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SUBJECT: HRP Titanium Fabrication Experience
From Loop T-1 Construction

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1.0 INTRODUCTION

One of the primary objectives of Loop T-1 of the Unit Operations Blanket Processing Program was development of, testing of, and obtaining experience with titanium fabrication methods. Most of the actual problem solving was done by the ORNL Metallurgy Division, represented by W. G. Leonard and the ORNL welding shops, under the direction of T. R. Housley.

This memo will summarize the present status of titanium for application to other Chemical Technology Division problems. Although welding procedures were the most important single problem, only a generalized discussion of welding experience will be given since the Metallurgy Division is issuing a revised welding procedure.

The most useful sources of information on titanium and titanium fabrication have been the technical bulletins of industrial fabricators (1)(2)(3). Metallurgical literature and government reports cover a huge number of individual projects which have been partially abstracted in a form for ready reference (4). However, the individual reports are generally too specialized to give a useful overall picture unless a large number are surveyed. Many of the older techniques and conclusions are no longer correct due to new developments in titanium technology.

2.0 SUMMARY

The experience with fabrication of titanium obtained from construction of loop T-1 is summarized for application to other Chemical Technology Division programs. Techniques developed now give acceptable welds without use of an inert gas dry box; this procedure and other improvements will be incorporated in a revised titanium welding procedure to be issued by the ORNL Metallurgy Division. Schedule 80, 1/4-in.-dia. and 1/2-in.-dia. titanium pipe was found to have defects; characteristics of the defects and a program for complete inspection of titanium pipe and tubing are being studied. Modification of specifications to permit use of standard grades of commercially pure titanium is suggested for any large future division purchases of titanium.

3.0 WELDING PROCEDURES

Titanium is easily arc-welded to give sound joints with a high tensile strength; the difficult problem during welding is to prevent the pickup of O_2 , N_2 and H_2 from air or H_2O vapor to give cold

embrittlement. Even small traces of H_2O vapor or air are picked up very rapidly during welding to give brittle welds. The metal must be protected by inert gases until it cools below $1100^{\circ}F$. This can be done in an inert gas dry-box whenever the titanium parts are small enough to go in a dry box. Most of the loop T-1 welds were made out of the dry box with careful use of inert gas to backup welds and in the shielded arc torches.

From various tests, including bend tests, hardness measurements, and radiographs, these welds are believed to be good welds with ductility comparable to that of the base metal. Tolerable limits of contamination for otherwise pure titanium are about 0.10% N_2 , 0.3% O_2 and 0.015% H_2 . The titanium ordered for Unit Operations use specified compositions with maximum percentages of 0.08 for N_2 , 0.12 for O_2 and 0.01 for H_2 .

The amounts and effects of N_2 , O_2 and H_2 pickups from various welding procedures including use of air or H_2O vapor contaminated inert gas have been systematically studied and reported in non-classified literature (5) (6). The appearance of the weld surface before cleaning or wire brushing is a sensitive indicator of O_2 or N_2 pickup. A silvery-gray metallic surface of the same appearance as other clean titanium has not picked up N_2 or O_2 , while darker grays through deep blues and black indicate increasing pickups of these undesirable gases.

The tentative ORNL specifications for welding titanium (7) have been modified from experience to improve and, to a certain extent, simplify them. A revised set of specifications is being prepared and will soon be issued by the ORNL Metallurgy Division. The X-10 area now has one welder qualified for the more common types of welds with titanium.

4.0 MACHINING AND THREADING

The machinability of titanium is comparable to that of stainless steels. The commercially pure titanium used for loop T-1 was generally easier to turn and grind than 347 stainless steel. Threads were machined whenever possible since threading and tapping operations tend to give poor or partially stripped threads because of titanium's tendency to seize and gall. This galling tendency is also apparent in both titanium-to-titanium and titanium-to-347 stainless steel threaded connections. Because of this, threaded connections should use "sloppy" fits and good lubricants whenever possible. Titanium tubing and pipe is reported to be able to take bends of the same minimum radius as annealed stainless steel tubing.

Small radius bends were avoided for loop T-1 fabrication and should probably be avoided for other titanium since the 1/4- and 1/2-in.-dia., Schedule 80 pipe used in the T-1 loop was found to have numerous small defects which might cause stress concentrations and cracking at bends.

Industrial literature (2)(3) gives detailed machining techniques and should be consulted for up-to-date information.

5.0 TITANIUM QUALITY AND TEST PROCEDURES

The requisitions under which the Unit Operations stock of titanium was purchased asked for metal to meet Specification HRT-CP-2 or equivalent specifications. These specifications required the purest commercial grades available in limited quantities such as Titanium Metals Ti-55A or Rem-Cru A-40. The advantage of using this high purity metal is slightly more latitude for O₂, N₂ and H₂ pickup during welding because of the lower initial concentrations of these contaminants. The standard commercially pure grades of titanium have no known differences in corrosion resistance, slightly higher yield and ultimate strengths, and slightly lower ductility as compared to the special grades.

Any large future orders of titanium by the Chemical Technology Division should consider using specifications which can be met by standard grades of commercially pure metal. Where welds will not be made, the less pure metal has higher strengths and no important disadvantages. Where welding is to be done, a good procedure will give a good weld with the standard grades of titanium while a poor procedure will give a poor weld, even with the special purity metal.

There were no noticeable defects in the 1- to 6-1/4-in.-dia. bars used for fabrication of loop T-1 components. An inspection procedure to locate inclusions, laminations, or other defects may be needed and is being developed for all the titanium pipe and tubing. The 1/4- and 1/2-in.-dia., Schedule 80 pipe used in loop T-1 fabrication showed numerous minor and one major defect. The minor defects were indicated by eddy current testing and were detectable on the surface by dye-checking. The major defect was a several-inch long split which was not noticed until the assembled loop was filled with liquid. Both the surface dye-check and radiographs show the defects as being parallel to the pipe axis; this would be expected if they were present in the ingot from which the pipe was drawn.

The Metallurgy Division can test titanium for defects by several methods including cyclograph inspection, radiographs, and surface dye checks. After the cyclograph is set up and calibrated for a given diameter stock, it can rapidly inspect large amounts of material. This instrument detects changes in eddy currents and is very sensitive to small defects without indicating anything about the nature of the defect. Dye-checking is the same procedure used for checking welds and is sensitive to surface defects only. Radiographs can locate defects that are below the surface and they indicate more about the defects than the cyclograph. Present plans are to identify

by piece numbers and cyclographically examine all the titanium pipe and tubing of less than 1 in. dia. Then areas showing major defects on the cyclograph will not be used or will be radiographed. The small amounts of the above 1-in.-dia. pipe (for ORNL pumps) will not justify setting up the cyclograph for them and will be radiographed before being used.

6.0 AVAILABILITY OF TITANIUM

On February 1, 1956, the Unit Operations Section had about 1000 lb of titanium with a value of about \$19,000 on hand or scheduled for delivery (see Appendix, Table 1). The listed titanium includes all the material ordered for the Unit Operations HRP Blanket Processing Program. Equipment which could not be fabricated from the material available would require additional orders. At the present time, deliveries have required three to five months for rod, bar, block, and other massive titanium and three to nine months for more finished forms. The large-diameter rods (3-1/2- and 6-1/4-in.-dia.) and pipes (1-1/4-, 2- and 2-1/2-in.-dia.) are reserved for fabrication of all-titanium ORNL canned rotor pumps; the other sizes are largely available for other uses. Even the simple fabricated forms such as heavy wall tubing or schedule 80 pipe are not standard when made of titanium and are fabricated specially to fill orders. The cost of rod, wire, plate, bar, and sheet titanium ranged from \$13.25 for 2-3/4-in.-dia. rod to \$25.25 for 0.010-in. thick sheet and \$29.50 for 1/16-in.-dia. welding rod.

7.0 BIBLIOGRAPHY

- (1) Welding Titanium, Mallory Sharon Titanium Corporation, Niles, Ohio.
- (2) Machining Recommendations for Titanium, Mallory Sharon Titanium Corporation, Niles, Ohio.
- (3) Handbook on Titanium Metal, 7th Edition, Titanium Metals Corporation of America, 233 Broadway, New York 7, New York, August 1, 1953.
- (4) Titanium and Titanium Alloys Program, Books I, II, III, IV, and V, Air Materials Command.
- (5) Effects of Atmospheric Contaminants on Arc Welds in Titanium, J. C. Barrett and I. R. Lane, Jr., Welding Journal, June, 1953.
- (6) Effects of Atmospheric Contaminants on Arc Welds in Titanium, Part II, J. C. Barrett and I. R. Lane, Jr., Welding Journal, March, 1954.
- (7) Tentative Specifications for Welding Titanium Sheet, Plate and Shapes, E. C. Miller (memo to S. E. Beall), April 1, 1955.

8.0 APPENDIX

8.1 Titanium Inventory

A system has been set up to provide storage and controlled distribution of titanium bought for UNOP-HRT blanket processing studies. Stores series 500-, as shown on Table 1, has been designated for the titanium. This titanium presently under account 33705-18-1424 will be charged to the proper work order or account numbers when material is issued. E. O. Nurmi or P. A. Haas will keep up to date with and can authorize withdrawals of titanium. The unfabricated titanium (rod, wire, plate, pipe, and sheet) is the equivalent to Titanium Metals Corporation Ti-55 with less than 100 ppm H₂ and other specifications as given by HRT-CP-2.

8.2 Blanket Processing Loop T-1

The T-1 loop (see Figures 1, 2 and 3) was designed to use titanium immediately available for fabrication. This limited titanium components to 1/2- and 1/4-in.-dia., Sch. 80 pipe and components machined from 1-, 1-1/2-, and 2-1/2-in.-dia. bar stock. Autoclave engineers-type fittings were used for room temperature tubing connections to stainless steel valves and a surge tank. The pump was a 347 stainless steel, ORNL canned rotor pump with a titanium scroll case and impeller. Calrod heaters and cooling coils were cast in aluminum to give good heat transfer. Design details are given by schematic drawing D-24181, layout drawing D-24194, and listed detail drawings.

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TABLE I

Titanium Available or ordered for UNOP-HRT Blanket Processing Development Studies

Date: March 1, 1956

Shape	Distinguishing Dimensions (in.)	Stores Numbers	Approximate Amount		Unit Costs		Total Value \$
			Weight (lbs.)	Length in in. or other amt. as noted	\$/lb	\$/in.of length or other units as noted	
Rod	6-1/4 dia.	500-480	57	11-1/2	13.75	69.00	790.
	3-1/2 dia.	500-435	26	16-1/2	14.25	22.50	370.
	2-3/4 dia.	500-430	116	120	13.25	13.00	1537.
	2-3/4 dia.	500-430	75	78	13.25	13.00	1000.
	1-3/4 dia.	500-422	71	180	15.50	6.10	1100.
	1-1/2 dia.	500-420	15	52	15.50	4.50	234.
	1-1/4 dia.	500-418	24	120	15.50	3.10	372.
	1 dia.	500-415	15-1/2	120	16.50	2.15	256. ^c
	3/4 dia.	500-412	2-1/2	36	16.50	1.15	42.
	1/2 dia.	500-408	7-3/4	264	16.75	0.50	130. ^c
	3/8 dia.	500-405	1-3/4	96	17.25	0.32	31.
	3/16 dia.	500-490	1/4	48	23.00	0.12	6. ^c
	1/8 dia.	500-510	1	--	25.00	----	25.
	1/16 dia.	500-505	25	--	29.50	----	740.
Pipe	2-1/2 dia. Sch.40	500-350	23	84	23.00	6.40	530.
	2 dia. Sch.80	500-340	7	30	22.00	5.20	154.
	1-1/4 dia. Sch.80	500-385	18-1/2	132	24.00	3.40	445.
	1/2 dia. Sch.80	500-370	24-1/2	480	25. ^a	1.25 ^a	600. ^a
	1/4 dia. Sch.80	500-365	122	4800	25. ^a	0.65 ^a	3000. ^a
Tubing	1/4 o.d. 0.083 i.d.	500-320	8-1/2	1200	27.00	0.20	230.
	1/4 o.d. 0.05 wall	500-315	3	420	60.	0.46	190.
	1/8 o.d. 0.02 wall	500-310	1/3	240	150.	0.20	50.
	0.09 o.d. 0.02 wall	500-305	2-3/4	3000	100.	0.09	272.
Plate	13/16 thick	500-180	114.	6 sq. ft.	15.00	285./sq.ft.	1710.
Bar	4-3/4 x 1	500-185	19-1/4	25	15.00	11.60	290.
Block	2 x 3 x 4	500-190	7-1/2	2 pcs.	13.50	50./pc	100.
Sheet	0.094 thick	500-230	177	80 sq.ft.	19.50	43./sq.ft.	3450.
	0.010 thick	500-215	1-1/4	5 sq.ft.	25.25	6.40/sq.ft.	32.

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TABLE I (continued)

Shape	Distinguishing Dimensions (in.)	Stores Numbers	Approximate Amount		Unit Costs		Total Value \$
			Weight (lbs.)	Length in in. or other amt. as noted	\$/lb	\$/in. of length or other units as noted	
Scrap	-----	500-1000	5	-----	{b}	-----	50. ^b
Valves	For 1/4 o.d. tubing	500-610	3	6 pcs	---	80.00	480.
Tees	1-1/2 dia. Sch.80	500-760	---	5 pcs	---	80. ^a	400. ^{a,c}
Ells	1-1/2 dia. Sch.80	500-720	---	10 pcs	---	40. ^a	400. ^{a,c}
TOTALS	-----	-----	982	---	Ave. 19.00	---	19070.

^a Estimated values.

^b Charge \$10./lb for odd sizes or scrap titanium when used.

^c Items have not been received before March 1, 1956.

Fig.1. Blanket Processing Loop T-1.

Fig. 2 Blanket Processing Loop T-1 (Front View)

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Fig. 3 Blanket Processing Loop T-1 (Rear View)