PROCUREMENT OF V-Cr-Ti ALLOYS TO STUDY MINOR VARIATIONS ON V-4Cr-4Ti — M. L. Grossbeck (Oak Ridge National Laboratory)

OBJECTIVE

The goal of this procurement is to provide commercially prepared alloy product form using minor variations in composition from the candidate alloy, V-4Cr-4Ti.

SUMMARY

The alloys V-6Cr-3Ti, V-4Cr-4Ti-Si, V-6Cr-6Ti, and V-3Cr-3Ti, were prepared by Teledyne Wah Chang Albany Corp. In 1994. Plate and sheet ranging from 0.76 mm to 6.35 mm with residual material being left in 12-20 mm thick bar were fabricated. Although the heats were prepared on a pilot plant scale using different equipment, an effort was made to keep the processing as close to Wah Chang Heat 832665, the reference fusion heat of V-4Cr-4Ti, as possible.

INTRODUCTION

Although work had been done on a number of V-Cr-Ti alloys in the process of developing the V-4Cr-4Ti alloy, minor variations of this specific composition are needed to optimize this alloy composition. This procurement was made to obtain commercially prepared product forms for physical property, mechanical property, irradiation performance, and welding studies in order to optimize the composition of the V-Cr-Ti alloy system.

RESULTS AND DISCUSSION

Four nominally 14 kg vacuum arc remelt heat of the alloys were ordered. Each heat was to be individually melted, extruded, and rolled. The compositions are shown in Table 1, and the product forms are shown in Table 2.

Table 1. Compositions of Vanadium Alloys, wt. %

Element	V-6Cr-3Ti	V-4Cr-4Ti-Si	V-6Cr-6Ti	V-3Cr-3Ti
Cr	6	4	6	3
Ti	3	4	6	3
Si*	400-1000	800-1000	400-1000	400-1000
V	bal	bal	bal	bal

*wt. ppm

Table 2. Product Forms*

Item	Form	Mass, g	Thickness, mm	Approximate Size, mm	No. Pieces
1	Sheet	730	0.76	300 × 500	1
2	Sheet	950	1.02	300 × 500	1
3	Plate	2180	3.81	300 × 300	1
4	Plate	3580	6.35	300 × 190	1
5	Rect. Bar†	bal	12-20	>50	1

Chemical Composition

The maximum impurity concentrations specified in the order appear in Table 3. Also in the table are the compositions of the alloys as determined by the vendor, Teledyne Wah Chang, and the compositions as measured by glow discharge mass spectrometry by an independent laboratory, Charles Evans & Associates. The major elements were specified to be within ±0.5% based on the total alloy. The GDMS technique is very useful for trace elements but less useful for the major

	Table 3. Chemical Compositions of Alloys (wt. ppm except where noted)								
		V-6Cr-3Ti		V-4Cr-4Ti-Si		V-6Cr-6Ti		V-3Cr-3Ti	
		Heat T92		Heat T89		Heat T90		Heat T91	
Element	Specification	Vendor	GDMS	Vendor	GDMS	Vendor	GDMS	Vendor	GDMS
B			3.4		3.5		3.9		3.8
C	200	105	<92	112	<120	104	<120	120	<140
N	200	95	92	79		85		62	
O	400	280		270		250		230	
Al	200	255	300	200	270	235	270	200	240
Si	400-1000*	950	1000	1000	1100	960	1400	940	1200
P	30	<50	22	<50	24	<50	24	<50	26
S	30	10	21	10	23	10	20	10	27
Cl	2		0.11		<0.048		<0.19		<0.15
Ca	10		<0.19		<0.11		<0.12		<0.14
Ti (%)		2.94	3.0	4.1	5.3	5.98		3.02	3.1
V		bal	bal	bal	bal	bal	bal	bal	bal
Cr (%)		5.97	6.2	3.7	4.9	5.74		2.84	3
Mn			1.7		1.9		1.7		1.1
Fe	300	165	140	170	140	195	120	130	110
Co			0.22		0.35		0.19		0.60
Ni			8.3		12		10		7.6
Cu	50	140	130	83	50	55	48	83	79
Zn			4.5		4.7		4.0		5.3
Ga			7.6		5.9		5.0		3.9
As			1.4		2.4		2.0		1.7
Sr			70		<120		<110		<76
Y			6.1		<9.3		8.6		<5.9
Zr			56		<63		<66		<48
Nb	50	<50	50	<50	≤56	<50	<54	<50	≤55
Mo	500		380		360		340		380
Ag			0.091		0.081		0.081		0.076
Cd			0.44		0.45		0.29		0.40
Hf			0.45		1.2		0.82		0.41
Ta			<9.0		<5.2		<98		<9.7
W			32		32		28		32
*800-1000 for V-4Cr-4Ti-Si, range not max.									

element compositions. Therefore, for Cr and Ti, the vendor's analysis is likely to be more accurate. Oxygen and nitrogen measured by GDMS were not given because of inconsistencies found previously between this technique and inert gas fusion analysis which is considered to be the method of choice for oxygen and nitrogen.

The minor element specifications were met very well. An exception is copper where measurements were as high as 140 ppm in contrast to the 50 ppm specified. This is not usually a concern in this alloy, and it is not a concern for neutron activation at this level. Measurements of aluminum were often above the specification of 200 ppm. This is a concern for two reasons: aluminum is a limiting element for neutron activation, and aluminum is used to reduce the V_2O_5, so it is a necessary part of the process.

Processing

All of the vacuum arc remelted ingots were machined to a nominal diameter of 117 mm by about 250 mm in length. The ingots were then welded into type 304 stainless steel cans 124 mm in diameter. The billets were then preheated 5 hours to 1149°C and then heated an additional 40 minutes to 1193°C in order to avoid stalling the extrusion press. The V-3Cr-3Ti billet was successfully extruded to 25 × 76 mm in cross section. The V-4Cr-4Ti-Si and the V-6Cr-3Ti were extruded to 35 × 79 mm since they stalled the press at a load of 1500 tons on the first try. The V-6Cr-6Ti was extruded through the same die after remachining and enclosing in a 114 mm diameter steel can. All extrusions were end cropped and sawed into about 300 mm lengths and fully machined to remove the steel cans.

Following the extrusion process, all material was acid pickled and vacuum annealed for two hours at 1075°C. After preheating for 45 minutes at 400°C, all pieces were cross-rolled to 12.7-13.7 mm in thickness. This required three roll passes for the thin extrusion and five passes tor the thicker extrusions. The annealed pieces were preheated for 25 minutes at 400°C and cross-rolled to 6.1-6.6 mm in seven passes. Each piece was reheated 10-30 minutes when about 9.7 mm in thickness. All but one piece of each alloy was pickled and annealed as before. The annealed pieces were then preheated 20 minutes at 400°C and cross-rolled to 3.2-3.4 mm in six passes. The 3.2-3.4 mm pieces were then pickled and vacuum annealed as before. The annealed pieces were cross rolled with no preheat (at ambient temperature) to two different intermediate thicknesses, depending upon the final thickness desired (2 mm for the 1 mm thick sheet and 1.6 mm for the 0.76 mm sheet). The percent reduction per rolling pass for the pieces rolled to 2 mm was within a range of 3% to 5%, and for the pieces rolled to 1.6 mm within a range of 3% to 6%. Based on recrystallization studies performed on a 3 mm plate, the annealing temperature for the 1.6 and 2 mm sheets was lowered to 1060°C for 2 hours. The annealed 2 and 1.6 mm pieces were again cross-rolled at ambient temperature. The rolled thickness was slightly greater to allow for hand conditioning of the final sheets. The reduction per rolling pass was with the range of 3-6%.

All pieces were roller leveled, hand conditioned to remove scratches and other defects and pickled.

CONCLUSIONS

Four heat of variations around the V-4Cr-4Ti composition were prepared. With very minor exceptions, the composition was with specifications. The product forms had excellent surface quality, meeting specifications. The product forms were sheet and plate ranging from 0.76 to 6.35 mm.