MetalNet℠
SOLUCIONES METALICAS

Titanio

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PROPERTIES OF TITANIUM AND ITS ALLOYS

At one time only commercially pure (c.p.) titanium was used, primarily for its corrosion resistance, in marine and offshore applications. Requirements for higher strength have progressively introduced titanium alloys, the range of which is such that titanium can now satisfy almost every design and engineering requirement. A convenient and widely used system for specific identification of the various grades of commercially pure titanium and titanium alloys used for engineering and corrosion resisting applications is provided by ASTM which cover all the forms supplied in titanium and its alloys:- B 265 - Strip Sheet and Plate . B 337 - Seamless and Welded Pipe B 338 - Seamless and Welded Tube B 348 - Bars and Billets B 363 - Seamless and Welded Fittings B 367 – Castings B 381 – Forgings B 861 - Seamless Pipe (to replace B337) B 862 - Welded Pipe (to replace B337) B 863 – Wire Welding consumables are covered by AWS A5.16.

ASTM Grades 1,2,3,4 are commercially pure (alpha) titanium, used primarily for corrosion resistance. Strength and hardness increase, and ductility reduces with grade number. Grade 2 is the most widely used specification in all product forms. Grade 1 is specified when superior formability is required. Grade 3 may be used where higher levels of strength are necessary. Grade 4 is not recommended for sea water service Grade 5 is the 'workhorse' alpha-beta alloy of the titanium range. It is also specified with reduced oxygen content (ELI) for enhanced toughness (Grade 23), and with addition of .05% palladium for added corrosion resistance, (Grade 24). Restrictions on fabricability may limit availability in certain products. Current interest in this alloy for marine and offshore applications.Comparison of the strength weight ratio of titanium with other alloys used in marine and offshore applications clearly shows the advantage of titanium, and the poor – and costly - utilisation of the metal if titanium is directly substituted in a given design.

STRENGTH/DENSITY RATIO OF TITANIUM ALLOYS COMPARED WITH OTHER MATERIALS

Material	Yield Strength at 20°C MPa	Density kg/l	Strength/ weight ratio at 20°C MPa/kg/l	Strength /weight ratio Compared to	
				Grade 2 Ti	Grade 5 Ti
Titanium Grade 2, 7, 16	275	4.51	61	100	33
Titanium Grade 9, 18	485	4.48	108	177	58
Titanium Grade 23, 29	759	4.42	172	281	92
Titanium Grade 32	586	4.43	132	216	70
Titanium Grade 5, 24	828	4.42	187	307	100
Stainless Steel 13%Cr AISI 410	350	7.72	45	74	24
Stainless Steel 316L	173	7.94	22	36	12
Stainless Steel 6%Mo– 254SMO	300	8.00	38	62	20
Duplex S/S SAF 2205 ASTM A699	450	7.80	58	95	31
Super Duplex S/S SAF 2507	550	7.80	70	115	37
Monel *400	200	8.83	23	38	12
Inconel *625	415	8.44	49	80	26
Copper Nickel 90-10	90	8.90	10	16	5
Bronze AB2	250	7.95	31	51	17

SUMMARY OF KEY PROPERTIES OF TITANIUM AND TITANIUM ALLOYS

Property **ASTM Grade** **UNS ref**	**Units**	**CP Titanium** **Grade 2** **R50400**	**Ti-6Al-4V ELI** **Grade 23 (29)** **R56407 (04)**	**Ti-3Al-2.5V** **Grade 9 (18,28)** **R56320 (22,23)**	**Ti-5111** **Grade 32** **R55111**
Alloy type		Alpha	Alpha/beta	Lean alpha/beta	Lean alpha/beta
0.2% Proof Stress	MPa	275	760 - 900	500 - 800	680 - 800
UTS	MPa	345	830 - 1000	620 - 950	750 - 900
Elongation	%	20	10 - 15	10 - 20	10 - 20
Tensile Modulus	GPa	103 (Tube 110)	110 -115	91 - 105	109 - 112
Torsion Modulus	GPa	45	40 - 43	34 - 39	42 - 44
Density	kg/l	4.51	4.42	4.47	4.51
Thermal Expansion	10^{-6}/K	8.9	8.3	8.1	8.2
Thermal Conductivity	W/mK	18.6	6.7	7.1	7.5
Specific Heat	J/Kg/K	519	565	540	533

LOW TEMPERATURE PROPERTIES

Titanium and its alloys possess a very low ductile to brittle transition temperature and have useful levels of elongation and fracture toughness even at subzero temperatures. All titanium alloys are mechanically safe at temperatures down to at least –100ºC. (–150ºF). The ASME Boiler and Pressure Vessel Code allows room temperature stress levels to be used for operational service to – 60ºC (–75ºF).

Typical properties of Ti-6Al-4VELI at –75ºC	UTS 1000MPa	Yield Strength 900MPa	El. 12%
Tensile Modulus 115GPa	Fatigue 10^6 400MPa	Fracture Toughness 100 MPam$^{-1/2}$	

ELEVATED TEMPERATURE PROPERTIES

Although loss of strength with increasing temperature occurs more rapidly for titanium than for steel, the following table shows that even at 350ºC Grade 5 titanium alloy possesses a strength to weight ratio superior to the strongest marine steel at room temperature. (See table opposite).

Metal Temperature ºC (ºF)	**Room**	**150 (300)**	**200 (390)**	**250 (480)**
Grade 2 UTS MPa	450	330	280	240
Grade 5 UTS MPa	900	730	675	630
Grade 5 YS MPa	775	610	545	496
Grade 5 Elongation %	15	17	18	18
Grade 5 Modulus E GPa	116	104	99	91
Grade 5 s/w ratio MPa/kg	187	151	153	143

THE DESIGN OF TITANIUM PIPING SYSTEMS

The design codes for pipework, plant and equipment set maximum stress levels against metal operating temperature. The mechanical design of systems in titanium has two equally important principal requirements. 1. Meeting the design standards for pressure and temperature in the various parts of the system using the minimum thickness of pipe, the lowest cost manufacturing process and the most economical selection and use of fittings, flanges etc. National and international standards are available which cover the design, manufacture and testing of pipework, vessels etc. in extensive detail. 2. Meeting operational and reliability requirements for the system as a whole by attention to expansion, flexibility and supporting structures. The time and skill required to deal with this aspect of the design will depend on the complexity of the system and the imposed loadings. Design standards such as ANSI B31.3 offer some guidance and definitive rules for pipework for assessing the need to carry out a flexibility analysis. Where such analysis is required there are a number of computer programmes available for operation on a PC. These two requirements hold good irrespective of the type of material, and the rules which apply to carbon and stainless steels apply equally to titanium and its alloys. An important difference with titanium pipework is always to minimise the need for welded joints and fabricated fittings, by considering the use of cold bending, or, when fittings are essential, making the best use of readily available or easily fabricated parts. Specialised or complicated components which require to be individually manufactured may be relatively much more expensive.

Application of code values to the associated design formula for metal thickness frequently produces surprising results. The ANSI B31.1 pipe wall thickness formula shows how the high strength and corrosion resistance of titanium combine to provide low weight, low cost, pipework of high integrity:-

$$Tm = \frac{PD}{2(S + PY)} + A$$

Tm=Minimum required wall thickness P =System Pressure MPa D =Pipe outside diameter mm S =Maximum allowable stress for material at design temperature, MPa Y =Coefficient equal to 0.4 for non-ferrous metals A =Additional corrosion allowance, mm, (zero for titanium) The additional allowance for corrosion varies for other metal systems, but for copper-nickel is typically assumed to be 1.25mm, (.05 inch). Commonly used schedules for pipework wall thickness frequently result in a substantial overspecification where titanium is concerned. Thin wall welded Grade 2 titanium piping is an ideal product to handle low pressure ambient temperature sea water, for example in service water or fire main duties. Impressive savings of weight are available when this design strategy is followed. In practice the pressure rating of a system is determined by the flanges, and it is not always possible to take full advantage of the pressure resistance of the standard pipe wall thickness. One solution, applicable to some designs, and which maintains standard flange geometry, is to use stronger Grade 3 or Grade 9 flanges in conjunction with Grade 2 pipe.

DESIGN TO RESIST CORROSION

Titanium offers a natural solution to marine and offshore corrosion problems being highly resistant, if not immune to most of the environments encountered. Titanium is protected by a stable, substantially inert, tenacious and permanent dioxide film which forms equally on welds as on parent metal, and there is consequently usually no reduction of weld or heat affected zone (HAZ) corrosion resistance. The oxide film is maintained or its formation is supported in mildly reducing to strongly oxidising conditions over a wide range of pH and temperature, and in these conditions titanium will survive erosion, cavitation, pitting and crevice corrosion. Titanium does not require the pitting allowance familiar to many other metals, and the practical benefit in designing titanium systems to handle sea water, is that equipment may be designed cost effectively, using the minimum thickness of material to satisfy the mechanical requirements of the system. The integrity of the titanium oxide film is maintained under marine fouling and other deposits which can be removed safely by mechanical methods or by regular or shock chlorination, or prevented by maintaining water velocity above 2m/sec. In many other fouling situations, the titanium oxide film will resist deposit adhesion, and facilitate cleaning. Titanium is immune to microbiologically influenced corrosion. The resistance of titanium is similarly excellent to all produced fluids encountered offshore and to all but few non-produced fluids. Titanium alloys recommended for sour service will be immune to corrosion including pitting and stress corrosion cracking in aerated and deaerated chloride containing waters (e.g. sea water and brines). Alloys are available for use to temperatures in excess of 250ºC. Titanium alloy liners are specified for geothermal wells handling concentrated brines in conditions which represent a 'worst case' environment for oil or gas wells. At temperatures above 280ºC titanium alloys suitable for use downhole are compatible with completion fluids in all oxygen free conditions. Acidising fluids used in conjunction with titanium require more care in their selection. All titanium alloys are compatible with organic acids without inhibition. Subject to the alloy selected special considerations are necessary for hydrochloric acid. Some of the most resistant alloys containing palladium may not require acid inhibition.

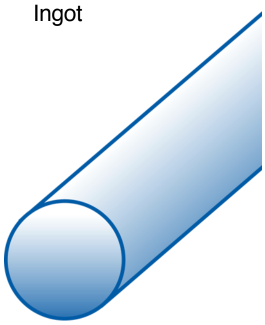
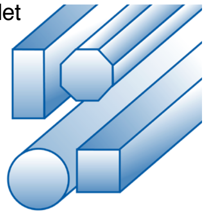
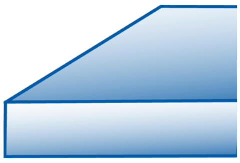
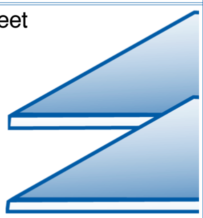
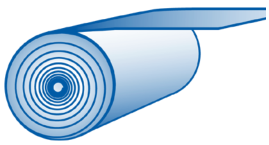
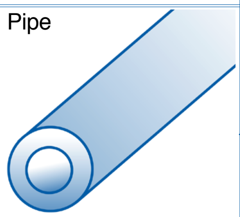
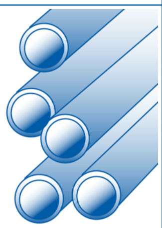
RESISTANCE TO WELL WORK OVER FLUIDS OF TITANIUM ALLOYS

	Alloy			
Well Workover Fluid	Grade 5, 23	Grade 9	Grade 24,29[1]	Grade 18,28
Methanol + x% water (see table page 23)	R > 10%	R > 3%	R > 10%	R > 3%
Amine Inhibitors	R	R	R	R
Glycols	R	R	R	R
Hydraulic Fluids	R	R	R	R
Hydrate Inhibitors	R[2]	R[2]	R[2]	R[2]
Scale Inhibitors	R	R	R	R
Paraffin Inhibitors	R	R	R	R
Emulsion Inhibitors	R[2]	R[2]	R[2]	R[2]
12% Hydrochloric +3% Hydrofluoric Acid	S[3]	S[3]	S[3]	S[3]
15% Hydrochloric Acid (HCl)	S[3]	S[3]	S[3]	S[3]
10 –12% HCl Sodium Molybdate inhibited	R	R	R	R
10% Acetic Acid	R	R	R	R
10% Formic acid	S	S	R	R

1. Also Grade 23 +.05% Pd R = Resistant to attack S = Susceptible to attack
2. Require >2% wt of water to avoid methanolic SCC in some commercial products
3. Severe uniform corrosion and hydrogen absorption ***DO NOT USE WITH TITANIUM***

[1] *WARNING: All titanium alloys are rapidly attacked by hydrofluoric acid (HF), even in very dilute concentrations and also in fluoride containing solutions below pH 7. Titanium should not be specified if regular HF acidising is anticipated. Gaskets made from, or containing, polymers which may release fluoride on thermal or acid decomposition must not be used. If, in exceptional circumstances titanium equipment is accidentally subjected to exposure for very short periods to hydrofluoric acid or active fluorides, limited general corrosion may be expected. Once the HF is removed or has been reduced to insignificant levels, (less than 20ppm), corrosion will not continue. The protective oxide film will reform spontaneously, restoring the original level of corrosion resistance.*

RMI TITANIUM COMPANY: TITANIUM ALLOY MILL PRODUCT CAPABILITIES

Product Form	Type	Alloy Grades	Sizes Offered	
			English Units	Metric Units
Ingot 	VAR-Double Melted	Most aero alloys and unalloyed C.P. alloys	30" Ø (10,000 lbs)	76.2 cm Ø (4545 kg)
			36" Ø (14,000 lbs)	91.4 cm Ø (6364 kg)
			36" Ø (21,000 lbs)	91.4 cm Ø (9545 kg)
	VAR-Triple Melted	Most high-strength aero alloys for critical rotating components	30" Ø (10,000 lbs)	76.2 cmØ (4545 kg)
			36" Ø (14,000 lbs)	91.4 cm Ø (6364 kg)
			36" Ø (21,000 lbs)	91.4 cm Ø (9545 kg)
			42" Ø (21,000 lbs)	106.7 cm Ø (9545 kg)
Billet 	Rounds	All	4.0-28.75" Ø	10.2-73 cm Ø
	Squares	All	≥3"	≥76 mm
	Rectangles + Slabs	All	3-14" thick, 4-84" width	76-356 mm thick, 10.2-213 cm width
	Octagons	All	6-14" (across flats)	152-356 mm (across flats)
Plate 	Alloy (Aircraft Quality)	Most high-strength aero alloys	0.188-4.0" thick, ≤60" width, ≤240" length (for ≤2.25" thick), ≤200" length (for >2.25" thick)	4.78-102 mm thick, ≤152 cm width, ≤610 cm length
	C.P. (Industrial Quality)	All unalloyed and modified C.P. grades, Ti-3Al-2.5V-based alloys	0.188-4.0" thick, ≤96" width, ≤300" length	4.78-121 mm thick, ≤244 cm width, ≤762 cm length
Sheet 	Alloy (Aircraft Quality)	Most high-strength alloys	0.016-0.188" thick, ≤60" width, ≤350" length	0.40-4.78 mm thick, ≤152 cm width, ≤889 cm length
Strip 	Aircraft Quality	1, 2, 3, 4, 9	0.020-0.075" thick, 24-48" width, ≤240" length	0.51-1.91 mm thick, 61-122 cm width, ≤610 cm length
	Industrial Quality	1, 2, 3, 4, 7, 9, 11, 12, 16, 17, 18, 26, 27, 28	0.020-0.188" thick, 24-48" width, ≤240" length	0.51-4.78 mm thick 61-122 cm width, ≤610 cm length
Pipe 	Seamless	All unalloyed and modified C.P. grades, and most high-strength alloys	1.9-36" OD, 0.25-1.5" wall	4.83-91.5 cm OD, 6.4-38 mm wall
	Seam-Welded	1, 2, 3, 7, 9, 11, 12, 16, 17, 18, 26, 27, 28	0.75-8" OD, ≤252" length Sch. 5-40	19-203 mm OD, ≤640 cm length Sch. 5-40
Tubing 	Seam-Welded		0.50-2.375" OD, ≤720" length, Sch. 5-40	12.7-60.3 mm OD, ≤1829 cm length, Sch. 5-40

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