TITANIUM

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Contents

Summary

The properties of titanium, as heat exchanger tube materials used for multi-stage flash (MSF) desalination plants, are described. Titanium has excellent corrosion resistance in oxidizing environments containing considerable amounts of chloride ion where various conventional heat exchanger materials may suffer corrosion damage. Since titanium

tubes applied to the condenser in a thermal power plant in 1969 demonstrated excellent performance, they have come to be used worldwide for plants with seawater cooling systems and for heat exchangers in desalination plants. Their excellent corrosion resistance and mechanical properties enable their wall thickness to be reduced to 0.5 mm or less, this reduction in wall thickness contributing not only to their cost reduction but also to improvement in their heat transfer efficiency. In fact, field studies revealed that a thin wall titanium tube may be superior to a conventional cupro-nickel tube. Fatigue strength of titanium in seawater is higher than that in air, while that of aluminum bronze is lowered in seawater because of corrosion. As corrosion of copper alloys is enhanced by coupling with titanium, cathodic protection in the potential range of between -0.5 and -0.65 or -0.75 V (SCE), depending on temperatures, should be applied to these metal combinations in order to avoid galvanic corrosion of copper alloys and hydrogen absorption of titanium. The relatively low Young's modulus of titanium requires thin wall titanium tube to be designed to avoid the decrease of rigidity and buckling strength this causes and also for care in expanding of the tube to obtain enough pull out strength. Several applications of thin wall titanium tubes for heat exchangers of thermal power plants and desalination plants are described.

1. Introduction

In the early days, titanium tubes of 1-2 mm in thickness were used for heat exchangers and piping in the chemical industry. Later advancement of mass production technology made the supply of high quality thin wall welded tubes more economical. Titanium tubes, since then, have attracted much more interest from those concerned with corrosion resistant materials. Aluminum brass tubes were mainly used for seawater-cooled steam condensers in power generating plants but they often experienced corrosion failure either from cooling water side or steam side, the former by polluted seawater and the latter by concentration of ammonia in the air removal zone. Titanium tubes were first applied to the condenser in a Japanese thermal power plant in 1969 replacing copper alloy tubes in the air removal zone. They demonstrated excellent performance in this application and since then have come to be used worldwide for plants with seawater cooling. Success in power plants led to the application of a large number of titanium tubes for heat exchangers in desalination plants.

Most countries in Europe and the United States of America mainly use titanium heat exchanger tubes of 0.7 mm in thickness, while France and Japan were more progressive in using 0.5 mm. The thin wall titanium tubes have not caused any failure in their field service because of their excellent corrosion resistance and mechanical properties. Reduction of wall thickness not only improves heat transfer but also contributes greatly to cost saving and improvement in total plant economy. Research work to improve heat transfer and economy by further reducing the wall thickness are continuing. At the Anniversary Symposium of Japan Titanium Society held in Kobe in 1982, recommendation of thinner wall titanium tubes was discussed (Kusamichi and Sato 1983, Hiraishi 1983).

This paper will give general outlines of titanium and explain various properties of thin wall titanium tubes for heat exchangers, giving examples of commercial tubes of 25.4 mm OD (Outside Diameter) with three different wall thickness of 0.3, 0.4 and

0.5 mm.

2. Physical Properties of Titanium

Titanium is an element of atomic number 22. It is light, strong and corrosion resistant and has hexagonal closed pack (HCP) crystal structure at room temperature and transforms to a body centered cubic (BCC) structure above the transformation temperature of 1158 K (885°C). Titanium metal of HCP is called α phase and that of BCC is called β phase. The addition of alloying elements, which lower the transformation temperature, create α - β duplex phase and β phase alloys at room temperature. The strength of commercially pure titanium is a little lower than that of stainless steels and carbon steels. When alloyed, higher strengths can be obtained.

Table 1 shows the physical properties of titanium and other materials. The specific gravity of titanium metal is 4.51, being only a half of that of copper and nickel alloys and 60 per cent that of steels. Thermal conductivity of titanium is almost as good as that of stainless steels, but about one-sixth as good as that of aluminum brass. Heat transfer of titanium tubes may, however, be improved to the level of copper alloys or over it by applying very thin wall, as it is not necessary to provide extra thickness against corrosion loss. Specific gravity and coefficient of thermal expansion are smaller than those of many other heat exchanger materials and are about half of those of aluminum brass.

Material	**Thermal conductivity W m^{-1} K^{-1}**	**Specific gravity**	**Coefficient of thermal expansion (×10^{-7} K^{-1})**	**Specific heat (R.T.) (J kg^{-1} K^{-1})**
Titanium	17.2	4.51	90	544
Aluminum brass	100.4	8.42	185	377
90-10 cupronickel	46.9	8.94	178	377
80-20 cupronickel	33.5	8.94	168	377
70-30 cupronickel	29.3	8.94	162	377
Stainless steel AISI 304	16.3	8.03	173	502
Stainless steel AISI 316	16.3	8.03	160	502

Kobe Steel (1967)

Table 1. Physical properties of Titanium and other materials.

3. Mechanical Properties of Titanium

3.1. Tensile Properties

ASTM B 265 and JIS H 4600 specifies four classes of titanium with different impurity contents. Chemical compositions and mechanical properties of titanium strip (ASTM B 265) are indicated in Table 2. Titanium ASTM B 338 Grade 2 and JIS H 4631 Class 2 are mainly used for heat exchanger tubes. As shown in Table 3, the tensile strength of titanium is slightly lower than that of stainless steels and a little higher than that of copper alloys, while its yield strength is slightly higher than all of the other metals. Elongation shows almost no difference between titanium and copper alloys, but elongation of titanium is lower than that of stainless steels. Young's modulus of titanium is about half of that of stainless steels and slightly smaller than that of copper alloys. Special care should be paid to avoid deflection.

	Chemical compositions (%)					Tensile properties		
	N Max.	C max.	H max.	Fe max.	O max.	Tensile strength min. (MPa)	Yield strength 0.2% offset (MPa)	Elongation min. (%)
ASTM Grade 1	0.03	0.08	0.015	0.020	0.18	240	170-310	24
ASTM Grade 2	0.03	0.08	0.015	0.030	0.25	345	275-450	20
ASTM Grade 3	0.05	0.08	0.015	0.030	0.35	450	380-550	18
ASTM Grade 4	0.05	0.08	0.015	0.050	0.40	550	483-655	15

Japan Titanium Society (1984)

Table 2. Chemical compositions and tensile properties of Titanium skelp (ASTM B 265).

Material	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Reduction of area (%)	Young's modulus (%)
Titanium ASTM Grade 2	502	393	35	51	114
Aluminum brass	455	246	39	65	128
70-30 cupronickel	365	144	41	75	147
Stainless steel AISI 304	589	245	60	70	193
Stainless steel AISI 316	563	230	65	74	202

Japan Titanium Society (1984)

Table 3. Mechanical properties of titanium and other materials (ASTM B 338).

3.2. Fatigue Properties

Fatigue strength to tensile strength ratio of titanium is approximately 0.6 at room temperature, and is higher than that for other heat exchanger tube materials (0.42-0.5) and structural steels (0.35-0.5) as indicated in Tables 4 and 5. The fatigue strength of aluminum bronze decreases in salt water from that in atmospheric air by approximately 25 per cent. This reduction is caused by corrosion of aluminum bronze in salt water. Titanium, being strongly corrosion resistant, shows higher fatigue strength in salt water rather than in air (Japan Titanium Society 1984). This excellent fatigue strength can be of benefit when titanium is used for heat exchangers using seawater.

Material	Tensile strength σ_B (MPa)	Fatigue strength σ_W (MPa)	σ_W/σ_B

Material	**Tensile strength σ_B (MPa)**	**Fatigue strength σ_W (MPa)**	**σ_W/σ_B**
Titanium ASTM B 265 Grade 2	373	221	0.59
Aluminum brass	451	226	0.50
70-30 cupronickel	392	167	0.42
Stainless steel AISI 316	563	279	0.50

Japan Titanium Society (1984)

Table 4. Rotary bend fatigue property of titanium and other materials.

Test condition				**Tensile strength**	**Fatigue strength σ_W (MPa)**		**σ_W/σ_B**	**β_K[e)]**
Temp. (K)	**Atmosphere**	**Notch**	**Repeat speed (cycle per min.)**	**σ_B (MPa)**	**Ono method[a]**	**Taira method[b]**		
293	Air	Flat	1700	372	221	-	0.592	1.36
293	Water inject	Flat	1700	372	235	-	0.632	-
293	Air	Notch[c]	1700	-	162	-	-	1.36
293	Water inject	Notch[c]	1700	-	162	-	-	1.45
293	Air		1500	372	-	240	0.646	-
293	Water inject	Notch[c]	1500	372	-	240	0.646	-
293	Air	Notch[c]	170	372	-	230	0.618	-
293	Water inject	Notch[c]	170	372	-	230	0.618	-
293	Air	Notch[d]	1500	-	-	108	-	2.23
573	Air	Flat	1500	162	-	149	0.940	-
573	Air		170		-	157	0.970	-
573	Air	Notch[d]	1500	-	-	78	-	1.94

[a] Tested under uniform bending moment.
[b] Tested under uniform deflection.
[c] 60° V shape, roundness at notched bottom R=1.2 mm, outside diameter: 12.5 mm, diameter of notched bottom: 10 mm.
[d] 60° V shape, roundness at notched bottom R=0.55 mm, outside diameter: 9 mm, diameter of notched bottom: 6 mm.
[e] Notch factor (flattering value/notched value).

Table 5. Rotary bend fatigue property of titanium ASTM Grade 2 under various test conditions.

4. Corrosion Resistance of Titanium

The excellent corrosion resistance of titanium is attributable to a passive film which forms readily on its surface. It shows high resistance to corrosion in oxidizing environments and to chloride ions. It is well known that titanium possesses as good a corrosion resistance as platinum in seawater and shows remarkable resistance to various forms of corrosion experienced in conventional copper alloy heat exchangers. The corrosion resistance of titanium used for heat exchanger tubes in condensers or MSF type desalination plants will be considered in detail.

4.1. Deposit Attack

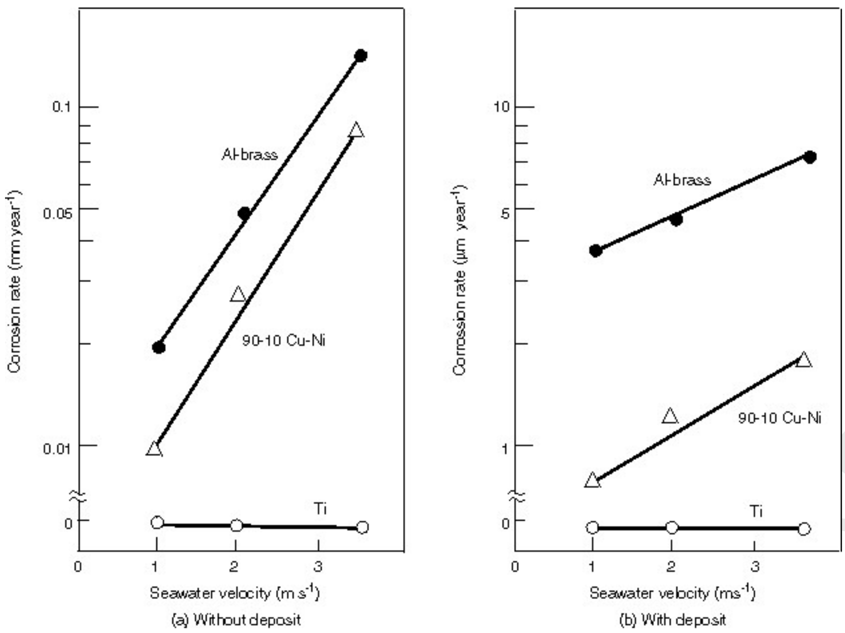

Figure 1. Corrosion rate of copper alloys and titanium with or without deposit in seawater (298 K).

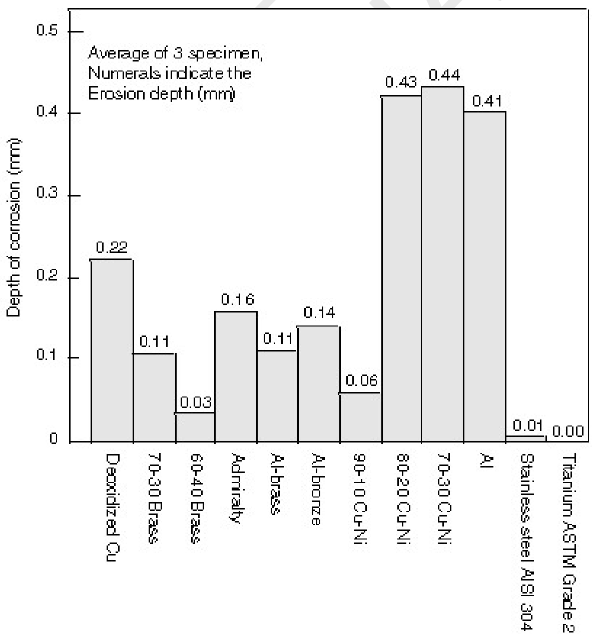

Figure 2. Resistance of various metals and alloys against vibration-type deposit attack.

When a solid body such as a shellfish deposits on the surface of a copper alloy tube of a heat exchanger, corrosion may easily occur under and/or around the deposits. This form of corrosion is called "deposit attack" and the corrosion progresses particularly when a deposit on the tube surface flutters. As shown in Figure 1, corrosion rates of aluminum brass and cupronickel tubes increase as seawater velocity increases. Corrosion rate reaches several mm per year with a vibrating deposit. Titanium tubes, on the other hand, experience no corrosion at seawater velocity up to 3.5 m s^{-1}, irrespective of existence of deposit, proving excellent deposit attack resistance. Figure 2 indicates that AISI 304 stainless steel shows a relatively good general corrosion resistance but with a tendency to pit.

4.2. Erosion-corrosion

It is known that conventional aluminum brass condenser tubes experienced rapid progress of corrosion when velocity of cooling seawater increases or sand is contained in seawater. Titanium shows excellent resistance against erosion-corrosion by high velocity seawater or against sand erosion.

Copper alloys such as naval brass, aluminum brass and cupronickel increase their corrosion rate as the sand content in seawater increases, while titanium shows no corrosion even with sand content up to 15 g l^{-1} at seawater velocity of 8 m s^{-1} as shown in Figure 3.

Hanson (1973) reported that no erosion occurred on titanium in clean and sand free seawater up to the velocity of 27 m s^{-1}, nor in seawater with sand up to 6 to 7 m s^{-1} in velocity. Titanium shows excellent resistance to any other type of corrosion occurring on conventional copper alloys. For instance, copper alloy tubes experience corrosion in polluted seawater or in seawater containing sulfide ions. The corrosion resistance of titanium, however, is not degraded in such adverse environments. Since titanium shows excellent resistance against NH_3 and non-condensable gas contained in steam in condensers or MSF desalination plants, it is considered as a reliable corrosion resistant material for heat exchangers.

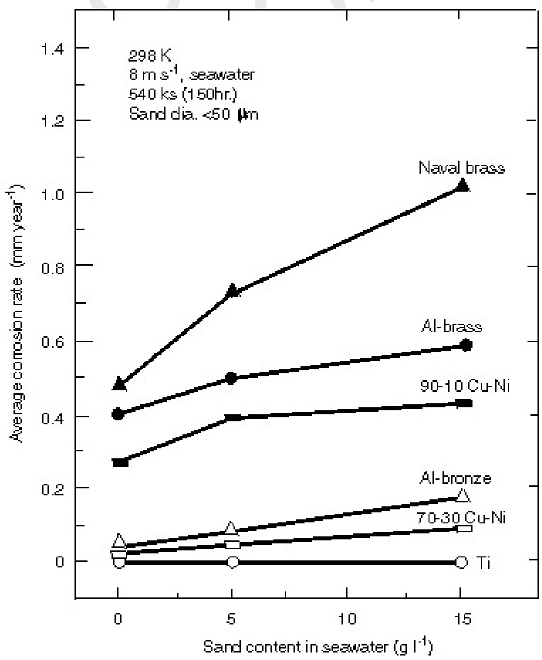

Figure 3. Effect of sand content on corrosion rate of copper alloys and titanium in flowing seawater.

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