Titanium New Dimension to the Fabrication Industry

S. L. DEVI*

Introduction

Titanium has created considerable interest both among mechanical and chemical engineers. Some of its intrinsic qualities often enable titanium to step in where more traditional metals have been found unsuitable. Despite the developments in new fields, titanium industry remains identified with space and air-craft industry for a long time. It is now finding its breakthrough in many areas of chemical engineering and has become a standard and major material of construction in the chemical, electro-plating and other mechanical industries. Titanium was recognised as a metallic element sometime during the 18th centry. Martin Heinrich Kleproth, a Hungarian, named it Titanium after the Titans—who in Greek mythology, were the sons of the earth—symbolizing power and strength. It is plentifully distributed on the earth, more than many commonly used structural metals such as Copper and Zinc. It is the ninth most plentiful element and the fourth most abundant structural metal, following aluminium, iron and magnesium. In fact, almost 20% of world's resources are available in the Indian soil.

Table I Physical properties of Titanium

Symbol : Ti	
Atomic Number : 22	Boiling Point : 3260°C
Atomic Weight : 47.90	Melting Point : 1668 °C
Oxidation State : 4.3	Density : 4.51 g/cm^3

*Dy. Factory Manager, Vulcan-Laval Ltd., Pune. Paper presented at National Welding Meet in Pune in August 1982.

The major problem of Titanium is the extraction of pure metal from the ore. It is difficult and very expensive. It was developed as an industrially oriented metal by Dr Kroll only in the year 1938, whereas it became available to industry in useful quantities in early 50's. Norman Feight has described this period as 'Formative years'. During this period, major applications have been in aero-space industry for manufacture of B-52 bombers, while only small quantities were tried out in laboratories for other chemical engineering applications. Breakthrough in other than space industry came in the early 60's when technical and economic evaluation and identified potential areas of interest were located. It was during the 60's that the technologists concentrated on evaluation of titanium usage, and thereafter it came out of laboratories for surgical and industrial applications.

Sudden drop of prices during the 60's also helped its sucessful entry in other than aero-space industry in the United States, United Kingdom, Europe and many other countries. Being still an expensive material and peculiar in nature, specialised fabrication practices became absolutely essential. Major areas of application during this period were surface cooling condensers. This prompted substantial investment in manufacture of seamless, welded & welded and redrawn tubes and in specialised fabrication facilities. There was also a development in England in the field of manufacture of titanium anodes, which, when put in a beaker of salt water produced Chlorine gas. This fundamental discovery of usage of non-consumable titanium anode has revolutionised the caustic soda industry.

Large sums of money were invested in the industrial market for use of titanium only during the 70's. Titanium specialists/technologists and specialised fabricators in the western world gained substantial experience and the laboratory and pilot plant evaluation studies were responsible for subsequent major investments in com mercial equipments. Initial breakthrough in this respect was made by the Heat Transfer Group of 'Westing house' by introducing titanium tubing to purify mine water wastage by distillation. It is claimed that over 400 miles length of tubing was put into a single project.

Applications of prototype anodes for chlorine production fetched very attractive and economic data and its application was further extended by using coated anode. Titanium anodes, especially coated ones, despite higher investment are favoured in view of their low potential drops (thereby lower power requirement) & lower operating costs. The previouly used anodes were plagued by such factors as wastage, short life and operational adjustments, etc.

Titanium has now made firm inroads into industry in spite of the following :

(a) Area of applications is related to sophisticated technology ;
(b) The scale of project demands high technological competence ;

High reliability of equipment and competence of equipment manufacturer offset high costs.

PROPERTIES OF TITANIUM

Physical and Mechanical Properties

Table 1 gives physical properties of titanium. A wide range of commercially pure titanium, and its alloys offers different properties and corrosion resistance.

Table 2 gives composition of various grades of titanium while Table 3 gives typical mechanical properties. Table 4 gives the nearest international equivalents of various types and grades of titanium.

Table 2 Chemical Composition of Titanium

Element	Composition, %									
	Grade									
	1	2	3	4	5	6	7	8	9	10
Nitrogen max	0.03	0.03	0.05	0.05	0.05	0.05	0.03	0.05	0.03	0.03
Carbon max	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.08
Hydrogen max	0.015	0.015	0.015	0.015	0.015	0.020	0.010	0.020	0.015	0.015
Iron max	0.20	0.30	0.30	0.50	0.40	0.50	0.30	0.35	0.20	0.30
Oxygen, max	0.18	0.25	0.35	0.40	0.20	0.20	0.25	0.18	0.18	0.25
Aluminum	..	..	..	..	5.5 to 6.75	4.0 to 6.0	..	..	..	..
Vanadium	..	..	..	..	3.5 to 4.5	..	..	..	..	..
Tin	..	..	..	..	..	2.0 to 3.0	..	3.75 to 5.25	..	..
Palladium	..	..	..	..	..	..	0.12 to 0.25	..	0.12 to 0.25	..
Molybdenum	..	..	..	..	..	..	..	10.0 to 13.0	..	0.2 to 0.4
Zirconium	..	..	..	..	..	..	..	4.50 to 7.50	..	..
Nickel	..	..	..	..	..	..	..	..	..	0.6 to 0.9
Residuals (each) max	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Residuals (total) max	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Titanium	Bal	Bal	Bal	Bal	Bal	Bal	Bal	Bal	Bal	Bal

Table 3 Mechanical Properties of Titanium

Grade	Tensile Strength, min		Yield Strength, (0.2% Offset)				Elongation in 2 in or 50 mm. min. %	Bend Test	
			min		max			Under 0.070 in. (1.8mm) in Thickness	0.070 to 0.187 in (1.8 to 4.75mms in Thickness
	ksi	MPa	ksi	MPa	ksi	MPa			
1	35	240	25	170	45	310	24	3T	4T
2	50	345	40	275	65	450	20	4T	5T
3	65	450	55	380	80	550	18	4T	5T
4	80	550	70	485	95	655	15	5T	6T
5	130	895	120	830	..	..	10	9T	10T
6	120	830	115	795	..	..	10	8T	9T
7	50	345	40	275	65	450	20	4T	5T
10	100	690	90	620	..	..	10	6T	6T
11	35	240	25	170	45	310	24	3T	4T
12	70	483	50	345	..	..	18	4T	5T

Table 4 International Equivalents of Various Grades of Titanium

	U. K.		*French*	*Germany*		*U. S. A.*	
	BS (TA)	*DTD*	*(T)*	*Aero Space*	*Engg.*	*AMS Aero Space*	*ASTM & ASME*
Commercial Purity	1	—	35	3.7024	3.7026	—	Grade 1
Commercial Purity	2-5	—	40	3.7034	3.7035	4902 41,42,51	Grade 2
Commercial Purity	—	5023 5273 5283 5293	50	—	—	4900	Grade 3
Commercial Purity	6-7-8	—	60	3.7074	3.7065	4901 & 4921	Grade 4
0.15 Pd	—	—	—	—	—	—	Grade 7
Ti Code 12	—	—	—	—	—	—	Grade 12

Although various grades of titanium are available for chemical plant applications, it has been usual to select one of the grades of commercially pure titanium. Ultimate Tensile Strength (U. T. S.) of such grades vary from 35 ksi to 70 ksi at room temperature. This range of strength is obtained as a result of variation in levels of some of the impurities. The greater the strength, the lower the ductility and ease of forming. This generally leads to the selection of medium and low strength grade of titanium. There is a sudden drop in the strength of commercially pure titanium above 300°C where the choice is to use alloy grades. Such alloyed titanium grades show significant improvement over unalloyed grades in several respects. Designer must be extremely careful while making the choice between unalloyed and alloyed grades since crevice corrosion is likely to occur with unalloyed grade at high temperatures. Commercially pure titanium has an extremely low magnetic susceptibility ; however, it can be treated to be totally non-magnetic. On a strength to weight basis, titanium is superior to many other structural metals, and it is this high strength—low density property even in high temperature ranges that has dramatically accelerated its demand. Density (4.51 gms/Cm^3) falls about a third on the way upto the range between aluminium and steel. In alloy form, it possesses upto three times the strength of aluminium alloys and five times the strength of magnesium alloys. It is also stronger than some of the alloy steels. Experts claim saving of upto 40% in weight basis for replacing steel with titanium in critical areas of application.

Corrosion Resistance

Titanium has exceptionally good resistance to corrosion in a very wide range of aggressive media. It is mainly because of its reactive characteristic that it readily forms an oxide film in the atmosphere and in many chemical environments. It has a very thin oxide film that is hard, continuous and very firmly adherent. So long as this film is maintained, it confers on titanium a high corrosion resistance. Conversely, if the film is not maintained, corrosion is rapid. It has excellent resistance to strongly oxidising environment such as chromic and nitric acids, ferric chlorides and to sulphide environments. It has also an outstanding contribution in chloride environment where stainless steel, in particular, can be found at a disadvantage. It is also found to be the best material of construction in sea-water application upto 130°C temperature beyond which there is an evidence of crevice corrosion. Newly produced grades such as Ti-Code 12 and Ti-Pd alloys offer adequate resistance both to crevice corrosion and pitting at elevated temperature.

Galvanic Corrosion/Coupling

There have been extensive studies to establish the galvanic coupling between titanium and other traditional metals. Due to the noble characteristic of oxide film, it is employed as a cathodic member especially in sea water application and in low concentrations of non-oxidising acids. Materials such as copper, tin, monel, etc. tend to corrode faster than normal in presence of titanium. More damaging effects are noticed on mild steels and aluminium than the on stainless steel and monel metal.

Crevice Corrosion

Many metals suffer from corrosion between themselves and other metallics or non-metallics due to a restriction in circulation of solution. This results in a differential concentration effect or differential aeration with the crevice. This further leads to a difference in electro-potential between the metal in crevice and that outside where there is a free circulation of solution. A galvanic reaction takes place in these areas. Titanium offers exceptionally good resistance ; however, its use is restricted to applications involving wet chlorine, depending upon the shape and size of the crevice. Titanium-palladium alloys or other newly developed titanium grades (Ti-Code 12) reduce the risk of crevice corrosion in brine solutions. Sometimes, platinum surface coating is recommended to avoid crevice corrosion.

Stress Corrosion

By and large, commercially pure titanium has an excellent resistance to stress corrosion. When subjected to stress levels around 70% of yield strengths and exposure to sea-water, there have been indications of stress corrosion cracking. It is intergranular in character. This is also reported in nitric acid application under special circumstance.

Fabrication Characteristics

In terms of mechanical working, it offers some variation in properties that a fabricator has to account for in terms of physical and economical terms. Softer the grade, the more workable it is. This also applies when working termperatures are increased. However, increasing temperature has an adverse effect as it absorbs Oxygen, Nitrogen, and Hydrogen. Alloyed grades of titanium have shown comparatively low degree of workability ; however, special care can minimise the risk. Extra-ordinary measures must be taken to assure absolute metal cleanliness and total inert gas shielding during welding. Since titanium is highly susceptible at higher temperatures to Carbon, Hydrogen, Oxygen, Nitrogen, and Iron, close follow up and attention is called for throughout the process of fabrication. Welding defects are mainly due to hydrogen content in the weld pool arising out of moisture of shielding gas and entrained air. The joint preparation also has bearing on defects. Therefore, special precautions are essential in terms of weld design, process selection and welding parameters. Iron pick up must be avoided by special precautions, as it has adverse effect upon corrosion resistance. Though the limit of content is specified upto 0.2%, lower percentages are preferred. Surface contamination in rolling should also be avoided. Various precautions at every step in fabrication call for sophisticated and specialised knowledge of fabrication and welding technology. Role of the consulting engineers who have knowledge both in fabrication and application in chemical engineering is of an added advantage.

Prospects and Applications

Titanium due to its exceptionally good corrosion resistance, is finding its way into chemical engineering. Some of the specialised areas of applications are discussed here. Nitric acid solutions are strongly oxidising and titanium is will accepted in various applications well below its boiling point. Corrosion resistance is reduced at higher temperature and shows adverse effects with corrosion rates upto 10 mm/year.

One has to be very particular when selecting the material by looking into critical temperature and concentration levels. Addition of silica compound or silicon oil in the solution restricts the corrosion rate. Also when used for red fuming nitric acids, there are instances of explosion hazards.

Research studies have revealed galvanic attack in presence of iron contamination picked up during fabrication. Levels must be controlled below 0.05%. Titanium is also used in equipment for manufacture of ammonium nitrate from nitric acid. Titanium is finding its way in the chemical reprocessing of nuclear fuel elements, involving HNO_3.

Compounds of chlorine in water are of an oxidising nature, hence titanium is quite suitable in such applications. It offers good resistance to even boiling solutions of sodium chlorate, chromate and hypo-chlorates, wet chlorine gas, etc.; however, it does not withstand dry chlorine gases. Addition of water upto 2% solves this problem. However, it is quite resistant to gases as well as solutions in bleaching processes. It is also resistant to wet chlorine and chlorine-di-oxide vapour in chorine bleaching. Titanium heat exchangers are commonly used for cooling of wet chlorine gas in brine cells. Valves, pipes and fittings, pumps and such similar products are used to handle chlorine gas. Heat exchangers are also used for production of chlorine-di-oxide in paper and pulp industry. Pumps and fans of titanium are also used in caustic soda industry. Designer should be careful and take care of crevice corrosion factor. Titanium is also found acceptable for wet bromine water, dry and wet iodine gas applications.

Designer should be particular while selecting grades of titanium for sulphuric acid solution as the corrosion resistance changes very catastrophically with change in percentage concentration and temperature.

Table 5 Permissible variation, in Product Analysis

Element	*Product Analysis Limits, max or Range, %*	*Permissible Variation in Product Analysis*
Nitrogen	0.05	± 0.02
Carbon	0.10	± 0.02
Hydrogen	0.02	± 0.002
Iron	0.50	± 0.15
Oxygen	0.30	± 0.03
Oxygen	0.31 to 0.40 max	± 0.04
Aluminum	4.0 to 6.75	± 0.40
Vanadium	3.5 to 4.5	± 0.15
Tin	2.0 to 3.0	± 0.15
Palladium	0.12 to 0.25	± 0.02
Molybdenum	10.0 to 13.0	± 0.25
Zirconium	4.5 to 7.5	± 0.30
Molybdenum	0.2 to 0.4	± 0.03
Nickel	0.6 to 0.9	± 0.05
Residuals (each)*	0.1	± 0.02

*A residual is an element present in a metal or an alloy in small quantities inherent to the manufacturing process but not added intentionally.

Table 6 Some of the Intrinsic Qualities of Titanium

- The high value of the strength to weight ratio combined with good fatigue and notch sensitivity performances.
- Excellent corrosion resistance in a wide range of media, even very corrosive such as chlorine compound solutions.
- High bend ductility due to its low modulus of elasticity.
- Paramagnetic.
- Fairly good cryogenic properties for some of the Titanium alloys.

Results have shown a corrosion rate as high as 9 mm per year in 1 % solution at boiling points starting from say Nil to 20 % concentration at room temperature. Corrosion resistance improves by addition of solutions of oxidising agents such as copper sulphate, ferric sulphate etc. in saturated wet chlorine. Same is the case in the application while handling hydrochloric acid and phosphoric acids. Titanium is attractive, though marginally by adding oxidising agents as mentioned above. Laboratory experiments have concluded that titanium is not suitable for hydrofluoric acid since the corrosion resistance rate deteriorates as much as 50 mm per year.

Titanium has excellent corrosion resistance for most of the inorganic acids provided they do not contain flouride radicals. In case of alkaline solutions, corrosion rate using titanium varies from Nil to around a millimetre per year. However, it is not used for handling boiling solutions of potassium or sodium hydroxide in concentrated form. It is also found extremely good for all concentrations of salts at room temperature. Titanium has shown good resistance to corrosion in atmosphere containing ammonia. However, one has to be very careful in selecting it at elevated temperatures. Titanium preferably alloyed grades are used for cyaniding baths in heat treatment furnaces.

One can conclude, with confidence, that titanium applications are now getting established and are being accepted along with other materials of construction, its greater reliability and high strength—low density ratio off-setting its higher cost.

Weld Spatter

It's 1985. You're in an automobile plant, walking along a body assembly line. You see lots of resistance spot welding. Whom do you see ? Almost no one. Machines are putting body panels in place and robots are doing the welding. Machines—not people—are tracking robot action, monitoring and recording weld parameters, and feeding corrections back to the robots. Workers dont's tear down every nth body to check welds-machines record & attest to weld quality. Workers are in the plant in central control room away from the line. They watch machine dials and check out and adjust robot controls at any sign of lowered weld quality.

This is no fantasy ! Robots are welding auto bodies in 1981 and automakers expect to achieve totally automated body assembly by 1985.

—Welding Design & Fabrication, June, 81

In 1957/58, the first year of the School of Welding Technology, 200 attended a series of six industry-based courses, but in 1981, nearly 3000 course members were enrolled in 180 courses and since 1957, over 30,000 people have attended our training activities.

—Reported during the AGM of the
Welding Institute of U.K.