

Titanium and Titanium Alloys

Wah Chang is a producer of zirconium, niobium, titanium, hafnium, and vanadium and high purity's including titanium, zirconium, and hafnium crystal bar. These products are available in forms of mill and cast products, hydride and/or dehydride powders, and chemicals. Wah Chang's products are utilized in aerospace, chemical processing, medical, recreational, electronic, military, and nuclear applications worldwide.

Titanium Production

Wah Chang entered the titanium market in the early 1970's when the demand arose for Ti-3Al-2.5V (ASTM Grade 9), a higher strength, ductile alloy for hydraulic tubing specified in high-performance military aircraft designs. Wah Chang developed the processes necessary to produce the starting tube-reduced extrusions (TRES) from which finished tube could be fabricated successfully. With 30 years of experience in manufacturing reactive and refractory metals, Wah Chang was well equipped to meet the stringent quality demands for this high-strength alloy. Since the '70s, our titanium interests have expanded into other product forms and alloys including sheet, plate, bar, and powder, in grades 1, 2, 3, 4, 9, and 12 and alloys such as Ti-15V-3Cr-3Al-3Sn (Ti 15-3).

Wah Chang's major areas of expertise in titanium production are:

- Manufacturing high-quality pipe and tubular products including specialized extrusions.
- Producing extra-low chloride (ELC) powders.
- Assisting end users in alloy development.
- Producing large sized castings

One of Wah Chang's major strengths in titanium production is our ability to meet unique product requirements -whether large or small. If you have a special application and think titanium might present a viable solution, let our engineers put their expertise to work for you. We are uniquely qualified to meet unusual alloy requirements.

In addition to manufacturing reactive and refractory metals, Wah Chang offers a wide range of conversion services. Our fabrication/conversion facility includes a 3,500-ton extrusion press, two pilger mills, a 2,000-ton forge press, a GFM rotary forge, hot and cold mills, and continuous annealing and pickling lines.

MILL PRODUCTS

Following is a list of the types and size ranges of Commercial Grade titanium mill products supplied by Wah Chang. Grades 1, 2, 3, 4, 7, 9, and 12 are fabricated and meet all Boiler and Pressure Vessel Code Specifications. Chemical compositions are listed on the Chemical Components Data Sheet.

Strip and Sheet

– **ASTM B 265** Flat sheet is supplied cold rolled and vacuum or protective gas annealed in thicknesses from 0.030" to 0.125", widths up to 25", by specified length. Coiled strip is routinely supplied cold rolled and vacuum or protective gas annealed in thicknesses from 0.030" to 0.125", widths up to 25", and weights up to 3,000 pounds (for 24" width). (Thinner strips and widths up to 39.37" are also available.)

Plate

– **ASTM B 265** Plate is hot rolled, annealed, and descaled with sheared edges and is available in thicknesses greater than 1/8", Widths up to 60", and lengths up to 165". On special order, widths are available up to 96", lengths up to 240", and thicknesses of 3/16" and over. Discs up to nominally 60" diameter for tube sheet can be machined from plate.

Billet

– **ASTM B 348** Ingots are pressed or rotary forged to round, square, hexagonal, octagonal or flat billets. All billets are annealed, descaled and cleaned. Rotary Forged billets are available up to 13" in diameter and up to 33' in length.

Bar

– **ASTM B 348** Bar products are supplied in annealed, descaled and cleaned condition and are available in 3/8" to 8" diameter by 6' to 20' random lengths.

Tube

– **ASTM B 338** Tube is seamless (extruded, cold reduced, and vacuum annealed). Standard diameters are 3/4" O.D., 1" O.D. and 1 1/2" O.D.. Standard wall thicknesses are 0.035", 0.049" and 0.065". A wide variety of sizes are available upon request

Tube Shell

– Wah Chang also supplies extruded tube shell in 3.4" O.D. x .790", .600" and .450" wall and 3.1 " O.D. x .525" and .370" wall for further conversion as well as once-reduced extrusion (TREX) with common sizes 2.5" O.D. x .430 wall; 2.0" x .430", .330" or .187" wall; 1.5" O.D. x .133" wall; 1.375" O.D. x .187" wall; and .840" O.D. x .083" wall, x nominally 10' to 15' lengths. Custom Sizes are available.

Castings

– Titanium castings are readily available. Please call Wah Chang for further information.

Ingot

– Ingot is available up to 27" diameter x 140" long.

Fittings

ASTM B 363 - Standard pipe fittings (both seamless and welded), including ells, tees, reducers, flanges, and stub ends, can be produced in all of Wah Chang's pipe sizes. Wah Chang also supplies starting stock for manufacture of pipe fittings and fastener stock for nuts, bolts, washers, dowel pins, etc. Flanged and dished heads are manufactured up to 90" diameter. For other sizes and types, such as 2:1 semi-elliptical, information is available upon request.

Clad Plate

– Titanium clad plate is produced by explosive bonding for process equipment.

Developmental Alloys

– Wah Chang welcomes requests for the melting and fabrication of specialty alloys. Small lots of forged barstock from the beta and near-beta titanium alloys, such as Ti-13V-11Cr-3Al and Ti-13V-3Cr-3Al-3Sn (Ti 15-3) are routinely produced. Seamless tubing has been fabricated in Ti 15-3. Ti Grade 7 is an alpha alloy formulated to have improved corrosion performance as compared to the commercially pure grades, especially crevice corrosion in hot brine environments.

Ti 15-3 is a near-beta composition that has potential as hydraulic tubing material. Ti 15-3 is a cold formable, age hardenable titanium alloy that exhibits improved engineering design properties and has a decided density advantage over comparable stainless steel alloy 21-6-9 (AMS 5561). Ti 15-3 is also available as cold rolled strip.

Pipe

- ASTM B 337 The following Pipe Schedule Table lists standard pipe sizes which are avail-able. All pipe is seamless (extruded, or extruded-cold reduced and vacuum annealed).

Pipe Schedules

Pipe Size	O.D (inches)	Pipe Schedule (inches)				
		5	10	20	40	80
3/8	0.675	.049	.065			
1/2	0.840	.065	.083*		.109*	.147
3/4	1.050	.065	.083*		.113*	.154*
1	1.315	.065	.109*		.133*	.179*
1 1/2	1.900	.065	.109		.145*	.200
2	2.375	.065	.109*		.154*	.218
2.5	2.875				.203*	.276
3	3.500	.083	.120*		.237*	.337
5	5.563				.256*	.375
6	6.625	.109	.134		.280*	.432
8	8.625	.109	.148	.250	.322	.500

*Typical stock items

CONVERSION SERVICES

In addition to supplying titanium mill products, Wah Chang offers a wide range of conversion services to customers with special melting and fabricating needs.

Our Consolidation Division can perform first melts using your raw material or remelt material into a full range of diameters from 6" to 27" and 140" in length.

Wah Chang has the ability to melt a diverse range of materials including zirconium, niobium, titanium, tantalum, hafnium, vanadium, molybde-num, tungsten and their alloys. Our consolidation facilities include both vacuum arc and electron beam furnaces.

Wah Chang's fabrication/conversion facility is one of the largest of its kind in the nation and includes:

- A GFM Rotary Forge capable of processing diameters from 15 3/4" starting size to 2 1/2" finishing size and lengths up to 33 feet.
- A 2-high hot mill capable of processing plate to a minimum thickness of 1/8" and a maximum width of 29".
- Two 4-High Cold Mills capable of processing coils to a minimum thickness of .016" x 18" wide or .025x25" wide.
- A Sendzimir Mill capable of rolling foil gauges x 13" maximum width.
- Two Cold Pilger Mills - a 4" mill and a 2" mill capable of producing standard final tube sizes from 1/2" OD to 3 1/2" OD, and pipe schedule from 1/2" to 2 1/2".
- Electric heated air furnaces.
- Vacuum Annealing furnaces.

CHEMICAL COMPOSITION OF TITANIUM

Grade 1

Composition Limits, %	
0.03	Maximum N
0.10	Maximum C
0.015	Maximum H (a)
0.18	Maximum O
0.20	Maximum Fe
0.10	max. others (each)
0.40	max. others (total)
Remainder	Ti
Min. Ti content 99.175	

Grade 3

Composition Limits, %	
0.05	Maximum N
0.10	Maximum C
0.015	Maximum H (a)
0.35	Maximum O
0.30	Maximum Fe
0.05	max. others (each)
0.30	max. others (total)
Remainder	Ti
Min. Ti content 98.885	

Grade 2

COMPOSITION LIMITS, %	
0.03	Maximum N
0.10	Maximum C
0.015	Maximum H (a)
0.25	Maximum O
0.30	Maximum Fe
0.05	max. others (each)
0.30	max. others (total)
Remainder	Ti
Min. Ti content 98.885	

Grade 4

Composition Limits, %	
0.05	Maximum N
0.10	Maximum C
0.015	Maximum H (a)
0.40	Maximum O
0.50	Maximum Fe
0.05	max. others (each)
0.30	max. others (total)
Remainder	Ti
Min. Ti content 98.635	

Grade 7

Composition Limits, %	
0.03	Maximum N
0.10	Maximum C
0.015	Maximum H (a)
0.25	Maximum O
0.30	Maximum Fe
0.12 to 0.25	Pd
0.05	max. others (each)
0.30	max. others (total)
Remainder	Ti
Min. Ti content 99.005	

Grade 9

Composition Limits, %	
2.5 to 3.5	Al
2.0 to 3.0	V
0.15	Maximum O
0.02	Maximum N
0.10	Maximum C
0.30	Maximum Fe
0.015	Maximum H
0.10	max. others (each)
0.40	max. others (total)
Remainder	Ti

Grade 12

Composition Limits, %	
0.03	Maximum N
0.08	Maximum C
0.015	Maximum H (a)
0.25	Maximum O
0.30	Maximum Fe
0.2 to 0.4	Mo
0.6 to 0.9	Ni
0.10	max. others (each)
0.40	max. others (total)
Remainder	Ti

HIGH PURITY TITANIUM ALLOYS

Applications of sputtered metal coatings have expanded rapidly over recent years, especially in the electronic industry. Applications range from glass coating to filter sunlight to semiconductor chip coating in microprocessors. The type of application determines the purity required of the sputtered coating. Glass coating requires significantly lower purity than semiconductor coatings. Also, as microprocessor technology advances in reducing the size of computers, chip sizes must also be reduced. This is possible mainly through improved purity. Titanium sputtering target levels of 99.995% are currently available commercially from numerous sources. However, the process used by Wah Chang produces pure titanium with a very low oxygen content. This reportedly is equally important as the low metallic impurity levels in the performance of the coating.

Shown in the table are descriptions of titanium metal purities produced by Wah Chang for producers of sputtering targets. These are available in all mill shapes including powder. Nonmetallic impurity levels will vary with the powder size desired.

Element	Tiadyne 4N	Tiadyne 4N5	Tiadyne 5N
Non-metals, ppm			
O	≤500	<400	≤150
N	≤50	≤50	≤50
C	≤50	≤50	≤50
Cl	≤5	≤5	≤5
S	≤10	≤10	≤10
Metals, ppm			
Fe	≤50	≤10	≤5
Al	≤20	≤10	≤2
Ni	≤10	≤5	≤1
Cr	≤20	≤5	≤3
Si	≤10	≤5	≤1
Cu	≤5	≤5	≤1
Sn	≤10	≤5	≤1
Mo	≤2	≤2	≤1
Sb	≤5	≤5	≤1
Na	≤5	≤0.2	≤0.1
Ca	<5	≤2	≤1
As	<5	<5	≤1
K	<5	≤0.1	≤0.1
U	≤0.007	≤0.002 Total	≤0.002 Total
Th	≤0.007		
% Titanium	99.9	99.995	99.999

PHYSICAL PROPERTIES OF TI-3AL-2.5V

Titanium and its alloys are used in areas where their corrosion-resistance and strength efficiency can be successfully applied. They have the ability to passivate, thus exhibiting a high degree of immunity to attack by most mineral acids and chlorides. Ti-3Al-2.5V has proved to be a sufficiently malleable material for tube manufacture. It can be cold worked by standard tube making processes, is weldable and can be strength-ened by cold working and subsequent heat treatment to a wide range of strengths and ductility's.

Density	lb/cu.in.	0.162	
	g/cu.cm	4.48	
Melting Point	3100°F(1700°C)		
Beta Transus	1715°F(935°C) approx.		
Electrical Resistivity	Microhm-in.	49.6	
	Microhm-cm.	126	
Thermal Conductivity	BTU/hr/ft ² /°F/ft Calculated	at 72°F	4.8
		at 200°F	5.3
		at 400°F	6.2
		at 600°F	6.8
Coef. of Thermal Expansion	10 ⁻⁶ in/in/°F	5.3	
Modulus of Elasticity,	at RT, psi	15.0 × 10 ⁶	
	at 1450°F, psi	14.0 × 10 ⁶	
Shear Modulus, psi	6.2-6.5 × 10 ⁶		
Poisson's Ratio	0.30		

MECHANICAL PROPERTIES OF TI-3AL-2.5V

Table A Tensile and Yield Strength

Temp °C(°F)	Tensile Strength MPa (ksi)	Yield Strength MPa (ksi)	%Elong. in 50mm
Cold worked and stress-relieved			
RT	895 (130)	760 (110)	19
150 (300)	785 (114)	640 (93)	17
250 (480)	715 (104)	585 (85)	15
Annealed			
RT	655 (90)	560 (72)	29
150 (300)	565 (82)	455 (66)	25
250 (480)	490 (71)	380 (55)	23

Table B Creep and Stress-Rupture Data for Titanium Alloys (5)

Alloy	Stress to 1.0% Creep in 1000 hrs. at		Stress to Rupture in 1000 hrs. at	
	250°C MPa	(482°F) ksi	250°C MPa	(482°F) ksi
CP Grade 1	90	13	103	15
CP Grade 2	103	15	117	17
CP Grade 3	131	19	138	20
Ti 3Al 2.5V (Grade 9)	400	58	421	61
Ti 0.3Mo 0.8Ni (Grade 12)	221	32	297	43

MECHANICAL PROPERTIES OF TI-3AL-2.5V

Table C Ultimate Tensile Strength Comparison of Aerospace Materials

Material	Condition	psi	(MPa)
AM 350 Steel	SCT 850	206,000	(1419)
Ti 6Al 4V	STA	160,000	(1102)
Ti 15V 3Cr 3Al 3Sn	Aged	135,000	(930)
Ti 6Al 4V	A	134,000	(909)
Ti 3Al 2.5V	CWSR	132,000	(909)
21-6-9 Steel	10% CW	130,000	(896)
21-6-9 Steel	A	111,000	(765)
304 SS	CW	100,000	(689)
Ti 3Al 2.5V	A	90,000	(655)
304 SS	A	85,000	(586)
CP Titanium Ti 70	A	80,000	(551)

Key:

A = Annealed

CW = Cold Worked, Unannealed

CWSR = Cold Worked, Stress Relief

Annealed

SCT = Subcooling and Tempering

STA = Solutions Treated and Aged

Table D Yield Strength Comparison of Aerospace materials

Material	Condition	psi	(MPa)
AM 350 SS	SCT 850	173,000	(1192)
Ti 6Al 4V	STA	145,000	(999)
Ti 15V 3Cr 3Al 3Sn	Aged	125,000	(861)
Ti 6Al 4V	A	126,000	(896)
Ti 3Al 2.5V	CWSR	1165,000	(579)
21-6-9SS	10% CW	115,000	(792)
Ti 3Al 2.5V	A	72,000	(579)
CP Titanium Ti 70	A	70,000	(482)
304 SS	CW	70,000	(482)
21-6-9 SS	A	64,000	(441)

Table E Elevated Temperatures Tensile Properties Comparison

Alloy	Cond.	Test Temp.		Ultimate		Yield		%Elong.
		°F	°C	psi	Mpa	psi	MPa	
CP Ti	A	RT	RT	75,000	520	48,700	336	36
		392	200	46,100	318	25,400	175	59
		662	350	33,200	229	16,600	114	58
		932	500	19,000	131	12,300	85	78
Ti 3Al 2.5V	A	RT	RT	94,500	651	86,500	596	30
		392	200	72,600	500	61,900	426	30
		662	350	63,600	438	52,200	360	29
		932	500	46,200	318	35,800	247	50
Ti 3Al 2.5V	CWSR	RT	RT	131,900	909	116,100	800	20
		392	200	108,600	748	92,600	638	17
		662	350	97,700	673	80,000	336	16
		932	500	65,400	451	48,700	336	51

CORROSION RESISTANCE

Titanium is, by nature, a reactive metal. It is protected by a titanium dioxide surface film with high thermodynamic stability in many corrosives such as natural waters, oxidizing acidic brines and many other environments. As with any metal, titanium is not immune to all environments and should not be misapplied. Ti-3Al-2.5V was developed for use in the aerospace industry because of its high strength and excellent fabricability as well as the resistance to corrosion by seawater that characterizes all of the titanium alloys. This alloy is now being used in other industries because of its corrosion resistance to many troublesome chemicals. When used in these applications the alloy is known as ASTM Grade 9 and appears in most of the titanium product specifications.

It should be noted that while the alloy is normally used in the cold-worked and stress-relieved condition in aerospace applications, it is usually used in the annealed condition for corrosion resistant applications. Grade 9 is superior to Grades 2 and 12 in strength-density ratio. The higher weight efficiency advantage offers new opportunities to the designer of chemical process equipment.

The results of immersion corrosion tests conducted by Wah Chang are given in Corrosion Table F. The corrosion behavior of Grade 9 is similar to that of unalloyed titanium, and thus its usefulness extends to a wide spectrum of chemicals. The particular areas of interest are oxidizing acids, salt solutions and organic compounds. Grade 9 is also very resistant to inhibited reducing acids. The inhibiting effect of the ferric ion can be seen in the test results shown in Table E while the beneficial effects of other oxidizing agents such as Cu^{+2} , Cr^{+6} , Ti^{+4} , chlorine and oxygen are yet to be determined.

Welds in Grade 9 to the extent tested thus far show corrosion resistance equivalent to the base metal. Prior to application in a corrosive media, welded specimens should always be tested in the actual service solutions. Researchers in Wah Chang's fully equipped corrosion laboratory are available to assist customers in need of testing services and advice.

Grade 9 is essentially immune to stress corrosion cracking in boiling seawater and simulated sour gas well brines at room temperature. Table G shows these test results and also indicates that coupling Grade 9 to steel does not degrade its resistance to stress cracking. All U-bends remained ductile, although the steel component of the couple showed accelerated corrosion during these tests.

Crevice corrosion specimens of Grade 9 were tested in boiling seawater for 130 days. No general, pitting, or crevice corrosion was detected. Grade 9 has improved resistance to crevice corrosion as compared to Grade 2 titanium. Crevice corrosion has often limited titanium's usefulness in handling chloride-containing environments.

By taking advantage of excellent fabricability, me-chanical properties, and corrosion properties, Grade 9 is a cost effective material for many applications which include marine, flue gas desulfurization systems, and construction of pressure vessel equipment.

Table F Corrosion of Ti-3Al-2.5V and Titanium in Nonareated Solutions

Solution	Temp. °C	Ti 3Al 2.5V	Titanium
Acids			
10% HNO ₃	Boiling	3.3	4.4
20% HNO ₃	Boiling	10.5	8.0
30% HNO ₃	Boiling	19.6	20.0
40% HNO ₃	Boiling	27.9	24.4
50% HNO ₃	Boiling	18.1	24.6
60% HNO ₃	Boiling	14.1	15.9
70% HNO ₃	Boiling	5.4	5.2
65% HNO ₃	204	0.3	0.1
Aqua Regia	Boiling	51.0	44.0
Aqua Regia	R.T.	0.6	nil
10% Chromic	Boiling	0.3	0.1
30% Chromic	Boiling	2.1	0.4
50% Chromic	Boiling	10.1	1.4
1% HCl	Boiling	110.0	85.0
1% HCl +0.2% FeCl	Boiling	0.2	<5.0
5% HCl	Boiling	1055.0	840.0
5% HCl +0.2% FeCl	Boiling	1.3	<5.0
10% HCl	Boiling	>3000	>2000
10% HCl +0.2% FeCl	Boiling	12.0	<5.0
0.5% H ₂ SO ₄	Boiling	334.0	>200
Alkalis			
50% NaOH	150	19.4	2.2
50% KOH	150	363.0	108.0
8% NH ₄ OH	150	nil	nil
28% NH ₄ OH	150	nil	nil
Organic Compounds			
50% Citric Acids	Boiling	15.0	14.0
50% Sulfamic Acid	Boiling	175.0	160.0

50% Formic Acid	Boiling	200.0	433.0
50% Urea	150	0.2	nil
100% Methanol	Boiling	nil	nil
100% Acetic Aci	Boiling	nil	nil
Salts			
Seawater	Boiling	nil	nil
5% NaCl+0.5% CH ₃ COOH+Saturated H ₂ S	R.T.	nil	nil
5%NaCl+0.5%CH ₃ COOH+1%S+Saturated H ₂ S	R.T.	nil	nil

Table G Test Results of Longitudinal and Transverse Cut U-Bends of Ti-3Al-2.5V

Solution	Temp °C	No Galvanic Effect	U-Bend/ Steel Coupled
Seawater	Boiling	(130)	(130)
5% NaCl + 0.5% CH ₃ COOH +Saturated H ₂ S	R.T.	(100)	(100)
5% NaCl+0.5% CH ₃ COOH +0.1%S+Saturated H ₂ S	R.T.	(100)	(1000)

HEALTH AND SAFETY

Titanium is nontoxic and consequently does not require serious limitations on its use because of health hazards. It is pyrophoric, however, because of its heat-producing reaction with oxidizing elements such as oxygen. Large pieces of sheet, plate, bar, tube and ingot can be heated to high temperatures without excessive oxidation or burning. However, small pieces with a high surface area to mass ratio, such as machine chips and turnings, are easily ignited and burn at extremely high temperatures.

Large accumulations of chips and other finely divided materials should be avoided. When storing the chips and turnings, care should be taken to place the material in nonflammable containers and isolated areas. One effective storage method is to keep the material covered with water in the containers and in turn, use oil on the water. Use dry sand, powdered graphite, or commercially available Metal-X* powder. Other flammables in the vicinity of a titanium fire can be extinguished with large quantities of water.

*Metal-X is a registered trademark for powder produced by Ansul Manufacture in Marinette, Wisconsin.

MATERIAL SAFETY DATA SHEETS

A Material Safety Data Sheet (MSDS) is available for titanium products produced by Wah Chang. The list below gives the MSDS reference number by product line.

MSDS Reference Numbers

Product	Reference Number
Titanium Metal	801
Titanium Sponge	802
Titanium Powder, Fines & Dust	803
Titanium Hydride	806
Titanium Base Alloys	833