229384	5" OD Extruded Tube, T6, 0.052" wall	0.46	0.15	0.03	0.01	0.53	0.87	0.01	0.01
End cap top plate	70044751	0.25" Rolled Plate4, T651	0.7	0.3	0.25	0.08	1.07	0.65	0.06	0.01
End cap bailing bar	20862695	0.5" Extruded Rod T6511	0.73	0.37	0.33	0.07	0.92	0.79	0.08	0.05
Body base*	21165946	4.25" Extruded Tube, T6511. 0.25" wall	0.67	0.22	0.24	0.03	0.93	0.72	0.05	0.02

*Part not tested during this study.

ASTM Standard[8]	Alloys	Composition (wt %)						
		Si	Fe	Cu	Mn	Mg	Cr	Zn
B221-14*	Al-6061	0.4-0.8	<0.7	0.15-0.4	<0.15	0.8-1.2	0.04-0.35	<0.25
	Al-6063	0.2-0.6	<0.35	<0.1	<0.1	0.45-0.9	<0.1	<0.1

*This specification is for extruded bar, rod, wire, and tube. Other standards (B209-14,[12] etc.) cover different product forms (sheet and plate).

Appendix A. End Cap and HFIR Aluminum Material Certified Material Test Report

ALASKAN COPPER & BRASS COMPANY
Stainless Steel Aluminum
TO: ABW Technologies
PO#: 5088-7216
SALES ORDER #: 501016-1
LINE #: 3
COMPLETED BY: FFU

06-14-2017 114021

sapa: Sapa Industrial Extrusions
1550 KIRBY LANE
--
SPANISH FORK, UT
84660-1349

Sapa Extrusions Inc., a Subsidiary of Sapa AB

Certified Inspection Report

Sales Order Number	Line No.	Customer P/O	Cert Number	Page
1101242573	45	10142622-45	SAPA2673812	Page 1 of 2
			Cert Creation Date	**Cert Print Date**
			12-JUN-17	12-JUN-17

Invoice To Customer
ALASKAN COPPER & BRASS COMPANIES INC
3223 6TH AVENUE SOUTH
--
--
SEATTLE, WA - 98134

Ship To Customer
ALASKAN COPPER & BRASS COMPANIES INC
27402 72ND AVE S.
--
--
KENT, WA - 98032-7366

Quantity Shipped	Date Shipped	Item Description	Specification
555 LB	12-JUN-17	ACC-U-LINE Extruded ACC-U-ROD 1.250 DIA +/-.004 SECT 555343 144.000 IN LN FIN M-MILL W/F 1.443 F 3 CS 1.25 6061/T6511H Marking CONTINUOUS;	ASTMB221 REV 14 AMS-QQ-A-200/8 REV A ASMESB221 REV 09 UNS#A96061 REV SAEJ454 REV Meets 6061-T6511H, 6061-T6511 REV
B/L 841689	**Item No.** G03967457		
Delivery Id 4905489	**Item No. Rev** --		
CustomerPart No. 135392			

Applicable Specifications, Revisions and Exceptions

COMPOSITION NOTE: The values for 'Others Each' and 'Others Total' have met the limits as shown on this certified inspection report. Remainder is Aluminum.

Legal Statement

We hereby certify that, unless otherwise indicated, the material covered by this report has been manufactured, inspected,and tested in accordance with, and has been found to meet, the applicable requirements described herein, including anyspecifications forming a part of the description and that samples representative of the material met the composition andhad the mechanical properties shown on the face of this certification. Also, note that mercury is not a normal contaminantin aluminum alloys and neither it nor any of its compounds are used in the manufacture of our product. This certificationis not to be reproduced in partial form without prior written approval of our Quality Assurance Dept.

Sig nd Title

Steven Tanner 12-JUN-17
Quality Control Manager

Quantities per Lot / Packages

Package Number	Lot Number	Quantity	UOM	Weight Gross	Weight Net
G14-PKG1932904	22839311	32	PCS	561	554
G14-PKG1932904	22839311	--	--	--	--

Composition Limits

Alloy	Si Min	Si Max	Fe Min	Fe Max	Cu Min	Cu Max	Mn Min	Mn Max	Mg Min	Mg Max	Cr Min	Cr Max	Zn Min	Zn Max
6061	0.40	0.80	---	0.70	0.15	0.40	---	0.15	0.80	1.20	0.04	0.35	---	0.25

P.O. 5088-7216
Line 3

sapa:
Sapa Industrial Extrusions
1550 KIRBY LANE
–
SPANISH FORK, UT
84660-1349

Certified Inspection Report

Sales Order Number	Line No.	Customer P/O	Cert Number	Page
1101242573	45	1014262[illegible]-45	SAPA2673812	Page 2 of 2
			Cert Creation Date	**Cert Print Date**
			12-JUN-17	12-JUN-17

Alloy	Ti		Others Each		Others Total	
	Min	Max	Min	Max	Min	Max
6061	---	0.15	---	0.05	---	0.15

Composition Results

Heat / Cast	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Others Total
S17060109	0.67	0.38	0.26	0.06	0.90	0.06	0.06	0.02	--	--
Heat / Cast	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Others Each**	**Others Total**
S17060202	0.70	0.36	0.30	0.05	0.92	0.04	0.06	0.02	--	--

Mechanical Property - Test Limits

		Test Type	UTS - L		TYS - L		EL 4D-Long	
		UOM	KSI		KSI		PCT	
		# of Test	--		--		--	
Test Temper	Lot Number	# of Tests	MIN Value	MAX Value	MIN Value	MAX Value	MIN Value	MAX Value
T6511H	22839311	8	45.2	46.5	41.0	42.6	15.5	16.0

Cert Notes

Products manufactured with a T6511 temper also meet T6 temper requirements.

Yield strength has been determined by the 0.2% offset method

All mill finish alloys produced at Sapa Industrial Extrusions comply with Directive 2011/65/EU (RoHS 2) with the exception of 6262 alloy

In accordance with EN 10204 Inspection Certificate Type 3.1

Melted in the USA or Qualifying Countries (as defined in Defense Federal Acquisition Regulation Supplement (DFARS) Section 225.872-1)

Manufactured in the United States

Manufactured in the United States

P.O. 5088-7216
Line 3

ABW TECHNOLOGIES, INC
REVIEWED BY Q.C.
BY: Rick Kam
DATE: 10-26-17

REVIEWED TO ASTM B221-08
TP 6061-T6

ALASKAN COPPER & BRASS COMPANY
Stainless Steel Aluminum
TO: ABW
PO#: 5814-7216
SALES ORDER #: 520911-1
LINE #: 2
COMPLETED BY ITH

10-04-2017 117025

sapa: Sapa Industrial Extrusions
1550 KIRBY LANE
--
SPANISH FORK, UT
84660-1349

Sapa Extrusions Inc., a Subsidiary of Sapa AB

Certified Inspection Report

Sales Order Number	Line No.	Customer P/O	Cert Number	Page
1101291314	32	10145515-32	SAPA2741940	Page 1 of 2
			Cert Creation Date	**Cert Print Date**
			02-OCT-17	02-OCT-17

Invoice To Customer
ALASKAN COPPER & BRASS COMPANIES INC
3223 6TH AVENUE SOUTH
--
--
SEATTLE, WA - 98134

Ship To Customer
ALASKAN COPPER & BRASS COMPANIES INC
27402 72ND AVE S.
--
--
KENT, WA - 98032-7366

Quantity Shipped	Date Shipped	Item Description	Specification
529 LB	02-OCT-17	ACC-U-LINE Extruded ACC-U-ROD 0.625 DIA +/-.003 SECT 555316 144.000 IN LN FIN M-MILL W/F .361 F.5 CS .63 6061/T6511II Marking CONTINUOUS;	ASTMB221 REV 14 AMS-QQ-A-200/8 REV A ASMESB221 REV 09 UNS#A96061 REV SAEJ454 REV Meets 6061-T6511H, 6061-T6511 REV
B/L	**Item No.**		
871136	G03967433		
Delivery Id	**Item No. Rev**		
4937907	---		
CustomerPart No.			
135350			

Applicable Specifications, Revisions and Exceptions

COMPOSITION NOTE: The values for 'Others Each' and 'Others Total' have met the limits as shown on this certified inspection report. Remainder is Aluminum.

Legal Statement

We hereby certify that, unless otherwise indicated, the material covered by this report has been manufactured, inspected,and tested in accordance with, and has been found to meet, the applicable requirements described herein, including anyspecifications forming a part of the description and that samples representative of the material met the composition andhad the mechanical properties shown on the face of this certification. Also, note that mercury is not a normal contaminantin aluminum alloys and neither it nor any of its compounds are used in the manufacture of our product. This certificationis not to be reproduced in partial form without prior written approval of our Quality Assurance Dept

Signature And Title

Steven Tanner
Quality Manager
02-OCT-17

Quantities per Lot / Packages

Package Number	Lot Number	Quantity	UOM	Weight Gross	Weight Net
G14-PKG1974534	22952144	121	PCS	535	529

Composition Limits

Alloy	Si		Fe		Cu		Mn		Mg		Cr		Zn	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
6061	0.40	0.80	---	0.70	0.15	0.40	---	0.15	0.80	1.20	0.04	0.35	---	0.25

P.O 5814-7216
LINE 5

sapa: Sapa Industrial Extrusions
1550 KIRBY LANE
--
SPANISH FORK, UT
84660-1349

Certified Inspection Report

Sales Order Number	Line No.	Customer P/O	Cert Number	Page
1101291314	32	10145515-12	SAPA2741940	Page 2 of 2
			Cert Creation Date	Cert Print Date
			02-OCT-17	02-OCT-17

Alloy	Ti		Others Each		Others Total	
	Min	Max	Min	Max	Min	Max
6061	---	0.15	---	0.05		0.15

Composition Results

Heat / Cast	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Others Total
S17092405	0.73	0.35	0.22	0.07	0.87	0.05	0.06	0.02	--	--
Heat / Cast	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Others Total
S17092409	0.72	0.31	0.21	0.08	0.84	0.05	0.05	0.02		--

Mechanical Property - Test Limits

		Test Type	UTS - L		TYS - L		EL 4D-I ong	
		UOM	KSI		KSI		PCT	
		# of Test	--		--		--	
Test Temper	Lot Number	# of Tests	MIN Value	MAX Value	MIN Value	MAX Value	MIN Value	MAX Value
T651111	22952144	4	47.0	47.7	42.9	44.0	14.5	17.0

Cert Notes

Products manufactured with a T6511 temper also meet T6 temper requirements.

Yield strength has been determined by the 0.2% offset method

All mill finish alloys produced at Sapa Industrial Extrusions comply with Directive 2011/65/EU (RoHS 2) with the exception of 6262 alloy

In accordance with EN 10204 Inspection Certificate Type 3.1

Melted in the USA or Qualifying Countries (as defined in Defense Federal Acquisition Regulation Supplement (DFARS) Section 225.872-1)

Manufactured in the United States

Manufactured in the United States

P.O 5814-7216
LINE 5

ABW TECHNOLOGIES, INC
REVIEWED BY Q.C.
BY Rick Kain
DATE 02-22-18

REVIEWED TO ASTM B-221-09
TP 6061 T6511

ALASKAN COPPER & BRASS COMPANY
Stainless Steel Aluminum
TO: ABW Tech.
PO#: 5088 7216
SALES ORDER #: 501 1061
LINE #: 6
COMPLETED BY: FFU

06-28-2017 114390

sapa: Sapa Industrial Extrusions
1550 KIRBY LANE
--
SPANISH FORK, UT
84660-1349

Sapa Extrusions Inc., a Subsidiary of Sapa AB

Invoice To Customer
ALASKAN COPPER & BRASS COMPANIES INC
3223 6TH AVENUE SOUTH
--
--
SEATTLE, WA - 98134

Ship To Customer
ALASKAN COPPER & BRASS COMPANIES INC
27402 72ND AVE S.
--
--
KENT, WA - 98032-7366

Certified Inspection Report

Cert Number	Page
SAPA2681995	Page 1 of 2

Sales Order Number	Line No.	Customer P/O	Cert Creation Date	Cert Print Date
1101249260	48	10143052-48	25-JUN-17	25-JUN-17

Quantity Shipped	Date Shipped	Item Description	Specification
559 LB	25-JUN-17	ACC-U-LINE Extruded ACC-U-ROD 0.625 DIA +/-.003 SECT 555316 144.000 IN LN FIN M-MILL W/F .361 F 5 CS .63 6061/T6511H Marking CONTINUOUS;	ASTMB221 REV 14 AMS-QQ-A-200/8 REV A ASMESB221 REV 09 UNS#A96061 REV SAEJ454 REV Meets 6061-T6511H, 6061-T6511 REV
B/L	**Item No.**		
845301	G03967433		
Delivery Id	**Item No. Rev**		
4909796	--		
CustomerPart No.			
135350			

Applicable Specifications, Revisions and Exceptions

COMPOSITION NOTE: The values for 'Others Each' and 'Others Total' have met the limits as shown on this certified inspection report. Remainder is Aluminum.

Legal Statement

We hereby certify that, unless otherwise indicated, the material covered by this report has been manufactured, inspected,and tested in accordance with, and has been found to meet, the applicable requirements described herein, including anyspecifications forming a part of the description and that samples representative of the material met the composition andhad the mechanical properties shown on the face of this certification. Also, note that mercury is not a normal contaminantin aluminum alloys and neither it nor any of its compounds are used in the manufacture of our product. This certificationis not to be reproduced in partial form without prior written approval of our Quality Assurance Dept

Signature And Title

Steven Tanner
Quality Control Manager
25-JUN-17

Quantities per Lot / Packages

Package Number	Lot Number	Quantity	UOM	Weight Gross	Weight Net
G14-PKG1938796	22850550	129	PCS	565	559

Composition Limits

Alloy	Si Min	Si Max	Fe Min	Fe Max	Cu Min	Cu Max	Mn Min	Mn Max	Mg Min	Mg Max	Cr Min	Cr Max	Zn Min	Zn Max
6061	0.40	0.80	---	0.70	0.15	0.40	---	0.15	0.80	1.20	0.04	0.35	---	0.25

P.O. 5088-7216
Line 6

sapa:

Sapa Industrial Extrusions
1550 KIRBY LANE
--
SPANISH FORK, UT
84660-1349

Certified Inspection Report

Sales Order Number	Line No.	Customer P/O	Cert Number	Page
			SAPA2681995	Page 2 of 2
			Cert Creation Date	Cert Print Date
1101249260	48	10143052-48	25-JUN-17	25-JUN-17

Alloy	Ti		Others Each		Others Total	
	Min	Max	Min	Max	Min	Max
6061	---	0.15	---	0.05	---	0.15

Composition Results

Heat / Cast	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Others Total
S17061704	0.75	0.36	0.31	0.06	0.85	0.05	0.06	0.02	--	--

Mechanical Property - Test Limits

		Test Type	UTS - L		TYS - L		EL 4D-Long	
		UOM	KSI		KSI		PCT	
		# of Test	--		--		--	
Test Temper	Lot Number	# of Tests	MIN Value	MAX Value	MIN Value	MAX Value	MIN Value	MAX Value
T6511H	22850550	4	47.7	48.3	42.8	44.0	15.0	19.0

Cert Notes
Products manufactured with a T6511 temper also meet T6 temper requirements.
Yield strength has been determined by the 0.2% offset method
All mill finish alloys produced at Sapa Industrial Extrusions comply with Directive 2011/65/EU (RoHS 2) with the exception of 6262 alloy
In accordance with EN 10204 Inspection Certificate Type 3.1
Melted in the USA or Qualifying Countries (as defined in Defense Federal Acquisition Regulation Supplement (DFARS) Section 225.872-1)
Manufactured in the United States
Manufactured in the United States

P.O. 5088-7216
Line 6

ABW TECHNOLOGIES, INC
REVIEWED BY Q.C.
BY Rick Kain
DATE 10-26-17

REVIEWED TO ASTM B221-08
TP 6061-T6

ALASKAN COPPER & BRASS COMPANY
Stainless Steel Aluminum

TO: ABW Tech
PO#: 5088 7216
SALES ORDER #: 5017106-1
LINE #: 1
COMPLETED BY: FFU

06-08-2017 113818

sapa: Sapa Industrial Extrusions
53 POTTSVILLE STREET
CRESSONA, PA
17929-0187

Sapa Extrusions Inc., a Subsidiary of Sapa AB

Certified Inspection Report

Sales Order Number	Line No.	Customer P/O	Cert Number	Page
1101217795	3	10141312-3	SAPA2666723	Page 1 of 2
			Cert Creation Date	**Cert Print Date**
			31-MAY-17	31-MAY-17

Invoice To Customer
ALASKAN COPPER & BRASS COMPANIES INC
3223 6TH AVENUE SOUTH
--
--
SEATTLE, WA - 98134

Ship To Customer
ALASKAN COPPER & BRASS COMPANIES INC
27402 72ND AVE S.

KENT, WA - 98032-7366

Quantity Shipped		Date Shipped	Item Description	Specification
4895	LB	31-MAY-17	Extruded Seamless Pipe 10.000 DIA x SCHEDULE 80 240.000 IN LN FIN M-MILL W/F 22.252 F 3 CS 10.75 6061/T6 Marking CONTINUOUS;	ASTMB241 REV 16 ASMESB241 REV 01 ASTMB345 REV 11 ASTMB221 REV 14 AMS-QQ-A-200/8 REV A
B/L		**Item No.**		
838616		G03231852		
Delivery Id		**Item No. Rev**		
4900127		--		
CustomerPart No.				
734926				

Applicable Specifications, Revisions and Exceptions

COMPOSITION NOTE: The values for 'Others Each' and 'Others Total' have met the limits as shown on this certified inspection report. Remainder is Aluminum.

Legal Statement

We hereby certify that, unless otherwise indicated, the material covered by this report has been manufactured, inspected,and tested in accordance with, and has been found to meet, the applicable requirements described herein, including anyspecifications forming a part of the description and that samples representative of the material met the composition andhad the mechanical properties shown on the face of this certification. Also, note that mercury is not a normal contaminantin aluminum alloys and neither it nor any of its compounds are used in the manufacture of our product. This certificationis not to be reproduced in partial form without prior written approval of our Quality Assurance Dept.

Signature And Title

Michael D. Hammer

Mike Hammer 31-MAY-17
Cressona Plant Manager

Quantities per Lot / Packages

Package Number	Lot Number	Quantity	UOM	Weight Gross	Weight Net
G12-PKG2992875	22822038	2	PCS	898	890
G12-PKG2992877	22822038	2	PCS	898	890
G12-PKG2992881	22822038	2	PCS	898	890
G12-PKG2992881	22822038	--	--	--	--
G12-PKG2992882	22822038	2	PCS	898	890
G12-PKG2992887	22822038	3	PCS	1343	1335

Composition Limits

P.O 5088-7216
Line 1

sapa:

Sapa Industrial Extrusions
53 POTTSVILLE STREET
CRESSONA, PA
17929-0187

Certified Inspection Report

Sales Order Number	Line No.	Customer P/O	Cert Number	Page
1101217795	1	10141312-3	SAPA2666723	Page 2 of 2
			Cert Creation Date	Cert Print Date
			31-MAY-17	31-MAY-17

Alloy	Si		Fe		Cu		Mn		Mg		Cr		Zn	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
6061	0.40	0.80		0.70	0.15	0.40	---	0.15	0.80	1.20	0.04	0.35	---	0.25

Alloy	Ti		Others Each		Others Total	
	Min	Max	Min	Max	Min	Max
6061	---	0.15	---	0.05		0.15

Composition Results

Heat / Cast	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Others Total
3007511	0.69	0.25	0.21	0.04	0.93	0.06	0.02	0.02	--	

Mechanical Property - Test Limits

		Test Type	UTS - L		TYS - L		EL 4D-Long	
		UOM	KSI		KSI		PCT	
		# of Test			--		--	
Test Temper	Lot Number	# of Tests	MIN Value	MAX Value	MIN Value	MAX Value	MIN Value	MAX Value
T6	22822038	1	44.5	44.5	41.2	41.2	14.7	14.7

Cert Notes
Products manufactured with a T6511 temper also meet T6 temper requirements.
Yield strength has been determined by the 0.2% offset method
All mill finish alloys produced at Sapa Industrial Extrusions comply with Directive 2011/65/EU (RoHS 2) with the exception of 6262 alloy
In accordance with EN 10204 Inspection Certificate Type 3.1
Melted in the USA or "Qualifying Countries" (as defined in Defense Federal Acquisition Regulation Supplement (DFARS) Section 225.872-1)
Manufactured in the United States

P.O. 5088-7216
LINE 1

ABW TECHNOLOGIES, INC
REVIEWED BY Q.C.
BY Rick Kam
DATE 10-26-17

REVIEWED TO ASTM B-~~209~~ 241-2013
TP 6061-T6
RK

Alcoa Europe

European Mill Products
Alcoa Trasformazioni srl
Stabilimento di Fusina
Via dell' Elettronica 31
30176 Malcontenta
Loc. Fusina (Venezia)
Italia
Tel.: 39 041 2917111
Fax: 39 041 2917250

09-06-2017 116141

ALCOA

INSPECTION CERTIFICATE

EN 10204 3.1

Ordernumber Alcoa	154834003
Date	8/03/16
Certificate number	W16100108
Shipment doc.ref.	002840

Your order nr	Your alloy	Your temper	Quantity	Your Art nr
CHARLE 7800-I	6061	T6	38735 Pounds	

Global specification

ALU SHEET 6061 T6 ASTM B209 AMS Mill finish
Dimensions T*W*L 0.0630 x 48.00 x 144.00 Inches

Remarks

Chemical composition 6061

Cast no		%Si	%Fe	%Cu	%Mn	%Mg	%Cr	%Ni	%Zn	%Ti	Others %Each	Others Total
86040C2	TXP2A	0.68	0.43	0.18	0.069	1.02	0.11	0.0068	0.025	0.017		
86040C4	TXP3A	0.68	0.37	0.20	0.067	0.97	0.12	0.0063	0.020	0.022		
86040A4	TXP4A	0.74	0.46	0.18	0.094	1.18	0.16	0.0070	0.017	0.013		
Limit	Min.	0.40		0.15		0.80	0.040					
	Max.	0.80	0.70	0.40	0.15	1.20	0.35		0.25	0.15	0.050	0.15

Mechanical properties

Coil nr: Pallet	Rm KSI	Rp0.2 KSI	A50 %
TXP2A	47	41	14
TXP2A	47	41	14
TXP2A	46	41	13
TXP2A	47	42	13
TXP2A	47	42	13
TXP2A	47	41	13
TXP2A	46	41	13
TXP2A	46	41	14
TXP2A	46	41	14
0968844			
0968848			
0969357			
TXP3A	48	42	13
TXP3A	47	42	13
TXP3A	48	42	13
TXP3A	47	42	14
TXP3A	48	42	13
TXP3A	48	42	14

ALASKAN COPPER & BRASS COMPANY
Stainless Steel Aluminum
TO ABW Tech
PO#. 5814-7216
SALES ORDER #: S20911-1
LINE #: 1-4
COMPLETED BY: ITH

P.O. 5814-7216
LINE 1,2,3,4

We hereby certify, that the material described above has been tested and complies with the terms of the confirmation of order.

Alcoa Europe

European Mill Products
Alcoa Trasformazioni srl
Stabilimento di Fusina
Via dell' Elettronica 31
30176 Malcontenta
Loc. Fusina (Venezia)
Italia
Tel.: 39 041 2917111
Fax: 39 041 2917250

ALCOA

INSPECTION CERTIFICATE

EN 10204 3.1

Ordernumber Alcoa	154834003
Date	8/03/16
Certificate number	W16100108
Shipment doc.ref.	002840

Mill finish

Mechanical properties			
Coil nr: / Pallet	Rm KSI	Rp0.2 KSI	A50 %
TXP3A	48	42	13
TXP3A	48	42	13
TXP3A	48	42	14
TXP3A	48	42	13
0968936			
0969357			
0969358			
0969359			
TXP4A	46	40	13
TXP4A	46	40	13
TXP4A	46	40	13
TXP4A	46	40	13
TXP4A	46	40	14
TXP4A	46	40	14
TXP4A	46	40	13
TXP4A	46	40	14
TXP4A	46	40	14
TXP4A	46	40	13
0968929			
0968931			
0968937			
Min.	42	35	10
Max.			

MATERIAL MELTED AND MANUFACTURED IN ITALY
PRODUCT PRODUCED TO THE REQUIRMENT OF AMS 4027 REV N AND
ASTM B209 ALSO MEET THE REQUIRMENTS OF AMS-QQ-A-250_11
ORIGINAL REVISION DATED 1997-08-01

Approved by
Roberto Signori
Test Laboratory Supervisor

P.O. 5814-7216
Line 1,2,3,4

ABW TECHNOLOGIES, INC
REVIEWED BY Q.C.
BY: Rick Kain
DATE: 02-22-18

We hereby certify, that the material described above has been tested and complies with the terms of the confirmation of order.

ALASKAN COPPER & BRASS COMPANY
Stainless Steel Aluminum
TO: ADW Technologies Inc
PO#: 5088-7216
SALES ORDER #: 501106-1
LINE #: 4
COMPLETED BY: FFU

09-26-2017 116575

sapa: Sapa Industrial Extrusions
1550 KIRBY LANE
--
SPANISH FORK, UT
84660-1349

Sapa Extrusions Inc., a Subsidiary of Sapa AB

Invoice To Customer
ALASKAN COPPER & BRASS COMPANIES INC
3223 6TH AVENUE SOUTH
--
--
SEATTLE, WA - 98134

Ship To Customer
ALASKAN COPPER & BRASS COMPANIES INC
27402 72ND AVE S.
--
--
KENT, WA - 98032-7366

Certified Inspection Report

Sales Order Number	Line No.	Customer P/O	Cert Number	Page
1101287394	21	10145227-21	SAPA2736129	Page 1 of 3
			Cert Creation Date	**Cert Print Date**
			23-SEP-17	23-SEP-17

Quantity Shipped		Date Shipped	Item Description	Specification
1061	LB	23-SEP-17	ACC-U-LINE Extruded ACC-U-ROD 0.750 DIA +/-.003 SECT 555324 144.000 IN LN FIN M-MILL W/F .520 F 5 CS .75 6061/T6511II Marking CONTINUOUS;	ASTMB221 REV 14 AMS-QQ-A-200/8 REV A ASMESB221 REV 09 UNS#A96061 REV SAEJ454 REV Meets 6061-T6511II, 6061-T6511 REV
B/L		**Item No.**		
868770		G03967437		
Delivery Id		**Item No. Rev**		
4936211		--		
CustomerPart No.				
135368				

Applicable Specifications, Revisions and Exceptions

COMPOSITION NOTE: The values for 'Others Each' and 'Others Total' have met the limits as shown on this certified inspection report. Remainder is Aluminum.

Legal Statement

We hereby certify that, unless otherwise indicated, the material covered by this report has been manufactured, inspected,and tested in accordance with, and has been found to meet, the applicable requirements described herein, including anyspecifications forming a part of the descripton and that samples representative of the material met the composition andhad the mechanical properties shown on the face of this certification. Also, note that mercury is not a normal contaminantin aluminum alloys and neither it nor any of its compounds are used in the manufacture of our product. This certificationis not to be reproduced in partial form without prior written approval of our Quality Assurance Dept.

Signature And Title

Steven Tanner
Quality Manager
23-SEP-17

Quantities per Lot / Packages

Package Number	Lot Number	Quantity	UOM	Weight Gross	Weight Net
G14-PKG1966048	22925640	88	PCS	556	550
G14 PKG1970337	22945258	83	PCS	517	511

Composition Limits

Alloy	Si		Fe		Cu		Mn		Mg		Cr		Zn	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
6061	0.40	0.80	---	0.70	0.15	0.40	---	0.15	0.80	1.20	0.04	0.35	--	0.25

P.O. 5088-7216
Line 4

sapa:

Sapa Industrial Extrusions
1550 KIRBY LANE
SPANISH FORK, UT
84660 1349

Certified Inspection Report

Sales Order Number	Line No.	Customer P/O	Cert Number	Page
1101287394	21	101-15227-21	SAPA2736129	Page 2 of 3
			Cert Creation Date	**Cert Print Date**
			23-SEP-17	23-SEP-17

Alloy	Ti		Others Each		Others Total	
	Min	Max	Min	Max	Min	Max
6061	-	0.15	-	0.05		0.15

Composition Results

Heat / Cast	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Others Total
S17082807	0.74	0.35	0.23	0.06	0.85	0.06	0.05	0.02	--	-
Heat / Cast	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Others Total
S17090110	0.74	0.32	0.23	0.06	0.88	0.06	0.03	0.02	--	-
Heat / Cast	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Others Total
S17091203	0.75	0.35	0.23	0.08	0.87	0.07	0.06	0.02	--	--

Mechanical Property - Test Limits

		Test Type	UTS - L		TYS - L		EL 4D-Long	
		UOM	KSI		KSI		PCT	
		# of Test	--		--		--	
Test Temper	Lot Number	# of Tests	MIN Value	MAX Value	MIN Value	MAX Value	MIN Value	MAX Value
T651111	22925640	7	47.2	49.2	44.1	46.6	13.0	19.5
		Test Type	UTS - L		TYS - L		EL 4D-Long	
		UOM	KSI		KSI		PCT	
		# of Test	--		--		--	
Test Temper	Lot Number	# of Tests	MIN Value	MAX Value	MIN Value	MAX Value	MIN Value	MAX Value
T651111	22945258	5	47.5	48.8	42.3	44.8	15.0	17.0

Cert Notes
Products manufactured with a T6511 temper also meet T6 temper requirements.
Yield strength has been determined by the 0.2% offset method

P.O. 5088-7216
Line 4

sapa: Sapa Industrial Extrusions
1550 KIRBY LANE
--
SPANISH FORK, UT
84660-1349

Certified Inspection Report

Sales Order Number	Line No.	Customer P/O	Cert Number	Page
1101287394	21	10145227-21	SAPA2736129	Page 3 of 3
			Cert Creation Date	Cert Print Date
			23-SEP-17	23-SEP-17

All mill finish alloys produced at Sapa Industrial Extrusions comply with Directive 2011/65/EU (RoHS 2) with the exception of 6262 alloy
In accordance with EN 10204 Inspection Certificate Type 3.1
Melted in the USA or Qualifying Countries (as defined in Defense Federal Acquisition Regulation Supplement (DFARS) Section 225.872-1)
Manufactured in the United States
Manufactured in the United States

ABW TECHNOLOGIES, INC.
REVIEWED BY Q.C.
BY Rick Kam
DATE 10-26-17

REVIEWED TO ASTM B-221-08
TP 6061

P.O. 5088-7216
LINE 4

ALASKAN COPPER & BRASS COMPANY
Stainless Steel Aluminum
TO: ABW Tech Inc
PO#: 5088-7216
SALES ORDER #: 5U#-1061
LINE #: 5
COMPLETED BY: FFU

sapa:

Certificate of Mechanical Properties

Customer: ALASKAN COPPER & BRASS-RENT

Test Date: 5/20/2017

Description: 3/8 IN ROD

Cust Purchase Order #: 10142010

Profile: 000321

CastNum: 5334

Production Order #: 1176505

Customer Part Number: 135334

Sales Order: SO-352417

PT/LT Number: 3049418

Test Number: 170520145539

Alloy/Temper: 6061-T6511

	Actual		Min	Max	
Tensile	44.6	kpsi	38.00	N/A	kpsi
Yield	41.3	kpsi	35.00	N/A	kpsi
Elongation	18.0	%	10.0	N/A	%

Note: Elongation Method Used Available on Request

Sapa Extrusions. certifies Aluminum Extrusions are produced and tested in accordance with ASTM-B221-14 and ASTM-B557-15 and meet or exceed minimum requirements

ABW TECHNOLOGIES, INC
REVIEWED BY Q.C.
BY Rick Kam
DATE 10-26-17
REVIEWED TO ASTM B221-08
TP 6061-T6

Manufactured in the U.S.A.

Dean Brito
Quality Manager

All alloys and cast numbers have been inspected and found to be within Aluminum Association Chemical Composition Limits
(Composition in percent by weight maximum unless shown as a range)

Alloy	Silicon	Iron	Copper	Manganese	Magnesium	Chromium	Zinc	Titanium	Other Elements Each	Other Elements Total
6005A	.5 - .9	.35	.3	.5	.4 - .7	.3	.2	.1	.05	.15
6061	.4 - .8	.7	.15 - .4	.15	.8 - 1.2	.04 - .35	.25	.15	.05	.15
6063	.2 - .6	.35	.1	.1	.45 - .9	.1	.1	.1	.05	.15
6082	.7 - 1.3	.5	.1	.4 - 1.0	.6 - 1.2	.25	.2	.1	.05	.15
6351	.7 - 1.3	.5	.1	.4 - .8	.4 - .8	....	.2	.2	.05	.15
7075	.40	.5	1.2 - 2.0	.30	2.1 - 2.9	.18 - .28	5.1 - 6.1	.20	.05	.15
2024	.5	.5	3.8 - 4.9	.30 - .90	1.2 - 1.8	.10	.25	.15	.05	.15

P.O. 5088-7216 Line 5

Sapa Extrusions
Address: 7933 NE 21st Avenue, P.O. Box 11263, Portland, OR 97211 USA
Telephone: 503-802-3000 Toll Free: 800-547-0790 Fax: 503-802-3052
Website: www.sapagroup.com/us/profiles

DOCUMENT NO.: TLF-0103-A-2

ALASKAN COPPER & BRASS COMPANY
Stainless Steel Aluminum
TO: ABW Tech INC
PO#: 5088-7216
SALES ORDER #: 501106-1
LINE #: 2
COMPLETED BY: FFU

sapa: Sapa Industrial Extrusions
1550 KIRBY LANE
--
SPANISH FORK, UT
84660-1349

Sapa Extrusions Inc , a Subsidiary of Sapa AB

Invoice To Customer
ALASKAN COPPER & BRASS COMPANIES INC
3223 6TH AVENUE SOUTH
--
--
SEATTLE, WA - 98134

Ship To Customer
ALASKAN COPPER & BRASS COMPANIES INC
27402 72ND AVE S.
--
--
KENT, WA - 98032-7366

Certified Inspection Report

Cert Number	Page
SAPA2664888	Page 1 of 2

Sales Order Number	Line No.	Customer P/O	Cert Creation Date	Cert Print Date
1101236455	47	10142235-47	27-MAY-17	27-MAY-17

Quantity Shipped	Date Shipped	Item Description	Specification
1113 LB	27-MAY-17	ACC-U-LINE Extruded ACC-U-ROD 5.000 DIA +/-.017 SECT 503296 144.000 IN LN FIN M-MILL W/F 23.091 F 1 CS 5 6061/T6511H Marking CONTINUOUS;	ASTMB221 REV 14 AMS QQ A-200/8 REV A ASMESB221 REV 09 UNS#A96061 REV SAEJ454 REV Meets 6061-T6511H, 6061-T6511 REV
B/L 837872	**Item No.** G03305804		
Delivery Id 4901409	**Item No. Rev** --		
CustomerPart No. 135465			

Applicable Specifications, Revisions and Exceptions

COMPOSITION NOTE: The values for 'Others Each' and 'Others Total' have met the limits as shown on this certified inspection report. Remainder is Aluminum.

Legal Statement

We hereby certify that, unless otherwise indicated, the material covered by this report has been manufactured, inspected,and tested in accordance with, and has been found to meet, the applicable requirements described herein, including anyspecifications forming a part of the description and that samples representative of the material met the composition andhad the mechanical properties shown on the face of this certification. Also, note that mercury is not a normal contaminantin aluminum alloys and neither it nor any of its compounds are used in the manufacture of our product. This certificationis not to be reproduced in partial form without prior written approval of our Quality Assurance Dept.

Signature And Title

Steven Tanner 27-MAY-17
Quality Control Manager

Quantities per Lot / Packages

Package Number	Lot Number	Quantity	UOM	Weight Gross	Weight Net
G14-PKG1926836	22830985	4	PCS	1119	1113

Composition Limits

Alloy	Si Min	Si Max	Fe Min	Fe Max	Cu Min	Cu Max	Mn Min	Mn Max	Mg Min	Mg Max	Cr Min	Cr Max	Zn Min	Zn Max
6061	0.40	0.80	---	0.70	0.15	0.40	---	0.15	0.80	1.20	0.04	0.35	---	0.25

P.O. 5088-7216
Line 2

sapa: Sapa Industrial Extrusions
1550 KIRBY LANE
--
SPANISH FORK, UT
84660-1349

Certified Inspection Report

Sales Order Number	Line No.	Customer P/O	Cert Number	Page
1101236455	47	10142235 47	SAPA2664888	Page 2 of 2
			Cert Creation Date	**Cert Print Date**
			27-MAY-17	27-MAY-17

Alloy	Ti		Others Each		Others Total	
	Min	Max	Min	Max	Min	Max
6061	---	0.15	---	0.05	---	0.15

Composition Results

Heat / Cast	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Others Total
S17043005	0.74	0.46	0.33	0.11	0.86	0.15	0.08	0.03	--	--
Heat / Cast	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Others Each**	**Others Total**
S17051407	0.74	0.49	0.29	0.12	0.90	0.13	0.12	0.03	--	--

Mechanical Property - Test Limits

		Test Type	UTS - L		TYS L		EL 4D-Long	
		UOM	KSI		KSI		PCT	
		# of Test	--		--		--	
Test Temper	Lot Number	# of Tests	MIN Value	MAX Value	MIN Value	MAX Value	MIN Value	MAX Value
T6511H	22830985	1	53.8	53.8	50.4	50.4	16.0	16.0

Cert Notes

Products manufactured with a T6511 temper also meet T6 temper requirements.

Yield strength has been determined by the 0.2% offset method

All mill finish alloys produced at Sapa Industrial Extrusions comply with Directive 2011/65/EU (RoHS 2) with the exception of 6262 alloy

In accordance with EN 10204 Inspection Certificate Type 3.1

Melted in the USA or Qualifying Countries (as defined in Defense Federal Acquisition Regulation Supplement (DFARS) Section 225.872-1)

Manufactured in the United States

Manufactured in the United States

PO 5088-7216
Line 2

ABW TECHNOLOGIES, INC
REVIEWED BY Q.C.
BY Rick Kam
DATE 10-26-17

REVIEWED TO ASTM B-221-08
TP 6061-T6

01-06-2017 041330

CERTIFIED INSPECTION REPORT **Arconic** DAVENPORT WORKS 4879 State Street Bettendorf, IA 52722

We hereby certify that the material covered by this certificate has been inspected with, and has been found to meet the applicable requirements described therein, including any specifications forming a part of the description and that samples representative of the material met the composition limits and had the mechanical properties shown on the face of this sheet.

This test report shall not be reproduced except in full, without the written approval of the Quality Department. No alteration, addition or other change is authorized to be made to this certificate. The recording of false, fictitious, or otherwise fraudulent statements or entries on this certificate by any recipient may be punished as a felony under applicable law.

Per

Rob Woodall
Director of Manufacturing Davenport Works

Terrence Thom
Quality Assurance Manager

Ship From: RIVERDALE,IA.

3100033 Ship Date	0 B.L. No.	Invoice No.	Arconic No.	
2016-12-23	11150963	00000	1000872679-9	DP-72679-9

Item P.O. No./Govt Contract No.	Customer	Arconic Item
03137417 Ln#: 2	ALASKAN COPPER & B	G041015464R17

Page 1 of 2

Ship To: ALASKAN COPPER & BRASS COMPANIES, INC.
2440 SE RAYMOND ST
PORTLAND 97202 OR

Item Description
0.25 IN TK (+.015 -0.000) X 72.5 IN W (+.375 - 0.000) X 144.5 IN LN (+.5 -0.0) CAT D 145223 (N) A/T 6061-T651 TYPE 200 WROUGHT TOOLING PLATE MILL FINISH. AMS4027 REV N ANSIH35.2 REV 2013 EXC_MRK ASME-SB-209 REV 15 EXC_MRK ASTMB209 REV 14 ((MARKED)) KRAFT PAPER INTERLEAVED MAX GROSS SKID WGT: 4500 LB QUAN TOL +/- 25 % CQR D145223 REV 54 CUST REQ 16-12-19 *** W/E 16-12-24 ***

Num	Package Ticket	Lot	Weight	Quantity	UOM	Inspector Clock Numbers
1	316021	535662	1584	6	PC	47163 47002
2	316021	535663	1584	6	PC	47163 47002
3	316021	535664	794	3	PC	47163 47002
			3962	15		

Notes for CQR: D145223.54
PRODUCT PRODUCED TO THE REQUIREMENTS OF AMS4027 REV N ALSO MEET THE REQUIREMENTS OF AMS-QQ-A-250_11 ORIGINAL REVISIO N DATED 1997-08-01.

CQR: D145223.54 -Specification Limits

Tmpr	Dir		UTS KSI	TYS KSI	EL4D PCT
T651	Long Transv.	Max			
		Min	42.0	35.0	10

Chemical Composition		SI	FE	CU	MN	MG	CR	ZN	TI	Other Each	Other Total	Aluminum
	Max	0.8	0.7	0.40	0.15	1.2	0.35	0.25	0.15	0.05	0.15	
Alloy 6061	Min	0.40		0.15		0.8	0.04					REMAIN

P.O. 5088-7216
LINE 7

ALASKAN COPPER & BRASS COMPANY
Stainless Steel Aluminum
TO: ABW Tech
PO#: 501106-1
SALES ORDER #: 5088-7216
LINE #: 7
COMPLETED BY: FFU

CERTIFIED INSPECTION REPORT **Arconic** DAVENPORT WORKS 4879 State Street Bettendorf, IA 52722

We hereby certify that the material covered by this certificate has been inspected with, and has been found to meet the applicable requirements described therein, including any specifications forming a part of the description and that samples representative of the material met the composition limits and had the mechanical properties shown on the face of this sheet

This test report shall not be reproduced except in full, without the written approval of the Quality Department. No alteration, addition or other change is authorized to be made to this certificate. The recording of false, fictitious, or otherwise fraudulent statements or entries on this certificate by any recipient may be punished as a felony under applicable law.
Per:

Rob Woodall — Director of Manufacturing Davenport Works
Terrance Them — Quality Assurance Manager

Ship From: RIVERDALE, IA.

Ship Date	B.L. No.	Invoice No.	Arconic No.	
3100033	0			
2016-12-23	11150963	00000	1000872679-9	DP-72679-9

P.O. No./Govt Contract No.	Item	Customer	Arconic Item
03137417 Ln#: 2		ALASKAN COPPER & B	G041015464R17

Page 2 of 2

CQR: D145223.54 -Specification Limits (cont.) --

Lot: 535662 - Mechanical, Physical, Metallography, Quantometer Results --

Tmpr	Dir	No-> Test	UTS KSI	TYS KSI	EL4D PCT
T651	Long Transv.	2	48.5	40.7	17.5
			48.6	40.9	17.3

Cast Number	Chemical - OES	SI	FE	CU	MN	MG	CR	ZN	TI	Other Each	Other Total
H8122011	Actuals	0.66	0.4	0.25	0.05	0.9	0.15	0.04	0.02	< 0.05	< 0.15

Lot: 535663 - Mechanical, Physical, Metallography, Quantometer Results --

Tmpr	Dir	No-> Test	UTS KSI	TYS KSI	EL4D PCT
T651	Long Transv.	2	47.8	39.8	17.6
			47.6	39.7	17.7

Cast Number	Chemical - OES	SI	FE	CU	MN	MG	CR	ZN	TI	Other Each	Other Total
H8122011	Actuals	0.66	0.4	0.25	0.05	0.9	0.15	0.04	0.02	< 0.05	< 0.15

Lot: 535664 - Mechanical, Physical, Metallography, Quantometer Results --

Tmpr	Dir	No-> Test	UTS KSI	TYS KSI	EL4D PCT
T651	Long Transv.	2	48.1	40.1	17.7
			48.2	40.2	17.6

Cast Number	Chemical - OES	SI	FE	CU	MN	MG	CR	ZN	TI	Other Each	Other Total
H8122011	Actuals	0.66	0.4	0.25	0.05	0.9	0.15	0.04	0.02	< 0.05	< 0.15

This material was melted in the United States or a Qualifying Country [REF DPARS 225.872.1(a)]; it was manufactured in the United States

P.O. 5088-7216
Line 7

ABW TECHNOLOGIES, INC
REVIEWED BY Q.C
BY Rick Kam
DATE 10-26-17

REVIEWED TO ASTM B209-10
TP 6061-T6

sapa: Sapa Industrial Extrusions
53 POTTSVILLE STREET
--
CRESSONA, PA
17929-0187

Sapa Extrusions Inc., a Subsidiary of Sapa AB

Certified Inspection Report

Sales Order Number	Line No.	Customer P/O	Cert Number	Page
1100523535	1	P20907PP001-1	SAPA671266	Page 1 of 3
			Cert Creation Date	Cert Print Date
			25-NOV-12	25-NOV-12

Invoice To Customer
YARDE METALS INC
45 NEWELL STREET
--
--
SOUTHINGTON, CT - 06489

Ship To Customer
YARDE METALS INC
1247 ELRON PLACE
--
--
HIGH POINT, NC - 27262

Quantity Shipped		Date Shipped	Item Description	Specification
2427	LB	25-NOV-12	Extruded Structural Tube 5.000 OD x ID 0.052 WALL OD TOL +/-.020 MR +/- .100 IR SECT 569284 144.000 IN LN +.188/- .000 FIN M-MILL W/F .941 F 33 CS 5 6063/T6	ASTMB221 REV 12
B/L		Item No.		
381754		G03974058		
Delivery Id		Item No. Rev		
4377283		--		
Customer Part No.				
569284				

Applicable Specifications, Revisions and Exceptions

COMPOSITION NOTE: The values for 'Others Each' and 'Others Total' have met the limits as shown on this certified inspection report. Remainder is Aluminum.

Legal Statement

We hereby certify that, unless otherwise indicated, the material covered by this report has been manufactured, inspected, and tested in accordance with, and has been found to meet, the applicable requirements described herein, including any specifications forming a part of the description and that samples representative of the material met the composition and had the mechanical properties shown on the face of this certification. Also, note that mercury is not a normal contaminant in aluminum alloys and neither it nor any of its compounds are used in the manufacture of our product. This certification is not to be reproduced in partial form without prior written approval of our Quality Assurance Dept.

Signature And Title

William T. Martin, III
William Martin III 25-NOV-12
Tech/Quality Manager

Quantities per Lot / Packages

Package Number	Lot Number	Quantity	UOM	Weight Gross	Weight Net
G12-PKG1822511	21229384	28	PCS	521	316
G12-PKG1822511	21229384	--	--	--	--
G12-PKG1823415	R21229384	35	PCS	670	395
G12-PKG1823427	R21229384	45	PCS	778	508
G12-PKG1823446	R21229384	45	PCS	758	509
G12-PKG1823446	R21229384	--	--	--	--
G12-PKG1823446	R21229384	--	--	--	--
G12-PKG1823459	R21229384	45	PCS	758	508
G12-PKG1823480	R21229384	17	PCS	405	192

TRIUMPH FABRICATIONS - ORANGEBURG
Q.A. REVIEW AND APPROVAL
INITIALS: CB DATE 12-12-12
W.O. # C988 P.O. # P22640
P.O. ITEM # #1

YARDE METALS Inc
S209072B001-1 TRIUMPH FABLICATIONS PO: 002640 Part #:
12-12-12

sapa

Sapa Industrial Extrusions
53 POTTSVILLE STREET
CRESSONA, PA
17929-0187

Certified Inspection Report

Sales Order Number	Line No.	Customer P/O	Cert Number	Page
1100523535	1	P20907PP001-1	SAPA671266	Page 2 of 3
			Cert Creation Date	Cert Print Date
			25-NOV-12	25-NOV-12

Composition Limits

Alloy	Si Min	Si Max	Fe Min	Fe Max	Cu Min	Cu Max	Mn Min	Mn Max	Mg Min	Mg Max	Cr Min	Cr Max	Zn Min	Zn Max
6063	0.20	0.60	--	0.35	--	0.10	--	0.10	0.45	0.90	--	0.10	--	0.10

Alloy	Ti Min	Ti Max	Others Each Min	Others Each Max	Others Total Min	Others Total Max
6063	--	0.10	--	0.05	--	0.15

Composition Results

Heat / Cast	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Others Total
3001025	0.49	0.15	0.05	0.02	0.55	0.01	0.01	0.02	--	--
3001156	0.46	0.14	0.05	0.01	0.54	0.01	0.02	0.01	--	--
5030321	0.47	0.15	0.02	0.01	0.52	0.00	0.01	0.01	--	--
6000085	0.44	0.12	0.01	0.00	0.50	0.00	0.01	0.01	--	--

Mechanical Property - Test Limits

		Test Type	UTS - L		TYS - L	
		UOM	KSI		KSI	
		# of Test	--		--	
Test Temper	Lot Number	# of Tests	MIN Value	MAX Value	MIN Value	MAX Value
T6	21229384	6	31.1	36.4	26.5	32.2

TRIUMPH FABRICATIONS - ORANGEBURG
Q.A. REVIEW AND APPROVAL
INITIALS: CB DATE 12-12-12
W.O. # C488 P.O. # P2640
P.O. ITEM # #1

TA SSR

YARDE METALS Inc

S209072B001-1 TRIUMPH FABRICATIONS PO: P002640 Part #:

12-12-12

sapa: Sapa Industrial Extrusions
53 POTTSVILLE STREET
–
CRESSONA, PA
17929-0187

Certified Inspection Report

Sales Order Number	Line No.	Customer P/O	Cert Number	Page
			SAPA671266	Page 3 of 3
			Cert Creation Date	Cert Print Date
1100523535		P20907PP001-1	25-NOV-12	25-NOV-12

		Test Type	UTS - L		TYS - L	
		UOM	KSI		KSI	
		# of Test				
Test Temper	Lot Number	# of Tests	MIN Value	MAX Value	MIN Value	MAX Value
T6	R21229384	5	34.9	37.4	30.9	33.8

Cert Notes
Products manufactured with a T6511 temper also meet T6 temper requirements.
Yield strength has been determined by the 0.2% offset method
All Mill Finish Alloys produced at Sapa Extrusions comply with 0.4% Maximum Lead per RoHS, with the exception of 6262 alloy
In accordance with EN 10204 Inspection Certificate Type 3.1
Melted in the USA or Other Qualified Countries as Defined by DFARS 225.872.1
Made in USA

TRIUMPH FABRICATIONS - ORANGEBURG
Q.A. REVIEW AND APPROVAL
INITIALS: CB DATE 12-12-12
W.O. # C488 P.O. # P2640
P.O. ITEM # #1

TA
SSR

YARDE METALS Inc

12-12-12

S209072B001-1 TRIUMPH FABRICATIONS PO: 0002640 Part #:

sapa: Sapa Industrial Extrusions
53 POTTSVILLE STREET
--
CRESSONA, PA
17929-0187

Sapa Extrusions Inc., a Subsidiary of Sapa AB

Certified Inspection Report

Cert Number	Page
SAPA679969	Page 1 of 2
Cert Creation Date	Cert Print Date
11-DEC-12	11-DEC-12

Sales Order Number	Line No.	Customer P/O
1100523535	1	P20907PP001-1

Invoice To Customer
YARDE METALS INC
45 NEWELL STREET
--
--
SOUTHINGTON, CT - 06489

Ship To Customer
YARDE METALS INC
1247 ELRON PLACE
--
--
HIGH POINT, NC - 27262

Quantity Shipped	Date Shipped	Item Description	Specification
650 LB	11-DEC-12	Extruded Structural Tube 5.000 OD x ID 0.052 WALL OD TOL +/-.020 MR +/- .100 IR SECT 569284 144.000 IN LN +.188/-.000 FIN M-MILL W/F .941 F 33 CS 5 6063/T6	ASTMB221 REV 12
B/L: 386158	Item No.: G03974058		
Delivery Id: 4382784	Item No. Rev: --		
CustomerPart No.: 569284			

Applicable Specifications, Revisions and Exceptions

COMPOSITION NOTE: The values for 'Others Each' and 'Others Total' have met the limits as shown on this certified inspection report. Remainder is Aluminum.

Legal Statement

We hereby certify that, unless otherwise indicated, the material covered by this report has been manufactured, inspected, and tested in accordance with, and has been found to meet, the applicable requirements described herein, including any specifications forming a part of the description and that samples representative of the material met the composition and had the mechanical properties shown on the face of this certification. Also, note that mercury is not a normal contaminant in aluminum alloys and neither it nor any of its compounds are used in the manufacture of our product. This certification is not to be reproduced in partial form without prior written approval of our Quality Assurance Dept.

Signature And Title

William T. Martin, III

William Martin III
Tech/Quality Manager

11-DEC-12

Quantities per Lot / Packages

Package Number	Lot Number	Quantity	UOM	Weight Gross	Weight Net
G12-PKG1834493	RR21229384	28	PCS	521	317
G12-PKG1834493	RR21229384	--	--	--	--
G12-PKG1834505	RR21229384	28	PCS	521	316
G12-PKG1834505	RR21229384	--	--	--	--

Composition Limits

TA
55R

TRIUMPH FABRICATIONS - ORANGEBURG
Q.A. REVIEW AND APPROVAL
INITIALS: [signature] DATE 12/17/12
W.O. # C488 P.O. # P2640
P.O. ITEM # 1

YARDE METALS Inc

S20907ZB001-3 TRIUMPH FABRICATIONS PO: 000002640 Part #:

12-14-12

sapa: Sapa Industrial Extrusions
53 POTTSVILLE STREET
CRESSONA, PA
17929-0187

Certified Inspection Report

Sales Order Number	Line No	Customer P/O	Cert Number	Page
			SAPA679969	Page 2 of 2
			Cert Creation Date	Cert Print Date
1100523535	1	P20907PP001-1	11-DEC-12	11-DEC-12

Alloy	Si		Fe		Cu		Mn		Mg		Cr		Zn	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
6063	0.20	0.60	---	0.35	---	0.10	---	0.10	0.45	0.90	---	0.10	---	0.10

Alloy	Ti		Others Each		Others Total	
	Min	Max	Min	Max	Min	Max
6063	---	0.10	---	0.05	---	0.15

Composition Results

Heat / Cast	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Others Total
5030317	0.45	0.17	0.03	0.02	0.54	0.01	0.01	0.01	--	--

Mechanical Property - Test Limits

		Test Type	UTS - L		TYS - L	
		UOM	KSI		KSI	
		# of Test	-		-	
Test Temper	Lot Number	# of Tests	MIN Value	MAX Value	MIN Value	MAX Value
T6	RR21229384	1	37.7	37.7	34.6	34.6

Cert Notes

Products manufactured with a T6511 temper also meet T6 temper requirements.

Yield strength has been determined by the 0.2% offset method

All Mill Finish Alloys produced at Sapa Extrusions comply with 0.4% Maximum Lead per RoHS, with the exception of 6262 alloy

In accordance with EN 10204 Inspection Certificate Type 3.1

Melted in the USA or Other Qualified Countries as Defined by DFARS 225.872.1

Made in USA

YARDE METALS, INC CERTIFIES THAT THIS IS A TRUE COPY OF THE ORIGINAL MILL TEST REPORT NOW ON FILE RECEIVED AND WRITTEN
DEC 13 2012
BY [signature]
Gloria Y Covington, Certification Processor

TRIUMPH FABRICATIONS - ORANGEBURG
Q.A. REVIEW AND APPROVAL
INITIALS: [initials] DATE 12/17/12
W.O. # C488 P.O. # P21640
P.O. ITEM # 1

TJA
SSP

YARDE METALS Inc

S20907ZB001-3 TRIUMPH FABRICATIONS PO: P00002640 Part #:

12-14-12

M4926394? 12-15-11

CERTIFICATE OF ANALYSIS	No: 14734 Date: 9/27/2011	CERTIFIED SRAC-IQNet ISO 9001/2008 No. 10/4-2011	vimetco alro SLATINA

CUSTOMER :

CONTRACT/ORDER : 1037836
BILL OF DELIVERY : 80110946
TRUCK/CONTAINER : TGHU 4075659
6061 T651 ALUMINUM PLATES

TW METALS TEST REPORTS DEC 1 5 2011 ACCEPTED BY

MATERIAL : ALUMINUM PLATES
ALLOY : 6061
DIMENSIONS (mm) : 70044751 0.25"X48.5"X96.5"
TEMPER: T651

ACCORDING TO : ASTM B209; AMS 4027N; ANSI H35.2 ; ASME SB209

MECHANICAL PROPERTIES 1 MPa = 1 N/mm2 = 0.145 ksi = 0.102 kgf/mm2

1 lbs = 0.4536 kg			UTS ksi min.	UTS ksi max.	YTS ksi min.	YTS ksi max.	Elong. % 50mm min.	Hardness* HB min.
		Specified values:	42		35		10	
LOT / BATCH	CASE	NET WEIGHT lbs	Measured values:					
70044751 S11070690	111365;111367; 111379;111377; 111359;111357; 111361;111363	21,124.711	47.6 48		37.7 38		21 20	

CHEMICAL COMPOSITION %

BATCH	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Ga	V	Al
S11070690	0.7	0.39	0.26	0.08	1.07	0.055	0.004	0.012	0.011	0.002	0.015	REM. REM REM
Acc. Standard Min.	0.4		0.15		0.8	0.04						REM.
Acc. Standard Max.	0.8	0.7	0.4	0.15	1.2	0.35	0.05	0.25	0.15	0.05	0.05	
Remarks:						Other- Each- Max.: 0.05			Others Total- Max.: 0.15			

REMARKS: UC; 850150-02
Melted and manufactured in Romania
ACCORDING TO: ASTM B209-10 ; AMS 4027N:2008; ANSI H35.2:2000
* Typical value, for information only.

We hereby certify that the material detailed hereon has been produced and tested according to the requirements of the relevant specification and/or order. Keep in dry conditions, without larges temperatures variations. The differences between metal and air must be maxim 11 degrees C.

Also we certify that the material respects HG 1022 and does not endanger life, health, job security (if handled properly) have no negative impact on the environment.

According to EN 10204:2004 3.1

QUALITY CONTROL DEPT.

S.C. ALRO S.A. SLATINA Punct de lucru Slatina Str. Milcov Nr. 1, Jud. Olt Serv. CTC - Laborator Alt Prelucrari

ALRO S.A. No.116, Pitesti Street Slatina +(40) 0249 435 117; 0249 432 056 alro@alro.ro
230048-Slatina-ROMANIA Fax: (40) 0249 411 487; 0249 415 802 www.alro.ro
cod f1/PO-051/Rev.2/2011

S.C. ALRO S.A. SLATINA CTC 25 Punct de lucru Slatina Str. Milcov Nr. 1, Jud. Olt

TRIUMPH FABRICATIONS—ORANGEBURG
Q.A. REVIEW AND APPROVAL
INITIALS: AR DATE 7-25-12
W.O.# C448 P.O.# P2368

TA SSR

sapa: Sapa Industrial Extrusions
53 POTTSVILLE STREET
--
CRESSONA, PA
17929-0187

Sapa Extrusions Inc., a Subsidiary of Sapa AB

Certified Inspection Report

Cert Number	Page
SAPA450924	Page 1 of 3

Sales Order Number	Line No.	Customer P/O	Cert Creation Date	Cert Print Date
1100369456	1	M49263258-001	17-SEP-11	17-SEP-11

Invoice To Customer
TW METALS INC
THE ARBORETUM SUITE 204
760 CONSTITUTION DR
--
EXTON, PA - 19341

Ship To Customer
TW METALS INC
10404 SUITE 0 (ZERO)
GRANITE ST
--
CHARLOTTE, NC - 28241

Quantity Shipped	Date Shipped	Item Description	Specification
996 LB	17-SEP-11	Extruded ECON-O-ROD Plus 0.500 DIA +/-.004 SECT 555310 144.000 IN LN FIN M-MILL W/F 0.231 F 7 CS .5 6061/T6511 Marking CONTINUOUS;	ASTMB221 REV 08' AMS-QQ-A-200/8 REV ASMESB221 REV 09 UNS#A96061 REV SAEJ454 REV
B/L 261310	**Item No.** G03298076		
Delivery Id 4243994	**Item No. Rev** --		
CustomerPart No. 04607			

TW METALS
TEST
SEP 21 2011
BBV
ACCEPTED BY
REPORTS

Applicable Specifications, Revisions and Exceptions

Profiles supplied are "domestic end products" as defined in FAR 52.225-1 entitled "Buy American Act - Supplies" and DFARS 252.225-7001 entitled "Buy American Act and Balance of Payments Program", and are "U.S.-made end products" as defined in FAR 52.225-5 entitled "Trade Agreements." This profile is manufactured at one of Sapa's US facilities. Aluminum billet, which is the principal component u sed in the manufacturing process, is purchased from sources in the US and/or in qualifying countries as described in DFARS 225.872.1. DFARS clause 252.225-7014 entitled "Preference for Domestic Spec ialty Metals," does not relate to aluminum extrusions that would be produced by Sapa since 6061 or 6 063 alloys do not fall within the definition of Specialty Metals.

Certificate in accordance with EN10204 3.1

COMPOSITION NOTE: The values for 'Others Each' and 'Others Total' have met the limits as shown on this certified inspection report. Remainder is Aluminum.

Legal Statement

We hereby certify that, unless otherwise indicated, the material covered by this report has been manufactured, inspected, and tested in accordance with, and has been found to meet, the applicable requirements described herein, including any specifications forming a part of the description and that samples representative of the material met the composition and had the mechanical properties shown on the face of this certification. Also, note that mercury is not a normal contaminant in aluminum alloys and neither it nor any of its compounds are used in the manufacture of our product. This certification is not to be reproduced in partial form without prior written approval of our Quality Assurance Dept.

Signature And Title

William T. Martin, III

William Martin III 17-SEP-11
Tech/Quality Manager

TA
SSR

TRIUMPH FABRICATIONS - ORANGEBURG
Q.A. REVIEW AND APPROVAL
INITIALS: LLF DATE 1/10/13
W.O.# C488 P.O.# P3113

sapa: Sapa Industrial Extrusions
53 POTTSVILLE STREET
–
CRESSONA, PA
17929-0187

Certified Inspection Report

Cert Number	Page
SAPA450924	Page 2 of 3
Cert Creation Date	Cert Print Date
17-SEP-11	17-SEP-11

Sales Order Number	Line No.	Customer P/O
1100369456	1	M49263258-001

Quantities per Lot / Packages

Package Number	Lot Number	Quantity	UOM	Weight Gross	Weight Net
G12-PKG1520559	20862695	180	PCS	503	498
G12-PKG1520568	20862695	180	PCS	503	498

Composition Limits

Alloy	Si Min	Si Max	Fe Min	Fe Max	Cu Min	Cu Max	Mn Min	Mn Max	Mg Min	Mg Max	Cr Min	Cr Max	Zn Min	Zn Max
6061	0.40	0.80	—	0.70	0.15	0.40	—	0.15	0.80	1.20	0.04	0.35	—	0.25

Alloy	Ti Min	Ti Max	Bi Min	Bi Max	Pb Min	Pb Max	Others Each Min	Others Each Max	Others Total Min	Others Total Max
6061	—	0.15	—	0.05	—	0.05	—	0.05	—	0.15

Composition Results

Heat / Cast	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Bi	Pb	Others Each	Others Total
4026003-US	0.73	0.37	0.33	0.07	0.92	0.08	0.05	0.03	—	—	—	—

Mechanical Property - Test Limits

		Test Type	UTS - L		TYS - L		EL 4D-Long	
		UOM	KSI		KSI		PCT	
		# of Test	–		–		–	
Test Temper	Lot Number	# of Tests	MIN Value	MAX Value	MIN Value	MAX Value	MIN Value	MAX Value
T6511	20862695	14	41.3	46.0	36.5	41.3	11.5	20.8

Cert Notes

Products manufactured with a T6511 temper also meet T6 temper requirements.

Yield strength has been determined by the 0.2% offset method

TW METALS
TEST
SEP 21 2011
RRV
REPORTS
ACCEPTED BY

TA 53R

TRIUMPH FABRICATIONS - ORANGEBURG
Q.A. REVIEW AND APPROVAL
INITIALS [initials] DATE 1/10/13
W.O.# C488 P.O.# P3113

sapa: Sapa Industrial Extrusions
53 POTTSVILLE STREET
CRESSONA, PA
17929-0187

Certified Inspection Report

Cert Number	Page
SAPA450924	Page 3 of 3

Sales Order Number	Line No.	Customer P/O	Cert Creation Date	Cert Print Date
1100369456	1	M49263258-001	17-SEP-11	17-SEP-11

All Alloys Produced at Sapa Industrial Extrusions comply with 0.4% Maximum Lead per RoHS, with the exception of 6262 alloy
In accordance with EN 10204, Test Report Type 2.2 and Certificate Type 3.1
Melted in the USA or Other Qualified Countries as Defined by DFARS 225.872.1
Made in USA

TW METALS
TEST REPORTS
SEP 21 2011
RBV
ACCEPTED BY

TA
SSR

TRIUMPH FABRICATIONS - ORANGEBURG
Q.A. REVIEW AND APPROVAL
INITIALS: ddf DATE 1/10/13
W.O.# C488 P.O.# P3113

:1206ZB034-1 TRIUMPH FABRICA PO: P000003038 Part #:
60.00FT

YARDE METALS Inc 12-07-12

sapa: Sapa Industrial Extrusions
53 POTTSVILLE STREET
—
CRESSONA, PA
17929-0187

Sapa Extrusions Inc., a Subsidiary of Sapa AB

Certified Inspection Report

Cert Number	Page
SAPA622786	Page 1 of 2
Cert Creation Date	**Cert Print Date**
22-AUG-12	22-AUG-12

Sales Order Number	Line No.	Customer P/O
1100486925	25	P20627CG008-25

Invoice To Customer
YARDE METALS INC
45 NEWELL ST
--
--
SOUTHINGTON, CT - 06489

Ship To Customer
YARDE METALS INC
45 NEWELL ST
--
--
SOUTHINGTON, CT - 06489

Quantity Shipped	Date Shipped	Item Description	Specification
576 LB	22-AUG-12	Extruded Structural Tube 4.250 OD x ID 0.250 WALL 144 IN LN FIN M-MILL W/F 3.695 F 7 CS 4.25 6061/T6511 Marking CONTINUOUS;	ASTMB221 REV 12 AMS-QQ-A-200/8 REV ASTMB429 REV 10
B/L	**Item No.**		
356575	G03382595		
Delivery Id	**Item No. Rev**		
4349413	--		
Customer Part No.			
4.25X.25			

Applicable Specifications, Revisions and Exceptions

Certificate in accordance with EN10204 3.1

COMPOSITION NOTE: The values for 'Others Each' and 'Others Total' have met the limits as shown on this certified inspection report. Remainder is Aluminum.

Legal Statement

We hereby certify that, unless otherwise indicated, the material covered by this report has been manufactured, inspected, and tested in accordance with, and has been found to meet, the applicable requirements described herein, including any specifications forming a part of the description and that samples representative of the material met the composition and had the mechanical properties shown on the face of this certification. Also, note that mercury is not a normal contaminant in aluminum alloys and neither it nor any of its compounds are used in the manufacture of our product. This certification is not to be reproduced in partial form without prior written approval of our Quality Assurance Dept.

Signature And Title

William T. Martin, III
William Martin III
Tech/Quality Manager
22-AUG-12

TRIUMPH FABRICATIONS - ORANGEBURG
Q.A. REVIEW AND APPROVAL
INITIALS: CB DATE 12-13-12
W.O. #C488 Ref P.O. # P3038
P.O. ITEM # #1

Quantities per Lot / Packages

Package Number	Lot Number	Quantity	UOM	Weight Gross	Weight Net
G12-PKG1759545	21165946	13	PCS	582	576

Composition Limits

Alloy	Si Min	Si Max	Fe Min	Fe Max	Cu Min	Cu Max	Mn Min	Mn Max	Mg Min	Mg Max	Cr Min	Cr Max	Zn Min	Zn Max
6061	0.40	0.80	—	0.70	0.15	0.40	—	0.15	0.80	1.20	0.04	0.35	—	0.25

TIA
SSR

sapa: Sapa Industrial Extrusions
53 POTTSVILLE STREET
–
CRESSONA, PA
17929-0187

Certified Inspection Report

Sales Order Number	Line No.	Customer P/O	Cert Number	Page
			SAPA622786	Page 2 of 2
			Cert Creation Date	Cert Print Date
1100486925	25	P20627CG008-25	22-AUG-12	22-AUG-12

Alloy	Ti		Bi		Pb		Others Each		Others Total	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
6061	—	0.15	—	0.05	—	0.05	—	0.05	—	0.15

Composition Results

Heat / Cast	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Bi	Pb	Others Each	Others Total
3000853	0.67	0.22	0.24	0.03	0.93	0.05	0.02	0.02	—	—	—	—

Mechanical Property - Test Limits

		Test Type	UTS - L		TYS - L		EL 4D-Long	
		UOM	KSI		KSI		PCT	
		# of Test	—		—		—	
Test Temper	Lot Number	# of Tests	MIN Value	MAX Value	MIN Value	MAX Value	MIN Value	MAX Value
T6511	21165946	1	45.1	45.1	42.4	42.4	12.3	12.3

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W.O. # C4881AF P.O. # P3038
P.O. ITEM # #1

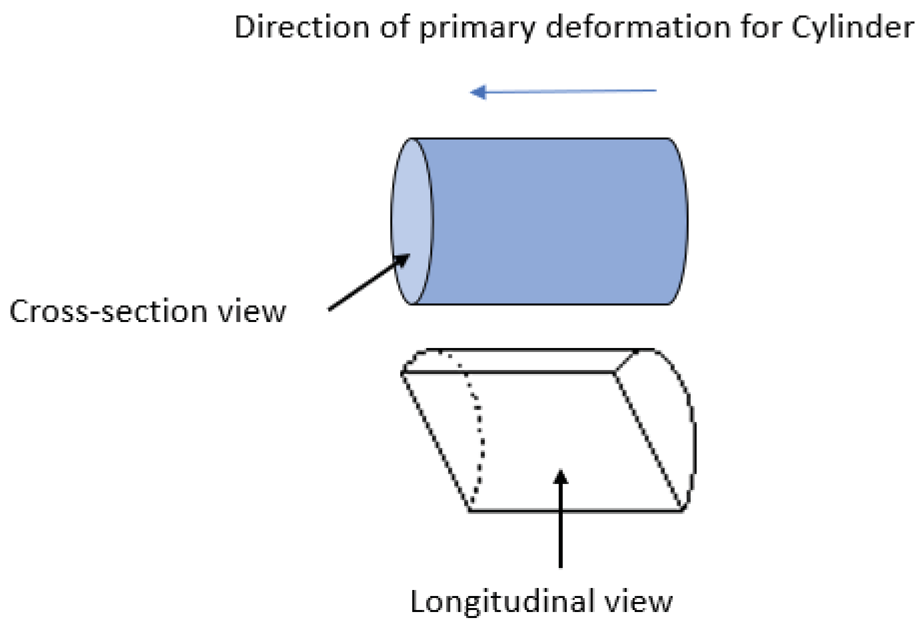
Cert Notes
Products manufactured with a T6511 temper also meet T6 temper requirements.
Yield strength has been determined by the 0.2% offset method
All Mill Finish Alloys produced at Sapa Extrusions comply with 0.4% Maximum Lead per RoHS, with the exception of 6262 alloy
In accordance with EN 10204 Inspection Certificate Type 3.1
Melted in the USA or Other Qualified Countries as Defined by DFARS 225.872.1
Made in USA

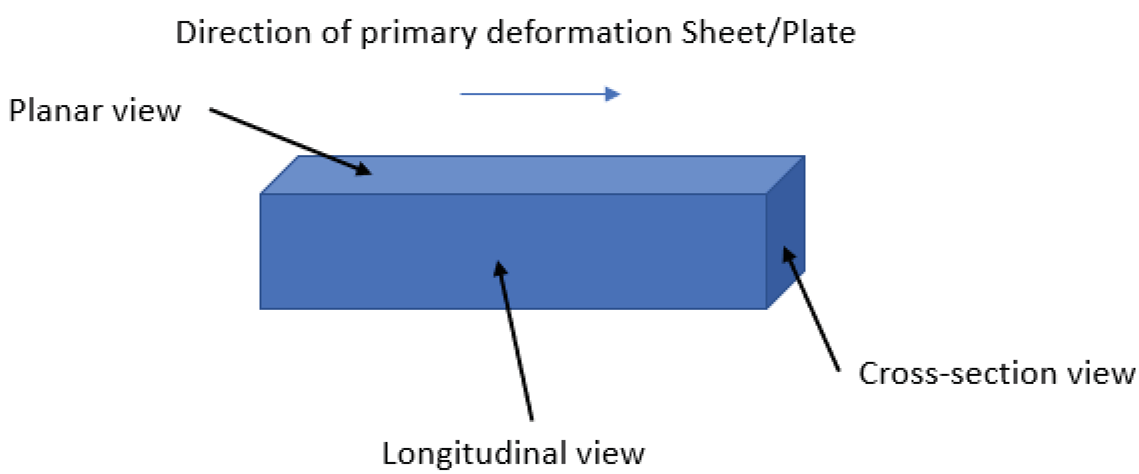
YARDE METALS, INC. CERTIFIES THAT THIS IS A TRUE COPY OF THE ORIGINAL MILL TEST REPORT NOW ON FILE RECEIVED AND INSPECTED
AUG 23 2012
BY
Ryan McDonald, Certification Processor

TA
SSP

21206ZB034-1 TRIUMPH FABRICA PO: P000003038 Part #:
60.00FT
YARDE METALS Inc 12-07-12

Appendix B. Orientation Planes of Coupon Shapes





Appendix C. Experimental Dissolution Data

Table C-1. Experiment 141 End Cap Lifting Bail Straight Section (EC-C) Dissolution Data

Dissolution Time (min)	Mass (g)	Dissolved Al (M)	Length (mm)	Mid Diameter (mm)	Surface Area (cm^2)	Mass/SA (g/cm^2)
0	4.218	0.00	12.36	12.67	7.44	0.567
10.00	4.166	0.01	12.31	12.63	7.39	0.564
25.00	4.095	0.03	12.26	12.56	7.32	0.560
41.00	4.024	0.05	12.15	12.49	7.22	0.558
52.00	3.974	0.06	12.09	12.46	7.17	0.554
75.50	3.878	0.08	11.99	12.35	7.05	0.550
94.50	3.798	0.10	11.93	12.31	6.99	0.543
111.00	3.733	0.12	11.81	12.24	6.89	0.541
129.00	3.663	0.14	11.72	12.18	6.81	0.537

Table C-2. Experiment 149 HFIR Fuel Outer Carrier Lifting Bail Straight Section (HF-1) Dissolution Data

Dissolution Time (min)	Mass (g)	Dissolved Al (M)	Length (mm)	Mid Diameter (mm)	Surface Area (cm^2)	Mass/SA (g/cm^2)
0	9.011	0.00	16.93	15.88	12.40	0.726
10.50	8.923	0.02	16.86	15.83	12.32	0.724
25.50	8.793	0.05	16.76	15.76	12.20	0.721
40.50	8.673	0.08	16.72	15.71	12.13	0.715
55.50	8.539	0.12	16.60	15.65	12.01	0.711
70.50	8.421	0.15	16.56	15.59	11.93	0.706
86.50	8.292	0.18	16.44	15.52	11.80	0.703
101.50	8.165	0.21	16.36	15.44	11.68	0.699
116.50	8.045	0.24	16.28	15.38	11.58	0.695

Table C-3. Experiment 151 HFIR Fuel Outer Carrier Lifting Bail Support Bar (HF-3) Dissolution Data

Dissolution Time (min)	Mass (g)	Dissolved Al (M)	Length (mm)	Mid Diameter (mm)	Surface Area (cm^2)	Mass/SA (g/cm^2)
0	12.422	0.00	16.16	19.08	15.40	0.807
10.00	12.315	0.03	16.12	19.04	15.34	0.803
25.00	12.173	0.06	16.05	18.99	15.24	0.799
40.00	12.038	0.09	15.97	18.93	15.13	0.796
55.00	11.904	0.13	15.90	18.88	15.03	0.792
70.00	11.771	0.16	15.87	18.83	14.95	0.787
85.00	11.648	0.19	15.78	18.77	14.84	0.785
100.00	11.516	0.22	15.69	18.73	14.74	0.781
115.00	11.390	0.25	15.61	18.67	14.63	0.778

Table C-4. Experiment 142 L-Bundle End Cap Lifting Bail Bent Section (EC-F) Dissolution Data

Dissolution Time	Mass	Dissolved Al	Length	Circular Diameter (D_C)	Middle Diameter (D_M)	Large Elliptical Diameter (D_L)	Parameters of Quadratic Fit of D_x			Surface Area (SA)	Mass/SA
							a	b	c		
(min)	(g)	(M)	(mm)	(mm)	(mm)	(mm)	---	---	---	(cm^2)	(g/cm^2)
0	4.618	0.00	12.36	12.68	12.77	16.40	0.0463	-0.2718	12.68	8.08	0.571
10.50	4.551	0.02	12.36	12.43	12.79	16.47	0.0435	-0.2104	12.43	8.00	0.569
25.50	4.461	0.04	12.30	12.46	12.74	16.02	0.0397	-0.1984	12.46	7.90	0.564
41.00	4.370	0.06	12.34	12.66	12.79	16.14	0.0423	-0.2399	12.66	8.03	0.544
62.75	4.244	0.09	12.26	12.67	12.74	15.79	0.0397	-0.2316	12.67	7.93	0.535
77.75	4.158	0.11	12.17	12.54	12.68	15.55	0.0369	-0.2013	12.54	7.79	0.534
93.25	4.080	0.13	12.19	12.41	12.47	15.60	0.0413	-0.242	12.41	7.70	0.530
108.25	4.002	0.15	11.95	12.30	12.33	15.33	0.0416	-0.2435	12.30	7.48	0.535
124.25	3.920	0.17	11.95	12.18	12.16	15.32	0.0445	-0.2695	12.18	7.39	0.530
139.08	3.840	0.19	11.86	12.09	12.04	14.69	0.0384	-0.2361	12.09	7.20	0.534
153.92	3.760	0.21	11.60	12.33	11.95	15.08	0.0522	-0.3681	12.33	7.22	0.521

Table C-5. Experiment 150 HFIR Fuel Outer Carrier Lifting Bail Bent Section (HF-2) Dissolution Data

Dissolution Time	Mass	Dissolved Al	Length	Circular Diameter (D_C)	Middle Diameter (D_M)	Large Elliptical Diameter (D_L)	Parameters of Quadratic Fit of D_x			Surface Area	Mass/SA
							a	b	c		
(min)	(g)	(M)	(mm)	(mm)	(mm)	(mm)	---	---	---	(cm^2)	(g/cm^2)
0	8.696	0.00	16.36	15.71	15.72	16.12	2.91E-03	-2.26E-02	1.57E+01	12.04	0.722
10.00	8.606	0.02	16.29	15.75	15.70	16.39	5.58E-03	-5.16E-02	1.58E+01	12.07	0.713
25.00	8.489	0.05	16.30	15.78	15.78	16.32	4.07E-03	-3.31E-02	1.58E+01	12.11	0.701
40.00	8.367	0.08	16.20	15.58	15.50	16.22	6.10E-03	-5.93E-02	1.56E+01	11.85	0.706
60.00	6.813	0.46	14.94	14.83	14.82	14.86	4.48E-04	-4.69E-03	1.48E+01	10.42	0.654
70.00	6.753	0.48	14.86	14.70	14.68	14.76	9.06E-04	-9.42E-03	1.47E+01	10.26	0.658
85.00	6.668	0.50	14.85	14.68	14.61	14.79	2.27E-03	-2.63E-02	1.47E+01	10.23	0.652
100.00	6.579	0.52	14.68	14.68	14.54	14.71	2.88E-03	-4.02E-02	1.47E+01	10.12	0.650
115.00	6.491	0.54	14.64	14.60	14.64	14.50	-1.68E-03	1.78E-02	1.46E+01	10.06	0.645
130.00	6.403	0.57	14.61	14.58	14.55	14.57	4.69E-04	-7.53E-03	1.46E+01	10.02	0.639

Table C-6. Experiment 143 L-Bundle End Cap Top Plate with Weld (EC-D) Dissolution Data

Diss-olution Time	Mass	Diss-olved Al	W_1	W_2	W_3	W_4	D_1	D_2	D_3	DD_1	DD_2	DD_3	Surface Area	Mass/SA
(min)	(g)	(M)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(cm^2)	(g/cm^2)
0	6.189	0.00	18.41	18.69	18.44	18.69	9.39	7.22	7.18	6.60	6.60	6.60	12.05	0.514
11.00	6.068	0.03	18.32	18.63	18.4	18.69	9.09	7.29	6.98	6.54	6.52	6.52	11.92	0.509
26.00	5.913	0.07	18.25	18.53	18.33	18.57	9.17	7.16	6.91	6.44	6.44	6.45	11.79	0.502
41.00	5.759	0.11	18.16	18.46	18.23	18.45	9.06	7.14	6.88	6.35	6.35	6.35	11.62	0.496
56.50	5.602	0.14	18.09	18.43	18.17	18.57	8.77	7.06	6.72	6.29	6.29	6.29	11.54	0.485
71.50	5.453	0.18	18.03	18.39	18.04	18.39	8.48	7.03	6.28	6.21	6.21	6.21	11.37	0.480
87.00	5.300	0.22	17.94	18.22	18.06	18.29	8.76	7.04	6.24	6.13	6.14	6.13	11.26	0.471
102.00	5.154	0.26	17.9	18.1	17.95	18.15	8.67	6.94	6.03	6.06	6.06	6.07	11.11	0.464
117.50	5.007	0.29	17.81	18.04	17.85	18.04	8.37	6.69	5.98	5.92	5.8	6.03	10.90	0.459

Table C-7. Experiment 143 L-Bundle End Cap Top Plate with Weld: Depth Change Rates

Depth	Depth Change (mm/min)	Depth Change Variability (2*σ) (mm/min)	Low Depth Change (mm/min)	High Depth Change (mm/min)
D1	-0.00749	0.00260	-0.01009	-0.00489
DD1	-0.00549	0.000318	-0.00581	-0.00517
D2	-0.00395	0.001278	-0.00523	-0.00267
DD2	-0.00594	0.00092	-0.00686	-0.00502
D3	-0.00703	0.00262	-0.00965	-0.00441
DD3	-0.00492	0.000346	-0.00527	-0.00457

Table C-8. Experiment 145 Al-6061-T6 Plate (G-2) Dissolution Data

Dis-solution Time	Mass	Dis-solved Al	W_1	W_2	W_3	W_4	D_1	D_2	D_3	Surface Area	Mass/SA
(min)	(g)	(M)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(cm^2)	(g/cm^2)
0	3.524	0.00	11.41	18.22	11.41	18.17	6.38	6.38	6.38	7.93	0.444
11.00	3.458	0.02	11.31	18.11	11.31	18.23	6.35	6.35	6.35	7.85	0.440
28.50	3.340	0.05	11.26	17.98	11.25	18.09	6.25	6.25	6.25	7.72	0.433
43.50	3.238	0.07	11.18	17.84	11.16	17.98	6.19	6.19	6.19	7.60	0.426
58.50	3.138	0.10	11.09	17.74	11.09	17.88	6.12	6.12	6.12	7.49	0.419
70.50	2.030	0.37	9.58	15.85	9.66	15.78	5.4	5.59	5.17	5.78	0.351
77.50	2.009	0.37	9.61	15.78	9.64	16.07	5.59	5.61	5.24	5.87	0.342
88.00	1.967	0.38	9.5	15.72	9.44	16.04	4.9	5.55	5.43	5.69	0.346
104.50	1.561	0.48	8.84	15.25	8.85	14.94	4.93	5.23	5.03	5.09	0.306
119.50	1.519	0.50	8.85	14.99	8.86	15.23	4.60	5.19	4.82	5.01	0.303
134.50	1.469	0.51	8.78	14.68	8.69	15.05	5.00	5.10	4.77	4.94	0.298
149.50	1.009	0.62	6.96	13.59	7.56	13.78	4.31	4.58	4.17	3.81	0.265
164.50	0.976	0.63	7.41	13.09	7.33	13.73	4.31	4.50	4.26	3.79	0.258

Table C-9. Experiment 144 L-Bundle End Cap Sidewall (EC-E) Dissolution Data

Dissolution Time	Mass	Dissolved Al	L	W	D	Surface Area	Mass/SA
(min)	(g)	(M)	(mm)	(mm)	(mm)	(cm^2)	(g/cm^2)
0	1.434	0.00	18.72	18.85	1.58	8.24	0.174
4.50	0	0.35	18.72	18.85	1.58	8.24	0

Table C-10. Experiment 152 HFIR Fuel Outer Carrier Lifting Bail Support Band (HF-4) Dissolution Data

Dissolution Time	Mass	Dissolved Al	L	W	D	Surface Area	Mass/SA
(min)	(g)	(M)	(mm)	(mm)	(mm)	(cm^2)	(g/cm^2)
0	3.282	0.00	19.98	9.81	6.30	7.67	0.428
10.00	3.230	0.01	19.93	9.75	6.24	7.59	0.426
20.00	2.029	0.31	18.66	8.18	5.74	6.13	0.331
30.00	1.991	0.32	18.65	8.13	5.69	6.08	0.327
45.00	1.935	0.33	18.59	8.01	5.65	5.98	0.323
60.00	1.884	0.35	18.35	7.89	5.56	5.81	0.324
75.00	1.833	0.36	18.36	7.87	5.51	5.78	0.317
90.00	1.786	0.37	18.35	7.82	5.48	5.73	0.311
105.00	1.739	0.38	18.33	7.68	5.36	5.60	0.310

Table C-11. Experiment 153 HFIR Fuel Outer Carrier Sidewall Near Support Band (HF-5) Dissolution Data

Dissolution Time	Mass	Dissolved Al	L	W	D	Surface Area	Mass/SA
(min)	(g)	(M)	(mm)	(mm)	(mm)	(cm^2)	(g/cm^2)
0	0.847	0.00	20.19	9.92	1.61	4.97	0.170
3.00	0.832	0.00	20.14	9.91	1.59	4.94	0.168
8.00	0.811	0.01	20.06	9.87	1.58	4.90	0.165
14.00	0.792	0.01	20.05	9.84	1.54	4.87	0.163
24.00	0.756	0.02	20.03	9.77	1.49	4.80	0.157
40.00	0.706	0.03	19.90	9.67	1.42	4.69	0.151
55.00	0.656	0.05	19.79	9.58	1.35	4.58	0.143
70.00	0.611	0.06	19.69	9.49	1.29	4.49	0.136
85.00	0.564	0.07	19.61	9.39	1.21	4.38	0.129
100.00	0.522	0.08	19.54	9.31	1.14	4.30	0.122

Table C-12. Experiment 97 – Al-1100 Dissolution Data Calculated from Offgas Generation Measurements

Dissolution Time	Mass	Dissolved Al	Mass/SA
(min)	(g)	(M)	(g/cm^2)
2.28	5.94	0.04	1.20
2.47	5.87	0.06	1.19
2.67	5.79	0.08	1.17
2.85	5.72	0.10	1.16
3.03	5.62	0.13	1.14
3.23	5.53	0.16	1.12
3.42	5.46	0.18	1.10
3.60	5.40	0.20	1.09
3.80	5.34	0.21	1.08
3.98	5.29	0.23	1.07
4.17	5.23	0.25	1.06
4.37	5.16	0.26	1.04
4.55	5.10	0.28	1.03
4.73	5.03	0.30	1.02
4.93	4.97	0.32	1.01
5.12	4.92	0.34	0.99
5.32	4.84	0.36	0.98
5.50	4.78	0.38	0.97
5.68	4.73	0.39	0.96
5.88	4.69	0.41	0.95
6.07	4.64	0.42	0.94
6.27	4.59	0.43	0.93
6.45	4.55	0.45	0.92
6.63	4.49	0.46	0.91
6.83	4.42	0.48	0.89
7.02	4.37	0.50	0.88
7.22	4.32	0.51	0.87
7.40	4.26	0.53	0.86
7.60	4.20	0.55	0.85
7.78	4.16	0.56	0.84
7.98	4.10	0.58	0.83

Table C-13. Experiment 155 Al-6063 Coupon Dissolution Data

Dissolution Time	Mass	Dissolved Al	L	W	D	Surface Area (SA)	Mass/SA
(min)	(g)	(M)	(mm)	(mm)	(mm)	(cm^2)	(g/cm^2)
0	2.298	0.00	16.00	19.03	2.89	8.11	0.283
1	1.703	0.15	15.20	18.20	2.72	7.35	0.232
2	1.396	0.22	14.70	17.73	2.61	6.91	0.202
3.5	1.007	0.31	13.88	16.85	2.2	6.03	0.167
5.5	0.801	0.37	13.16	16.35	2.08	5.53	0.145
7.50	0.488	0.44	11.71	15.25	1.62	4.45	0.110

Table C-14. Experiment 154 Partial Dissolution Data

Coupon	Dissolution Time	Mass	Dissolved Al	L	W	D	Surface Area
---	(min)	(g)	(M)	(mm)	(mm)	(mm)	(cm^2)
Al-6061-007	0	7.481	0.00	50.74*	18.84	2.97	4.92
Al-6061-007	5	6.325	0.29	49.47*	18.18	2.64	4.65
Al-6061-008	0	7.536	0.29	50.64*	18.87	2.98	4.93
Al-6061-008	7	6.761	0.48	49.82*	18.60	2.74	4.78
Al-1100-101	0	7.299	0.48	50.73*	18.77	2.90	4.88
Al-1100-101	5	6.432	0.69	50.42*	18.40	2.63	4.69
Al-1100-102	0	7.403	0.69	50.71*	18.78	2.94	4.90
Al-1100-102	5.17	6.427	0.93	50.20*	18.50	2.63	4.71
EC-E-0306	0	1.439	0.93	18.72	18.75	1.56	8.19
EC-E-0306	2	1.243	0.98	18.66	18.68	1.48	8.07
EC-E-113	0	1.409	0.98	18.79	18.53	1.57	8.14
EC-E-113	2	1.278	1.01	18.31	18.68	1.52	7.97

*Full length but only 10 mm immersed into solution. Surface area is only for immersed section.

Distribution:

alex.cozzi@srnl.doe.gov
kristine.zeigler@srnl.doe.gov
josesph.manna@srnl.doe.gov
samuel.fink@srnl.doe.gov
bruce.wiersma@srnl.doe.gov
john.mickalonis@srnl.doe.gov
gene.daniel@srnl.doe.gov
tracy.rudisill@srnl.doe.gov
jonathan.duffey@srnl.doe.gov
marissa.reigel@srnl.doe.gov
thomas.shehee@srnl.doe.gov
john.scogin@srnl.doe.gov
robert.pierce@srnl.doe.gov
eddie.kyser@srnl.doe.gov
nicholas.karay@srnl.doe.gov
harris.eldridge@srnl.doe.gov
gregg.morgan@srnl.doe.gov
kenneth.burrows@srs.gov
timothy.tice@srs.gov
steven.brown@srs.gov
brett.clinton@srs.gov
james.therrell@srs.gov
kenneth.burrows@srs.gov
bill.clifton@srs.gov
tara.smith@srnl.doe.gov
matthew.brantley@srs.gov
hayley.williams@srs.gov
sara.shirley@srs.gov
jaclyn.fitzpatrick@srs.gov
nina.smith@srs.gov
kevin.usher@srs.gov
richard.burns@srs.gov
Records Administration (EDWS)