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HIGH STRENGTH STAINLESS STEEL PROPERTIES THAT AFFECT RESISTANCE WELDING

ABSTRACT

Selected properties that effect resistance welding were determined for several high strength stainless steel alloys. The austenitic alloys A-286, JBK-75 (Modified A-286), 21-6-9, 22-13-5, 316 and 304L were investigated and compared. The former two are age hardenable and the latter four obtain their strength through work hardening. Properties investigated include corrosion and its relationship to chemical cleaning, the effects of heat treatment on strength and surface condition and the effect of mechanical properties on strength and weldability.

Huey corrosions rates for various materials and heat treatments were measured and shown to correspond to surface appearance results for an inhibited nitric acid cleaning solution. Heat treatment procedures for A-286 and JBK-75 that will not oxidize the alloys are discussed. Material hardness is related to the burst strength of tubes (1/8" OD x 1/16" ID) as well as to tensile properties and heat treatment history.

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CONTENTS

I. INTRODUCTION

Properties of the new high strength stainless steels require characterization as they pertain to resistance welding requirements.

A. PROPERTY REQUIREMENTS

Material properties that are important for resistance welding include surface cleanliness and mechanical strength.

To define surface cleaning conditions, corrosion tests were performed using the standard Huey test and using cleaning solutions. Surface cleanliness also became an important consideration during heat treatment of materials. Resistance welding strength requirements necessitate materials in specific metallurgical conditions obtained by either annealing or aging of the alloys. Oxidation must be minimized or in some cases eliminated to meet resistance welding requirements.

Mechanical strength is best characterized for small tubes by hardness measurements since this is a nondestructive technique. Since tensile strength is the more common reference for mechanical strength, tensile properties of the alloys were related to hardness. A common strength measurement for tubes is hydrostatic burst strength and this was also related to hardness. Heat treatments necessary to obtain the hardnesses required for resistance welding were determined.

B. STAINLESS STEEL MATERIAL DESCRIPTION

Selected properties of the alloys 21-6-9, 22-13-5, A-286 and JBK-75 were measured and compared with properties of 316 and 304L.

All six alloys are austenitic stainless steels with good corrosion resistance and high strength. Types 21-6-9 and 22-13-5 are nitrogen strengthed (1) with the numbers signifying the percent composition of chromium, nickel and manganese respectively. Type 21-6-9 is used for hydraulic tubing in jet aircraft because of its good corrosion and heat resistance combined with good weldability and formability for a high strength to weight alloy (2). Type 22-13-5 has a combination of corrosion resistance and strength not found in other competitive materials (3). These alloys are also designated Nitronic 40 and Nitronic 50 for 21-6-9 and 22-13-5 respectively. Both are stronger than 316 or 304L and obtain their strength through work hardening.

The alloys A-286 and JBK-75 are precipitation hardening and obtain their strength through a combination of work hardening and heat treating. A-286 is used in jet engine parts. The strengthening precipitate in both alloys is the eta phase familiar in nickel-base superalloys which is the intermetallic compound Ni_3 (Ti, Al). The alloy JBK-75 is a modification to increase its weldability (4, 5) and performance in hydrogen service (6). JBK-75 is reduced in carbon, manganese, silicon and boron with an increase of 5% in nickel content. Cracking of Gas Tungsten Arc (GTA) welds is reduced by these modifications and the RA (Reduction of Area, a measure of ductility) loss in hydrogen was reduced from about 50% to about 10%.

Typical compositions of the six alloys are shown in Table I. Typical mechanical properties are given in Table II.

C. RESISTANCE WELDING

The investigation of these alloys was undertaken to meet the needs of resistance welds to close tubes made from these materials. Tubes are typically 1/8 inch OD by 1/16 inch ID. Typical welding parameters are 4,000 amps and 1,000 pounds force applied for 0.1 to 0.5 seconds. A typical tube closure weld is shown in Figure 1. Quality of resistance welds is affected by material properties as well as by welding parameters. These include tube cleanliness and strength. Unclean tubes will not weld adequately and hard tubes may crack.

II. RESULTS AND DISCUSSION

A. HEAT TREATMENT OF JBK-75 AND A-286

1. Aging Requirements

Properties of age hardenable alloys such as JBK-75 and A-286 are determined to a large extent by the heat treatment they receive. Aging and annealing conditions are well known for A-286 (7). Optimum conditions for JBK-75 are being developed elsewhere (8).

Hardness of the material has been used as one measure of the suitability of these materials for resistance welding. Table III presents several aging treatments and the corresponding hardnesses. The treatments, other than the standard fully hard conditions, were developed to obtain a hardness for which the material retains a high strength yet is sufficiently soft to be resistance welded in the form of a tube. Figure 2 shows the internal tearing and the external cracking which can develop when welding tubes harder than R_c30.

A good balance between strength and weldability for 1/8 inch OD by 1/16 inch ID tubing occurs at R_c25-30.

2. <u>Short Time Heat Treatments</u>

In order to obtain the desired hardness of R_c25-30 on tubes, heat treatments at very short times were made. Starting material is generally in a worked (forged) condition which, when aged, results in a hardness of R_c35. Two approaches were taken to obtain final hardnesses of R_c25-30:

(a) Partially anneal the aged material

(b) Anneal the worked material and then fully age the resulting soft material.

Conditions for the short time heat treatments and the resulting hardnesses are given in Table IV. Times of seven minutes were found adequate to equilibrate the small samples in the furnace and achieve the desired hardness changes. Partial annealing of aged material at 1400-1450°F or annealing at 1800°F followed by the normal aging yielded the desired hardness. As a followup to this work, conditions were duplicated using induction heating.

3. <u>Oxidiation During Heat Treatment</u>

(a) <u>General Requirements</u>

Parts must be heat treated following fabrication by TIG welding. Prior to heat treatment, parts are chemically cleaned and any oxidation during heat treatment prevents satisfactory bonding during resistance welding.

Experience has shown that prevention of oxidation of JBK-75 and A-286 during heat treatment requires proper equipment and controls. The titanium in both alloys is a strong getter for oxygen and very low oxygen concentration must be maintained to prevent titanium oxide from forming. Heating in either vacuum or hydrogen atmospheres was done in an attempt to prevent oxidation.

(b) <u>Heat Treatment in Hydrogen</u>

In a hydrogen atmosphere, under conditions that will bright anneal 304L (reduce any oxides and leave the surface bright and shiny), both A-286 and JBK-75 will oxidize. A photograph in Figure 3 shows the difference between two pieces heated together in an induction unit using a hydrogen atmosphere. In spite of attempts to insure gas purity, samples always oxidized. A vendor whose literature (10) indicates success with Hydrogen brazing of A-286 was contacted. His attempts to heat treat in hydrogen also resulted in an oxidized surface (11).

It was noted that previously oxidized surfaces that were then cleaned by sand blasting oxidized less in hydrogen than freshly machined surfaces. This would indicate a zone on the surface that becomes depleted in titanium during oxidation. Analytical techniques were used to examine surfaces of JBK-75. Both Electron Probe Micro Analysis (EPMA) and Electron Spectroscopy for Chemical Analysis (ESCA) were used to look for a depleted layer and for other inhomogeneities.

ESCA will determine elements on the surface. Analysis can be made below the surface by removing the surface in small increments by ion bombardment. This was done on the surface of JBK-75 on a piece that had been machined and then oxidized. Results are plotted in Figure 4 for iron and titanium. The results are fairly straightforward in that the titanium concentration is very high in the oxide and then tapers off to the alloy concentration at a depth of 1.0 microns (4×10^{-5} in.). The oxide is therefore titanium oxide with almost no iron oxide present.

EPMA was used to look at a cross section of forged JBK-75 with oxide on the surface. The titanium rich oxide layer is clearly visible in the concentration profile of Figure 5 but again no depleted layer can be identified. A scan into the material identified inclusions which are rich in titanium and low in iron and nickel, Figure 6. These inclusions can be identified metallographically and exist randomly rather than just at grain boundaries. The titanium concentration within the alloy is not very homogeneous.

(c) Heat Treatment in Vacuum

Because of the high affinity of titanium for oxygen, vacuum heat treatment requires good conditions to prevent discoloration of JBK-75 and A-286. Temperatures and times used were those for aging of JBK-75 (1250°F for 16 hours) and annealing of JBK-75 (1750°F for 1 hr.).

High vacuum Centor furnaces (Model 50) were used for initial work. These furnaces have oil diffusion pumped vacuum systems with liquid nitrogen traps. Furnace chambers are of refractory metal with reflective foil for insulation and water cooled shells. These furnaces are used for a variety of heat treating work.

Experience heat treating JBK-75 and A-286 in the Centor furnaces was mixed. At the aging temperature samples would come out clean (no discoloration when compared to fresh samples), if satisfactory precautions were taken. Precautions included having the furnaces clean and baked out from previous use. At the annealing temperature satisfactory cleanliness of samples was never achieved.

A more successful method for keeping samples clean during heat treatment used a titanium getter. This work was done in a stainless steel vacuum tube placed in a Glo-Bar furnace. A portable diffusion pumped vacuum system pulled a vacuum on the tube. Samples were surrounded by titanium turnings and placed in a stainless steel foil bag in the vacuum tube, Figure 7. Satisfactory cleanliness was obtained at both the annealing and aging temperatures.

B. CLEANING AND CORROSION

Cleanliness of material surfaces is of primary importance in order to obtain high quality diffusion bonds from resistance welds. Tube surfaces can be contaminated by oxidation (from heat treatment, TIG welding nearby metal or burnishing during machining), by machining lubricants, by dirt, by processing vapors, etc.

Faying surfaces of parts are cleaned in acid prior to welding to remove contaminants.

1. Huey Corrosion Tests

The effectiveness of chemical cleaning and the appearance of the parts is associated with the corrosion rate of the material. Corrosion rates were measured using the standard boiling nitric acid (Huey) test given in ASTM A262 (9). Rates for each material of interest were measured and, where available, rates for different lots of the same material were measured. All lots meet the specifications for the material. Corrosion rates were measured in the as received condition. Rates were also measured in the sensitized condition to determine what could be expected from material in a poor metallurgical condition and in the annealed condition to determine the lowest expected rates.

Huey corrosion rates are summarized in Table V. Rates for 21-6-9 vary from 0.000 to 0.007 in./mo. depending upon lot of material and metallurgical condition. For comparison, rates for 304L are typically less than 0.002 in./mo. even in the sensitized condition. Rates for the 22-13-5 forged bar are in the same range as those for 21-6-9. The age hardenable materials, A-286 and JBK-75, have much higher corrosion rates and are affected more by metallurgical condition.

2. Inhibited Nitric Acid-HF Cleaning

The standard cleaning process that has been used to clean 304L parts is based on an inhibited nitric acid solution. The procedure is outlined in Table VI. The procedure was applied to the other materials with mostly satisfactory results. Approximate corrosion rates were measured in the inhibited nitric acid-HF solution. Table VII summarizes material appearance and corresponding corrosion rates. Corrosion tests were run for 1 hour at 150°F. Rates are generally higher than for the Huey test.

Appearance of cleaned surfaces may not directly effect weldability of parts but it does effect inspection that is a final check on part cleanliness. Dull gray surfaces are generally suspect for cleanliness. In the case of aged JBK-75, the dull appearance coupled with the high corrosion rate led to a concern about the cleanliness of the surface and the nature of the attack. Samples were examined by Electron Spectroscopy for Chemical Analysis (ESCA) for any foreign material. Only the usual trace of chlorine typical of clean stainless steel was found as an impurity on the surface. Scanning Electron Microscopy (SEM) of the cleaned surface also showed no impurities in x-ray scans. SEM metallography indicated the dull appearance to be a surface texture phenomenon. Considerable grain boundary attack takes place on aged material as compared with unaged material, Figure 8. Aged A-286 behaves in a similar manner. The temperature for cleaning aged JBK-75 and A-286 was reduced to 125°F to minimize the attack. Samples resistance welded subsequent to cleaning by this procedure welded satisfactorily, Figure 9.

C. MECHANICAL PROPERTIES

1. Hardness

Hardness, as indicated in the previous section, is used as a criterion for welding acceptability. It is, of course, measured nondestructively which is essential in many cases. Correlation with destructive tests that are more widely used as criterion for material acceptability, therefore, becomes important. This section relates hardness of materials to strength in the form of hydrostatic pressure tests and tensile tests.

Hardness is measured by any of several different methods. In this study, bulk material was measured on the Rockwell scales A, B, or C. The R_A scale has the advantage of being continuous over the range on interest for the alloys of this study. The R_B and R_C scales are more generally used and are more meaningful to most people.

To measure the hardness of tubes 1/8 inch OD, either a superficial scale R_{15T} or R_{15N}) or a microhardness scale (Diamond Pyramid - DPH or Knoop) was used. The DPH scale has the advantage of being continuous (R_{15T} and R_{15N} are not) and not significantly affected by indentation orientation (as is Knoop).

Conversions between these scales were necessary in order to obtain all data on one scale for comparison. The conversions shown in Table VIII, which is made up from ASTM E-140 (9), were used in all cases.

2. Hydrostatic Strength vs. Hardness

Strength of tubes to be resistance welded is measured by hydrostatic pressure. Tubes 1/8 inch OD by 1/16 inch ID are prepared for pressure testing by sealing one end by resistance welding or tungsten inert gas (TIG) welding. A high pressure fitting is connected to the other end, Figure 10. Tubes are then pressurized with oil using an Aminco Model 46-13918 hydrostatic pump.

Hydrostatic strengths were measured for 20 different lots of tubing. The data is tabulated in Table IX and plotted in Figure 11. Fairly accurate predictions of tube hdyrostatic strength can be made for 1/8 inch OD by 1/16 inch ID tubing using the curve in Figure 11.

3. Tensile Strength vs. Hardness

Tensile strength of tubes 1/8 inch OD by 1/16 inch ID was measured and correlated with hardness. Data are tabulated in Table X and plotted in Figure 12 using a parabolic least-squares representation. Curves follow the same pattern as the hydrostatic strength vs. hardness. The curves for yield strength and hydrostatic strength are, it turns out, nearly identical.

Data for all materials falls together with some degree of scatter. Two types of samples were used depending upon the available material, Figure 10.

Correlations of tensile strength with hardness are available in the literature (9, 12). Drawn on the plot of Figure 12 is the data from ASTM A370 for steels. The fit is fairly close at higher hardness down to where the curve breaks. The difference could be due to the material or to the nature of the test (tubes vs. bar).

4. Impact Strength

Impact strength of materials is important as it relates to the likelihood of failure of tubes in impact. Charpy V-notch impact tests were made per ASTM designation E23 (9). A test of JBK-75 and A-286 at -41.5°F showed good impact strengths of 46.5 and 42 ft-lbs respectively. Comparison samples of A-286 at room temperature resulted in slightly lower impact energy. Additional data on fracture toughness, dynamic yield strength and critical crack dimensions were obtained from the Dynatup - instrumented output of the impact tester, Table XI. Fracture toughness, which measures the resistance of a material to rapid crack propagation, resulted in relatively high numbers indicating a crack resistant material. Dynamic yield strength, critical crack depth and length are also good. Calculating fracture toughness data by impact tests may result in high (nonconservative) numbers because of higher strain rates than standard fracture toughness tests. Dynamic yield strength and critical crack length and depth are also high for the same reason. The critical crack length and depth are measurements of the critical size of a hypothetical flaw subjected to a nominal stress. The nominal stress is based on the dynamic yield strength that would cause rapid crack propagation in the material at the test temperature (13). The fracture surface, shown in Figure 13, had a typical ductile appearance.

III. CONCLUSION

Properties of materials were related to weldability of tubes. Mechanical properties were related to hardness which in turn has a part in the collapsing of tube walls during welding. Tubes may crack as they are deformed during welding if they are hard. Tubes must therefore have an upper limit to hardness.

Chemical cleaning of materials is necessary to remove oxide and other contaminants from surfaces to be bonded. Corrosion resistance of the materials plays a part in the amount of material removed and ease of inspection of tubes. The Nitradd cleaning solution is adequate for all materials with reduced temperature for aged JBK-75 alloy cleaning.

Heat treatment of materials must impart acceptable mechanical properties. Special aging or annealing of JBK-75 may be necessary to achieve adequate strength while not hardening tubes beyond acceptable limits. Heat treatment must also not oxidize tubes that cannot be chemically cleaned after heat treatment. Oxidation must be kept to a minimum in all cases.

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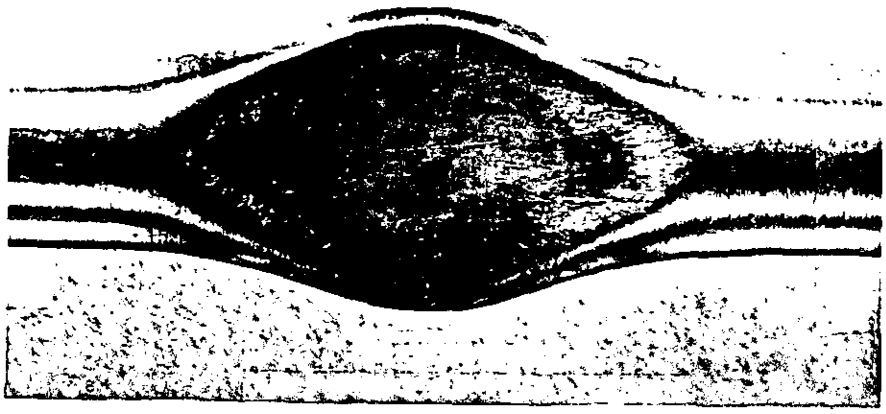
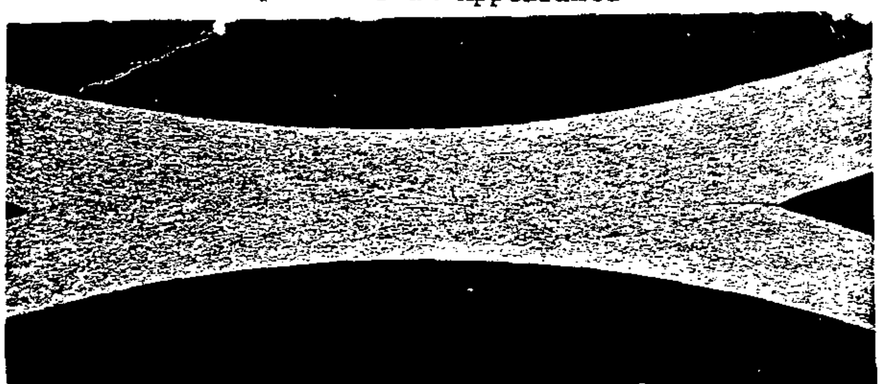


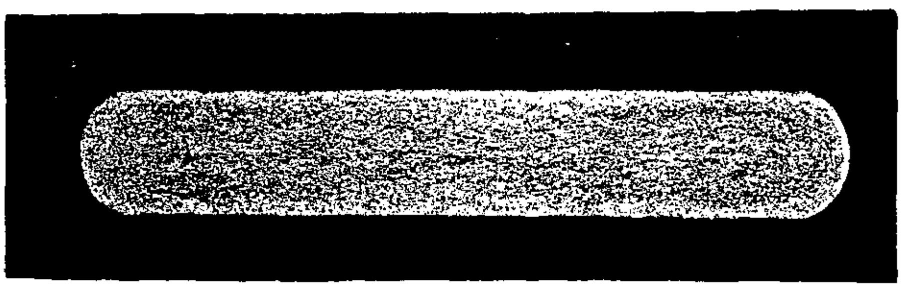
8X EE 53566-M

8X EE 53559-M

a) External Appearance



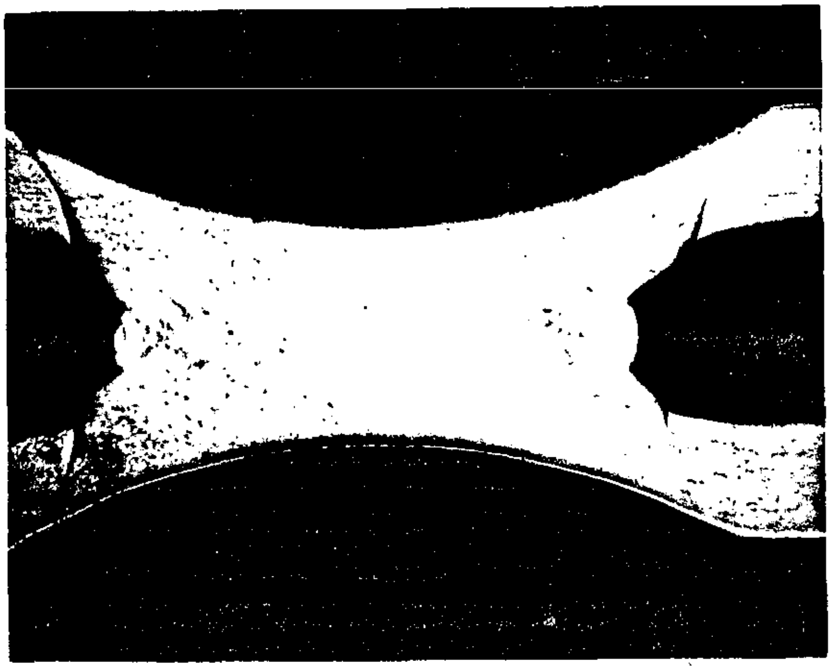
20X EE 53574-M



20X EE 53570-M

b) Longitudinal (top) and Tranverse Cross Sections

Figure 1. Resistance Weld in 21-6-9 Tube



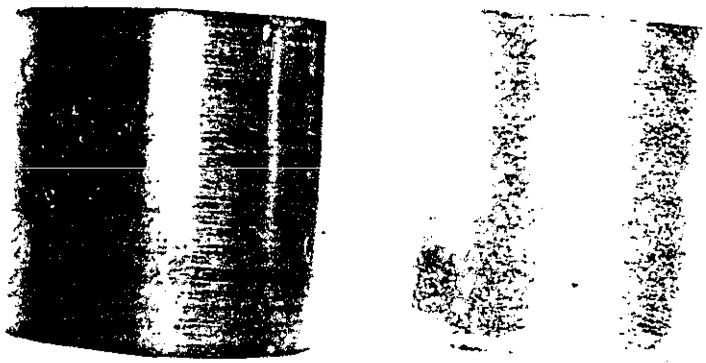
20X EE 25662-A

a) Tearing of JBK-75 Tube Wall Adjacent to Weld

10X EE 27033-A

b) Cracks in Weld Edge of A-286 Tube Weld

Figure 2. Tearing and Cracking of Resistance Welds in Hard (Over R_c30) Tube



5X EE 27064-A

Figure 3. Samples Induction Heated in a Hydrogen Atmosphere

Left JBK-75 (oxidized) and right 304L (bright and shiny)

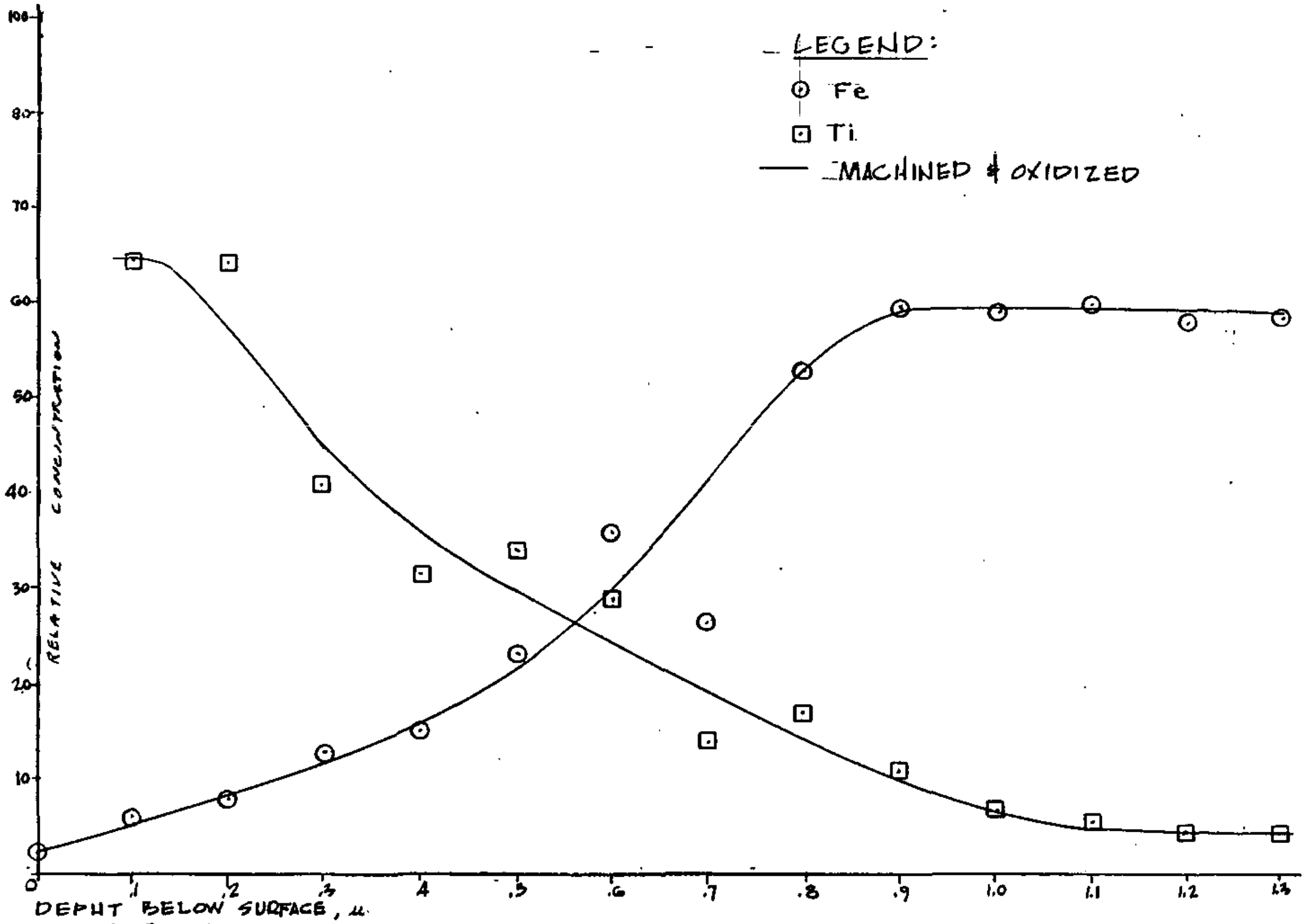


FIGURE 4 JBK-75 SURFACES ESCA DATA

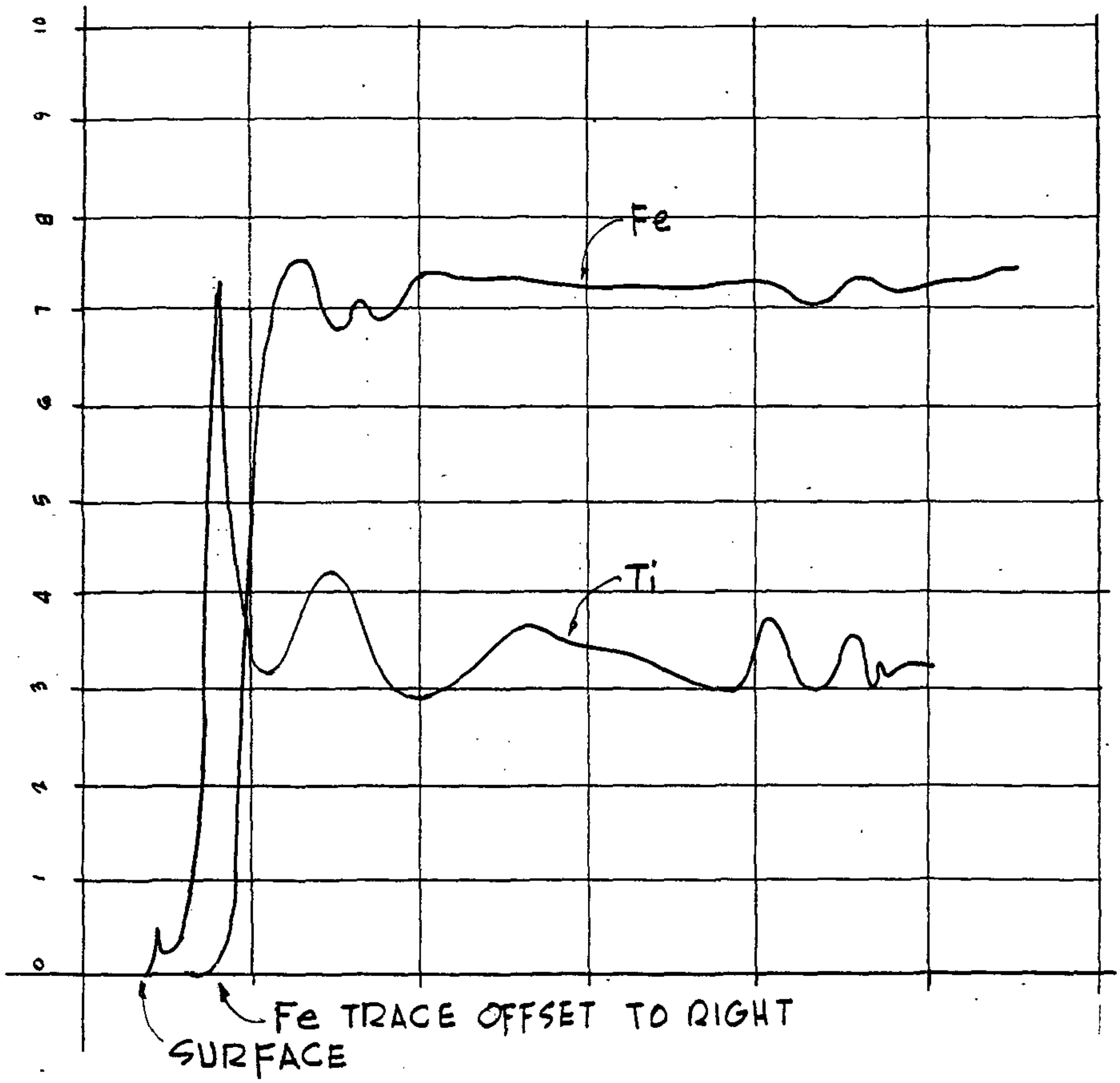
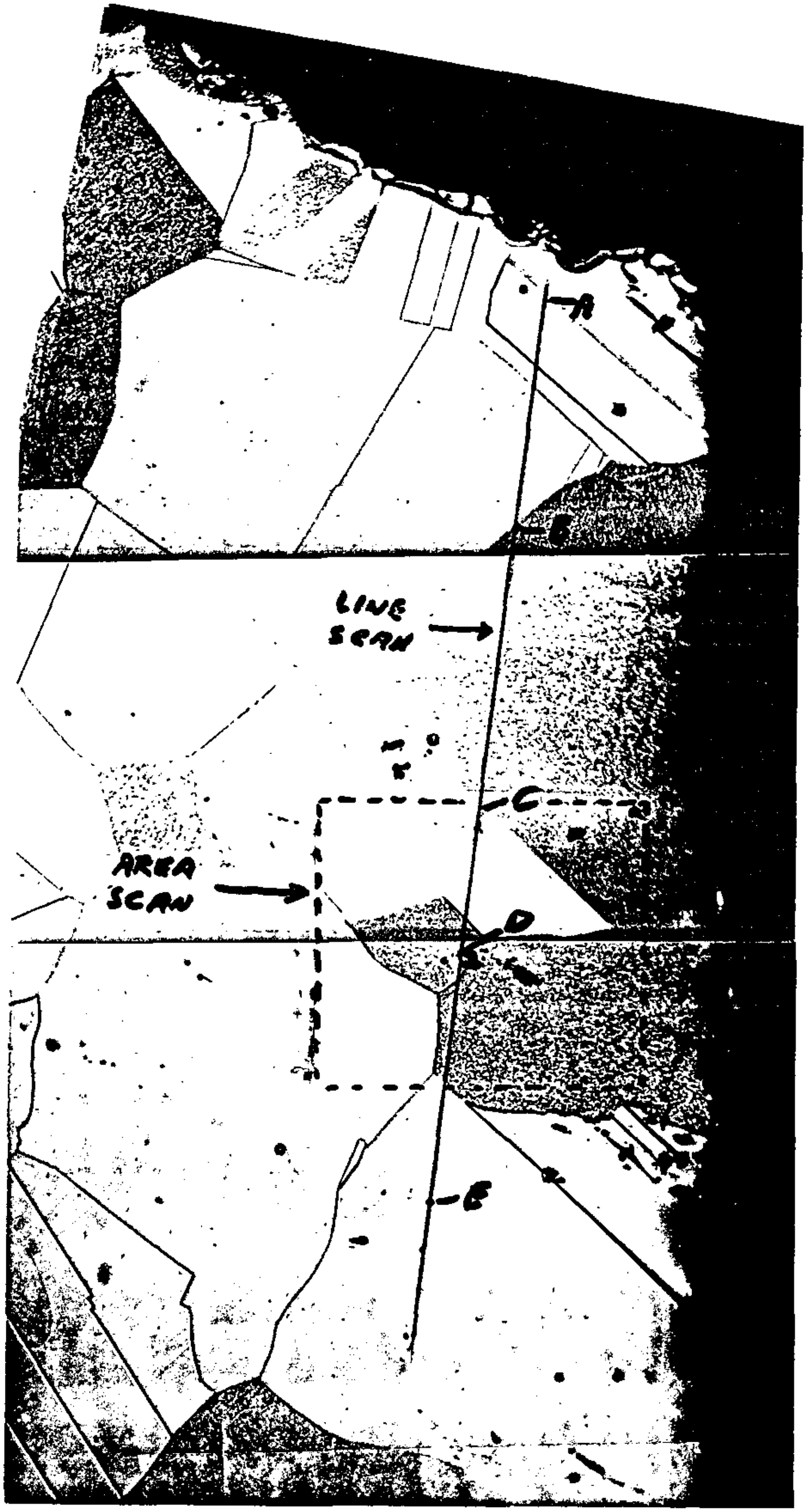


FIGURE 5. ELECTRON PROBE MICRO ANALYSIS (EPMA) SHOWING CONCENTRATION PROFILE FOR IRON AND TITANIUM STARTING AT THE SURFACE OF A J13K-75 FORGING.

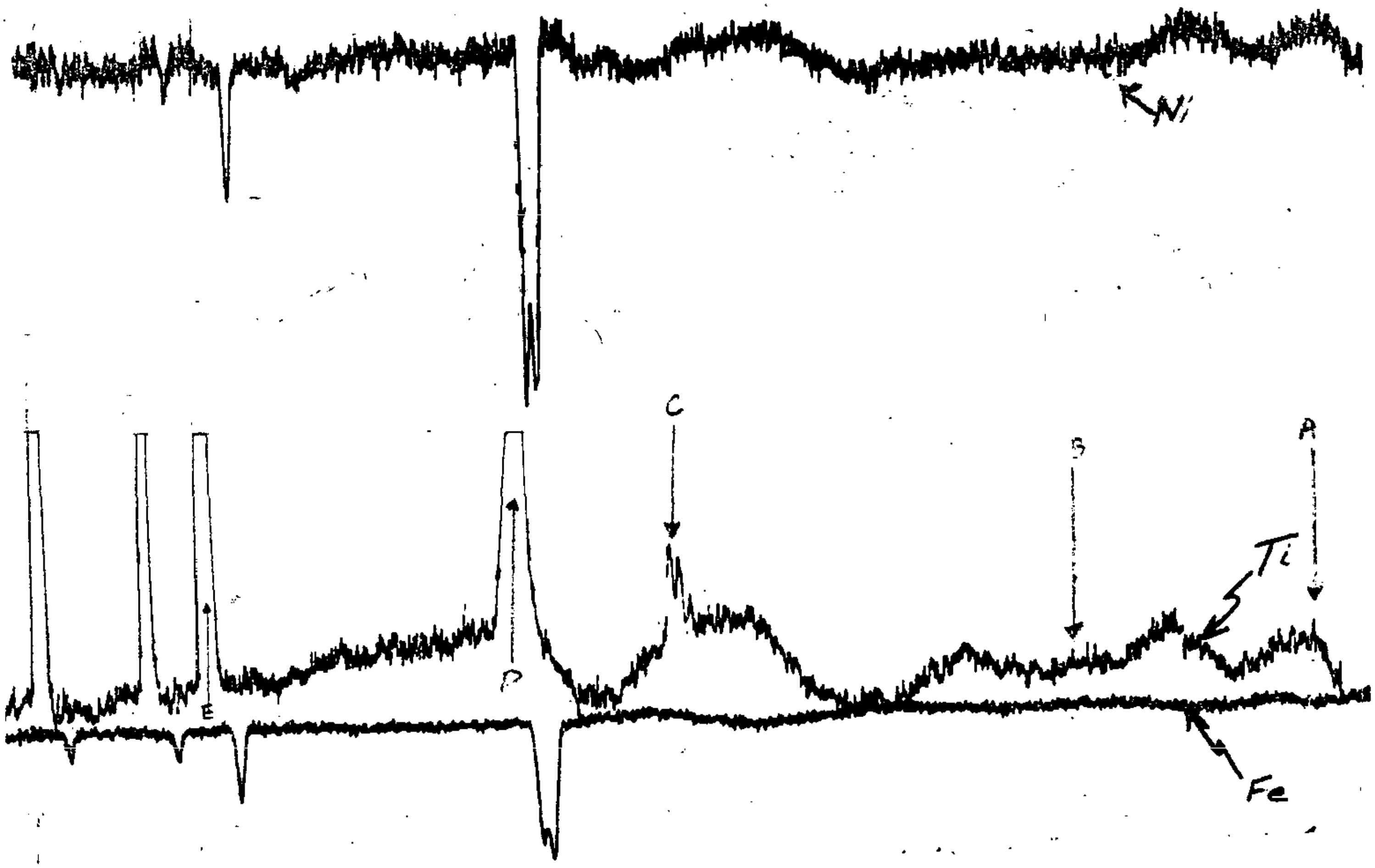


250X EE 26230, 31, 32

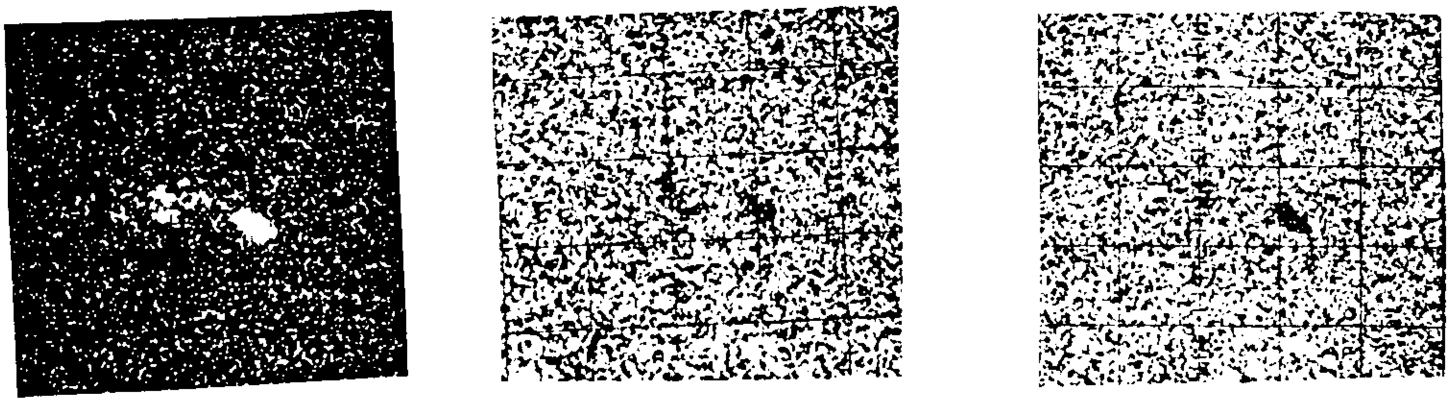
a) Photomicrograph showing inclusions (dark spots) and x-ray scan locations.

Figure 6. EPMA of Annealed JBK-75 Sample

Figure 6 (Continued)



b) Line scan showing high titanium and low iron and nickel content of inclusions.



Ti
250X EE 28872 250X

Ni
EE 26871

Fe
250X EE 26849

c) Area scan with inclusions in center.

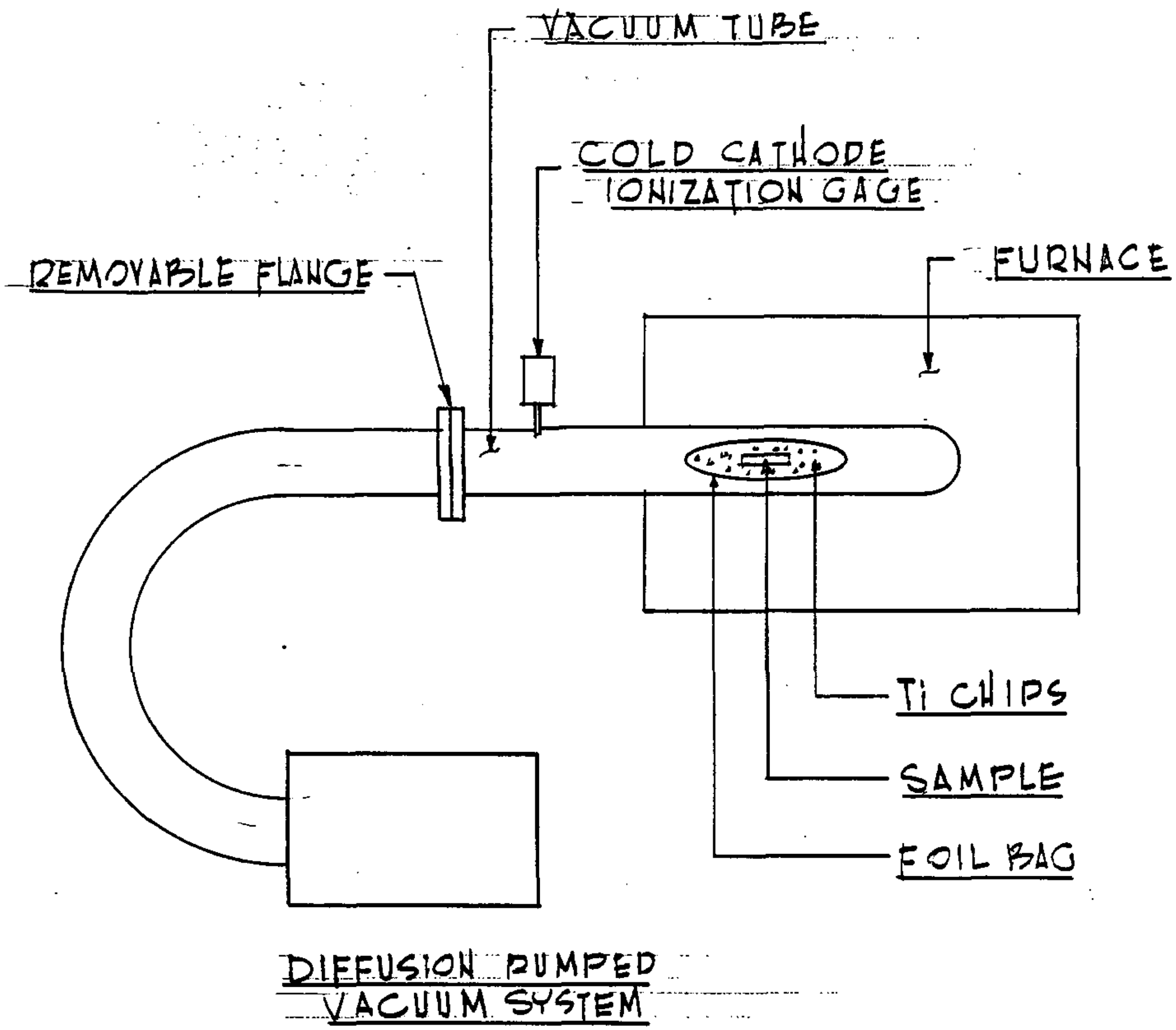
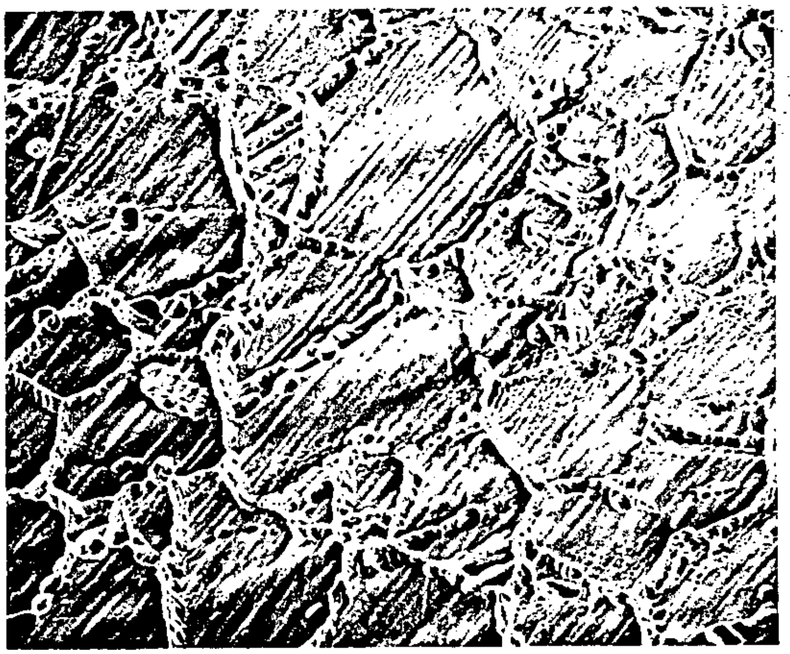


FIGURE 7
VACUUM HEAT TREATMENT STATION
USING TITANIUM GETTERING



425X EE 25734-A

a) Aged material. Note grain boundary attack.

425X EE 25733-A

b) Forged material. No grain boundary attack.

Figure 8. SEM Photomicrographs of JBK-75 Surfaces Cleaned in Inhibited Nitric Acid Solution

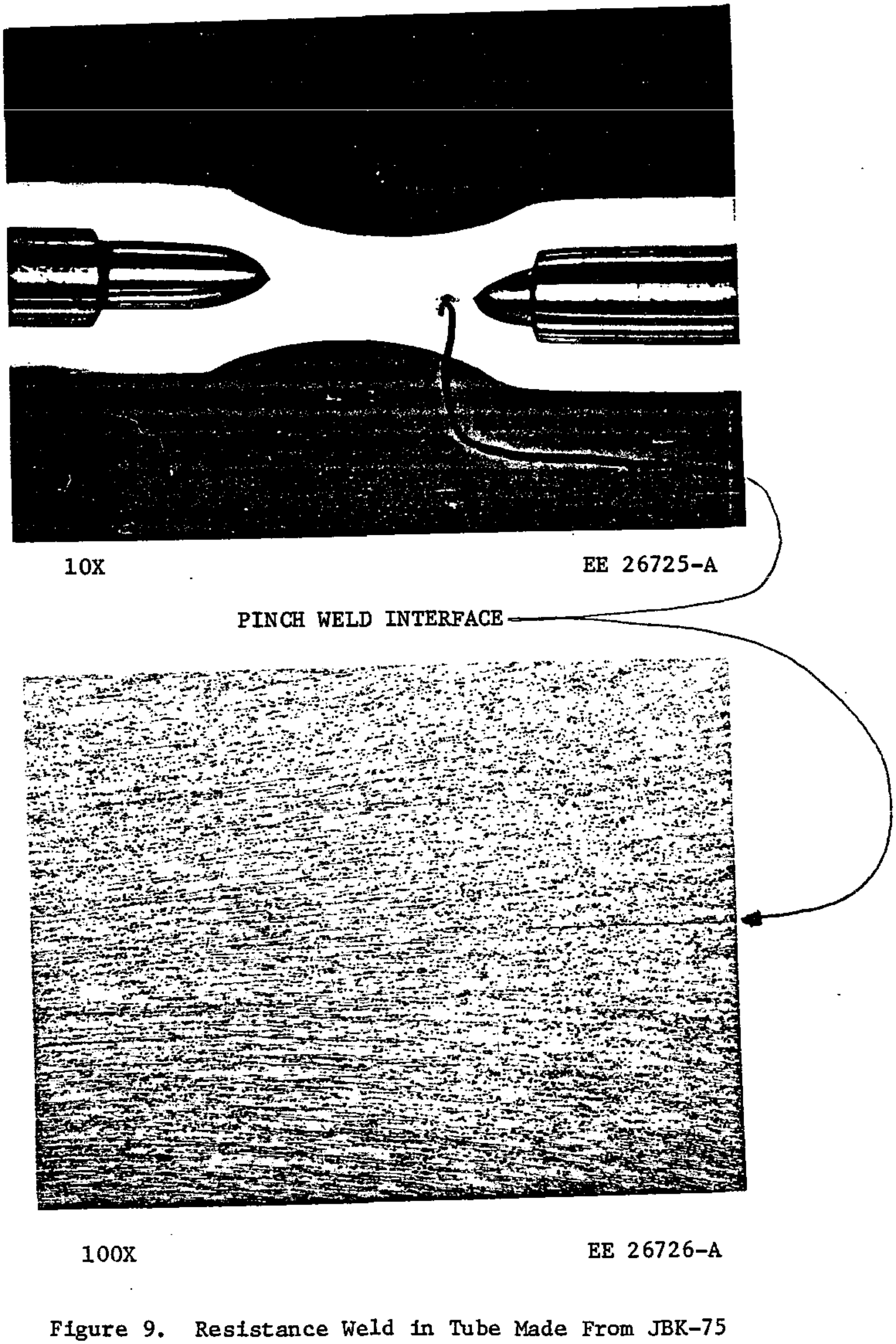
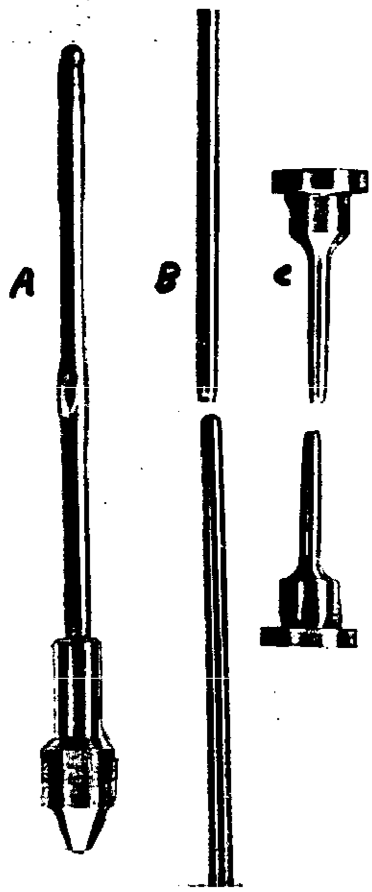


Figure 9. Resistance Weld in Tube Made From JBK-75



1X EE 27065-A

a) Hydrotest sample with TIG weld at upper end and high pressure fitting at lower end.

b) Tensile test tubing sample that is clamped directly in grips.

c) Tensile test sample machined to 1/8" OD X 1/16" ID in gage length.

Figure 10. 1/8" OD X 1/16" ID Tubes After Mechanical Testing Showing Failure Modes

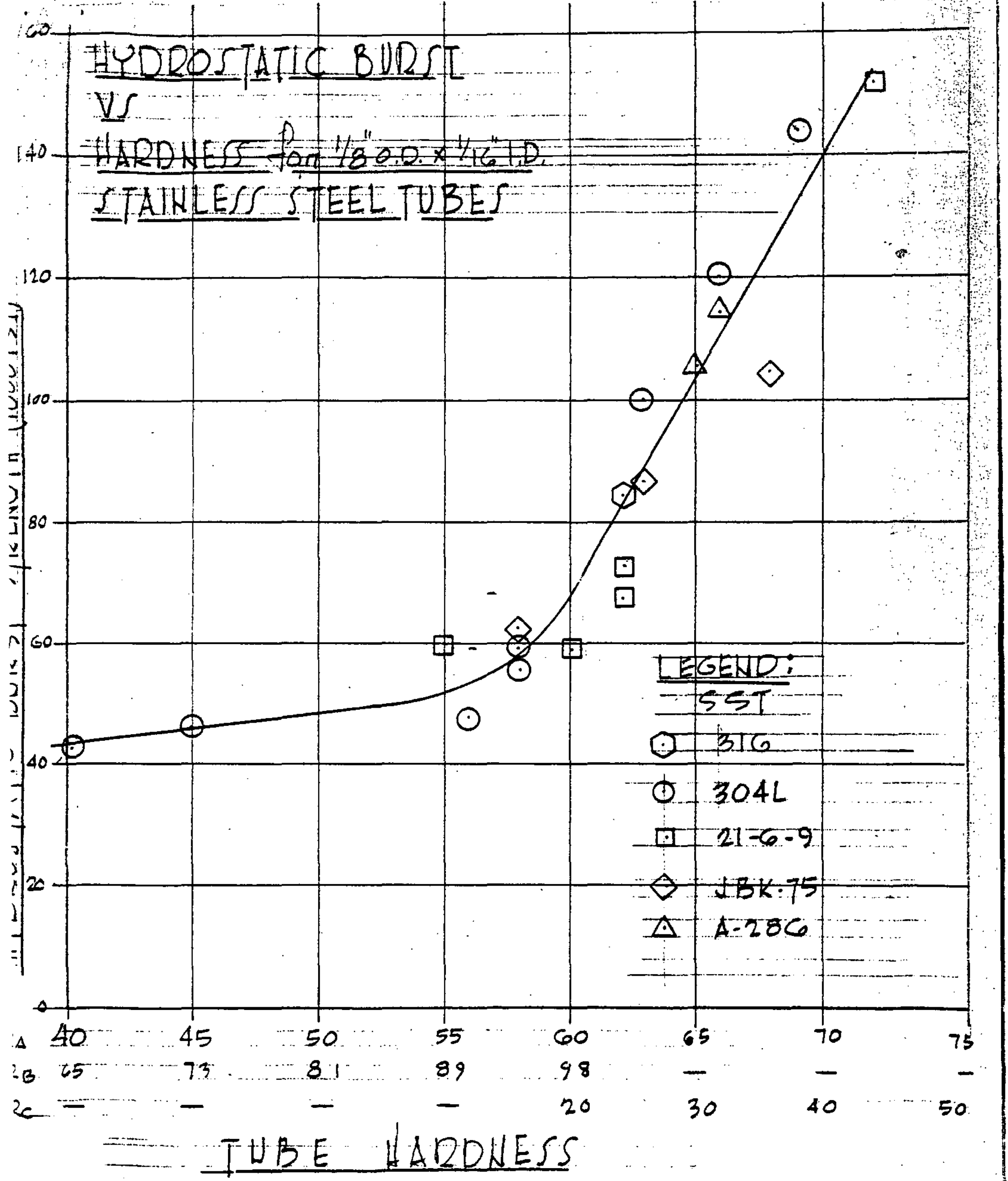
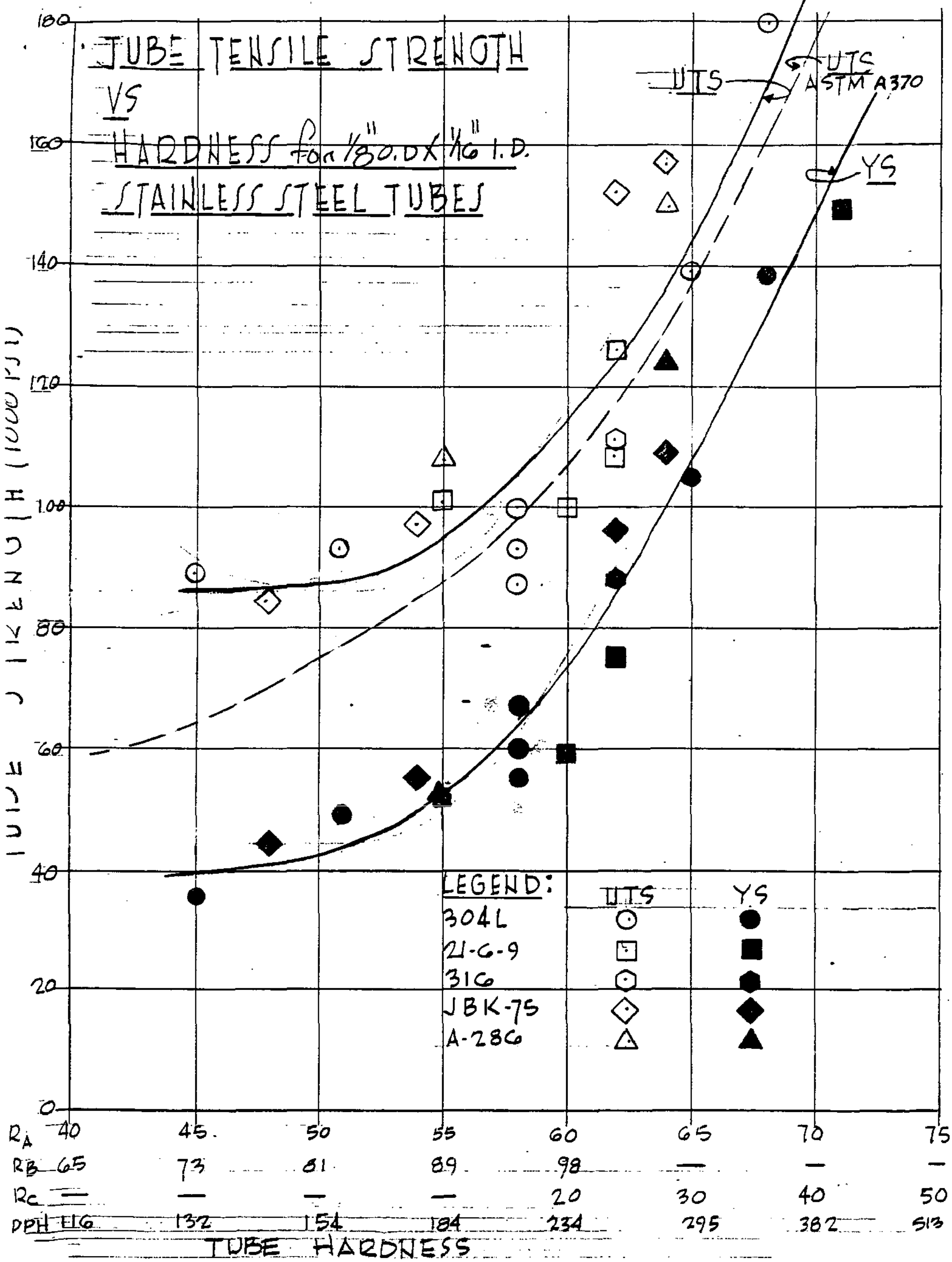
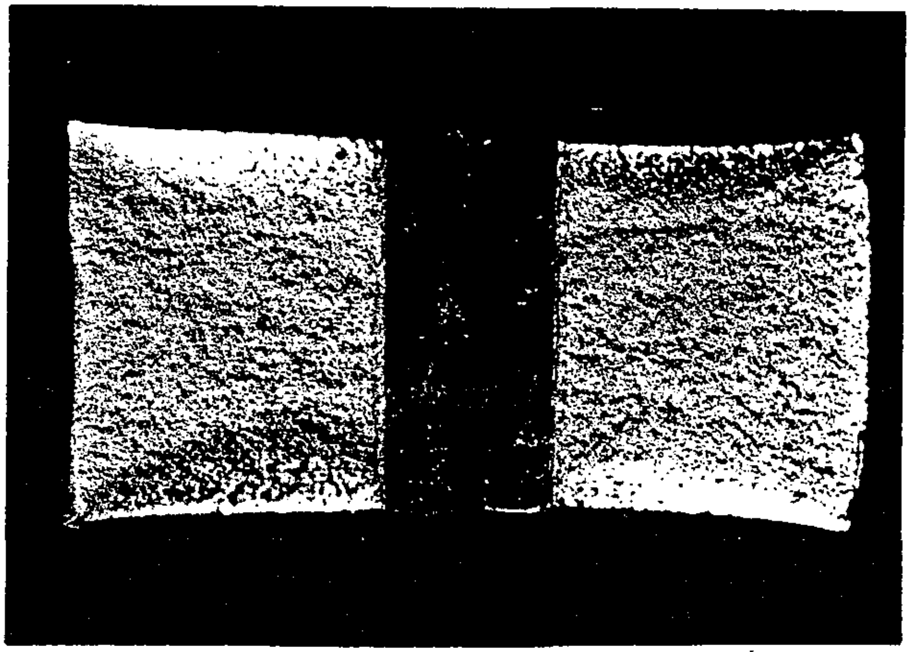

HYDROSTATIC BURST
VS
HARDNESS for 1/8" O.D. x 1/16" I.D.
STAINLESS STEEL TUBES
LEGEND:
SST
316
304L
21-6-9
JBK-75
A-286
A 40 45 50 55 60 65 70 75
B 65 73 81 89 98
C 20 30 40 50
TUBE HARDNESS

FIGURE 11



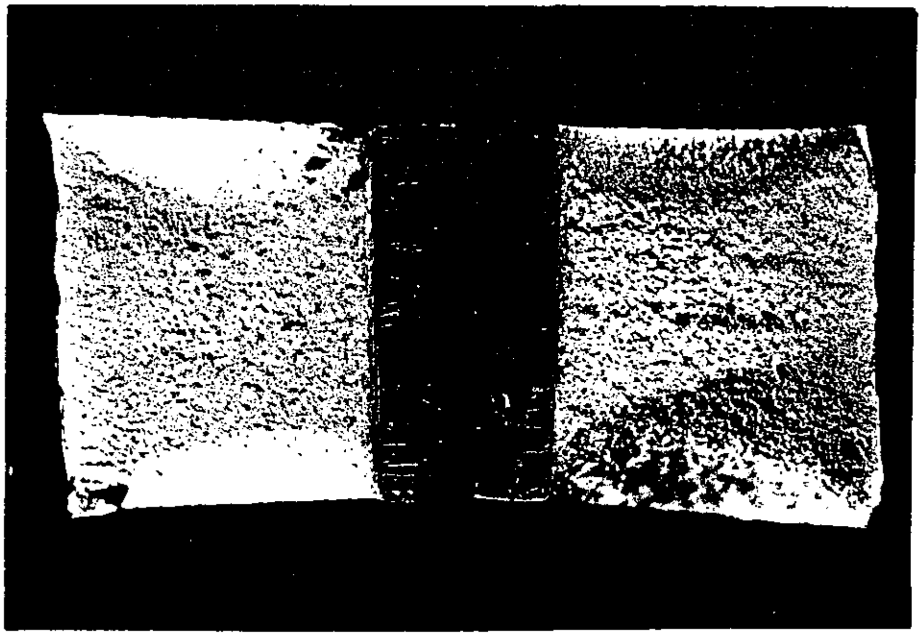
TUBE TENSILE STRENGTH VS HARDNESS for 1/8" O.D. X 1/16" I.D. STAINLESS STEEL TUBES
TUBE STRENGTH (1000 PSI)
UTS
UTS ASTM A370
YS
LEGEND:
UTS
YS
304L
21-6-9
316
JBK-75
A-286
RA 40 45 50 55 60 65 70 75
RB 65 73 81 89 98 — — —
RC — — — — 20 30 40 50
DPH 116 132 154 184 234 295 382 513
TUBE HARDNESS

FIGURE 12



5X Neg. No. 56957-M

a) A-286



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b) JBK-75

Figure 13. Fracture Surfaces of Impact Samples Tested at -41.5°F.

TABLE I

TYPICAL COMPOSITION

ALLOY	Cr	Ni	Mn	C	N	P	S	Si	V	Ti	Al	Mo	B	Nb
JBK-75	15	30	0.3	0.03	-	0.01	0.01	0.2	0.3	2.15	0.15	1.3	0.001	-
A-286	15	25	1.45	0.05	-	0.01	0.01	0.5	0.3	2.15	0.15	1.3	0.005	
304L	18	8	2	0.03	-	0.045	0.03	1.00	-	-	-	-	-	-
316	16	10	2	0.08	-	0.045	0.03	1.00	-	-	-	3.0	-	-
21-6-9	21	6	9	0.04	0.4	0.06	0.03	1.00	-	-	-	-	-	-
22-13-5	22	13	5	0.04	0.4	0.04	0.03	1.00	0.3	-	-	3.0	-	0.3

TABLE II

TYPICAL MECHANICAL PROPERTIES

ALLOY	CONDITION	HARDNESS (R_B OR R_C)	YS (KSI)	UTS (KSI)	ELONGATION (%)	R.A. (%)	SOURCE
21-6-9	ANNEALED	B-96	68	112	44	-	ARMCO
	TYPICAL HERF	C-38	125	145	25	-	LLL
	COLD REDUCED 60%	C-45	188	204	7	-	ARMCO
	MAXIMUM HERF	-	190	200	12	64	RF
JBK-75	ANNEALED	B-77	44	85	25	41	EED
	TYPICAL HERF AND AGE	C-32	120	160	18	40	EED-RF
	MAXIMUM HERF AND AGE	C-41	150	180	12	34	RF
304L	ANNEALED	B-70	28	75	50	-	INCO
	TYPICAL HERF	-	75	95	50	-	LLL
	COLD REDUCED 60%	C-40	160	174	2	-	ARMCO
	MAXIMUM HERF	-	150	170	50	-	LLL
22-13-5	ANNEALED	B-98	60	120	50	-	ARMCO
	COLD REDUCED 60%	-	216	234	9	42	ARMCO
316	ANNEALED	B-85	40	90	50	-	INCO
A-286	ANNEALED	B-80	35	85	48	72	ARMCO
	ANNEALED AND AGED	C-34	100	150	25	40	ARMCO
	WORKED AND AGED	-	200	215	9	31	ARMCO

TABLE III

HEAT TREATMENTS AND HARDNESS*

ALLOY	ANNEAL TEMP (°F)	ANNEAL TIME (HR)	AGE TEMP (°F)	AGE TIME (HR)	HARDNESS (ROCKWELL B OR C)
A-286	1650	2	-	-	B-83
A-286	1800	1	-	-	B-80
A-286	1650	2	1325	16	C-34
A-286	1800	1	1325	16	C-34
JBK-75	(F O R G E D)		-	-	B-95
JBK-75	(F O R G E D)		1250	16	C-35
JBK-75	1750	1	-	-	B-80
JBK-75	1750	1	1250	16	C-27
JBK-75	(F O R G E D)		1250	2	C-27
JBK-75	(F O R G E D)		1200	8	C-27

*A-286 data from Armco Product Data Bulletin SA-16.
JBK-75 data measured as part of this project.

TABLE IV

HEAT TREATMENT OF JBK-75
SHORT TIME TEST

STARTING CONDITION	TIME (MIN.)	TEMP (°F)	COOL METHOD		HARDNESS R_B OR R_c	AFTER AGING 16 HRS. AT 1250°F HARDNESS (R_c)
AGED	7	1500	QUENCH		C21	-
AGED	7	1450	QUENCH		C26	-
AGED	7	1400	QUENCH		C27	-
AGED	7	1300	QUENCH		C30	-
FORGED	7	1800	QUENCH		B76	C27
FORGED	7	1700	QUENCH		B78	C29
FORGED	3	1700	QUENCH		B91	C32

TABLE V

HUEY CORROSION RATES (ASTM 262)

MATERIAL		CORROSION RATES (IN./MO.)		
ALLOY	FORM	AS RECEIVED	SENSITIZED*	ANNEALED**
21-6-9	Forged Plate I	0.005	0.007	0.001
21-6-9	Forged Bar I	0.003	0.004	0.001
21-6-9	Forged Bar II	0.000	0.001	0.000
21-6-9	Forged Part III	0.000	0.001	0.000
21-6-9	Forged Plate II	0.001	0.001	0.001
21-6-9	Forged Plate III	0.001	0.001	0.001
21-6-9	Bar	0.001	0.007	0.002
21-6-9	Forged Bar IV	0.000	0.002	0.001
21-6-9	Forged Bar V	0.002	0.006	0.001
22-13-5	Forged Bar	0.001	0.003	0.001
304L	Bar	0.001	0.002	0.001
304L	Sheet		0.001	
A-286	Drawn Tube	0.008	0.030	0.011
JBK-75	Forged Bar	0.001	0.033	0.001

*Sensitized 1 hr at 1250°F (A-286 and JBK-75 16 hrs)

**Annealed 1 hr at 1950°F (A-286 at 1800°F, JBK-75 at 1750°F)

Table VI

INHIBITED NITRIC ACID-HF CLEANING PROCEDURE

I. Chemicals

A. Nitradd solution

1. 30 parts HNO_3 by volume (commercial grade 70% HNO_3)
2. 20 parts "Nitradd" by volume (proprietary product of Turco, contains 30% available acid ammonium fluoride)
3. 50 parts H_2O by volume

B. 95% ethyl alcohol

II. Procedure

1. Rinse piece with water at 100-140°F.
2. Immerse piece in Nitradd solution at 160$\pm$20°F for 5 minutes.
3. Repeat step 1.
4. Rinse with ethyl alcohol.
5. Dry piece with dry nitrogen.

TABLE VII

INHIBITED NITRIC ACID-HF CLEANING RESULTS

ALLOY	FORM	SURFACE APPEARANCE	CORROSION RATE (IN./MO.)
21-6-9	Forged Plate I	Dull To Shiny	0.3
21-6-9	Forged Bar I	Dull To Shiny	0.3
21-6-9	Forged Bar II	Shiny	0.1
12-6-9	Forged Bar III	Shiny	0.2
12-6-9	Forged Plate II	Shiny	0.0
21-6-9	Forged Plate III	Shiny	0.0
21-6-9	Bar	Shiny	0.2
21-6-9	Forged Bar IV	Dull To Shiny	0.6
21-6-9	Forged Bar V	Shiny	0.1
22-13-5	Forged Bar	Shiny	0.0
304L	Bar	Shiny	0.3
304L	Sheet	Shiny	0.3
A-286	Aged	Dull	0.9
JBK-75	Forged	Shiny	0.3
JBK-75	Aged	Dull	0.6

TABLE VIII

Metallurgical Laboratory Hardness Conversion Chart for Stainless Steels*

Rockwell A	Rockwell B	Rockwell C	Rockwell 15_T	Rockwell 15_N	Diamond Pyramid	Knoop
41	66		79		119	136
41.5	67		79.4			
42.1	68		79.7		122	140
42.7	69		80.1			
43.3	70		80.5		126	144
43.9	71		80.9			
44.6	72		81.1		130	149
45.3	73		81.5			
46.0	74		81.9		135	154
46.6	75		82.3			
47.3	76		82.6		140	160
47.9	77		83.0			
48.6	78		83.4		145	166
49.2	79		83.8			
49.8	80		84.1		151	173
50.4	81		84.5			
50.9	82		84.9		157	179
51.5	83		85.2			
52.1	84		85.6		164	187
52.7	85		86.0			
53.3	86		86.4		171	195
53.9	87		86.7			
54.5	88		87.1		179	204
55.0	89	(9.0)	87.5	(65.0)		
55.6	90		87.8		188	215
56.2	91		88.2			
56.8	92	(12.0)	88.6	(66.5)	198	226
57.4	93		88.9			
58.0	94	(14.5)	89.3	(68.0)	209	239
58.5	95		89.7			
59.1	96	(17.0)	90.1	(69.0)	220	251
59.7	97		90.4			
60.3	98	20	90.8	69.8	234	267
60.9	99	21	91.2	70.3		
61.5	100	22	91.5	70.8	248	283
61.8		23		71.3		
62.3		24		71.9	255	291
62.8	(102)	25	(92.5)	72.4		
63.3		26		72.9	269	308
63.8		27		73.4		
64.3	(104)	28	(94.0)	73.9	282	321
64.8		29		74.4		
65.3		30		74.9	295	336
65.8		31		75.4		
66.3	(106)	32	(94.5)	75.9	309	352
66.8		33		76.5		
67.3		34		77.0	326	372
67.8		35		77.5		
68.3		36		78.0	344	392
68.8		37		78.5		
69.3		38		79.0	362	413
69.9		39		79.5		
70.4		40		80.0	382	436
70.9		41		80.5		
71.4		42		81.0	404	
71.9		43		81.6		
72.4		44		82.1	427	
72.9		45		82.6		
73.4		46		83.1	452	
73.9		47		83.6		
74.4		48		84.1	481	
75.0		49		84.7		
75.5		50		85.3	513	

* Data obtained from ASTM E 140: Part 31, May 1967.

[NOTE] Conversion between hardness numbers are approximations only.

TABLE IX

HARDNESS AND HYDROSTATIC STRENGTH MEASUREMENTS

		HARDNESS						HYDROTEST (KSI)			
		MEASURED				CONVERTED					
ALLOY	PURCHASE ORDER NO.	SCALE	MAX.	MIN.	AVG.	R_A	NO. OF READINGS	MAX.	MIN.	AVG.	NO. SAMPLES
304-L	AX 347306	DPH	215	184	196	57	4	47	44	47 (b)	4
304-L	AX 363990	R_{15T}	89.5	89.5	89.5	58	3	54	56	55 (b)	4
304-L	AX 303697	DPH	241	191	212	58	6	61	56	59	2
304-L	AX 170760	R_{15N}	73	73	73	63	3	100	100	100	1
304-L	AX 191715-1	R_{15N}	75.5	75.5	75.5	66	3	118	121	120	2
304-L	AX 191715-2	R_{15N}	79.5	78.5	79	69	3	143	143	143	1
304-L	Machined Tube					40		43	43	43	2
304-L	AX 363990-A	R_{15T}	82	81	81	45	108	46	45	45	7
316	AX 412155					62		86	83	84	4
21-6-9	AX 387814-2	R_{15T}	91	86	90.5	60	12	58	58	58	2
21-6-9	AX 362665	DPH	274	234	251	62	12	69	65	67	4
21-6-9	AX 343119	R_{15T}	92.5	91.3	92	62	12	72	71	71 (b)	2
21-6-9	AX 387814-1	R_{15N}	81.5	81	81	72	12	148	148	148	1
21-6-9	AX 362665-A	R_{15T}	88	87	87.5	55	54	59	55	59	4
JBK-75	AX 389667-F (c)	R_{15T}	91.8	86.9	89	58	120	68	60	62	5
JBK-75	AX 389667-AA (c)	R_{15N}	74.5	71.9	73	63	30	91	83	86	4
JBK-75	AX 389667-FA (c)	DPH	349	331	340	68	12	104	104	104	1
A-286	AX 395084-1	R_{15T}	87	89	87.5	55	9	59	59	59	3
A-286	AX 395084-2	R_{15N}	74	76	74.5	65	9	114	114	114	1
A-286	AX 395084-1A (c)	DPH	332	291	307	66	12	105	105	105	2

a) Hardness data is reported for a batch of tubing where the overall average was used as the reference. Two to 6 readings were taken on each length of tube.

b) Adjusted for tube dimensions.

c) F - Forged AA - Annealed and Aged FA - Forged and Aged 1A - Partial Age

TABLE X

HARDNESS AND TENSILE STRENGTH MEASUREMENTS

ALLOY	TUBE LOT	HARDNESS (RA)	UTS (KS1)	YS (KS1)	NO. SAMPLES
304L	AX 363990	58	93	55	8
304L	AX 303697	58	87	60	11
304L	AX 347306	58	100	67	11
304L	1/2 Hard-AX 191715	65	139	105	2
304L	3/4 Hard-AX 191715	58	180	138	2
304L	Annealed-AX 363990	45	89	36	5
304L	Tensile Tube	51	93	49	1
316	AX 412155	62	111	88	4
A-286	Annealed	55	108	53	2
A-286	Drawn	64	150	124	2
JBK-75	Annealed	48	84	44	1
JBK-75	Forged	54	97	55	1
JBK-75	Annealed & Aged	62	152	96	1
JBK-75	Forged & Aged	64	157	109	1
21-6-9	AX 362665	62	109	-	8
21-6-9	AX 343119	62	126	75	2
21-6-9	" 60K"-AX 387817	60	100	59	1
21-6-9	"130K"-AX 387817	71	189	149	2
21-6-9	Annealed-AX 362665	55	101	52	2

TABLE XI

RESULTS OF DYNATUP-INSTRUMENTED CHARPY IMPACT TEST OF JBK-75 AND A-286 STAINLESS STEELS

SAMPLE TYPE	SAMPLE TEMPERATURE (°F)	ENERGY (FT.-LB.)	FRACTURE TOUGHNESS (KSI - $in^{1/2}$)	DYNAMIC YIELD STRENGTH (KSI)	CRITICAL CRACK DEPTH (IN)	CRITICAL CRACK LENGTH (IN)
A-286	-41.5	42	138.94	143.53	.247	.597
JBK-75	-41.5	46.5	157.83	153.159	.279	.676
A-286	70	36				
A-286	70	37				