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**HEAVY WATER
ORGANIC COOLED REACTOR**

**METALLURGICAL EVALUATION OF DISPERSION
STRENGTHENED ALUMINUM ALLOY BILLET
MATERIAL**

AEC RESEARCH AND DEVELOPMENT REPORT

ATOMICS INTERNATIONAL—COMBUSTION ENGINEERING

A Joint Venture for Heavy Water Organic Cooled Reactors

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HEAVY WATER ORGANIC COOLED REACTOR

METALLURGICAL EVALUATION OF DISPERSION STRENGTHENED ALUMINUM ALLOY BILLET MATERIAL

By
W. E. NAGEL

Contract: AT(38-1)-430
FOR THE
U.S. ATOMIC ENERGY COMMISSION

ISSUED: SEPTEMBER 15, 1967

ATOMICS INTERNATIONAL-COMBUSTION ENGINEERING
A Joint Venture for Heavy Water Organic Cooled Reactors

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ABSTRACT

Dispersion strengthened aluminum alloys were selected as the fuel cladding and pressure tube materials for the Heavy Water Moderated Organic Cooled Reactor (HWOCR). With the inception of the HWOCR Program, large quantities of Al-7 Al₂O₃ and Al-10 Al₂O₃ alloy billet were procured for fabrication into tubing. Since this represented the first large-scale procurement of this type of billet for nuclear use, a metallurgical evaluation was performed to permit establishment of the level and variability of certain metallurgical characteristics. The characteristics determined were room and elevated temperature mechanical properties, chemical composition, macrostructure and microstructure, and internal soundness. This type of information was obtained to supplement the limited data normally generated by supplier acceptance testing for quality control purposes. The evaluation also resulted in a comparison of aluminum-alumina billets produced by two suppliers. In general, the results of the evaluation demonstrated that the billet met the mechanical property and chemical composition requirements of the procurement specification. Ultrasonic and structural studies indicated that soundness in the billet material from one of the suppliers was considerably better than from the other.

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I. INTRODUCTION

Dispersion strengthened aluminum alloys consist of fine aluminum oxide particles in a matrix of commercially pure aluminum produced by powder metallurgy techniques. These alloys have been produced with Al_2O_3 contents up to 20 wt %. The Al- Al_2O_3 alloys have been commercially designated SAP (sintered aluminum product) by European producers, and XAP (experimental aluminum powder) alloys by the sole United States producer. Aluminum-alumina dispersion strengthened alloy tubing was selected as the fuel cladding and pressure tube material for the HWO CR. Selection of this type of alloy was based on its low neutron absorption, adequate strength at reactor operating temperature (575 to 750°F), good thermal conductivity, compatibility with fuel and coolant, and favorable radiation behavior. Two alloys were considered for this application, containing 10 wt % and 7 wt % aluminum oxide.

With the inception of the HWO CR Program, large quantities of Al- Al_2O_3 alloy stock were required for fabrication into fuel cladding and pressure tubing. Stock suitable for further fabrication into tubing is procured as partially or fully wrought circular cross-section bar extruded from sintered compacts. The initial receipts of this stock or billet constituted about 10,000 lb of bar. Since this represented the first large scale procurement of this type of billet for nuclear use, a fairly comprehensive metallurgical evaluation was performed to gain information for evaluation of the level and variability of certain metallurgical characteristics. These characteristics included room and elevated temperature mechanical properties in the longitudinal and transverse directions, aluminum oxide content, chemical impurities, microstructure and macrostructure characteristics, and internal soundness. This report describes the materials tested, the evaluation procedure, and the results of the tests.

II. BILLET DESCRIPTION

The billet material used in the evaluation comprised two basic sizes and alloys. These were 2- and 7-in. diameter, and 7- and 10-wt % aluminum oxide material. Table 1 summarizes the pertinent information concerning alloy designation, supplier, quantity, and receipt date of the billet material involved in the test program.

TABLE 1
SUMMARY OF PROCUREMENT INFORMATION FOR Al-Al₂O₃
ALLOY BILLET FOR METALLURGICAL EVALUATION

Alloy Designation	Supplier	Nominal Al ₂ O ₃ Content	Billet Size (Supplier Furnished Lengths)		Quantity (lb)	Receipt Date(§) (1966)
			Diameter (in.)	Lengths (ft)		
XAP 005	Alcoa(*)	7	2	1, 2, and 3	2000	May 6
XAP 005	Alcoa	7	7	2, 3, and 4	1200	Aug 3
SAP 930	Montecatini(†)	7	2	18	2300	Feb 13
SAP 895	Montecatini	10	2	18	2000	Sept 12
SAP 895	Montecatini	10	7 OD by 2.4 ID	2	3000	Sept 8

*Aluminum Company of America, Pittsburgh, Pennsylvania

†Montecatini Edison SpA, Servizio Nucleare, Milano, Italy

§At Atomics International, Canoga Park, California

The billet stock was furnished by both suppliers as bar produced by the direct extrusion process using shear dies. The starting stock was compacted and sintered billet. Both sizes of XAP 005 alloy were extruded from 11-in. diameter billet, while each alloy and size of the SAP 895 and SAP 930 alloy billet were extruded from 10-in. diameter billet. The 7-in. diameter SAP 895 alloy stock was extruded as a heavy wall tube with a 2.4-in. inside diameter. The billet was predrilled prior to extrusion. The supplier of this alloy found this practice to be necessary to prevent excessive surface tearing during extrusion.

Finish cut lengths were those given in Table 1. Based on available information and on received stock lengths, the "as-extruded" lengths of the stock were as follows:

Alloy	Diameter (in.)	Length (ft)
XAP 005	2	~50
XAP 005	7	~4
SAP 895 and SAP 930	2	~20
SAP 895	7	~3

The above dimension data show the XAP 005 alloy material to have been produced from substantially larger compacts than were the SAP 895 and SAP 930 material and also indicate that the XAP 005 alloy extruded material was a more highly worked material at the rear of the extrusion charge. The latter observation may be of significance in analyzing billet structure and mechanical property results.

All material was received impression stencilled with the number of the compact from which it was produced. This identification was applied to the rear end, relative to the extrusion direction of the bars by both suppliers. In the instance of the XAP 005 alloy stock, a secondary identification system was used to identify intermediate lengths relative to their original location in the extrusion charge. This was not necessary for the SAP alloy stock, since only one length was produced and shipped from each billet. This information is of concern since direct extrusion from shear dies is a nonuniform metal working process, and, for valid comparison of stock, it is necessary to sample and test in approximately equivalent locations. The very first metal out of the extrusion die is worked little more than the sintered compact; the amount of mechanical working then increases from front-to-rear and from center-to-surface of the charge. The degree of work may become more evenly distributed at the rear of long extrusions.

III. EVALUATION PROCEDURE

The essential attributes of the evaluation procedure include: (1) the types of testing required to meet the evaluation program objectives, (2) the quantity of testing including sampling, and (3) sample location and selection. These are described in this section.

The types of testing that formed this billet evaluation program are listed below.

- 1) Analytical chemistry for aluminum oxide and impurities
- 2) Mechanical properties for ultimate tensile strength, tensile yield strength, and elongation at,
 - a) Room temperature
 - b) 900°F
 - c) Longitudinal direction (parallel to extrusion metal flow)
 - d) Transverse direction (normal to extrusion metal flow)
- 3) Metallurgical structure studies at the front and rear of the extrusion charge, including both macrostructure and microstructure
- 4) Internal soundness as determined by ultrasonic testing.

Requirements based on the above types of tests formed a major basis on which the SAP billet material was procured. This evaluation program was established to obtain additional data and supplement the more limited supplier and quality control acceptance test results. These additional data would demonstrate more clearly product variability and process capability, and could then furnish a more realistic basis for setting specification limits and indicate any areas in which development effort should be channeled to improve the stock. Additionally, this information could be correlated with subsequent fabricating and service experience for further demonstration of product capability.

In some instances, the quantity of supplier test results or the acceptance quality control data were deemed adequate, and no further testing was performed as part of this evaluation. Hereafter, to identify the testing and results of the supplementary testing program from that performed by the supplier as well as the acceptance inspection, the information of the program will be designated "engineering evaluation results." In most cases, the amount of stock and number of powder compacts represented by the stock was too large to permit 100% testing or sampling. Therefore, the number of items sampled and number of

tests performed were based on obtaining adequate data points for statistical analysis. The tables of data results (Appendices I through V) show the number of tests and the billets sampled. The billets sampled were selected using tables of random numbers.

Figures 1, 2, and 3, respectively, show the location and sizes of the specimens used for mechanical property, chemistry, and microstructure studies of the 2-in. diameter, 7-in. diameter solid, and 7-in. diameter hollow stock. Full cross-section specimens for macrostructure evaluation were taken immediately adjacent to the microstructure sample. Sampling at the front as well as the rear of the extrusion charge was performed primarily for the 2-in. diameter stock, while only rear end sampling was employed for the 7-in. diameter stock. Sampling was limited to the rear end only of the larger stock because of the small amount of mechanical work at the front. The high reduction ratios and supplier front end cropping removed the metal containing the small amount of working from the smaller stock.

Figure 1. Engineering Evaluation Specimen Location for 2-in. Diameter XAP 005, SAP 930, and SAP 895 Alloy Billet

Figure 2. Engineering Evaluation Specimen Location for 7-in. Diameter XAP 005 Alloy Billet

Figure 3. Engineering Evaluation Specimen Location for Hollow 7-in. Diameter SAP 895 Alloy Billet

IV. DESCRIPTION OF TESTS

This description applies only to the testing that comprised the acceptance inspection and engineering evaluation studies. The details of supplier test methods were not available, but were certified to be in conformance with ASTM E8, "Methods of Tension Testing of Metallic Materials," and ASTM E21, "Practice for Short-Time Elevated-Temperature Tension Tests for Materials."

A. MECHANICAL PROPERTY TESTING

Both room temperature and 900°F tensile testing were performed using round tensile bars having a gage length equal to four times the reduced section diameter. A gage diameter of 0.250 in. was used for all tests except the transverse testing of the 2-in. diameter stock, where a 0.125-in. diameter gage was used. Mechanical property tests were performed on a 60,000-lb capacity hydraulic universal tensile testing machine. The strain rate was controlled with room and high temperature extensometers to just beyond the estimated 0.2% offset yield strength. Beyond this point, the test was controlled to a load rate of 300 lb per minute to fracture. The strain rate employed below the yield strength was 0.001 in./in./minute. Tensile yield strength was taken at 0.2% offset. Elongation was obtained by measurement of gage length extension, after fracture, with the test specimens held in a constant pressure jig.

Elevated temperature testing was accomplished in a resistance-heated furnace attached to the tensile testing machine. Temperature was maintained within $\pm 2\frac{1}{2}^{\circ}\text{F}$ of the 900°F nominal value. Chromel-Alumel thermocouples were attached to the reduced section and to one shoulder of each test specimen to assure proper temperature control. The furnace atmosphere was ambient air. Time at temperature prior to applying the load was 30 minutes.

B. ANALYTICAL CHEMISTRY

The aluminum oxide analyses were performed by the fast neutron activation method.* Briefly, the method involves the activation of O^{16} by 14 Mev neutrons obtained by bombarding a titanium tritide target with deuterons in a small linear

*The development of the technique and standards for this technique of analysis is described in AI-CE-74, "Oxygen Determination in Aluminum-Alumina Alloys by Neutron Activation," by E. L. Bramlitt.

accelerator. The nuclear reactions are as follows, with the intensity of the gamma photons above an energy of 4.5 Mev being a measure of the oxygen present,

The oxygen amount determined was then reported as Al_2O_3 .

The methods for determining the impurity elements in stock samples are given in Table 2. Many elements checked by emission spectrography were detected in concentrations below the levels for which standards were available, and this resulted in reported values "less than" that of the available standard.

TABLE 2
ANALYTICAL METHODS USED FOR IMPURITY
ANALYSES OF SAP ALLOYS

Element	Method
Carbon	Convert carbon to CO_2 by standard combustion techniques, and measure CO_2 by conductimetric techniques.
Hydrogen	Vacuum extraction at 950°C and manometric readout
Nitrogen	Kjeldahl distillation
Others*	Emission spectrography

*Boron, cadmium, calcium, copper, gallium, iron, lead, molybdenum, silicon, sodium, tin, zinc, and zirconium.

C. STRUCTURE STUDIES

Macrostructure evaluations were performed on caustic-etched full cross section samples removed from the stock in 3/4- to 1-in. lengths. Prior to etching, one surface was machined to a surface finish of $32 \mu\text{in. rms}$ or less.

Etching was accomplished by total immersion of individual samples in a 10 wt % aqueous solution of sodium hydroxide. Etching time was ten minutes with the temperature of the solution maintained in the range 140 to 160°F during this time period. Representative samples were photographed for this report.

Microstructure samples were prepared by conventional grinding and polishing methods. All examinations were performed after etching. For inclusion counts, the etchant was 1% cold NaOH solution; for general microstructure studies, an 0.5% HF solution was used. The NaOH etchant facilitated inclusion particle detection by not emphasizing structure, while the HF etchant emphasized the general microstructure. Inclusions having their longest dimension less than 0.0005 in. were not of interest during particle count studies; therefore, a magnification of 100 diameters was used to reduce the time required to scan the 1-in.² surfaces. General microstructure examinations were performed at 500 diameters magnification to disclose the desired detail.

D. INTERNAL SOUNDNESS

Pulse-echo immersion ultrasonic testing through the diameter of the extruded stock served as the method of evaluating internal soundness. For the purposes of this test, it became necessary to cut the 18-ft long SAP 895 and SAP 930, 2-in. diameter bar. For convenience in scanning, 3-ft long test lengths were used.

The 2-in. diameter billet stock was tested at a frequency of 10 MHz using 3/8-in. diameter focused lithium sulphate transducers. The 7-in. diameter stock was also tested at 10 MHz; in view of its larger diameter, a 3/8-in. flat lithium sulphate transducer performed satisfactorily. The instrumentation and equipment for ultrasonic testing included a UM 721 Reflectoscope, scanning bridge, stock rotating fixture, and a X-Y or C-scan recorder. The recorder was employed for stock from which numerous discontinuity indications were detected, and a permanent record was used to extract data for subsequent analysis and correlation.

Because of the surface curvature of the stock, standard aluminum alloy reference blocks were not particularly applicable to the evaluation of this stock. Sound energy losses by refraction entering and leaving the stock preclude meaningful comparisons with standard reference blocks, all of which have flat sound

entry surfaces. However, these standard blocks do afford a method of providing a constant test sensitivity, and they were used for this purpose. During the earlier testing, only Alcoa area-amplitude blocks were available; later in the test program, a set of Automation Industries distance-amplitude blocks was available. The test sensitivities used for ultrasonic testing of the various alloys and sizes of stock are given in Table 3.

TABLE 3
ULTRASONIC SENSITIVITY FOR BILLET TESTING

Billet Alloy and Size	Test Sensitivity
XAP 005, SAP 895, and SAP 930, 2-in. diameter	Adjust instrument for a 50% of CRT saturation indication from the flat bottom hole in an Alcoa No. 5 Area-Amplitude Reference Block. Record, as a discontinuity in the stock, any CRT signal greater than 25% of saturation.
XAP 005 and SAP 895, 7-in. diameter	Adjust instrument for a 90% of CRT saturation signal from the flat bottom hole in an Alcoa No. 3 Area-Amplitude Reference Block. Record, as a discontinuity in the stock, any CRT indication greater than 50% of saturation.

V. RESULTS AND DISCUSSION

All individual analytical chemistry and mechanical property test results are tabulated in Appendices I through V, respectively, for (1) the 2-in. diameter SAP 005 alloy billet, (2) the 2-in. diameter SAP 930 alloy billet, (3) the 2-in. diameter SAP 895 alloy billet, (4) the 7-in. diameter XAP 005 alloy billet, and (5) the 7-in. diameter SAP 895 alloy billet. These data tabulations separate supplier, acceptance inspection, and engineering evaluation results. Where three or more data points were obtained for equivalent situations, the arithmetic mean, and unbiased standard deviation were calculated and included in the tables. Procurement specification acceptance limits are included in all tables of supplier and acceptance inspection results. With several exceptions, the chemical composition and mechanical property summaries and comparisons in this portion of the report will be limited to those data obtained from the engineering evaluation. The exceptions include instances where supplier or acceptance inspection data were particularly abundant and no additional testing was necessary.

A. CHEMICAL COMPOSITION RESULTS

Aluminum oxide content is one of the more important aluminum-alumina alloy characteristics that can be investigated in the billet form. The sampling used for the engineering evaluation studies was established to detect any center-to-surface Al_2O_3 gradient in the sintered compact, as well as to determine compact-to-compact variability. As a result of the nature of the metal flow and the amount of reduction during extrusion, a comparison of Al_2O_3 content at the front and rear of extrusion charge for the 2-in. diameter billet, and at the center and surface for the 7-in. diameter billet, may detect center-to-surface Al_2O_3 segregation in the compact. The results of this comparison, given in Table 4, indicate that the Al_2O_3 content at the outside surface of the XAP 005 and SAP 895 alloy compacts was slightly higher than at the center. Segregation of this nature could result from stratification during filling of the compact molds.

A summary of the mean, standard deviation, and number of tests for the Al_2O_3 analyses performed for material involved in the engineering evaluation is contained in Table 5 for all alloys and stock sizes. Individual test maximum

TABLE 4
COMPARISON OF FRONT-TO-REAR AND SURFACE-TO-CENTER
Al₂O₃ CONTENT IN EXTRUDED BILLET

Billet		Mean Al ₂ O ₃ Contact (wt %)		
Diameter (in.)	Alloy	Front/ Center	Rear/ Surface	Difference* (%)
2	XAP 005	5.84	5.96	+2.1
2	SAP 930	6.33	6.29	-0.6
2	SAP 895	10.48	10.66	+1.7
7	XAP 005	5.96	6.02	+1.0
7	SAP 895	10.42	10.45	+0.3

*Rear or surface values relative to front or center values.

TABLE 5
SUMMARY OF ENGINEERING EVALUATION
ALUMINUM OXIDE ANALYSES
(wt %)

Comparison Statistic	2-in. Diameter Billet			7-in. Diameter Billet	
	XAP 005	SAP 930	SAP 895	XAP 005	SAP 895
Mean	5.98	6.31	10.57	5.99	10.42
Standard Deviation	0.32	0.08	0.26	0.25	0.17
Number of Tests	28	12	12	8	20
Minimum Observed	5.43	6.24	10.27	5.56	10.20
Maximum Observed	6.42	6.43	11.03	6.29	10.66

and minimum results are also shown. The individual test results within a billet, and probably within certain sequences of billets, cannot be considered independent values for purposes of rigorous statistical analysis. This is because several extrusion charges may have been made from some more fundamental production unit of powder, in which Al_2O_3 level would vary in some random or independent manner. However, the standard deviation can be used as an indicator to compare variability among alloys, sizes, and suppliers. The mean can probably be used as a comparison statistic with more confidence, since the billet selection was random and fairly equal numbers of samples were tested from each extrusion charge.

With the above limitations in mind, the following pertinent observations can be made based on the data of Table 5.

- 1) Very little difference exists in Al_2O_3 level between the same alloy produced by the same supplier.
- 2) Variability in the XAP 005 alloy is somewhat greater than in the SAP alloys.
- 3) For the equivalent alloys, SAP 005 and SAP 930, the latter exhibits a higher Al_2O_3 level and substantially less variability.

Also of significance is the fact that no individual Al_2O_3 analysis result performed for acceptance testing or engineering evaluation, or submitted by the suppliers, was outside the specification limits.

Certain impurities may result primarily from the milling operations used to convert the high purity aluminum metal to the powder for the Al- Al_2O_3 alloys. These are hydrogen, nitrogen, and carbon, and residues from the milling media (liquids, air, and lubricant additives) which were not volatilized during sintering. Table 6 contains chemical analyses summaries of these elements. The results show that the SAP alloys are lower in carbon and hydrogen, and higher in nitrogen level, than the XAP 005 alloy. Also, in three instances, samples of the SAP alloys exceeded the 0.080 wt % maximum acceptance limit for nitrogen. The samples were the only instances where chemical composition acceptance limits were not met in any of the alloys.

The iron and silicon levels were good indicators of the purity of the primary aluminum used for powder production and contamination during fabrication.

TABLE 6
COMPARISON OF HYDROGEN, NITROGEN, AND
CARBON RESIDUAL LEVELS IN BILLET

Element	Comparison Statistic	(wt %)				
		2-in. Diameter Billet			7-in. Diameter Billet	
		SAP 005	SAP 930	SAP 895	XAP 005	SAP 895
Hydrogen	Minimum	0.0010	0.0004	0.0004	0.0011	0.0004
	Mean	0.0014	0.0005	0.0006	0.0014	0.0004
	Maximum	0.0018	0.0008	0.0009	0.0023	0.0007
	No. of tests	8	12	6	4	10
Nitrogen	Minimum	0.010	0.015	0.014	0.003	0.006
	Mean	0.025	0.036	0.084	0.012	0.024
	Maximum	0.080	0.090	0.377	0.018	0.036
	No. of tests	8	12	6	4	10
Carbon	Minimum	0.37	0.18	0.28	0.46	0.24
	Mean	0.54	0.32	0.32	0.65	0.27
	Maximum	0.76	0.28	0.35	0.78	0.31
	No. of tests	8	12	6	4	8

Analysis results indicate that equivalent high purity primary metal was used for both the XAP 005 and SAP alloys and "tramp" impurity pickup during fabrication was minimal.

B. MECHANICAL PROPERTY RESULTS

In the following discussion of billet mechanical properties, some explanation is required for the type of data obtained. Longitudinal testing was not performed for the 7-in. diameter billet since the 5- to 6-in. specimen length needed shortened billets to the extent they could not be used to obtain full-length pressure tubing. This billet size was procured solely for the large diameter pressure tubing, and even the somewhat limited testing requirements for this program would have substantially depleted the initial billet inventory. However, some supplier longitudinal test data at room and elevated temperature were available, and were used to infer some correlation between the properties of the two directions.

Because of the very limited amount of mechanical working introduced into the 7-in. billets (their front ends being worked little more than the sintered compacts), only rear end mechanical property testing was performed for this billet size. However, the 2-in. diameter billet received adequate working (greater than 90% area reduction from the compact) to permit meaningful front end mechanical property testing after cropping the nose of the extrusion. Also, because of the long extruded length of the 2-in. diameter XAP 005 alloy (~50 ft) as compared to the SAP alloys (~20 ft), some center-of-extrusion-length mechanical property testing was performed for the former alloy.

The elevated temperature testing was performed at 900°F because of the requirement for tests at this temperature in the billet specifications, as well as the fact that a considerable body of data was available for this temperature from past work on these alloys.

Elongation of the tensile bar gage length is a common mechanical property used as a measure of ductility. However, this property is strongly affected by testing parameters, specimen geometry, and test conditions. Therefore, the tensile yield strength to ultimate tensile strength ratio (TYS/UTS) was also calculated and included in all data tabulations to represent a less test-sensitive indicator of ductility.

Table 7 summarizes the 2-in. diameter billet, longitudinal direction, mechanical property results at room and elevated temperatures for all alloys produced in this size. The XAP 005 alloy data shown in this table were summarized from supplier results, while the remaining data were from the engineering evaluation program. It is believed that supplier results were performed from coupons taken near the rear of the extrusion charge, while the remaining results represent both front and rear of charge results, as shown in the appropriate tables in the appendices from which the data were summarized. The most striking factor evident from Table 7 is the lower room temperature and 900°F strength of the SAP 930 billet as compared to the XAP 005 alloy billet. These are equivalent alloys, produced by different suppliers, and it would be expected their mechanical properties would be similar. This difference becomes more striking considering that the amount of the Al_2O_3 dispersion hardening component of the SAP 930 alloy is higher (6.31 wt %) than that of the XAP 005 alloy (5.98 wt %). Further, the strength difference is more pronounced for the yield strength than for the tensile strength.

TABLE 7
COMPARISON OF LONGITUDINAL DIRECTION MECHANICAL
PROPERTIES FOR 2-in. DIAMETER BILLET

Mechanical Property	Tests					
	Room Temperature			900°F		
	Alloy					
	XAP 005	SAP 930	SAP 895	XAP 005	SAP 930	SAP 895
UTS (ksi)						
Mean	35.5	33.6	42.5	9.3	8.7	12.5
Standard deviation	1.4	0.4	1.2	0.4	0.2	0.5
No. of tests	24	12	11	14	11	11
TYS (ksi)						
Mean	28.0	20.6	28.6	8.7	7.8	11.4
Standard deviation	0.9	1.1	1.1	0.4	0.2	0.6
No. of tests	24	12	11	14	11	11
Elongation (%)						
Mean	20.0	17.2	13.4	6.3	8.7	5.7
Standard deviation	2.2	1.5	0.7	1.9	0.8	1.1
No. of tests	24	12	11	14	11	11
TYS/UTS Ratio						
Mean	0.79	0.61	0.67	0.94	0.90	0.93
Standard deviation	0.03	0.03	0.02	0.01	0.02	0.03
No. of tests	24	12	11	14	11	11

Based on elongation differences, the XAP 005 alloy was more ductile at room temperature, but less ductile at 900°F than the SAP 930 billet. The UTS/TYS ratio reflecting the individual strength difference characteristics shows the SAP 930 to be the most ductile under both test temperature conditions.

The higher Al_2O_3 content (10.57 wt %) SAP 895 alloy 2-in. diameter billet was higher in strength than either the XAP 005 or SAP 930 bar, as was expected. However the room temperature yield strength of the SAP 895 was the same as the low Al_2O_3 content XAP 005 alloy billet. In all other respects, the SAP 895 alloy results were as expected compared to the SAP 930 and XAP 005 alloy results, i. e., higher strength and lower ductility as indicated by elongation.

In these dispersion hardened alloys, it is known that the quantity of the dispersed phase is but one of a number of factors that affect the strength and ductility of the alloy. Aluminum oxide morphology, orientation, size, and distribution are also factors affecting properties; and one or more of these, in all likelihood, contributed to the differences noted in the above comparisons. These differences suggest that the proprietary powder fabrication processes used by the two suppliers are significantly different. The starting metal appears to be of equivalent purity, and, for this stock size, fabrication differences would not be expected to cause the large property differences noted.

Table 8 compares the transverse mechanical properties of the 7-in. diameter XAP 005 alloy and SAP 895 alloy billet. For two reasons, it was expected that

TABLE 8
COMPARISON OF TRANSVERSE DIRECTION MECHANICAL
PROPERTIES FOR 7-in. DIAMETER BILLET

Mechanical Property	Tests			
	Room Temperature		900° F	
	Alloy			
	XAP 005	SAP 895	XAP 005	SAP 895
UTS (ksi)				
Mean	35.8	43.6	8.4	9.8
Standard deviation	1.6	1.5	1.0	0.8
No. of tests	5	10	6	10
TYS (ksi)				
Mean	25.1	28.0	8.0	8.5
Standard deviation	2.4	1.0	1.1	0.7
No. of tests	5	10	6	10
Elongation (%)				
Mean	14.8	7.7	3.3	3.6
Standard deviation	2.5	0.5	0.8	0.4
No. of tests	5	10	6	10
TYS/UTS Ratio				
Mean	0.70	0.65	0.95	0.87
Standard deviation	0.40	0.02	0.03	0.05
No. of tests	5	10	6	10

these mechanical properties would be substantially lower than those for the 2-in. diameter billet, first, because of the lower amount of the mechanical working received by the larger billet, and second, because the test direction was transverse to the metal flow direction. It is characteristic of the conventional highly alloyed aluminum alloys (2XXX and 7XXX series) that transverse mechanical properties are lower than longitudinal properties for wrought products. These conventional alloys are sensitive to degree of working, optimum mechanical properties not being developed until the unworked billet has been reduced in area by at least 80 to 90%. However, a comparison of Tables 7, 8, and 9 indicates the XAP 005 and SAP 895 alloys to be less sensitive than expected to amount of mechanical work and directionality. The data of Table 9 were summarized from both supplier and engineering evaluation test results. Mechanical property comparisons for the data in these three tables show no appreciable tensile and yield strength variation at room temperature and 900°F for any one alloy as a result of the substantially different test directions and area reductions represented. Only the elongation was lower for the transverse direction tests and less worked billet.

The mechanical properties differences between the XAP 005 and SAP 895, 7-in. diameter billet are in agreement with the differences between the same alloys of 2-in. diameter billet. The SAP 895 alloy has the higher strength and lower ductility of the two. Differences were less pronounced between yield strength than between tensile strengths.

Since direct extrusion through shear dies is a nonuniform metal working operation from the front to rear of the extrusion charge, it was of interest to determine if any difference in mechanical properties was evident because of this nonuniform working. Table 10 summarizes front and rear mechanical properties for the two SAP alloy stock types at room temperature and 900°F. No appreciable differences are evident in strength or ductility at room or elevated temperatures between the front and rear of this stock.

C. MACROSTRUCTURE STUDY RESULTS

The macrostructure studies for this evaluation involved unaided eye examination of the deep etched (caustic) cross-sections of samples from near the front end and rear of the extrusion charge. All samples were etched for 10 minutes in 10 wt % NaOH of 140 to 160°F. They were examined for large-scale

TABLE 9
COMPARISON OF LONGITUDINAL AND TRANSVERSE MECHANICAL
PROPERTIES OF XAP 005 ALLOY BILLET

Billet Diameter (in.)	Comparison Statistic	UTS (ksi)		TYS (ksi)		Elongation Percent		TYS/UTS Ratio	
		Long.	Trans.	Long.	Trans.	Long.	Trans.	Long.	Trans.
Room Temperature Tests									
2	Mean	35.4	31.9	28.0	20.8	20.0	9.4	0.79	0.65
	Standard deviation	1.4	0.9	0.9	0.6	2.2	2.6	0.03	0.02
	No. of tests	24	18	24	18	24	18	24	18
7	Mean	35.8	35.8	25.3	25.1	18.3	14.8	0.71	0.70
	Standard deviation	0.7	1.6	0.7	2.4	3.5	2.5	0.01	0.04
	No. of tests	7	5	7	5	7	5	7	5
900°F Tests									
2	Mean	9.3	7.6	8.7	6.1	6.3	2.7	0.94	0.81
	Standard deviation	0.4	0.2	0.4	0.1	1.9	0.3	0.01	0.03
	No. of tests	14	3	14	3	14	3	14	3
7	Mean	8.7	8.4	8.4	8.0	4.6	3.3	0.97	0.95
	Standard deviation	0.4	1.0	0.3	1.1	1.8	0.8	0.01	0.03
	No. of tests	7	6	7	6	7	6	7	6

*Testing was limited because of difficulty experienced in handling the subsize test coupons at elevated temperature.

TABLE 10
COMPARISON OF FRONT AND REAR LONGITUDINAL
DIRECTION MECHANICAL PROPERTIES FOR
2-in. DIAMETER EXTRUDED BILLET

Alloy	UTS (ksi)		TYS (ksi)		Elongation Percent		TYS/UTS Ratio	
	Front	Rear	Front	Rear	Front	Rear	Front	Rear
Room Temperature Tests								
SAP 930								
Mean	34.0	33.4	21.4	19.9	17.7	16.7	0.63	0.60
Standard deviation	0.2	0.4	0.4	1.0	1.5	1.4	0.01	0.03
No. of tests	6	6	6	6	6	6	6	6
SAP 895								
Mean	43.3	41.9	28.7	28.6	13.2	13.5	0.67	0.68
Standard deviation	1.0	0.9	0.9	1.4	0.8	0.5	0.02	0.02
No. of tests	5	6	5	6	5	6	5	6
900°F Tests								
SAP 930								
Mean	8.8	8.6	7.9	7.7	9.2	8.2	0.90	0.89
Standard deviation	0.2	0.2	0.2	0.2	0.4	0.8	0.02	0.01
No. of tests	6	5	6	5	6	5	6	5
SAP 895								
Mean	12.6	12.4	11.5	11.4	5.4	6.0	0.92	0.93
Standard deviation	0.4	0.5	0.5	0.7	0.5	1.4	0.03	0.03
No. of tests	5	6	5	6	5	6	5	6

structure variations from the front to rear of the extrusion charge, as well as charge-to-charge and alloy-to-alloy variation. The specimens were also evaluated for the presence of gross discontinuities and segregation conditions.

Figures 4 and 5 are photomicrographs of the front and rear of extrusion charge for full cross section samples from two 2-in. diameter XAP 005 alloy billets. The small dark areas in these views are pits, and are believed to have resulted from etch removal of numerous particles that are characteristic of this

a. Front

8-3-67 UNC

7621-1-1

b. Rear

8-3-67 UNC

7621-8-1

Figure 4. Front and Rear Specimens From 2-in. Diameter XAP 005 Alloy Extruded Billet No. 54

a. Front

8-3-67 UNC

7621-6-1

b. Rear

8-3-67 UNC

7621-5-1

Figure 5. Front and Rear Specimens From
2-in. Diameter XAP 005 Billet No. 65

a. Front

8-3-67 UNC

7621-1-1

b. Rear

8-3-67 UNC

7598-3-2

Figure 6. Typical Macrostructure of Front and Rear of 2-in. Diameter Extruded SAP 930 Billet No. 610

alloy. Microstructure studies did not disclose any other structure feature which may have resulted in this condition. The appearance of the etched surfaces shown in Figure 4 indicate satisfactory macrostructure. The arrow in Figure 5 indicates a void which extended through the 1-in. thick sample. A billet containing this condition is unacceptable for further manufacturing. Flaws similar to that shown in Figure 5 probably were a major cause of the numerous ultrasonic discontinuity indications obtained from the 2-in. diameter XAP 005 alloy stock. It had been the practice to use macroetch sampling at the ends of the extrusion as a means of detecting excessive amounts of this flawing in the stock for rejection purposes. However, as a result of this investigation, ultrasonic testing which can be applied 100% nondestructively would be a more effective method of detecting these flaws and sorting out objectionable stock. Etch samples can be effectively used to detect occurrence of the "extrusion" or "rear end" defect. This rear end test, however, is more applicable for the extruder's use as a process control than for a purchaser's acceptance test. The rear end samples of the stock illustrated in Figures 4 and 5 exhibited the outer periphery banding that is characteristic of the rear end of shear die extrusions. Of the eleven billets sampled from the front and rear ends of the extrusion charge and macroetched and examined, three front and one rear sample exhibited unacceptable conditions similar to that illustrated in Figure 5.

Figure 6 shows photomacrographs typical of the front and rear SAP 930 alloy billet extrusion charge. No flaws or other structure abnormalities were found in any of the six SAP 930 billets sampled in this manner. This billet was strikingly free of discontinuities compared to the remaining 2-in. diameter billet alloys and it represents a very satisfactory billet macrostructure. Peripheral banding in these samples was less pronounced than for the same size XAP 005 alloy, and it offers further evidence of the smaller amount of mechanical working received by this size SAP material as compared to the XAP 005 alloy. The rear of the SAP 930 appears, on this basis, to have been worked to about the same degree as the front of the XAP 005 alloy 2-in. diameter billet received from the supplier. This is not improbable since analysis of the identification of the XAP 005 material received indicates a very substantial front end crop (as much as 9 ft) of this billet by the supplier.

Figures 7 and 8 are photomacrographs of the front and rear end of the 2-in. diameter SAP 895 alloy billet. The general structure is similar to that of the

a. Front

8-3-67 UNC

7621-4-1

b. Rear

8-3-67 UNC

7621-3-1

Figure 7. Typical Macrostructure of Front and Rear of 2-in. Diameter SAP 895 Alloy Extruded Billet No. 561

a. Front

8-3-67 UNC

7621-2-1

b. Rear

8-3-67 UNC

7621-1-1

Figure 8. Front and Rear Specimens From 2-in.
Diameter SAP 895 Billet Alloy No. 557

a. Front (0.5X)

8-3-67 UNC

7624-4-1

b. Rear (0.5X)

8-3-67 UNC

7624-3-1

Figure 9. Macrostructure of 7-in. Diameter XAP 005 Alloy
Extruded Billet No. 83

(Sheet 1 of 2)

c. Front (1.5X)

8-3-67 UNC

7624-4-2

d. Rear (1.5X)

8-3-67 UNC

7624-3-2

Figure 9. Macrostructure of 7-in. Diameter XAP 005 Alloy
Extruded Billet No. 83

(Sheet 2 of 2)

2-in. diameter SAP 930 alloy stock, and also represents a very satisfactory billet microstructure. However, two discontinuities were located on the rear end specimen from one of the SAP 895 alloy billets, as shown in Figure 8. The structure conditions indicated by the arrow extended through the specimen. This is the only billet of the six evaluated in this manner that exhibited discontinuities. The condition made the billet unacceptable for further processing.

Figure 9 shows photomicrographs of the front and rear end of a 7-in. diameter XAP 005 alloy billet. The front end structure is striking in that it is essentially that of the sintered compact from which the billet was extruded. Both the front and rear end samples show discontinuities considered to be unacceptable in the billet for further processing into pressure tubes. The etching characteristic of the rear end sample is representative of wrought XAP 005. Of the four billets sampled and macroetched, two exhibited unacceptable conditions, as indicated by the arrows on the figure. The most severe condition was a crack-like condition shown in Figure 10, an unetched sample.

Figure 11 shows the macrostructure of front and rear end samples of one of the ten 7-in. diameter SAP 895 alloy billets tested. The flaw shown in the rear end sample was the only unacceptable macrostructure condition detected in the large SAP 895 alloy billet samples. The general macrostructure is acceptable. It is of interest to note that the microstructure at the front of the SAP 895 billet shown in Figure 11 was substantially finer than for the XAP 005 alloy illustrated in Figure 9. Notwithstanding differences in fabrication methods, this indicates greater mechanical working at the front of the SAP 895 billet as compared to the front of the same size XAP 005 alloy billet. This in turn, indicates more preworking before extrusion, or a larger front end crop (or both) for the SAP 895. Because the billet must be greatly reduced during subsequent extrusion into pressure tubes, a large front end crop is not necessary unless it is to remove gross surface flaws. Less front end cropping would, if feasible, permit improved recovery and longer pressure tubes.

Figure 10. Flaws in Rear of Extrusion
Charge Sample From XAP 005 Alloy
7-in. Diameter Billet No. 45-1

a. Front (0.5X)

8 3 67 UNC

7624 2 1

b. Rear (0.5X)

8-3-67 UNC

7624-1-1

Figure 11. Macrostructure of 7-in. OD by 2.4-in. ID SAP 895
Alloy Extruded Billet No. 520

(Sheet 1 of 2)

c. Front (1.5X)

8-3-67 UNC

7624-2-2

d. Rear (1.5X)

8-3-67 UNC

7624-1-2

Figure 11. Macrostructure of 7-in. OD by 2.4-in. ID SAP 895
Alloy Extruded Billet No. 520

(Sheet 2 of 2)

D. MICROSTRUCTURE STUDIES

The primary purpose of the microstructure studies was to characterize the billet and compare alloys on the basis of an inclusion count. The results of this study are summarized in Table 11. These data clearly show that the inclusion

TABLE 11
MICROSTRUCTURE INCLUSION COUNT
RESULTS FOR BILLET MATERIAL

Billet Diameter (in.)	Alloy	No. of Billets and Samples*	Average Number of Inclusions/in. ²			Largest Inclusion Size (in.)†
			> 0.0005 in. to 0.0010 in.	> 0.0010 in. to 0.0030 in.	> 0.0030 in.	
2	XAP 005	12 (6)	10.0	16.3	15.1	0.0200 by 0.0045
	SAP 930	12 (6)	5.5	1.7	0.5	0.0090 by 0.0035
	SAP 895	6 (6)	4.0	0	0.1	0.0040 by 0.0015
7	XAP 005	4 (4)	14.2	14.2	3.0	0.0150 by 0.0110
	SAP 895	10 (10)	1.7	0.2	0.1	0.0050 by 0.0010

*Brackets show number of billets represented by indicated billet samples.

†Major and minor axes lengths.

particles occurred with a greater frequency, and were larger in size, in the XAP 005 alloy billet as compared to both the SAP 930 and SAP 895 alloy billet. The inclusions in all three alloys were predominantly metallic, primarily iron, as shown by electron beam microprobe studies. The photomicrograph shown in Figure 12 illustrates one of the larger inclusions found in the XAP 005 alloy billet. (The billet was etched in 1% NaOH at room temperature.) As described in the preceding section, it was removal of these inclusions during etching that apparently resulted in the pitted appearance characteristic of XAP 005 alloy

8-3-67 UNC

7681-3-1

Figure 12. Large Metallic Inclusion in a
Rear End Sample From 2-in. Diameter
SAP 005 Alloy Billet No. 54A

macrostructure specimens. Major-minor axis length measurement of the inclusion was 0.0120 by 0.0040 in.

The general microstructure appearances typical of the alloys involved in this study, and illustrating general microstructure and degree of working from front to rear of extrusion, are shown in the three-dimensional photomicrographs of Figures 13 and 14. The samples were etched 1 minute in 0.5% HF. Figure 13 shows front and rear of extrusion charge structure for a 2-in. diameter XAP 005 alloy billet, while Figure 14 consists of a similar set of photomicrographs for a SAP 895 alloy billet. Conventional metallurgical "grain structures," normally disclosed by optical metallography for metals and alloys, do not occur for the XAP and SAP alloys. The aluminum oxide particles appear to occur in a size range 0.02 to 1.5 μ diameter.* The banding structure on the longitudinal direction surfaces shown in Figures 13 and 14 probably resulted from an "apparent grain size" of the starting powder size. The starting powder size is about 10 μ for the XAP 005 and 70 to 140 μ for the SAP 930 and SAP 895.*

*"Heavy Water Organic Cooled Reactor SAP Handbook," AI-CE-MEMO-24.

8-3-67 UNC

7680-4761

a. Front

8-3-67 UNC

7680-4762

b. Rear

Figure 13. Three-Dimensional Photomicrographs of
Front and Rear of XAP 005 Alloy Billet No. 54

8-3-67 UNC

7680-4763

a. Front

8-3-67 UNC

7680-4764

b. Rear

Figure 14. Three-Dimensional Photomicrographs of
Front and Rear of SAP 895 Alloy Billet No. 557

The effect of the larger starting powder size is a coarser appearing microstructure for the SAP 895 material as compared to the XAP 005 alloy billet. Also, for the SAP 895 billet, the greater amount of mechanical working at the rear of the extrusion charge is evident from the finer structure appearance as compared to the front. Because of the smaller starting powder size, a similar difference is not evident for the front and rear of the XAP 005 alloy billet at the magnification used (500X).

E. ULTRASONIC TEST RESULTS

The ultrasonic test results are in agreement with both macrostructure and microstructure results, which demonstrated a higher level of unsoundness for the XAP 005 alloy billet as compared to either the SAP 930 or SAP 895 billet. Table 12 contains a summary of ultrasonic test results for comparison purposes.

TABLE 12
BILLET INTERNAL SOUNDNESS COMPARISON
BASED ON ULTRASONIC TESTING

Billet Diameter (in.)	Alloy	Total Length of Billet Tested (ft)	Number of Discontinuity Indications Detected per Foot of Billet Length
2	XAP 005	89	> 15
	SAP 930	108	0
	SAP 895	132	1.2
7	XAP 005*	5	1.2
	SAP 895	74	3.5

*Rough surface and transverse surface cracks prevented an effective test of additional billet.

The 7-in. diameter XAP 005 alloy results probably should not be considered representative for this material. From the initial shipment, only two short billets were smooth and straight enough for ultrasonic testing. Even these two billets were inferior, in this respect, to the worst of the 7-in. diameter SAP 895 billets; and it is probable that some discontinuities in the XAP 005 were not detected because of unfavorable surface and straightness conditions.

VI. CONCLUSIONS

The evaluation was primarily concerned with obtaining test data to supplement that which is normally generated by supplier acceptance testing for quality control purposes. (Individual mechanical property and analytical chemistry results for samples from the five combinations of billet size and alloy — 2-in. diameter XAP 005, SAP 930, and SAP 895 as well as 7-in. diameter XAP 005 and SAP 895 alloy — are given in the tables comprising Appendices I through V.) In addition, the evaluation resulted in a comparison of aluminum-alumina alloy billet produced by two suppliers, and certain significant differences between the type of billets were noted. The following conclusions and observations are presented, based on the results of the evaluation:

- 1) The aluminum oxide content results for all alloys were well within specification limits.
- 2) Of the impurity element maximum requirements, only nitrogen was found to exceed limits, in some instances, for SAP 930 and SAP 895 alloy billet. The XAP 005 alloy nitrogen content did not exceed, but approached closely or fell on maximum limit, for some samples.
- 3) Minimum mechanical property limits had been established for the 2-in. diameter billets only. All of the mechanical property tests performed for acceptance inspection and engineering evaluation met these limits.
- 4) The SAP 930 alloy 2-in. diameter billet was lower in strength at room temperature and at 900°F than equivalent (chemical composition) XAP 005. The difference was more pronounced for the yield strength than for the tensile strength, and at room temperature, as compared to 900°F.
- 5) Internal soundness of the SAP 930 and SAP 895 alloy billets was superior to that for the XAP 005 alloy billet, based on both structure studies and ultrasonic testing.

APPENDIX I
ANALYTICAL CHEMISTRY AND MECHANICAL PROPERTY TEST
RESULTS FOR 2-in. Diameter XAP 005 ALLOY BILLET

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TABLE A-1
SUPPLIER ANALYTICAL CHEMISTRY RESULTS
FOR XAP 005 2-in. DIAMETER BILLET

Element or Compound	Compact-Billet Sample Results (wt %)					Acceptance Limits (wt %)**
	5CC	40-6	47-6	81-9	751-2C	
AL ₂ O ₃ *	5.98	5.80	7.03	6.53	7.39	5.0 to 8.0
Boron	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.0003
Cadmium	<0.002	<0.002	<0.002	<0.002	<0.002	0.003
Calcium	<0.005	<0.005	<0.005	<0.005	<0.005	0.010
Carbon	0.69	0.53	0.46	0.74	0.56	0.80
Copper	0.00	0.00	0.00	0.00	0.00	0.010
Gallium	<0.20	<0.20	<0.20	<0.20	<0.20	0.030
Hydrogen	0.0007	0.0007	0.0004	0.002	0.002	0.002
Iron	0.05	0.04	0.06	0.05	0.05	0.20
Lead	<0.002	<0.002	<0.002	<0.002	<0.002	0.004
Molybdenum	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.005
Nitrogen	0.03	0.02	0.12	0.03	0.08	0.08
Silicon	<0.04	<0.04	<0.04	<0.04	<0.04	0.10
Sodium	<0.005	<0.005	<0.005	<0.005	<0.005	0.010
Tin	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.030
Zinc	0.00	0.00	0.00	0.00	0.00	0.050
Zirconium	<0.003	<0.003	<0.003	<0.003	<0.003	0.010

*Mean = 6.546 wt %

Standard deviation = 0.675 wt %

**AI specification ST0170NB0042; maximum unless otherwise noted.

TABLE A-2
 SUPPLIER RESULTS FOR ROOM TEMPERATURE
 LONGITUDINAL DIRECTION MECHANICAL
 PROPERTIES OF 2-in. DIAMETER
 XAP 005 ALLOY BILLET

Test Number	Compact Number	UTS (ksi)	TYS (ksi)	Elongation Percent in 4D	TYS/UTS Ratio
1	5	35.2	27.6	18.5	0.78
2	23	34.1	26.4	20.5	0.78
3	28	35.2	27.3	20.5	0.78
4	29	34.4	26.1	23.0	0.76
5	31	34.9	27.9	24.0	0.80
6	33	35.1	38.1	23.0	0.80
7	36	35.6	28.4	22.0	0.80
8	40	31.1	27.6	22.0	0.89
9	41	34.4	28.6	22.0	0.83
10	43	35.2	27.5	23.0	0.80
11	47	35.7	28.0	20.5	0.78
12	48	35.3	28.1	21.0	0.80
13	51	34.3	26.8	20.0	0.78
14	54	35.3	27.1	19.0	0.77
15	56	34.8	27.0	20.5	0.78
16	59	36.7	28.2	17.0	0.78
17	60	36.7	29.0	17.0	0.78
18	64	36.9	29.0	18.0	0.78
19	65	37.6	29.6	18.0	0.79
20	67	35.4	28.1	18.5	0.79
21	70	36.2	28.7	18.5	0.79
22	74	36.3	28.6	19.0	0.80
23	81	37.8	29.0	15.5	0.77
24	751	36.7	28.2	19.5	0.77
Mean		35.45	27.95	20.0	0.791
Standard deviation		1.38	0.87	2.2	0.026
Minimum limits, AI Specification ST0170NB0042		32.0	19.0	10	

TABLE A-3
 SUPPLIER RESULTS FOR 900°F LONGITUDINAL
 DIRECTION MECHANICAL PROPERTIES OF
 2-in. DIAMETER XAP 005 ALLOY BILLET

Test Number	Compact Number	UTS (ksi)	TYS (ksi)	Elongation Percent in 4D	TYS/UTS Ratio
1	5	9.0	8.2	4.0	0.91
2	28	9.6	8.9	6.5	0.93
3	29	8.9	8.2	7.5	0.92
4	31	8.8	8.4	9.5	0.96
5	33	9.1	8.5	9.5	0.94
6	36	9.3	8.9	6.0	0.96
7	43	9.5	8.8	8.5	0.93
8	47	9.3	8.8	5.0	0.95
9	48	9.3	8.7	7.0	0.94
10	51	9.1	8.5	5.0	0.93
11	54	9.2	8.5	6.0	0.94
12	59	10.0	9.3	4.0	0.93
13	60	9.7	9.1	3.5	0.94
14	64	9.8	9.2	6.0	0.94
Mean		9.33	8.71	6.3	0.937
Standard deviation		0.35	0.35	1.9	0.014
Minimum limits, AI Specification NB0170NB0042		6.0	5.0	2	

TABLE A-4
QUALITY CONTROL ACCEPTANCE TESTING ANALYTICAL CHEMISTRY RESULTS
FOR XAP 005 2-in. DIAMETER BILLET

Element or Compound	Compact-Billet Sample Results (wt %)								Acceptance Limits**
	70-A	81-A	41-3B	52-2B	59-1B	77-7	64-B	74-4A	
Al ₂ O ₃ *	6.39	6.58	5.69	5.35	6.24	6.36	6.09	6.34	5.0 to 8.0
Boron	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	0.0003
Cadmium	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	0.003
Calcium	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.010
Carbon	0.46	0.71	0.48	0.47	0.76	0.37	0.64	0.41	0.80
Copper	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.010
Gallium	0.005	0.005	0.005	0.008	0.008	0.005	0.008	0.005	0.030
Hydrogen	0.0012	0.0018	0.0012	0.0010	0.0018	0.0016	0.0014	0.0014	0.002
Iron	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	0.20
Lead	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.004
Molybdenum	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.005
Nitrogen	0.010	0.020	0.020	0.020	0.030	0.080	0.010	0.010	0.080
Silicon	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10
Sodium	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.010
Tin	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.030
Zinc	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.050
Zirconium	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.010

*Mean = 6.130 wt %

Standard deviation = 0.411 wt %

**A I Specification ST0170NB0042

TABLE A-5
 QUALITY CONTROL ACCEPTANCE TEST RESULTS
 FOR LONGITUDINAL DIMENSION MECHANICAL
 PROPERTIES OF XAP 005 ALLOY
 2-in. DIAMETER BILLET

Test Number	Compact-Billet Number	UTS (ksi)	TYS (ksi)	Elongation Percent in 4D	TYS/UTS Ratio
Room Temperature Tests					
1	77-7	35.6	28.0	20.0	0.79
2	55-1A	34.6	27.5	22.0	0.79
3	64-B	35.7	28.7	21.0	0.83
Mean		35.30	28.07	21.0	0.803
Standard deviation		0.61	0.60	1.0	0.023
Minimum limits, AI Specification ST0170NB0042		32.0	19.0	1.0	
900°F Tests					
1	77-7	9.1	8.3	3.0	0.90
2	55-1A	8.7	7.9	3.0	0.91
3	64-B	9.1	7.9	2.5	0.86
Mean		8.97	8.03	2.8	0.890
Standard deviation		0.23	0.23	0.3	0.026
Minimum limits, AI Specification ST0170NB0042		6.0	5.0	2	

TABLE A-6
ENGINEERING EVALUATION Al_2O_3 CONTENT ANALYSIS RESULTS FOR
2-in. DIAMETER XAP 005 ALLOY BILLET

Compact-Billet Number	Billet Location in Extrusion	Al_2O_3 Content (wt %)	One Standard Deviation Analysis Precision	
			% Absolute	No. of Replicates
43A	Rear	5.95	0.04	3
43-2C	Middle	5.76	0.29	3
43-2B	Middle	5.52	0.15	3
43-3A	Middle	5.71	0.08	4
43-5	Front	5.86	0.09	3
47B	Rear	5.57	0.19	3
47-1A	Rear	5.43	0.12	4
47-3B	Middle	5.61	0.06	3
47-4B	Front	5.63	0.06	3
47-5	Front	5.72	0.14	3
54-A	Rear	5.76	0.08	3
54-1A	Rear	5.85	0.18	3
54-3B	Middle	5.81	0.24	4
54-4	Front	5.62	0.15	3
54-5	Front	5.66	0.15	3
59-B	Rear	6.01	0.10	3
59-1B	Rear	6.37	0.07	3
59-3B	Middle	6.15	0.20	3
59-4	Front	6.15	0.13	3
59-5	Front	6.41	0.10	3
64B	Rear	6.17	0.16	3
64-1B	Rear	6.11	0.00	3
64-2A	Middle	6.34	0.16	3
64-2B	Middle	6.32	0.16	3
64-3A	Middle	6.16	0.13	3
65B	Rear	6.33	0.10	3
65-1A	Rear	6.42	0.16	3
65-2A	Middle	6.20	0.09	3
65-4	Front	6.45	1.57	3
65-5	Front	6.30	0.06	3
Front of Billet	Mean	5.84		
	Standard Deviation	0.21		
Rear of Billet	Mean	5.96		
	Standard Deviation	0.27		
Total of Billets	Mean	5.978		
	Standard Deviation	0.315		

TABLE A-7

ENGINEERING EVALUATION TEST RESULTS FOR TRANSVERSE DIRECTION
MECHANICAL PROPERTIES OF XAP 005 ALLOY 2-in.
DIAMETER BILLET

Test Number	Billet Number	Location in Billet Length	UTS (ksi)	TYS (ksi)	Elongation (%) in 4D	TYS/UTS Ratio
1	43-3A	Middle	31.4	20.0	14	0.64
2	43-2B	Middle	31.4	20.0	13	0.64
3	43-2C	Middle	31.8	20.7	13	0.65
4	47-1A	Rear	30.7	20.4	8	0.64
5	47-3B	Middle	30.7	20.8	6	0.68
6	47-4B	Front	31.3	20.4	12	0.65
7	54-4	Front	30.8	20.5	9	0.66
8	54-1A	Rear	31.4	20.8	10	0.66
9	54-3B	Middle	31.7	20.6	12	0.65
10	59-4	Front	32.2	22.2	5	0.69
11	59-1B	Rear	32.9	20.9	7	0.64
12	59-3B	Middle	32.4	21.7	7	0.68
13	64-2A	Middle	33.3	19.7	9	0.59
14	64-1B	Rear	31.4	20.3	10	0.61
15	64-2B	Middle	32.6	21.5	10	0.66
16	65-4	Front	33.8	20.9	8	0.62
17	65-1A	Rear	31.7	21.3	8	0.67
18	65-2A	Middle	33.0	20.8	9	0.63
Mean			31.92	20.75	9.4	0.648
Standard Deviation			0.91	0.63	2.6	0.025
900°F Tests						
1	43-A	Front	7.4	6.2	2.5	0.84
2	43-5	Front	7.7	6.0	2.5	0.78
3	54-A	Rear	7.6	6.1	3	0.80
Mean			7.57	6.1	2.7	0.807
Standard Deviation			0.15	0.1	0.3	0.030

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APPENDIX II
ANALYTICAL CHEMISTRY AND MECHANICAL PROPERTY TEST
RESULTS FOR 5-in. Diameter SAP 930 ALLOY BILLET

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TABLE A-8
SUPPLIER ANALYTICAL CHEMISTRY RESULTS
FOR 2-in. DIAMETER SAP 930 BILLET

Element or Compound	Billet Sample Results (wt %)				Acceptance Limits**
	603	608	629	640	
Al ₂ O ₃ *	6.45	6.50	6.45	6.45	5.0 to 8.0
Carbon	0.10	0.10	0.11	0.11	0.80
Copper	0.001	0.001	0.001	0.001	0.010
Iron	0.06	0.06	0.06	0.06	0.20
Nitrogen	0.020	0.049	0.038	0.033	0.080
Silicon	0.04	0.04	0.04	0.04	0.10
Titanium	0.001	0.002	0.002	0.002	0
Zinc	0.012	0.012	0.009	0.011	0.050

*Mean = 6.462 wt %

Standard deviation = 0.025 wt %

**AI Specification ST0170NB0041. Values are maximum
unless otherwise indicated.

TABLE A-9
SUPPLIER LONGITUDINAL DIRECTION MECHANICAL
PROPERTIES FOR 2-in. DIAMETER SAP 930 BILLET

Room Temperature Tests					
Test Number *	Billet Number	UTS (ksi)	TYS (ksi)	Elongation Percent in 4D	TYS/UTS Ratio
1	603	33.1	21.9	20.0	0.66
2	608	33.3	21.2	18.4	0.64
3	629	33.0	21.8	18.8	0.66
4	640	32.3	21.2	21.2	0.66
Mean		32.92	21.52	19.6	0.665
Standard deviation		0.43	0.38	1.3	0.010
Minimum limits **		32.0	19.0	10	
900°F Tests					
1	603	8.8	8.2	3.2	0.93
2	608	8.4	8.0	2.8	0.95
3	679	8.4	8.0	3.6	0.95
4	640	8.1	7.5	4.0	0.93
Mean		8.42	7.93	3.4	0.940
Standard deviation		0.29	0.30	0.5	0.012
Minimum limits **		6.0	5.0	2	

*All tests from rear of extrusion charge.

**AI Specification ST0170NB0041

TABLE A-10

ENGINEERING EVALUATION Al_2O_3 CONTENT RESULTS
FOR 2-in. DIAMETER SAP 930 BILLET

Billet Number	Location of Sample in Billet	Al_2O_3 Content (wt %)	One Standard Deviation Analysis Precision	
			Percent Absolute	Number of Replicates
605	Front	6.43	0.14	3
	Rear	6.36	0.13	3
610	Front	6.28	0.04	3
	Rear	6.25	0.09	3
615	Front	6.24	0.02	3
	Rear	6.27	0.17	3
625	Front	6.33	0.09	3
	Rear	6.24	0.08	4
627	Front	6.28	0.09	3
	Rear	6.22	0.02	3
637	Front	6.40	0.10	4
	Rear	6.42	0.14	5
Front	Mean	6.327		
	Standard deviation	0.075		
Rear	Mean	6.293		
	Standard deviation	0.079		
Combined front and rear	Mean	6.310		
	Standard deviation	0.075		

TABLE A-11
ENGINEERING EVALUATION IMPURITIES ANALYSIS
FOR SAP 930 2-in. DIAMETER BILLET

Element	Location	Billet Sample Impurities Content (wt %)					
		605	610	615	625	627	637
Boron	Front	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
	Rear	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Calcium	Front	0.005	0.005	0.005	0.005	0.005	0.005
	Rear	0.005	0.005	0.005	0.005	0.005	0.005
Cadmium	Front	0.003	0.003	0.003	0.003	0.003	0.003
	Rear	0.003	0.003	0.003	0.003	0.003	0.003
Carbon	Front	0.23	0.26	0.18	0.20	0.24	0.28
	Rear	0.18	0.26	0.26	0.26	0.23	0.28
Copper	Front	0.003	0.002	0.003	0.003	0.002	0.002
	Rear	0.002	0.002	0.005	0.002	0.002	0.002
Gallium	Front	0.015	0.005	0.008	0.008	0.015	0.008
	Rear	0.020	0.015	0.010	0.008	0.008	0.020
Hydrogen	Front	0.0004	0.0004	0.0004	0.0008	0.0004	0.0005
	Rear	0.0004	0.0005	0.0007	0.0005	0.0005	0.0006
Iron	Front	0.10	0.10	0.10	0.10	0.10	0.10
	Rear	0.10	0.10	0.10	0.10	0.10	0.10
Lead	Front	0.004	0.004	0.004	0.004	0.004	0.004
	Rear	0.004	0.004	0.004	0.004	0.004	0.004
Molybdenum	Front	0.005	0.005	0.005	0.005	0.005	0.005
	Rear	0.005	0.005	0.005	0.005	0.005	0.005
Nitrogen	Front	0.039	0.021	0.028	0.044	0.032	0.015
	Rear	0.046	0.028	0.033	0.090	0.034	0.023
Silicon	Front	0.07	0.07	0.07	0.07	0.07	0.07
	Rear	0.07	0.07	0.07	0.07	0.07	0.07
Sodium	Front	0.010	0.010	0.010	0.010	0.010	0.010
	Rear	0.010	0.010	0.010	0.010	0.010	0.010
Tin	Front	0.005	0.005	0.005	0.005	0.005	0.005
	Rear	0.005	0.005	0.005	0.005	0.005	0.005
Zinc	Front	0.020	0.020	0.020	0.020	0.020	0.020
	Rear	0.020	0.020	0.020	0.020	0.020	0.020
Zirconium	Front	0.007	0.007	0.007	0.007	0.007	0.007
	Rear	0.007	0.007	0.007	0.007	0.007	0.007

TABLE A-12
ENGINEERING EVALUATION LONGITUDINAL DIRECTION
MECHANICAL PROPERTIES OF 2-in. DIAMETER
SAP 930 BILLET

Test Number	Billet Number	Location in Billet	UTS (ksi)	TYS (ksi)	Elongation (%) in 4D	TYS/UTS Ratio
Room Temperature Tests						
1	605	Front	33.9	21.3	19	0.63
2		Rear	33.6	21.7	14	0.65
3	610	Front	33.9	21.8	17	0.64
4		Rear	33.3	19.9	17	0.60
5	615	Front	33.9	20.9	17	0.62
6		Rear	33.3	19.3	17	0.58
7	625	Front	34.4	21.7	16	0.63
8		Rear	33.4	20.2	17	0.61
9	627	Front	33.7	21.6	17	0.64
10		Rear	33.2	19.4	17	0.58
11	637	Front	33.9	20.8	20	0.61
12		Rear	33.3	18.8	18	0.57
Front Mean			33.95	21.35	17.7	0.628
Standard Deviation			0.23	0.42	1.5	0.012
Rear Mean			33.35	19.88	16.7	0.598
Standard Deviation			0.14	1.01	1.4	0.029
Front and Rear Mean			33.65	20.62	17.2	0.613
Standard Deviation			0.36	1.07	1.5	0.026
900°F Tests						
1	605	Front	8.9	8.2	10	0.92
2		Rear	8.5	7.6	9	0.89
3	610	Front	8.6	7.7	9	0.90
4	615	Front	8.9	7.7	9	0.87
5		Rear	8.8	7.7	9	0.88
6	625	Front	9.0	8.2	9	0.91
7		Rear	8.9	8.0	9	0.90
8	627	Front	8.7	8.0	9	0.92
9		Rear	8.3	7.5	7	0.91
10	637	Front	8.8	7.8	9	0.89
11		Rear	8.7	7.7	8	0.89
Front Mean			8.82	7.93	9.2	0.902
Standard Deviation			0.15	0.23	0.4	0.019
Rear Mean			8.64	7.70	8.2	0.894
Standard Deviation			0.24	0.19	0.8	0.011
Front Mean			8.74	7.83	8.7	0.898
Mean			0.21	0.24	0.8	0.016

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APPENDIX III
ANALYTICAL CHEMISTRY AND MECHANICAL PROPERTY TEST
RESULTS FOR 2-in. Diameter SAP 895 ALLOY BILLET

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TABLE A-13
 SUPPLIER ANALYTICAL CHEMISTRY RESULTS FOR
 2-in. DIAMETER SAP 895 ALLOY BILLET

Element or Compound	Billet Sample Composition (wt %)		Acceptance Limits*
	547 (Front)	562 (Front)	
Al ₂ O ₃	10.85	10.75	9.0 to 12.0
Carbon	0.18	0.19	0.80 max
Copper	N. D.	N. D.	0.010 max
Iron	0.06	0.05	0.20 max
Nitrogen	0.037	0.023	0.080 max
Silicon	0.04	0.04	0.10 max
Titanium	N. D.	N. D.	-
Zinc	0.004	0.007	0.050 max

N. D. = not detected

*AI Specification ST0170NB0041

TABLE A-14

SUPPLIER LONGITUDINAL DIRECTION MECHANICAL PROPERTY
TEST RESULTS FOR 2-in. DIAMETER SAP 895 ALLOY BILLET
(Front of Billet)

Test No.	Billet No.	UTS (ksi)	TYS (ksi)	Elongation (%)	TYS/UTS Ratio
Room Temperature Tests					
1	547	41.2	32.1	11.2	0.78
2	562	40.1	28.0	12.0	0.68
Mean		40.6	30.0	11.6	0.73
900°F Tests					
1	547	12.0	11.8	2.4	0.98
2	562	10.4	10.1	3.8	0.78
Mean		11.2	11.0	3.1	0.88

Minimum Acceptance Limits (AI Specification ST0170NB0041)

	Room Temperature	900°F
UTS (ksi)	40.0	10.0
TYS (ksi)	25.0	7.0
Elongation (%) in 4D	10.0	2.0

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TABLE A-15

QUALITY CONTROL ACCEPTANCE TESTING
ANALYTICAL CHEMISTRY RESULTS FOR
2-in. DIAMETER SAP 895 ALLOY BILLET

Element or Compound	Billet Sample Composition (wt %)		Acceptance Limits** (wt %)
	Billet No. 547	Billet No. 562	
Al ₂ O ₃	11.03	10.55	9.0 to 12.0
Boron	<0.0003	<0.0003	0.0003
Cadmium	<0.001	<0.001	0.003
Calcium	<0.010	<0.010	0.010
Carbon	0.27	0.22	0.800
Copper	0.002	0.002	0.002
Gallium	<0.004	<0.004	0.030
Hydrogen	0.0017	0.001	0.002
Iron	<0.20	<0.20	0.20
Lead	<0.004	<0.004	0.004
Molybdenum	<0.001	<0.001	0.005
Nitrogen	0.090	0.038	0.080
Silicon	<0.10	<0.10	0.10
Sodium	<0.010	<0.010	0.010
Tin	<0.005	<0.005	0.030
Zinc	<0.013	<0.013	0.050
Zirconium	<0.005	<0.005	0.010

*AI Specification ST0170NB0041. Values are maximums unless otherwise noted.

TABLE A-16
 QUALITY CONTROL ACCEPTANCE TEST RESULTS FOR
 LONGITUDINAL MECHANICAL PROPERTIES OF
 2-in. DIAMETER SAP 895 ALLOY BILLET

Test No.	Billet No.	UTS (ksi)	TYS (ksi)	Elongation (%) in 4D	TYS/UTS Ratio
Room Temperature Tests					
1	547	42.2	26.4	16.5	0.62
2	562	40.0	25.2	18.0	0.63
Mean		41.1	25.8	17.2	0.62
900°F Tests					
1	547	11.2	9.2	3.0	0.82
2	562	10.6	9.6	3.0	0.91
Mean		10.8	9.4	3.0	0.86

Minimum Acceptance Limits (AI Specification ST0170NB0041)

	Room Temperature	900°F
UTS (ksi)	40.0	10.0
TYS(ksi)	25.0	7.0
Elongation (%) in 4D	10.0	2.0

TABLE A-17

ENGINEERING EVALUATION Al_2O_3 CONTENT ANALYSIS RESULTS FOR
2-in. DIAMETER SAP 895 ALLOY BILLET

Billet No.	Billet Location in Extrusion	Al_2O_3 Content (wt %)	One Standard Deviation Analysis Precision	
			Absolute (%)	No. of Replicates
539	Rear	10.93	0.06	3
539	Front	10.69	0.18	3
540	Rear	11.03	0.14	3
540	Front	10.68	0.23	4
544	Rear	10.88	0.10	3
544	Front	10.54	0.14	3
533	Rear	10.45	0.17	4
533	Front	10.28	0.18	5
557	Rear	10.30	0.14	3
557	Front	10.43	0.24	7
561	Rear	10.40	0.32	3
561	Front	10.27	0.22	5
Rear	Mean	10.665	-	-
	Standard Deviation	0.316		
Front	Mean	10.482		
	Standard Deviation	0.187		
Combined Front and Rear	Mean	10.573		
	Standard Deviation	0.265		

TABLE A-18
ENGINEERING EVALUATION IMPURITIES ANALYSIS RESULTS
FOR 2-in. DIAMETER SAP 895 ALLOY BILLET

Element	Billet Sample Results (wt %)					
	539	540	544	553	557	561
Boron	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003
Cadmium	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Calcium	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Carbon	0.29	0.35	0.30	0.28	0.29	0.30
Copper	0.002	0.005	0.005	<0.002	<0.002	<0.002
Gallium	0.005	0.005	0.005	0.005	0.005	0.005
Hydrogen	0.0006	0.0004	0.0005	0.0007	0.0009	0.0006
Iron	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Lead	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Molybdenum	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Nitrogen	0.014	0.377	0.020	0.041	0.026	0.024
Silicon	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
Sodium	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Tin	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Zinc	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Zirconium	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007

TABLE A-19
ENGINEERING EVALUATION LONGITUDINAL MECHANICAL PROPERTY
RESULTS FOR 2-in. DIAMETER SAP 895 ALLOY BILLET

Test No.	Billet No.	Location in Billet	UTS (ksi)	TYS (ksi)	Elongation (%) in 4D	TYS/UTS Ratio
Room Temperature Tests						
1	539	Rear	41.9	28.3	14	0.66
2	539	Front	43.8	29.4	12	0.67
3	540	Rear	42.7	30.8	13	0.72
4	540	Front	44.6	28.3	13	0.63
5	544	Rear	43.0	29.8	13	0.67
6	544	Front	43.7	29.7	13	0.68
7	553	Rear	41.0	27.6	13	0.67
8	557	Rear	40.7	27.3	14	0.67
9	557	Front	42.3	28.4	14	0.69
10	561	Rear	41.9	27.9	14	0.68
11	561	Front	42.2	27.6	14	0.66
Rear	Mean		41.87	28.62	13.5	0.678
	Standard Deviation		0.90	1.38	0.5	0.021
Front	Mean		43.32	28.68	13.2	0.666
	Standard Deviation		1.04	0.86	0.8	0.023
Combined Front and Rear	Mean		42.53	28.64	13.4	0.673
	Standard Deviation		1.19	1.12	0.7	0.022
900°F Tests						
1	539	Rear	12.8	12.3	4	0.96
2	539	Front	12.7	12.0	5	0.94
3	540	Rear	12.8	11.8	5	0.97
4	540	Front	12.9	11.7	5	0.91
5	544	Rear	12.9	11.9	4	0.92
6	544	Front	12.5	11.3	6	0.96
7	553	Rear	11.9	10.8	6	0.91
8	553	Front	12.9	11.6	6	0.90
9	557	Rear	11.7	10.9	6	0.93
10	557	Front	12.0	10.7	5	0.89
11	561	Rear	12.1	10.5	8	0.89
Rear	Mean		12.37	11.37	6.0	0.930
	Standard Deviation		0.53	0.72	1.4	0.030
Front	Mean		12.60	11.46	5.4	0.920
	Standard Deviation		0.37	0.49	0.5	0.029
Combined Front and Rear	Mean		12.47	11.41	5.7	0.925
	Standard Deviation		0.46	0.60	1.1	0.029

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APPENDIX IV
ANALYTICAL CHEMISTRY AND MECHANICAL PROPERTY TEST
RESULTS FOR 7-in. Diameter XAP 005 ALLOY BILLET

TABLE A-20
SUPPLIER ANALYTICAL CHEMISTRY RESULTS REPRESENTING
7-in. DIAMETER XAP 005 ALLOY BILLET

Element or Compound	Billet Sample Composition Results (wt %)							Acceptance Limits*
	79	102	116	120	131	137	148	
Al ₂ O ₃ **	6.35	6.43	5.99	6.14	6.25	6.26	6.09	5.0 to 8.0
Bismuth	<0.0007	<0.0007	<0.0007	<0.0007	<0.0007	<0.0007	<0.0007	-
Boron	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.0003
Beryllium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
Cadmium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
Calcium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010
Carbon	0.73	0.65	0.38	0.43	0.40	0.62	0.62	0.80
Chromium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
Copper	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010
Gallium	0.010	0.010	0.010	0.011	0.010	0.011	0.010	0.030
Hydrogen	0.0003	0.0006	0.0004	0.0005	0.0005	0.0007	0.0006	0.002
Iron	0.043	0.045	0.043	0.041	0.042	0.041	0.042	0.20
Lead	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.004
Magnesium	0.001	0.001	0.001	0.001	0.001	0.001	0.001	-
Manganese	0.001	0.001	0.001	0.001	0.001	0.001	0.001	-
Molybdenum	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.005
Nickel	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
Nitrogen	0.04	0.04	0.01	0.01	0.01	0.02	0.03	0.08
Silicon	0.043	0.045	0.043	0.041	0.042	0.041	0.042	0.10
Sodium	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.010
Tin	<0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.030
Titanium	0.002	0.002	0.002	0.002	0.002	0.002	0.002	-
Vanadium	0.001	0.001	0.001	0.001	0.001	0.001	0.001	-
Zinc	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.050
Zirconium	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.010

*Al Specification ST0170NB0042. Maximum unless otherwise noted.

**Mean = 6.216 wt %

Standard deviation = 0.153 wt %

TABLE A-21
 SUPPLIER RESULTS FOR LONGITUDINAL AND TRANSVERSE
 DIRECTION MECHANICAL PROPERTIES OF 7-in.
 DIAMETER XAP 005 ALLOY BILLET

	Test Number	Billet Number	UTS (ksi)	TYS (ksi)	Elongation Percent in 4D	TYS/UTS Ratio
Longitudinal Direction						
Room Temperature Tests	1	102	36.2	25.7	17.5	0.71
	2	116	35.9	25.8	18.5	0.72
	3	120	35.4	24.7	17.5	0.70
	4	131	35.2	24.8	21.5	0.70
	5	137	35.8	25.0	12.0	0.70
	6	148	35.0	24.5	18.0	0.70
	7	1039	37.0	26.3	23.0	0.71
	Mean		35.79	25.26	18.3	0.706
	Standard deviation		0.68	0.68	3.5	0.008
900°F Tests	1	102	8.9	8.5	3.0	0.96
	2	116	8.7	8.4	5.0	0.96
	3	120	8.7	8.6	4.0	0.99
	4	131	8.6	8.3	5.5	0.97
	5	137	8.8	8.5	4.0	0.97
	6	148	7.8	7.7	2.5	0.99
	7	1039	9.2	8.7	8.0	0.96
	Mean		8.67	8.40	4.6	0.971
	Standard deviation		0.43	0.29	1.8	0.013
Transverse Direction						
Room Temperature Tests	1	102	34.6	24.3	16.5	0.70
	2	116	34.1	24.3	16.0	0.71
	3	120	34.4	23.8	13.0	0.69
	4	131	33.6	23.5	18.5	0.70
	5	137	34.2	23.9	17.0	0.70
	6	148	34.0	23.1	11.5	0.68
	7	1039	34.6	24.6	20.0	0.71
	Mean		34.21	23.93	16.1	0.699
	Standard deviation		0.36	0.52	3.0	0.011

TABLE A-22
 QUALITY CONTROL ANALYTICAL CHEMISTRY RESULTS
 FOR
 7-IN. DIAMETER XAP 005 ALLOY BILLET

Element or Compound	Compact-Billet Sample Results (wt%)					Acceptance Limits *
	27-1	30	34-1	52	85-1	
Al ₂ O ₃ **	6.16	5.54	6.02	5.50	6.44	5.0 to 8.0
Boron	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	0.0003
Cadmium	<0.001	<0.001	<0.0010	<0.0010	<0.0010	0.003
Calcium	<0.010	<0.010	<0.0100	<0.0100	<0.0100	0.010
Carbon	0.56	0.59	0.69	0.58	0.75	0.80
Copper	<0.002	<0.002	<0.002	<0.002	<0.002	0.010
Gallium	<0.020	<0.020	<0.020	<0.020	<0.020	0.030
Hydrogen	0.001	0.0009	0.0011	0.0017	0.0011	0.002
Iron	<0.20	<0.20	<0.20	<0.20	<0.20	0.20
Lead	<0.001	<0.001	<0.001	<0.001	<0.001	0.004
Molybdenum	<0.001	<0.001	<0.001	<0.001	<0.001	0.005
Nitrogen	0.013	0.019	0.019	0.014	0.025	0.080
Silicon	<0.10	<0.10	<0.10	<0.10	<0.10	0.10
Sodium	<0.010	<0.010	<0.010	<0.010	<0.010	0.010
Tin	<0.005	<0.005	<0.005	<0.005	<0.005	0.030
Zinc	<0.010	<0.010	<0.010	<0.010	<0.010	0.050
Zirconium	<0.005	<0.005	<0.005	<0.005	<0.005	0.010

*AI Specification ST017DNB0042. Values are maximums unless otherwise specified.

**Mean = 5.932 wt %

Standard Deviation = 0.406 wt %

TABLE A-23

ENGINEERING EVALUATION Al_2O_3 CONTENT ANALYSIS RESULTS
FOR 7-in. DIAMETER XAP 005 ALLOY BILLET

Compact-Billet Number	Sample Location on Billet Cross Section	Al_2O_3 Content (wt %)	One Standard Deviation Analysis Precision	
			Percent Absolute	Number of Replicates
45-1	Center	5.67	0.19	7
45-1	Outside Surface	5.56	0.12	6
81	Center	6.15	0.12	7
81	Outside Surface	6.29	0.20	6
83	Center	6.00	0.13	5
83	Outside Surface	6.18	0.13	5
86	Center	6.02	0.23	5
86	Outside Surface	6.07	0.21	5
Center	Mean	5.960		
	Standard deviation	0.204		
Outside Surface	Mean	6.025		
	Standard deviation	0.323		
Combined Center and Outside Surface	Mean	5.992		
	Standard deviation	0.250		

TABLE A-24
ENGINEERING EVALUATION IMPURITIES ANALYSIS RESULTS
FOR 7-in. DIAMETER XAP 005 ALLOY BILLET

Element or Compound	Compact-Billet Sample Results (wt %)				Acceptance Limits
	45-1	81	83	86	
Boron	<0.0003	<0.0003	<0.0003	<0.0003	0.0003
Cadmium	<0.003	<0.03	<0.003	<0.003	0.003
Calcium	<0.010	<0.010	<0.010	<0.010	0.010
Carbon	0.68	0.78	0.46	0.65	0.80
Copper	<0.002	<0.002	<0.002	<0.002	0.010
Gallium	<0.010	<0.010	<0.010	<0.010	0.030
Hydrogen	0.0012	0.0023	0.0012	0.0011	0.002
Iron	<0.20	<0.20	<0.20	<0.20	0.20
Lead	<0.004	<0.004	<0.004	<0.004	0.004
Molybdenum	<0.001	<0.001	<0.001	<0.001	0.005
Nitrogen	0.014	0.018	0.003	0.012	0.080
Silicon	<0.10	<0.10	<0.10	<0.10	0.10
Sodium	<0.010	<0.010	<0.010	<0.010	<0.010
Tin	<0.005	<0.005	<0.005	<0.005	<0.030
Zinc	<0.010	<0.010	<0.010	<0.010	<0.050
Zirconium	<0.005	<0.005	<0.005	<0.005	<0.010

TABLE A-25
 QUALITY CONTROL AND ENGINEERING EVALUATION
 TRANSVERSE MECHANICAL PROPERTY RESULTS
 FOR 7-in. DIAMETER XAP 005 ALLOY BILLET

Test Number	Compact-Billet Number	UTS (ksi)	TYS (ksi)	Elongation Percent in 4D	TYS/UTS Ratio
Room Temperature Tests					
1 *	85-1	35.4	21.5	15.0	0.64
2	45-1	33.6	23.6	17.0	0.70
3	81	37.4	26.6	11.0	0.71
4	83	35.4	26.4	14.0	0.74
5	86	37.3	27.2	17.0	0.73
Mean		35.84	25.06	14.8	0.704
Standard deviation		1.57	2.43	2.5	0.039
900°F Tests					
1 *	30	7.3	6.5	3.0	0.89
2 *	85-1	7.4	6.9	2.0	0.94
3	45-1	7.8	7.5	3.0	0.96
4	81	9.1	8.8	4.0	0.97
5	83	9.3	9.1	4.0	0.98
6	86	9.2	8.9	4.0	0.97
Mean		8.35	7.95	3.3	0.952
Standard deviation		0.95	1.13	0.8	0.033

*AI quality control data

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APPENDIX V
ANALYTICAL CHEMISTRY AND MECHANICAL PROPERTY TEST
RESULTS FOR 7-in. Diameter SAP 895 ALLOY BILLET

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TABLE A-26
SUPPLIER ANALYTICAL CHEMISTRY RESULTS FOR
7-in. DIAMETER SAP 895 ALLOY BILLET

Element or Compound	Billet Sample Results (wt %)											Acceptance Limits**
	504	510	568	569	517	573	523	531	579	583	594	
Al ₂ O ₃ *	10.55	10.70	10.80	10.95	10.70	11.00	10.75	10.65	11.00	11.00	10.30	9.0 to 12.0
Carbon	0.13	0.12	0.17	0.17	0.11	0.17	0.13	0.13	0.17	0.18	0.20	0.80 max
Copper	N. D.	N. D.	N. D.	N. D.	N. D.	0.0009	N. D.	N. D.	0.0009	0.0006	0.0006	0.010 max
Iron	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.20 max
Nitrogen	0.025	0.034	0.210	0.028	0.090	0.026	0.012	0.044	0.080	0.023	0.028	0.080 max
Silicon	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.10 max
Titanium	N. D.	N. D.	N. D.	N. D.	N. D.	0.001	N. D.	N. D.	0.001	0.001	0.001	-
Zinc	0.006	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.003	0.050 max

*Mean = 10.764 wt %

Standard deviation = 0.220 wt %

**AI Specification ST0170NB0041

N. D. = Not detected

TABLE A-27
 SUPPLIER RESULTS FOR TRANSVERSE DIRECTION MECHANICAL
 PROPERTIES OF 7-in. DIAMETER SAP 895 ALLOY BILLET

Test No.	Billet No.	Location in Billet	UTS (ksi)	TYS (ksi)	Elongation (%)	TYS/UTS Ratio
Room Temperature Tests						
1	504	Front	41.1	29.6	4.4	0.72
2	510	Front	41.8	30.6	6.4	0.73
3	568	Front	45.8	33.6	6.8	0.73
4	569	Front	43.0	32.0	6.8	0.74
5	517	Front	41.7	31.0	8.0	0.74
6	573	Front	44.8	32.5	7.2	0.73
7	523	Front	39.0	28.2	6.8	0.70
8	531	Front	42.1	30.2	6.8	0.75
9	579	Front	44.3	32.2	7.2	0.84
10	583	Front	43.9	32.5	7.2	0.74
11	594	Rear	39.1	26.2	8.0	0.67
Mean			42.42	30.78	6.9	0.735
Standard Deviation			2.20	2.16	1.0	0.041
900°F Tests						
1	504	Front	8.7	7.6	3.4	0.87
2	510	Front	9.1	8.3	3.2	0.91
3	568	Front	9.8	9.3	2.5	0.94
4	569	Front	9.8	9.4	2.5	0.96
5	517	Front	9.1	8.3	3.2	0.91
6	573	Front	10.2	9.5	4.0	0.81
7	523	Front	9.0	8.1	3.2	0.90
8	531	Front	9.4	8.4	3.2	0.90
9	579	Front	9.8	9.1	3.2	0.93
10	583	Front	10.0	9.5	2.4	0.96
11	594	Rear	9.0	8.4	3.6	0.94
Mean			9.45	8.72	3.3	0.912
Standard Deviation			0.49	0.66	0.5	0.044

TABLE A-28

QUALITY CONTROL ACCEPTANCE TESTING
ANALYTICAL CHEMISTRY RESULTS FOR
7-in. DIAMETER SAP 895 ALLOY BILLET

Element or Compound	Billet Sample Results (wt %)				Acceptance Limits*
	504	523	531	536	
Al ₂ O ₃ **	10.22	10.43	10.41	10.21	9.0 to 12.0
Boron	N.D.	N.D.	N.D.	N.D.	0.0003
Cadmium	<0.001	<0.001	<0.001	<0.001	0.003
Calcium	<0.010	<0.010	<0.010	<0.010	0.010
Carbon	0.64	0.60	0.58	0.64	0.80
Copper	<0.002	<0.002	<0.002	<0.002	0.010
Gallium	0.008	0.008	0.005	0.008	0.030
Hydrogen	0.0018	0.0016	0.0016	0.0017	0.002
Iron	<0.20	<0.20	<0.20	<0.20	0.20
Lead	<0.004	<0.004	<0.004	<0.004	0.004
Molybdenum	<0.001	<0.001	<0.001	<0.001	0.005
Nitrogen	0.028	0.013	0.040	0.023	0.080
Silicon	<0.10	<0.10	<0.10	<0.10	0.10
Sodium	<0.0100	<0.0100	<0.0100	<0.010	0.010
Tin	<0.005	<0.005	<0.005	<0.005	0.030
Zinc	<0.013	<0.013	<0.013	<0.013	0.050
Zirconium	<0.005	<0.005	<0.005	<0.005	0.010

*AI Specification ST0170NB0041. Values are maximums unless otherwise noted.

**Mean = 10.318 wt %

Standard deviation = 0.119 wt %.

N.D. = Not detected.

TABLE A-29

QUALITY CONTROL ACCEPTANCE TEST RESULTS
FOR LONGITUDINAL MECHANICAL PROPERTIES
OF 7-in. DIAMETER SAP 895 ALLOY BILLET

Test Number	Billet Number	UTS (ksi)	TYS (ksi)	Elongation Percent in 4D	TYS/UTS Ratio
Room Temperature Tests					
1	504	42.2	25.6	8.0	0.61
2	523	42.8	24.8	10.0	0.58
3	531	43.9	25.8	8.5	0.59
4	536	43.8	28.1	7.5	0.63
Mean		43.18	26.08	8.5	0.602
Standard deviation		0.82	1.42	1.1	0.022
900°F Tests					
1	523	8.3	7.6	2.0	0.91
2	531	9.3	7.6	5.0	0.84
3	536	8.5	7.6	4.0	0.90
Mean		8.70	7.6	3.7	0.883
Standard deviation		0.53	0.0	1.5	0.038

TABLE A-30

ENGINEERING EVALUATION Al_2O_3 CONTENT ANALYSIS RESULTS FOR
7-in. DIAMETER SAP 895 ALLOY BILLET

Billet No.	Sample Location on Billet Cross Section	Al_2O_3 Content (wt %)	One Standard Deviation Analysis Precision	
			Absolute (%)	No. of Replicates
501	Outside Surface	10.27	0.35	5
501	Center	10.20	0.17	5
510	Outside Surface	10.31	0.12	5
510	Center	10.30	0.11	5
512	Outside Surface	10.28	0.31	5
512	Center	10.16	0.26	5
518	Outside Surface	10.24	0.32	5
518	Center	10.25	0.09	5
520	Outside Surface	10.66	0.05	6
520	Center	10.56	0.27	5
522	Outside Surface	10.58	0.20	5
522	Center	10.55	0.20	5
528	Outside Surface	10.34	0.13	5
528	Center	10.30	0.14	5
530	Outside Surface	10.56	0.14	5
530	Center	10.40	0.20	7
533	Outside Surface	10.72	0.11	5
533	Center	10.59	0.20	9
535	Outside Surface	10.54	0.16	5
535	Center	10.59	0.16	5
Outside Surface		Mean	10.450	
		Standard Deviation	0.180	
Center		Mean	10.390	
		Standard Deviation	0.170	
Total		Mean	10.420	
		Standard Deviation	0.173	

TABLE A-31
ENGINEERING EVALUATION IMPURITIES ANALYSIS RESULTS
FOR 7-IN. DIAMETER SAP 895 ALLOY BILLET

Element	Billet Sample Results (wt %)										Acceptance Limits*
	501	510	512	518	520	522	528	530	533	535	
Boron	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	0.0003
Cadmium	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.003
Calcium	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.010
Carbon	0.30	0.25	0.26	0.25	0.24	0.31	0.25	-	0.27	-	0.80
Copper	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.010
Gallium	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.030
Hydrogen	0.0007	0.0004	0.0003	0.0003	0.0004	0.0004	0.0004	0.0004	0.0003	0.0006	0.002
Iron	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	0.20
Lead	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.004
Molybdenum	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.005
Nitrogen	0.032	0.036	0.027	0.019	0.006	0.010	0.026	0.025	0.028	0.027	0.080
Silicon	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10
Sodium	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.010
Tin	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.030
Zinc	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.050
Zirconium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.010

*AI Specification ST0170NB0041. All values are maximum.

TABLE A-32
ENGINEERING EVALUATION TEST RESULTS FOR
LONGITUDINAL MECHANICAL PROPERTIES OF
7-in. DIAMETER SAP 895 ALLOY BILLET

Test Number	Billet Number	UTS (ksi)	TYS (ksi)	Elongation Percent in 4D	TYS/UTS Ratio
Room Temperature Tests					
1	501	42.9	26.7	8.0	0.62
2	510	43.4	26.9	8.0	0.62
3	512	41.0	27.7	7.0	0.67
4	518	41.3	26.3	7.0	0.64
5	520	43.9	28.7	8.0	0.66
6	522	44.1	28.2	8.0	0.64
7	528	44.2	28.7	8.0	0.65
8	530	44.3	28.7	8.0	0.68
9	533	45.8	28.7	8.0	0.63
10	535	44.7	29.3	7.0	0.66
Mean		43.56	27.99	7.7	0.647
Standard deviation		1.48	1.03	0.5	0.021
900°F Tests					
1	501	8.7	7.3	3.5	0.84
2	510	10.8	8.3	3.5	0.77
3	512	9.2	7.8	3.5	0.95
4	518	8.7	7.6	4.0	0.88
5	520	9.6	8.7	3.0	0.91
6	522	10.0	9.0	3.0	0.90
7	528	10.3	8.9	4.0	0.88
8	530	10.4	9.2	4.0	0.88
9	533	10.2	8.5	4.0	0.83
10	535	10.5	9.5	4.0	0.90
Mean		9.84	8.48	3.6	0.874
Standard deviation		0.75	0.72	0.4	0.050