Titanium for Secondary Marine Structures

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Overview:

Materials of construction for secondary marine structures must exhibit an optimum combination of saltwater corrosion resistance, mechanical reliability, high strength-to- weight ratio, reliable fabricability and maintainability, and low life cycle cost. To minimize life cycle costs, design and materials selection must include engineering for reduced maintenance.

Titanium provides a unique combination of these features. Titanium exhibits:

Excellent corrosion resistance in all sea water environments
Non-toxicity to people, aquatic life , or the surrounding environment
Strength-to-weight ratio unmatched by any other common engineering metal
Structural stiffness comparable to the best other common engineering metals
Non-magnetic in all alloys and forms
Simple and reliable forming, fabrication, and welding processes
Reliable near net shape casting and forging processes
Reliable commercial availability in sheet, plate, tube, pipe, and bar form
Established industry standards worldwide

The greatest impediment to the increased use of titanium in marine structures is a lingering, age-old misconception that titanium is an expensive, exotic, difficult to process metal. Undeniably titanium is more expensive than most steel and aluminum alloys. It is cost comparable to many copper alloys and is lower cost than many of the nickel alloys. The key to cost effective use of titanium is to utilize its unique properties and characteristics in the design rather than to simply substitute it for another metal.

The broad range of titanium alloys available to the design engineer are listed in Table 1. Virtually all of the common titanium alloys, in plate and sheet form, are covered in the ASTM Specification B265. Marine structures are commonly constructed from one of the higher strength unalloyed grades, such as Grades 2 or 3. Where crevice corrosion may be an issue, such as gasketed sealing surfaces, the palladium alloy, Grade 7, is a common choice. Where higher strength is mandatory, Grades 9 or 12 are used.

Features of Titanium for Seawater Applications:

Corrosion Resistance:

Titanium is fully resistant to natural seawater regardless of chemistry variations and pollution effects (Ref 1). Corrosion rates of well below 0.01mpy have been measured in extended programs (exceeding 20 years) in subsea, splash, and tidal zones. The excellent corrosion performance is attributable to a very thin, tenacious and highly protective surface oxide film. If scratched or damaged, this surface oxide will immediately reheal and restore itself in the presence of air or seawater. Weldments, and castings of the common titanium marine grades exhibit corrosion resistance comparable to wrought materials, eliminating a concern over heat affected zones or a need to upgrade alloying in weld metal or castings.

The fatigue properties and toughness of common marine grade titanium alloys are unaffected by seawater exposure. The alloys are immune to seawater stress corrosion cracking. Unalloyed titanium is susceptible to crevice corrosion pitting in some severe seawater environments, such as at gasketed mechanical joints. The problem can be completely eliminated by upgrading to Grade 7 or similar alloys in these locations.

The resistance to seawater environmental corrosion eliminates the need for elaborate corrosion resistant coating systems and the inherent high cost of maintenance. Painting of titanium components becomes simply a cosmetic issue.

Erosion Resistance:

In seawater environments, titanium alloys are immune to all forms of localized erosion corrosion. The titanium alloys will withstand seawater impingement at flow velocities in excess of 100 ft/sec. Abrasion and cavitation resistance is outstanding. Table 2 presents a comparison of alloy erosion corrosion resistance at various seawater test locations. The erosion and caviation resistance make titanium an ideal alloy for seawater piping, pumps, and heat exchangers. (Ref 2)

Heat Transfer Efficiency:

Under “in service” conditions, the heat transfer properties of titanium approximate those of admiratly brass and copper-nickel. Although titanium has a lower coefficient of thermal conductivity, the reasons for the good heat transfer are:

>Titanium’s higher strength permits the use of thinner walled equipment

>The relative absence of corrosion in seawater leaves the surface bright and smooth for improved surface heat transfer

>The superior erosion-corrosion resistance permits significantly higher operating velocities.

Superior Strength to Weight Ratio:

The density of titanium and its common marine grade alloys is in the 0.163 lb/cu-in range while the yield strength is above 40,000 psi. The strength is equivalent to that of commonly used shipboard steels while being 43% lower weight for an equivalent section. The reduced weight is typically very beneficial. The overall weight and related space demand is lowered, reducing initial costs and ongoing transport costs.

Manufacturability:

The common marine titanium grades are readily manufacturable. Manufacturing techniques were initially developed for the aerospace industry. Over time the processes have been refined and cost optimized to a broad range of commercial products;

>Titanium piping, fitting, valves, and pumps have been produced for the chemical process and utility industries for over 40 years

>Titanium heat exchangers, both “shell and tube” and plate exchangers, are extensively used in these same industries. Titanium exchangers are the preferred choice for reliability and safety in the nuclear power industry.

>Reliable, low cost manufacture has helped titanium products to gain an exceptional position in many markets; for example, the highly competitive sports equipment industry and the medical equipment and implant industries. Factors driving success in these fields also apply to the marine industries.

Fabrication processes are reliable and well developed. Titanium components can be produced by near net shape processes such as forging and casting. The titanium alloys can be readily and reliably joined by welding. Like most non-ferrous alloys, welding of titanium requires special care (Ref 3). As with all metals, titanium must be clean for reliable welding. The weld metal must be protected from oxidation by inert gas shielding while above approximately 1000F. Production of high quality weldments in titanium is generally easier than with many of the marine grade aluminum, copper, and nickel alloys. Experienced welders claim that titanium welding is easier than stainless steel welding.

Toxicity:

Unlike many of the commonly used metals, titanium is truly non-toxic to people, marine creatures, and the environment. It can be used without concern for the health and safety of the fabricator or the end user. For example, this feature of titanium has made it a preferred material for medical and dental implants, pacemaker cases, heart valves, etc.

Availability:

The titanium grades that are commonly required for marine uses are readily available in sheet, plate, tube, pipe and rod form. There is a broad base of both mill and warehouse supply for these products. This availability results from the extensive range of uses for these versatile alloys. Designers and users are often misled regarding availability by the less common availability of the more complex aerospace alloys.

Industry Standards:

Titanium alloy standards are well established. The aerospace, chemical, and power industries have lead in assuring broad acceptance of industry standards worldwide. Established ASTM Standards cover plate, sheet, tube, pipe, rod, bar, etc. Since titanium is a relatively newer metal, industry standards are more universally equivalent worldwide than for many of the older metal families.

Current Applications of Titanium and its Alloys in Secondary Marine Structures:

Piping: Titanium has become an accepted metal for piping in Naval Ships (Ref 4, 5). The features of titanium provide cost reduction and enhanced reliability:

>Due to the superior corrosion and erosion resistance, combined with high strength, piping can be thinner wall.

>The erosion resistance permits higher water velocities. This in turn permits use of smaller diameter pipes to achieve the same volume transfer.

>The weight is significantly reduced due to the lighter wall, smaller diameter piping and reduced weight of the water contained within the pipes.

>The reduced diameter and tighter bend radii greatly reduce the space requirement, providing greater design flexibility.

Table 3 presents a list of applications of titanium piping in naval ships.

Heat Exchangers: The features that have made titanium a material of choice in piping have also driven its use in heat exchangers (Ref 5, 6). Titanium exchangers are now used extensively in commercial fishing and transport vessels, navy ships, and offshore platforms. Table 4 presents a list of current applications of titanium heat exchangers in secondary marine applications.

Exposed Hardware and Electrical Components: Corrosion of hardware and electrical components exposed to seawater conditions is a major maintenance concern. Unlike most other metal, titanium components can resist the severe corrosion conditions without periodic painting. In fact, the absence of a need for perpetual cleaning, painting, stripping, cleaning, painting, etc makes titanium a low cost choice of much of this equipment. Titanium is being used for ladders, electrical boxes, lighting fixtures, stanchions, hatches, covers, antennas, and a myriad of other topside components on naval ships (Ref 7). These relatively small, but very critical items, can be a very heavy demand upon the maintenance support team when constructed of less suitable metals.

Exposed Structures: Corrosion of exterior structures presents a high maintenance demand with most metal choices. This is not the case with titanium. Due to the excellent corrosion resistance, elaborate coating systems and the continuing maintenance demand is unnecessary. Titanium is being used for exterior bulkheads, roofing, and splash guards. For many of these applications, titanium clad steel is the low cost option; a thin titanium exterior layer is supported by an inexpensive steel base metal on the non exposed side (Ref 9).

Design and Fabrication Concerns:

The primary long term concerns of using titanium in secondary structures relates to inter-relationships with other metals. Proper repair, maintenance, and modification of any metal component requires an understanding of what the material of construction is and which procedures are suitable for that specific metal type. It is critical that maintenance personnel understand the differences in the various materials of construction. For example, welding of a steel attachment to a titanium component will only result in the damage of both components. (In this regard, titanium is no different than aluminum or most of the copper and nickel alloys.) Maintenance procedures which include material type identification prior to cutting, welding, etc are critical for any application where various metal and non-metal components are used together.

Corrosion of joints between components of differing metal types can also be a significant concern. The superior corrosion performance of titanium can result in accelerated galvanic corrosion of adjacent components of a less noble metal, such as steel, stainless steel, or aluminum. The extent of galvanic corrosion will depend on many factors such as anode to cathode ratio, seawater velocity and seawater chemistry. The most successful strategies eliminate this galvanic couple through material selection and design. By moving the dissimilar metal interface to a location that is corrosion protected, serious galvanic attack can be avoided. However, in many instances this cannot be achieved. In these cases it is best to electrically insulate the titanium components from adjacent lesser noble metals. A wide range of dielectric joint designs have been developed for this purpose. Some installations, such a naval combatant topside equipment, require universal grounding or bonding, in these cases insulation is not an option.

Galvanic corrosion is significantly frustrated if a crevice is present between the dissimilar metals, such as in a mechanical connection. Corrosion conditions can be significantly enhanced in the presence of a dissimilar metal crevice. Further, crevices at mechanical attachments are virtually impossible to protect with paint. Since titanium cannot be welded to steel using conventional fusion welding processes, a crevice-free joint is not readily achievable by direct welding. Titanium can be welded to most other metals using one of several cold welding processes, such as explosion welding, friction welding, and diffusion bonding. However, these technologies do no lend themselves to conventional marine fabrication environments.

Dissimilar metal transition joints provide a corrosion control mechanism where dissimilar metal joints cannot be avoided or are cost preferable to their elimination (Ref 9). Figure 1 shows the transition joint concept. The transition joint is produced by a non-conventional welding method, which produces a crevice free, mechanically strong, metallurgical bond between the dissimilar metals. For example, when joining titanium to steel, a titanium-steel transition joint would be procured from an explosion welding company. The titanium would then be welded to the titanium face using conventional titanium processes and the steel to the steel face likewise.

The transition joint provides a mechanically reliable, electrically conductive, crevice free joint between the dissimilar metals. However, it does not eliminate the galvanic corrosion potential. The elimination of the mechanical joint and the related crevice now makes painting a viable protection method.

Transition joints have been used since the late 1960's for corrosion control at aluminum-to-steel connections (Ref 10). Most of the naval ships constructed over the past 25 years have used welding transition joints for joining aluminum superstructures and deck houses to steel decks and hulls. Similar transition joints are readily available for joining titanium to steel, stainless steel, aluminum, and copper alloys.

Total Cost Overview:

When initial component cost is considered, titanium is rarely the low cost metal. The comparative cost of titanium and other metals is presented in Table 5. (The ratios are based upon 1996 metals costs, which may change significantly in the future. However, it is notable that these ratios have not changed appreciably in the prior two decades.) As displayed here, titanium is more than 10 times as expensive as carbon steel when compared on a volumetric basis. In a simple cost per unit weight comparison, it is more than 20 times as expensive as steel.

The cost benefits of titanium result from it lower weight and reduced maintenance costs. Corrosion prevention programs are not needed for titanium equipment. The costs of frequent inspections, cleaning, painting, and repeating in a few months to a few years is fully avoided. Naval estimates place the cost of re-painting for corrosion protection to exceed $40./square foot (Ref 11). For comparison, this is greater than the cost differential between a 0.188" thick sheet of titanium (Grade 2) and an equivalent piece of steel or aluminum.

In addition to the elimination of a regular corrosion maintenance program, the cost of maintenance of the maintenance team can be avoided. In shipboard and platform conditions, the cost of the related space for housing, feeding, recreation, etc. can be very significant. The savings are potentially exponential.

In comparison to aluminum, titanium structures offer improved fatigue performance; particularly where welds are involved. This reduces the need for regular inspections to assure component mechanical integrity. It further reduces the need for mechanical repairs as equipment becomes older and fatigue becomes a real cost issue.

In summary, for many secondary marine structure uses, titanium is the material of choice. Reductions in life cycle costs have been proven to be particularly significant in piping, heat exchangers and topside corrosion environments.

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Table 1

SELECTED TITANIUM ALLOYS AND PERFORMANCE FEATURES

Gr# (*)	Basic Alloy Components	Cost (**)	Features/Motivation for Alloy (***)
1	Ti (Chem. Pure)	1.1	Low Cost, Low Strength, Excellent formability
2	Ti (less pure)	1.0	Low Cost , Moderate Strength
3	Ti (less pure)	1.0	Low Cost, Higher Strength
5	Ti+6AL+4V	1.2	High Strength and Erosion Resistance
7	Ti Gr2+0.15Pd	1.9	Crevice Corrosion Resistance
9	Ti-3Al-2.5V	1.3	High Strength and Erosion Resistance
11	Ti Gr1+ 0.15Pd	1.9	Crevice Corrosion Resistance
12	Ti+.3Mo+.8Ni	1.2	High Strength and Erosion Resistance
16	Ti Gr2 + .05Pd	1.4	Crevice Corrosion Resistance, Lower Cost
17	Ti Gr1 + .05Pd	1.4	Crevice Corrosion Resistance, Lower Cost
18	Ti Gr 9 + .05Pd	1.6	Crevice Corrosion Resistance
24	Ti Gr5 + .05Pd	1.6	Crevice Corrosion Resistance
26	Ti Gr1 + 0.1Ru	1.2	Crevice Corrosion Resistance, Lower Cost
27	Ti Gr2 + 0.1Ru	1.2	Crevice Corrosion Resistnace, Lower Cost

Legend:
* ASTM B265 Grade Designation
** Cost Ratio to Lowest Cost Alloy, Current Metal Prices at time of Presentation
*** When Comp. shows "Gr.# + addition", alloy also exhibits features of the base Gr.

Table 2

Comparison of Alloy Erosion-Corrosion Resistance at Various Seawater Test Locations (Ref 1)

Location	Flow Rate (m/sec)	Duration (months)	Corrosion Rate (mm/y)		
			Titanium	Cu-Ni (70-30)	Aluminum
Brixham Sea	9.8	12	<0.0025	0.3	1.0
Kure Beach	1.0	54	7.5 x 10 (-7)	-	-
	8.5	2	1.2 x 10 (-4)	0.05	-
	9.0	2	2.8 x 10 (-4)	2.1	-
	7.2	1	5.0 x 10 (-4)	0.12	-
Wrightsville Beach	0.6-1.3	6	1.0 x 10 (-4)	0.02	-
	9.1	2	1.8 x 10 (-4)	-	-

Table 3

Titanium Applications in Shipboard Piping Systems (Ref 5)

Firemain Systems
Seawater Ballast Systems
Aegis Radar Cooling Water Systems
Oily Waste Systems
Deck Draining Systems
Magazine Sprinkling Systems
HVAC (Ducting)

Seawater Service System
Feedwater to Distilling Plants
Seawater Compensated Fuel Oil Systems
Bilges
Countermeasure Washdown Piping
Missile Deluge Systems
Stanchions

Table 4

Titanium Heat Exchanger Applications on
Navy Ships and Offshore Platforms (Ref 5)

Shipboard	**Offshore**
Ship service turbine generator condenser	Lube oil cooler
Racer Steam Condenser	Engine jacket cooler
Radar and other electronic coolers	Compressor cooler
De-Salination units	Central exchanger
Air conditioning freon condenser	Direct low pressure crude cooler
Distillation brine heater and preheater	Discharge cooler
Lube oil and engine jacket coolers (TAO oilers)	Quench water cooler
Low pressure air compressor cooler	Propane condenser
	Gas dehydrator cooler
	Natural gas cooler
	Glycol cooler
	Flash gas compressor
	Intercooler
	Interstage oil cooler

Table 5

Comparative Cost of Titanium with Other Marine Structural Materials

Comparison Costs of Plate Products in Late 1996
Basis is Carbon Steel at Ration of 1.0

Alloy	**Cost Ratio**
Carbon Steel	1.0
Aluminum 5456	1.8
Stainless Steel, 316L	4.3
Cu-Ni (90-10)	9.4
Cu-Ni (70-30)	11.8
Alloy 825	12.2
Titanium, Grade 2	12.8
Alloy 400	14.2
Titanium, Grade 16	16.3
Titanium, Grade 7	21.0
Nickel Alloy 600	23.1
Nickel Alloy 625	26.0

This Comparison is on a Volumetric Basis Only. It does not take into consideration strength and modulus factors.

Figure 1

Titanium-Steel welding transition joints permit welded, crevice free joints between titanium and steel. The planar concept is most commonly used in ship construction. In piping, the concentric option may be modified to a tapered bond configuration eliminating the internal step.