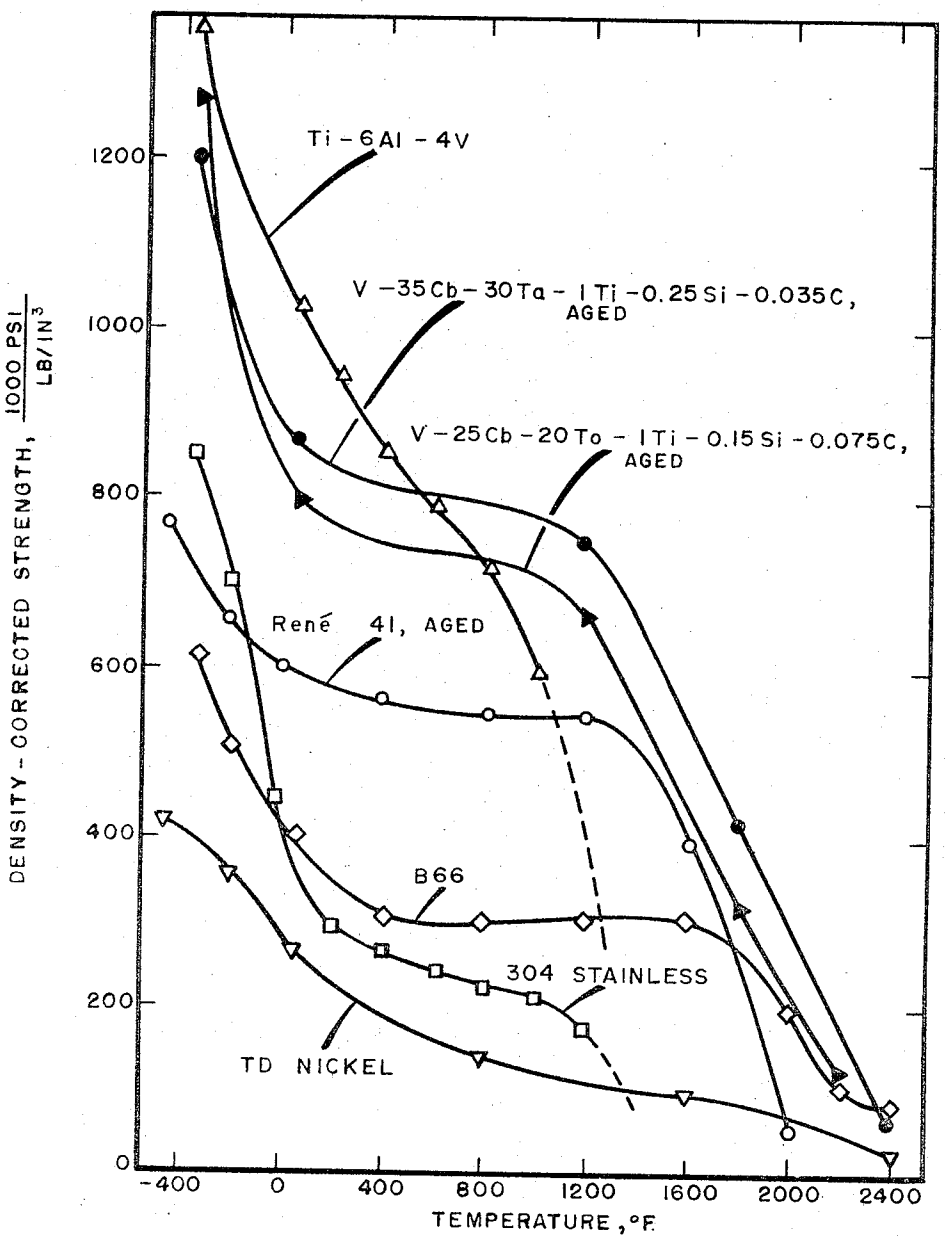
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VANADIUM-COLUMBIUM-TANTALUM ALLOYS

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ULTIMATE TENSILE STRENGTH DATA FOR STUCTURAL ALLOYS

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VANADIUM-COLUMBIUM-TANTALUM ALLOYS

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ABSTRACT OF THE DISCLOSURE

A vanadium-columbium-tantalum alloy with addition of titanium, silicon and carbon, characterized by high tensile strength and ductility at a range of temperatures from —320° F. to 2000° F.

This invention relates to a vanadium base alloy containing columbium and tantalum with small additives of silicon and carbon.

Previous vanadium alloy studies had indicated that vanadium-columbium base compositions had attractive short-time strength properties in the 1800° to 240° F. range. Limited testing at temperatures as low as —452° F. (—259° C.) showed these materials to be unusually strong and ductile. The present work was aimed at producing dispersion-strengthened compositions which would not only have good cryogenic properties but also good retention of strength at temperatures above that at which the nickel and cobalt base superalloys are used. Because of their comparatively low melting point, these alloys were not expected to be as strong as columbium, molybdenum, or other refractory alloys at temperatures in excess of 2400° F. However, the excellent fabrication characteristics and the ability to form reliable silicide oxidation-protective coatings indicate high potential for use over a wide range of temperatures. The development of space craft finds a need for alloys which will retain their strength at both low and high temperatures.

The object of the present invention is to provide an alloy or group of alloys which excel in fabricability, ductility and high strength over a range from —320° F. to at least 2400° F.

Another object of the present invention is to provide a group of alloys which will have high strength at extremes of low and high temperatures and which will form oxidation-protective coating.

Still another object of the present invention is to provide a vanadium based alloy containing columbium and tantalum and additives of silicon and carbon.

Other objects will be apparent from the subsequent disclosure and appended claims.

The drawing is a graph showing ultimate tensile strength data comparing two vanadium-columbium-tantalum base alloys with other alloys.

The alloys which are the subject of this invention are based on a V-Cb-Ta system with small additives of Si and C.

Materials used:

In the experimental procedures a single lot of vanadium melting stock was used with the following analysis of the V.

Oxygen	0.040
Nitrogen	0.028
Carbon	0.040
Hydrogen	0.004
Iron	0.050
Silicon	0.020

Nonconsumable-electrode arc-melted ingots of this melting stock had hardness levels in the VPN (10 kg.) 160–170 range.

Columbium sheet used as melting stock was electron-beam melted and had less than 0.01 wt. percent total oxygen and nitrogen. Tantalum sheet of similar purity was used. Minor additions such as Zirconium, silicon were made from high-purity commercial melting stock. Carbon was added as an arc-melted 95 V-5 C master alloy.

Percentages of materials used:

	Percent
Columbium	25–40
Tantalum	20–30
Titanium	1
Silicon	0.15–0.5
Carbon	0.037–0.125

Vanadium, remainder to make 100%.

INGOT PREPARATION

(1) *Melting*

All of the compositions were prepared by nonconsumable-electrode arc-melting under a highly purified argon atmosphere. Ingot weights ranged from 150 to 200 grams, depending on density, and the ingots were inverted and remelted five times to insure good homogeneity. These ingots were approximately 0.4 in. thick by 2.5 in. in diameter.

(2) *Thermal homogenization*

The arc-melted ingots were thermally homogenized in a tantalum-element resistance-heated furnace. These heat treatments were conducted under vacuum (10^{-5} torr or better) or in argon which was purified by passing the gas through hot titanium sponge and a liquid nitrogen trap. After heating for the desired length of time, the ingots were lowered from the hot zone and cooled by a stream of flowing argon at a rate of approximately 400° F./min.

(3) *Ingot fabrication*

The initial ingot breakdown for nearly all of the alloys was achieved by hammer forging. The ingots were jacketed in 0.030 in. thick stainless steel, then evacuated. Hammer forging was done at 2350°–2400° F. on a mechanical drop hammer. Reductions in thickness of 30 to 40% were used to obtain a final forged thickness of 0.25 to 0.30 in. The more difficult-to-work alloys required reheating to achieve this reduction. After forging, jackets were stripped and any edge or surface cracks were removed by grinding. The conditioned ingots were then cold-rolled, in most cases with intermediate vacuum annealing, to sheet ranging in thickness from 0.004 to 0.027 in. Rolling reduction was initially 10% per pass, although smaller reductions were used when the sheet was less than 0.030 in. thick. A list of representative compositions together with the procuring methods and results of ingot fabrication is presented in Table I.

TABLE I.—VANADIUM ALLOY FABRICATION DATA

Composition, wt. percent	Density, lb./in.³	Fabrication Procedures [a]	Results
V-40Cb-30Ta-1Ti-0.5Si-0.075C	0.31	TH 2,800° F.-HF	Cracked.
		HF-CR	Cracked at 0.2 in.
V-40Cb-30Ta-1Ti-0.25Si-0.037C	0.31	HF-CR	Slight cracking at 0.35 in.
V-40Cb-30Ta-1Ti-0.25Si-0.025C	0.31	HF-CR-Ann-CR	Some surface cracks in 0.004 in. foil.
V-35Cb-30Ta-1Ti-0.25Si-0.035C	0.31	HF-CR-Ann-CR	Good sheet, 0.028 in.
V-35Cb-30Ta-1Ti-0.25Si-0.05C	0.31	TH 2,600° F.-HF-CR-Ann-CR	Some cracking in 0.025 in. sheet.
		HF-CR-Ann-CR	Moderate cracking at 0.035 in.
V-35Cb-25Ta-1Ti-0.2Si-0.03C	0.30	HF-CR-Ann-CR	Slight surface cracking in 0.008 in. sheet.
V-30Cb-20Ta-1Ti-0.25Si-0.05C	0.28	HF-CR-Ann-CR	Slight surface cracking in 0.008 in.
V-25Cb-20Ta-1Ti-.15Si-0.075C	0.27	HF-CR	Very slight edge cracking at 0.04 in.
V-25Cb-20Ta-1Ti-0.15Si-0.125C	0.27	TH 2,600° F.-HF-CR	Cracked at 0.17 in.
		TH 2,300° F.-HF-CR	Cracked severely.

[a] TH=thermal homogenization: 3 hr. at 2,800° F., 4 hr. at 2,300 and 2,600° F.; HF=hammer forge; Ann=vacuum anneal ½ hr. at 2,000 to 2,400° F.; CR=cold roll.

RECRYSTALLIZATION

Alloys based on V-Cb-Ta were evaluated for recrystallizaion behavior. Sheet specimens were cold-rolled to reduction in thickness of about 80%, then annealed in a vacuum for 30 min. at temperatures in the 1600–2400° F. range. The extent of recrystallization was determined by metallographic observation, and hardness measurements were also taken on the annealed specimens. Table II lists the lowest temperatures at which complete recrystallization occurred after 30 min. annealing treatments conducted at 100° F. intervals. Hardness data for the fully recrystallized specimens are also included.

TABLE II.—RECRYSTALLIZATION AND HARDNESS DATA FOR VANADIUM ALLOYS

Composition, wt. Percent	Recrystallization Temp., ° F.	Hardness, VPN
V-40Cb-30Ta-1Ti-0.25Si-0.025C	1,900	426
V-35Cb-30Ta-1Ti-0.25Si-0.035C	2,000	426
V-35Cb-25Ta-1Ti-0.2Si-0.03C	1,900	390
V-30Cb-20Ta-1Ti-0.25Si-0.05C	1,907	308
V-25Cb-20Ta-1Ti-0.15Si-0.075C	1,900	358
V-25Cb-20Ta-1Ti-0.25Si-0.125C	2,000	348

AGING RESPONSE

Studies of aging behavior were carried out on selected alloys of the V-Cb-Ta system. Sheet specimens were fully annealed for 30 min. at 2000° F. The specimens were cooled from the annealing temperature at a rate of about 250° F./min. to room tempertaure, then cold-rolled to reductions in thickness of 60–80%. Aging was conducted at temperatures from 1200 to 1600° F. Most of the aged specimens were evaluated by room temperature tensile tests.

CRYOGENIC TENSILE PROPERTIES

The alloys were tested for tensile strength at temperatures as low as that of liquid nitrogen (−320° F.). The tested specimens had a ¼ by 1 in. gage section, and were tested at a strain of 0.005 in./in./min. The results are shown in Table III.

TABLE III.—TENSILE DATA FOR VANADIUM ALLOYS AT LIQUID NITROGEN TEMPERATURE (−320° F.)

Composition, wt. percent	Treatment [a]	Ultimate Tensile Strength, p.s.i.	Total Elongation, percent	Density-Corrected Strength, U.T.S./(lb./in.³)
V-35Cb-30Ta-1Ti-0.25Si-0.035C	Aged 1,300° F., 5 hr	370,000	7.7	1,200,000
V-25Cb-20Ta-1Ti-0.15Si-0.075C	Aged 1,300° F., 5 hr	350,000	14.2	1,282,000

[a] Aging treatments after 60–80% reduction by cold rolling.

TABLE IV.—ROOM-TEMPERATURE TENSILE DATA FOR FULLY ANNEALED VANADIUM ALLOYS

	Ultimate Tensile Strength, p.s.i.	0.2% Offset Yield Strength, p.s.i.	Elongation, percent	Density Corrected Strength, U.T.S (lb./in.³)
V-40Cb-30Ta-1Ti-0.25Si-0.025C [a]	200,000	194,000	3	637,000
V-35Cb-30Ta-1Ti-0.25Si-0.035C [a]	183,000	175,000	21	596,000
V-35Cb-25Ta-1Ti-0.2Si-0.03C [a]	191,000	185,000	9	648,000
V-30Cb-20Ta-1Ti-0.25Si-0.05C [a]	164,000	150,000	3	588,000
V-25Cb-20Ta-1Ti-0.15Si-0.07C [a]	145,000	133,000	13	531,000

[a] 2,200° F., 30 min.

ROOM TEMPERATURE TENSILE PROPERTIES

Tensile results for the V-Cb-Ta base alloys show generally decreasing strength with increasing vanadium content. One of the alloys shown in Table IV had an elongation of 21%, a value comparable to those of high vanadium alloys.

ELEVATED-TEMPERATURE TENSILE PROPERTIES

Tests for tensile strength were conducted on sheet specimens of alloys at 1200, 1800, 2000, 2200 and 2400° F. using a strain rate of 0.05 in./in./min. The sheet stock was approximately 0.008 in. thick and the specimens were tested in the as-rolled, fully annealed and cold-rolled and aged condition.

TABLE V.—ELEVATED-TEMPERATURE TENSILE DATA FOR V-Cb-Ta BASE ALLOYS

Composition, wt. percent	Treatment	Test Temp., ° F.	Ultimate Tensile Strength, p.s.i.	Elongation, percent	Density-Corrected Strength, U.T.S./(lb./in.^{3})
V-40Cb-30Ta-1Ti-0.25Si-0.025C	Annealed 2,400° F., 30 min.[a]	2,000	86,700	8	276,000
V-35Cb-30Ta-1Ti-0.25Si-0.035C	Annealed 2,200° F., 30 min.[a]	1,200	164,000	12	534,000
	Cold rolled; aged 1,200° F., 48 hr	1,200	232,000	3	736,000
	Cold rolled 60%	1,800	134,000	15	437,000
	Annealed 2,200° F., 30 min.[a]	1,800	120,000	7.5	392,000
	Cold rolled 60%	2,400	22,100	68	72,000
V-35Cb-25Ta-1Ti-0.2Si-0.03C	Annealed 2,400° F., 30 min.[a]	2,000	73,200	[b]	248,000
V-30Cb-20Ta-1Ti-0.25Si-0.05C	Annealed 2,400° F., 30 min.[a]	2,000	70,000	[b]	251,000
V-25Cb-20Ta-1Ti-0.15Si-0.075C	Cold rolled; aged 1,300° F., 4 hr	1,200	182,000	1.5	668,000
	Cold rolled; aged 1,300° F., 4 hr	1,800	84,000	20	307,000
	Annealed 2,200° F., 30 min.[a]	1,800	104,000	14	382,000
	Cold rolled; aged 1,300° F., 4 hr	2,200	31,700	40	116,000
	Annealed 2,200° F., 30 min.[a]	2,200	44,000	19	161,000

[a] Cooled at 250° F./min. [b] Broke outside of gage marks.

Referring to the drawings, it will be seen that two vanadium-columbium-tantalum base alloys compare favorably with the cryogenic alloys (stainless steel and titanium base) at low temperatures and do not exhibit the sharp decrease in strength. They are stronger on a density corrected basis than the nickel-base superalloy at all temperatures.

Density-corrected strength data for the high-vanadium alloys would show values similar to those reported for the V-25 CB-20 Ta base alloy at temperatures up to about 1200° F. At higher temperatures, the V-20 Cb-10 Ti base alloys lose strength more rapidly than the tantalum containing materials. At 2000° F., the high vanadium alloys have density corrected strengths in the 120,000 to 179,000-in. range; similar strengths are retained by the V-25 Cb-20 Ta base material at 2200° F.

On the basis of these strength data, the higher tantalum alloy appears to be the best for use over a wide range of temperature.

COMPARATIVE DATA

A comparison of the tensile strength of the experimental alloys with those of commercial cryogenic and refractory materials shows the temperature ranges over which the vanadium alloys demonstrate attractive properties. Vanadium alloys compare favorably with the cryogenic alloys (stainless steel and titanium base alloys) and the vanadium alloys do not exhibit the sharp decrease in strength above 1200° F.

The vanadium alloys, enriched with silicon and carbon, exhibit excellent fabricability. They are as good as stainless steel at low temperatures and surpass the nickel-base alloys at all test temperatures.

What is claimed is:

1. An alloy having high tensile strength and ductility at temperatures between −320° F. and 2200° F. consisting essentially of

25–40% Cb, 20–30% Ta, 1% Ti, 0.15–0.5% Si, .037–.125% C-remainder V.

2. An alloy according to claim **1** in which the specific proportions are 40 Cb-30 Ta-1 Ti-0.5 Si-0.075 C-remainder V.

3. An alloy according to claim **1** in which the specific proportions are 40 Cb-30 Ta-1 Ti-0.25 Si-0.075 C-remainder V.

4. An alloy according to claim **1** in which the specific proportions are 40 Cb-30 Ta-1 Ti-0.25 Si-0.037 C-remainder V.

5. An alloy according to claim **1** in which the specific proportions are 40 Cb-30 Ta-1 Ti-0.25 Si-0.025 C-remainder V.

6. An alloy according to claim **1** in which the specific proportions are 35 Cb-25 Ta-1 Ti-0.2 Si-0.03 C-remainder V.

7. An alloy according to claim **1** in which the specific proportions are 30 Cb-20 Ta-1 Ti-0.25 Si-0.05 C-remainder V.

8. An alloy according to claim **1** in which the specific proportions are 35 Cb-30 Ta-1 Ti-0.25 Si-0.035 C-remainder V.

9. An alloy according to claim 1 in which the specific proportions are 25 Cb-20 Ta-1 Ti-0.15 Si-0.075 C-remainder V.

10. An alloy according to claim **1** in which the specific proportions are 25 Cb-20 Ta-1 Ti-0.25 Si-0.125 C-remainder V.

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