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TITANIUM – PROPERTIES, ADVANTAGES AND APPLICATIONS SOLVING THE CORROSION PROBLEMS IN MARINE SERVICE

John A. Mountford, Jr.
Director of Marketing

Tico Titanium, Inc.
52900 Grand River Avenue
New Hudson, MI 48165

ABSTRACT

Titanium, at long last, is now being viewed, accepted and used as a material for the prevention of corrosion, the reduction and elimination of major corrosion related maintenance issues and for the advantages it offers in weight savings, replacement costs and life cycle cost benefits.

This presentation focuses on explaining the properties of titanium, the how and the why the metal is so suitably qualified for use in seawater and all water environments, and the advantages that titanium provides in marine service. The discussion will also include comparisons against materials currently being used, where these have or are being replaced, as well as experience and applications for titanium's use – both in industrial service and aboard ship.

The need to resolve corrosion, maintenance and weight issues is obviously apparent and ever ongoing. The use of titanium, in its many forms and with its many benefits, is a real, currently available solution to the corrosion problems in marine service.

INTRODUCTION

Titanium is well established for use in some of the most severe environments in many industries including the Chemical Process Industry (CPI), Energy (including Geothermal), Pulp & Paper, Desalination (in Multi-Stage Flash Desalination units), Refineries, and in the Utility Industry in Utility Steam Condensers. It is also playing a significant part in Offshore rigs in Ballast Tanks, Fire-Main systems and general Service Water piping systems, linings for Flue Gas Desulfurization (FGD), among many others.

In the past decade there has been a significant increase in the usage of titanium for military applications including armor, protective linings, and especially in naval applications where seawater is the environment and where corrosion, erosion and maintenance are of primary concern. Within the context of seawater environments, applications for titanium include Heat Exchanger seawater cooling (both Shell & Tube and Plate/Frame), in service water Lube Oil Coolers and other general heat exchanger systems. It is also used, both shipboard and in land-based plants, in Hot Water Heater units as well as for Refrigeration, as Air Chillers and air-conditioning systems[1]. Its products run the gamut from sheet for heat exchanger shells and baffles, plate for tubesheets and vessels, tubes for seawater cooling, pipe, fittings (elbows, tees, reducers, etc.), fasteners, flanges, pumps and valves for seawater service water input, fire protection systems and drainage.

Titanium's virtual immunity to seawater (and all waters) provides the service reliability, long-term proven life-cycle cost economies and reduction (or elimination) of maintenance that are driving its usage in solving the corrosion issues in marine service. Explanations with regard to some of the more appropriate Chemistries (Grades), Properties (Mechanical & Physical), Corrosion Resistance (Immunity), Weight Savings, Shock Resistance and other advantages that this metal provides, along with some of the most Frequently Asked Questions and Concerns are addressed.

CHEMISTRY [2]

[See Table I]

Grade 2 is the most widely used of the CP (Commercially Pure) Grades. Products include Tube (welded & seamless), Pipe, Plate, Sheet/Strip, Fasteners, Fittings, Pumps and Valve bodies. It is approximately 99.6% pure and is the primary material for marine applications.

Grade 1 is slightly purer than Grade 2 (at approximately 99.8%), and therefore more formable. It is used as the surface protective (titanium) layer in Explosively Clad (bonded) plate or parts, and also for the complex shaped plates in Plate & Frame heat exchangers, due to its ability to be deep drawn.]

Grade 5 is a very high strength and highly erosion resistant alloy used for valve internals, particularly in ball valves.

Grade 9 is a higher strength alloy, originally developed for increased corrosion resistance for the Chemical Process Industry (CPI) for use in severe corrosive environments, designed to withstand crevice corrosion at low pH levels and at higher temperatures to 500^0 F (260^0 C). It has application in ship service as stack liners, providing corrosion resistance from the hot combustion gases and extending the (material

replacement) life and port maintenance from every 6 months to several years.
[Retrofitting DDG 51 vessels; in service approx. 9 years.]

Grade 23 is an Extra Low Interstitial (ELI) version of Grade 5. It is used where Stress Corrosion Cracking (SCC) is a concern, in applications where the 6Al – 4V alloy would normally be thought to be the material of choice, BUT where the application is under stress conditions. The lower interstitials (Fe, O_2 and N_2) give significant improvement to eliminating the SCC concerns.
[Compare Grade 5 and Grade 23 for these values.]

MECHANICAL & PHYSICAL PROPERTIES

[See Table II]

A comparison of the Mechanical Properties between Grade 2 Titanium and the metals (90–10 Cu-Ni, 70-30 Cu-Ni, and 316 Stainless Steel) most commonly used aboard ship that exhibit corrosion problems and, in specific areas, are being replaced, is shown in Table II. Some of the more appropriate comments with respect to these properties follow:

Tensile Strength (TS) minimum for Grade 2 Ti (50 ksi) is above that of 90-10 Cu-Ni (40 ksi), at that of 70-30 Cu-Ni (52 ksi), and below that of 316 Stainless (75 ksi).

Yield Strength (YS) minimum (40 ksi) is well above that of both 90-10 and 70-30 Cu-Ni (15 and 18 ksi) and somewhat above 316 Stainless (35 ksi).

Elongation (El) minimum (20%) is below both 90-10 Cu-Ni (30%) and 316 Stainless (30%) but above 70-30 Cu-Ni (15%). Elongation for Grade 2 is generally at 25% to 28% or more. [Elongation for Gr. 1, the more formable Ti grade, is 24% minimum and is typically above 30%.]

Elastic Modulus (16×10^6 psi) is a measure of the rigidity (stiffness) or “flex” of the material (the lower the value, the greater the flex). Titanium is below that of the Cu-Ni alloys (18 and 22×10^6 psi) and well below that of 316 Stainless (28×10^6 psi). This is significant for shock resistance.

Thermal Expansion Coefficient (4.8 Micro in/in ^{0}F @ 32^0 F – 212^0 F) defines the amount of movement (expansion) as temperature increases. Significantly lower than 90–10 and 70-30 Cu-Ni (9.5 and 9.0 Micro in/in ^{0}F) and 316 Stainless (8.9 Micro in/in ^{0}F). This is a benefit for titanium since it is much closer to that of carbon steel (6.0 Micro in/in ^{0}F) and equates to lower stress during thermal fluctuations (expansion) when coupled to or within a system that is made primarily of carbon steel.

Thermal Conductivity (150 BTU/hr ft^2 – ^{0}F/in) [also given as 12.5 BTU/hr ft^2 – ^{0}F/ft] was proven within the last 10 years to be greater than the Stainless steels (@ 95 BTU/hr ft^2 – ^{0}F/in). This property is very significant for tubing applications, where heat transfer in heat exchangers is obviously one of the prime factors for determining cooling capacity.

Although below that of the 90-10 and 70-30 Cu-Ni alloys (348 and 204 BTU/hr ft^2 – ^{0}F/in), the tube wall thickness of titanium can be reduced, since there is no need for a corrosion allowance. Diameter sizes can also be reduced and flow rates increased due to titanium's significantly higher erosion resistance, making the effective overall heat transfer difference negligible or even higher for titanium. Density is one of the added major benefits affecting weight savings when using a titanium system. At 0.163 lbs./in^3, it is half that of the Cu-Ni alloys (0.323 lbs./in^3) and 56% that of Stainless Steels (0.291 lbs./in^3). This is very significant to weight reduction for piping systems throughout the ship, as well as in tubing and internals for heat exchangers and chillers.

ISSUES & BENEFITS

A List of the Issues and Benefits when using titanium is shown in Figure 1. Each of these items is discussed below:

DENSITY / WEIGHT SAVINGS [3, 4]

[See Tables III & IV]

Because of the lower density of titanium, there are significant weight reductions that accrue whenever or wherever titanium is substituted for these other metals. Entire systems are reduced by an approximate 50% or more in weight. This not only applies to the tubing or pipe, but also to associated fittings, flanges and valves. Weight comparisons made between Titanium and Copper-Nickel (Cu-Ni) piping are shown in Tables III and Table IV.

The first (Table III) shows a comparison between like Schedule 10 pipe sizes for the both metals, representing a 49.5% actual weight reduction when using titanium. The second comparison (Table IV) shows Schedule 10 Titanium pipe versus Class 200 Cu-Ni, (common to these systems). This comparison indicates weight savings of from 34% for the smaller pipe sizes, through 50% for the mid range - 6" & 8" nominal pipe sizes, and up to 63% weight savings for largest size at 12" nominal pipe size. In some cases where even heavier pipe sizes are used, it is often possible to reduce the gauge, further reducing weight, when using titanium.

CORROSION RESISTANCE / WATER IMMUNITIES

[See Figure 2 & Table V]

Titanium is virtually immune to seawater. It exhibits complete resistance to General corrosion and Crevice corrosion in all waters at temperatures up to 500^0 F [260^0 C] for general and to 180^0 F [82^0 C] (or somewhat above) for crevice corrosion.[5, 6, 7] Corrosion, in most all-marine applications, the greatest problem and the most costly, is no longer an issue. Titanium does not corrode in this environment!

Not only does titanium not corrode in any normal seawater environments, it also does not corrode in any polluted waters (ports and harbors are good examples). This can, and usually does, have devastating effects on other corrosion resistant materials, especially where the pollution is heavy. It is currently being used as a substitute tube material in hot water heat exchangers and chillers in hospitals and apartment complexes in New York City using polluted Hudson River cooling water (as well as in Hong Kong). Other tube materials are corroding in six months to less than two years, less time than warranty periods are valid.

Microbiologically Influenced Corrosion (MIC) [8, 9] [microbes, etc.] does not affect titanium. This form of corrosion is present in many fresh water systems, where corrosion is generally not anticipated. It is also a very serious concern during plant layovers where Stagnant water can be death to many materials as bacteria and microbes multiply, deposit corrosive material and grow rapidly under stagnant conditions, especially in a polluted environment.

These same stagnant conditions exist when ships anchor in port for maintenance and do not flush all the water systems. STAGNANT WATER left in pipes and tubes highly accelerates pitting corrosion in most metals, including Cu-Ni and Stainless Steels, primarily by a Crevice Corrosion mechanism. These systems must be flushed with fresh water and drained (a costly maintenance agenda) or be continually run to hopefully avoid situations noted above. Even if the water is fresh, bacteria will grow under stagnant water conditions, no matter what it is. Titanium is not affected by Stagnant Water conditions.

Shock chlorine treatments used to prevent fouling or to clean systems do not present a problem for Titanium either.

EROSION RESISTANCE

[See Figure3]

Titanium's (ceramic-like) outer protective oxide film (TiO_2) allows water velocities above 90 ft/sec (27 m/sec) and higher in the absence of suspended solids. Under sand-laden conditions, flow rates can be as high as 15-18 ft/sec (4.6 – 5.5 m/sec) without any erosion effects. This is in contrast to limitations put on some materials to as low as a range of from 7 to 12 ft/sec
(2.1 to 3.7 m/sec) under ordinary (non silt/sand-laden) conditions.[5, 10]

It should be remembered that when material is "trapped" inside pipe or tubes, water might be directed against the walls at increased velocity. Velocities can also be higher during cleaning or flushing operations. Designed flow conditions are not always the only consideration for maximum flow.

Mechanical scrapers for cleaning of titanium tubes or pipe may be used and are not detrimental to titanium. While these may act as corrosion sites in other metals, titanium instantly re-heals its protective oxide layer and maintains its corrosion immunity.

PROPERTY ADVANTAGES

[See Figure 4]

The specific properties of titanium make it very suitable for application in marine environments. Aside from its corrosion immunity in marine service, it's much lower density and high strength to weight ratio translates into significant weight savings for every pound of titanium used and is a measure of its structural integrity.

The Thermal Expansion Coefficient of titanium is lower than that of Cu-Ni alloys and Stainless Steels being much closer to that of carbon steel. This makes it more compatible equating to lower stress from thermal fluctuations (expansion) when coupled to or within a system that is made primarily of carbon steel.

The Thermal Conductivity of titanium being higher than that of stainless steels allows greater heat transfer in heat exchangers [1, 11, 26]. It can also be made to match that of the Cu-Ni alloys (much more easily when comparing to 70-30 Cu-NI) by reductions in wall thickness (with no need for a corrosion allowance) and increases in flow rate (due to its significantly higher erosion resistance), making the effective overall heat transfer difference negligible or even higher for titanium.

When considering the fact that the Elastic Modulus is on the low side, it makes titanium more flexible and more resistant to damage with superior shock tolerance (0.63 x 10^3 in/sec Shock Resistance Factor). The Shock Resistance of titanium is significantly higher than 316 Stainless Steel, 70-30 Cu-Ni and Nickel Base Alloys. (See Table VI)

The Yield Strength (min.), being the highest among its competing alloys, makes titanium suitable, strength wise, for use in a number of marine applications. It also provides the potential for lighter gauges, which translates in weight and cost reductions.

Titanium has good ballistic properties and is used for armor for the ground services.

It is non-magnetic with an Electrical Resistivity of 22 micro-ohm-in @ RT, allowing no electronic interference.

An extremely tight adhering, erosion resistant outer protective layer of a non-toxic material (it is used in prosthesis for body parts) does not release any toxic metals to the environment. It is entirely Environmentally Friendly.

FABRICATION AND WELDING [12, 13, 14, 15, 16, 17, 24, 25]

[See Figure 5]

Titanium has been formed and welded since the late 40's, practically speaking, in the early 50's. The "Industrial" segment began to emerge in the mid to late 50's and its introduction into the Chemical Process Industry (CPI) took place in the mid 60's. At this juncture, titanium was used in major chemical applications and in the Pulp and Paper Industry, particularly in chloride environments, due to its superior corrosion resistance in these applications and a proof of its immunities in seawater.

Fabricated parts from the early beginnings to the current day include small to very large vessels and heads made from formed and welded plate, pipe (both Press Brake formed and welded, and later Continuous welded), formed and welded fittings. Added to these are tubesheets and welded tubes, (presently for condenser applications alone are well over 400 million feet). Included also are tens of millions of feet used in an extensive array of heat exchangers in dozens of Chemical, Refinery, Desalination, Air Conditioning, Heater and other applications throughout the world. This and the thousands of parts cut, machined, drilled and formed attest to its fabricability.

One further example of the formability of Grade 2 is that ends of Sch 10 welded pipe have been specially flared to a full 90^0 to form the equivalent of Stub Ends for accommodating Slip-On Flanges for connections.

The above examples also attest to the ability to weld titanium. Yet, after all this time and all the welded production, there remain some who doubt and / or refuse to believe titanium is a weldable metal. There can be no doubt – titanium is weldable. It has been done for close to 60 years – from commercial industry to thousands of “garage shops” throughout the country.

The Commercially Pure (CP) grades are easy to weld. Like other metals, including the stainless steels and other Nickel Base Alloy corrosion resistant metals, precautions and methods need to be applied to yield good results. Compared against these other metals, CP titanium is very easy to weld. The CP Grades, being a single phase, do not have the segregation or element loss concerns of these other materials. The result is a smooth weld, with no roughness and easy to inspect.

The most common weld method is Tungsten Inert Gas (TIG) - Gas Tungsten Arc (GTA), although other methods include Gas Metal Arc (GMA) - Metal Inert Gas (MIG), Plasma, Resistance, Friction, Electron Beam, Laser, Pressure and Orbital welding is routinely performed for varying applications.

Certain precautions need to be taken – many of these being standard to other metals as well. These are comprised of using clean stainless tools, [Do Not Carbon Steel tools - a source of iron contamination], wiping surfaces clean of oil, grease, dirt, etc. Use an Argon purge gas and a trailing shield, holding it over the weld at the end of the bead for a period of time to allow the metal to cool to below 800^0 F (to avoid oxidation of the weld).

MAINTENANCE REDUCTION

The fact that titanium has the attributes that make it ideal for seawater service qualifies it as a material of choice that will not need replacement for any of the types of corrosion that affect other metals. Its use eliminates the need for material replacement, whether it is piping, tubing [18], ducting or parts fabricated for various other operations – lights, switches, and linings… It truly is a material that will last lifetimes and beyond. At the end of a ship's life, it would be readily feasible to cut out or disconnect the flanged titanium sections, clean and install the same material in a new ship since it will be as corrosion free as when it was first installed. (Offshore rigs design in titanium as a material that will allow a rig to attain a 50-year life. Titanium outlasts this time period.)

With the elimination of the need for replacement, maintenance can be significantly reduced. Since it does not corrode, maintenance would consist of the scheduled cleaning of tubes in Shell & Tube heat exchangers or plates in Plate & Frame heat exchangers, pipes in Service Water piping systems, drains, ballast tanks and the like. There would be no need to schedule inspections for corrosion-related leaks or ultrasonic inspections for pitting, weld failures by corrosion or integrity of the pipe or tube walls.

FREQUENTLY ASKED QUESTIONS

What size Pipe should be used? Why settle on Schedule 10?

- All Pipe sizes are available from 3/8" through 42" Schedule sizes. The most common pipe sizes used within the Navy, as an example, are 2" through 12" (with 14" on occasion). All sizes are designated by design by the shipbuilders or internally.

- Schedule 10 (gauge) titanium has been designed into Navy applications for the following reasons:

    1. For meeting the requirements of the "Shock Test" which is a necessary certification within the Navy for use of a material on board ship.

       [Although titanium is much stronger than the Cu-Ni alloys, this "Shock Test" is designed based on the material's inherent properties. For a stronger material, the requirements are more stringent, even though it is very capable of surpassing the parameters of a weaker material.]

    2. To best accommodate Bending.

       For the various spooled connections to be made, it was felt that the Sch 10 size to be best (or easiest) in preventing "rippling" during forming. Unfortunately, the ability to use thinner wall sections for additional weight savings (corrosion allowance not being required) could not be taken advantage of.

    3. Welding preference.

In some cases the heavier gauges are preferable for welding and is the more conservative approach, particularly in areas where experience is just being established.

4. Fire Testing indicated that the Sch 10 was the preferable size and passed this requirement for Naval pipe applications.

- For Industrial use, the thinner gauge Schedule 5 pipe can be accommodated in certain applications and, in so doing, can further reduce weight and initial cost.

Can you weld Titanium to Carbon or Stainless Steel or other common metals?

- No. Titanium can only be welded to titanium (or other Refractory metals like Zirconium or Tantalum).

  The reason is that the melting point of titanium is very high at 3040^0 F (1670^0 C) and the other metals would already have melted far ahead of titanium. [The melting point of HY 80 steel is 2700^0 F (1482^0 C); aluminum is 1050^0 F (565^0 C) and Cu-Ni is 2100^0 F (1150^0 C).]

What about Titanium's Susceptibility to Hydriding? [19]

Hydriding (Hydrogen absorption) is a very misunderstood concept. It is frequently brought up by those outside the industry making it appear that titanium has a serious fault, which is totally false.

- Hydriding (Hydrogen Absorption) is possible in high temperature / high-pressure anhydrous (no water) streams. The presence of 2% moisture or oxygen will prevent absorption. Even if it were absorbed onto the surface (which it is not in these applications), it would only cause problems if it diffused into the base metal, which it cannot under these operating marine environments (conditions). The factors that have to take place simultaneously for hydrogen absorption to be a problem are:

  1. Metal temperature has to be above 180^0 F (82^0 C). The conditions when discussing marine environments are room temperature (RT) or well below the 180^0 F (82^0 C). Below this temperature, the worst that can happen would be for Hydrogen to remain on the surface, with no effect on mechanical properties.

  2. Solution pH needs to be less than 3 or more than 12 or impressed potentials on the metal more negative than –0.7 volts (vs. Ag/AgCl). Conditions in marine environments are near neutral pH, at approximately 7, and there would be no negative potentials applied.

3. A mechanism such as a galvanic couple needs to be present to generate nascent hydrogen. This could occur through galvanic couples, impressed cathodic current, corrosion of the titanium or constant mechanical abrasion of the metal.

- Hydrogen embrittlement is avoided by elimination of one of the above three factors. In marine environments, the conditions are not met and there is no fear of a Hydriding problem.

- Most absorption problems arise from detrimental galvanic couples and overzealous cathodic protection. Titanium should not be coupled to active metals such as aluminum, zinc and magnesium in the presence of seawater but only at temperatures above 180^0 F (82^0 C).

Is Titanium susceptible to Stress Corrosion Cracking (SCC)?

- CP titanium, which includes Grades 1,2, 3 and 4 are IMMUNE to SCC in marine/seawater environments. [The only environments of concern for the CP grades would be absolute methanol, red fuming nitric acid, nitrogen tetroxide and cadmium metal.] Chloride SCC is not a consideration for these grades.

NOTE: In cases where the high alloy 6Al-4V would be looked at for providing a very high strength material in a seawater application, it is ESSENTIAL that Grade 23 (6Al-4V ELI) be used and not the standard Grade 5. Grade 23 is the Extra Low Interstitial version of Grade 5. The low level of interstitial elements prevents SCC in high stress conditions in seawater applications. (Refer to Figure 1).

How is the Galvanic situation handled between titanium and other coupled metals? [1, 20, 21, 22]

- Titanium is the noble metal and acts as the Cathode in seawater environments. Corrosion considerations and problems relate to the other metals (when coupled to titanium) that act as the Anode. This would be typical in situations where titanium pipe would be attached (coupled) to a 90-10 Cu-Ni valve, as an example.

- Galvanic effects that act on the less noble metal can be counter-acted by using insulators - non-conductive materials to break the connection. This would be the case in a flange-to-flange joining situation. In addition to gaskets, plastic bolt sleeves are also available to provide an insulation barrier between titanium and other metals. This is the most appropriate method used.

- Cathodic protection may also be suitable in certain specific areas where other methods are not readily possible. This is generally not the case for piping systems.

- Keep the Ratio of the titanium / susceptible metal low. Do not “overwhelm” the system by having a large amount of titanium coupled to a small amount of another susceptible metal. This would be a case where cathodic protection might be appropriate.

- Where Galvanic effects may be present, yet have a gradually decreasing, down-stream corrosion effect on the other metal, a very common method for control would be to install a short transition section of the alternate (other) metal. Preferably flanged, this section can be quickly and cheaply replaced in a set amount of time – 6 months, a year or more, etc. This small section could also be monitored for corrosion to determine a suitable replacement period. (Titanium would not require corrosion monitoring.)

- Lastly, an all titanium system would eliminate this concern.

How can titanium systems be cleaned? Are there any detrimental effects?

- The passive film on titanium provides a smooth, slick surface, which inhibits buildup for extended periods between cleaning. In marine environments, titanium is subject to Biofouling, which can be controlled with chlorine injection. This process is totally innocuous to titanium. Other chloride or bromine solutions can also be used for cleaning.

- Mechanical cleaning does not affect titanium, as the protective surface instantly re-heals itself. Scratches are therefore not detrimental and do not promote corrosion sites, as they may for other metals.

- Use Clean Stainless Steel equipment only (Carbon steel implements should Not be used [nor should they be used for other metals]. Stainless “bullets” for mechanical cleaning are totally appropriate for titanium.)

- Ultrasonic Shocking, Ultraviolet Exposure (UV), Ozonation and high velocity water flushing have all been tried and are all additional suitable methods for cleaning.

What about cost?

- Comparisons against materials that do not perform, corrode or are not generally suitable for the specific intended use - in this case a seawater/marine environment, are not appropriate, but the question of initial cost always comes up.

- It also must be kept in mind that the density of titanium is basically half that of its competing materials, so costs must be viewed on a per unit basis, not on a price per pound basis.

- Life-Cycle costs should be the consideration, not initial cost.

- Titanium is probably 20% or so higher than 90-10 Cu-Ni in initial cost, but it does not need maintenance and does not have to be replaced three or more times in the life of the ship. This is why titanium is beginning to replace Cu-Ni systems. It was estimated that the return on investment of a Titanium system versus a 90-10 Cu-Ni system is 800% over the ship's life (25% per annum). [23]

- Compared against 70-30 Cu-Ni, titanium is, in most cases, lower in cost. It is also lower in cost than Monel™. And, titanium does not need to be replaced over the life of the ship.

- Weight savings have value and allow additional defense related material on board ship.

- Titanium's high erosion/corrosion resistance enables higher velocities, thinner walls and reduced sized Piping, where designs allow.

- "What Price Maintenance"? With titanium, maintenance is substantially reduced, and in some to many cases it is virtually eliminated.

What Specifications Apply?

[See Table VII]

- Table VII includes most standard Industrial specifications used in Commercial applications for the products included for Marine Service. It is significant that the Navy, and other branches, are now using the standard Industrial specifications that greatly simplify meeting requirements that have been time tested for decades. It also eliminates a significant amount of effort in qualifying to military specifications and allows much freer competition and availability from the many companies that supply their products to commercial specifications. It also tends to avoid overcompensating requirements that oftentimes differ from those used in industry.

    - ASTM American Society for Testing and Materials B specs (Non-Ferrous)
    - ASME American Society of Mechanical Engineers SB specs (Non-Ferrous)
    - ANSI American National Standards Institute (A Division of the ASME) B specs [Written for steels, these are used <u>For Dimensions Only</u> - for Titanium]
    - MSS Manufacturers Standardization Society [Written for steels, these are used <u>For Dimensions Only</u> - for Titanium]

What are some Typical Applications that use titanium in Marine Service / Environments?

[See Table VIII]

A list of applications currently using titanium for seawater/marine use is shown in Table VIII. These include those for the Navy as well as those for Offshore Platforms (oil rigs). Additional areas where titanium would also be appropriate and should be considered for shipboard use, and for applications where it is used other than by the Navy are also indicated. The list is by no means complete but serves to show the uses specific to this area of interest. (Other industrial uses where seawater is involved are indicated throughout this paper.)

SUMMARY

Titanium continues to see increased usage in naval and commercial and marine applications for many reasons. It is unsurpassed in its corrosion immunities in marine service, its low density provides for significant weight reductions, it has a high strength / weight ratio, high erosion resistance and is highly shock resistant. All these factors allow design engineers the opportunity to provide systems that significantly reduce (or eliminate) maintenance time and costs while providing unexcelled performance and a practically unlimited service life. It is available as Fittings, Flanges, Pipe, Tube, Plate, Sheet, and Fasteners and is formable into most all required forms. It has a long history in Heat Exchanger service (Shell & Tube and Plate & Frame), in Pipe systems, as components, tanks and vessels. Its use has become the standard in many commercial marine applications and it is seeing greater usage in the Navy as well providing significant life cycle cost advantages in solving the corrosion problems in marine service.

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ISSUES & BENEFITS

- **DENSITY / WEIGHT SAVINGS**
- **CORROSION RESISTANCE [SEAWATER IMMUNITIES]**
- **EROSION RESISTANCE**
- **PROPERTY ADVANTAGES**
- **FABRICATION & WELDING**
- **MAINTENANCE REDUCTION**
- **FREQUENTLY ASKED QUESTIONS**

FIGURE 1

CORROSION RESISTANCE – SEAWATER IMMUNITIES

- **Titanium is virtually IMMUNE to seawater (all waters)**
- **Complete resistance to General Corrosion and Crevice Corrosion in all waters at temperatures to 180^0 F (or somewhat above)**
- **No Corrosion in Polluted Waters (i.e. ports and harbors)**
- **No Effects from Microbiologically Influenced Corrosion (MIC) [microbes etc.]**
- **Titanium is Not affected under Stagnant Water conditions**
- **Shock chlorine treatments can be used to prevent/clean fouling**
- **CP Grade 2 is Immune to Stress Corrosion Cracking under sea service conditions**
- **Seawater cooled tubes in service for 40 years with zero corrosion**

FIGURE 2

EROSION RESISTANCE

- **Titanium has a “ceramic-like” outer protective oxide film (TiO_2)**
- **Water velocities of 90 ft/sec (27 m/sec) and higher in the absence of suspended solids**
- **Flow rates of 15 to 18 ft/sec (4.6 to 5.5 m/sec) and higher under sand-laden conditions**
- **Mechanical Cleaning using Scrappers are not harmful to titanium**
- **Titanium’s Surface instantly re-heals itself**
- **High tolerance to pipe bend areas and directional flow changes**

FIGURE 3

PROPERTY ADVANTAGES

- **Density – Weight savings to 50% (and above)**
- **Low Thermal Expansion = Less Joint Stress**
- **Thermal Conductivity allows matching (or higher) Heat Transfer - ideal for Heat Exchanger applications**
- **Low Elastic Modulus = High Shock Tolerance**
- **High Yield Strength (min) = High Strength / Weight Ratio**
- **Excellent Ballistic properties = used for armor**
- **Non-Magnetic = No Electronic interference**

FIGURE 4

FABRICATION & WELDING

- **Machining – Slow Speeds, Deep Cuts, High Cooling Fluid**
- **Cutting - Drill, Saw, Shear, Water-Jet, Oxy-Acetylene or Plasma**
- **Bending – formable & forgiving [compensate for spring-back] (Pipe ends can be flared 90^0 to eliminate Stub Ends)**
- **Shearing – Standard Equipment - manual & automatic**

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- **Tungsten Inert Gas (TIG), Gas Tungsten Arc (GTA), Gas Metal Arc (GMA), Metal Inert Gas (MIG), Plasma, Resistance, Friction, Electron Beam, Laser and Orbital**
- **Training TIG welders – 2 weeks or less**
- **Fluid Welds (CP is single phase)**

FIGURE 5

TABLE I

CHEMISTRY - WGT. % [2]

	O_2 max.	Fe max.	H_2 max.	C max.	N_2 max.	Al	V	Other (each) max	Other (total) max	Ti
Grade 2	0.25	0.30	0.015	0.08	0.03			0.10	0.40	Bal.
Grade 9 (3Al - 2.5V)	0.15	0.25	0.015	0.08	0.03	2.5 - 3.5	2.0 - 3.0	0.10	0.40	Bal.
Grade 5 (6Al - 4V)	0.20	0.40	0.015	0.08	0.05	5.5 - 6.5	3.5 - 4.5	0.10	0.40	Bal.
Grade 23 (6Al - 4V ELI)	0.13	0.25	0.0125	0.08	0.03	5.5 - 6.5	3.5 - 4.5	0.10	0.40	Bal.

ELI = Extra **L**ow **I**nterstitials

TABLE II

MECHANICAL & PHYSICAL PROPERTIES [2]

PROPERTY	Titanium Grade 2		90-10 Cu-Ni		70-30m Cu-Ni		316 Stainless	
	KSI	MPa	KSI	MPa	KSI	MPa	KSI	MPa
Tensile Strength (min)	50	345	40	275	52	360	75	515
Yield Strength (min)	40	275	15	105	18	125	35	240
Yield Strength (max)	65	450	--		--		--	
Elongation (min)	20%		30%		15%		30%	
Elastic Modulus (10^6 psi)	16		18		22		28	
Thermal Expansion Coeff. (Micro in/in ^{O}F)	4.8		9.5		9.0		8.9	
Thermal Conductivity (BTU/hr-ft^2 ^{O}F/in)	150		348		204		95	
Density (lbs/in^3)	0.163		0.323		0.323		0.286	

Thermal Expansion Coefficient for HY 80 Steel = approx. 6.0 Micro in/in ^{O}F

TABLE III

WEIGHT COMPARISON - TITANIUM VS. COPPER - NICKEL

BASIS : SAME PIPE SIZE [SCH 10] -- Ti & Cu-Ni

OD Nominal [in.]	OD Actual [in.]	WALL Nominal [in.]	WEIGHT Gr. 2 Ti [lbs./100ft.]	WEIGHT Cu-Ni [lbs./100ft.]	49.50% WEIGHT REDUCTION [lbs./100ft.]
2	2.375	0.109	152	301	**149**
3	3.500	0.120	249	493	**244**
4	4.500	0.120	323	640	**317**
6	6.625	0.134	534	1,058	**524**
8	8.625	0.148	771	1,528	**757**
10	10.750	0.165	1,073	2,125	**1,052**
12	12.750	0.180	1,390	2,753	**1,363**

TABLE IV

WEIGHT COMPARISON - TITANIUM VS. COPPER - NICKEL

BASIS : TITANIUM [SCH 10] vs. CLASS 200 CU-NI

OD Nominal [in.]	OD Actual [in.]	Ti WALL Nominal [in.]	Cu-Ni WALL Nominal [in.]	WEIGHT Gr. 2 Ti [lbs./100ft.]	WEIGHT Cu-Ni [lbs./100ft.]	WEIGHT REDUCTION [lbs./100ft.]	WEIGHT REDUCTION %
2	2.375	0.109	0.083	152	229	77	**34**
3	3.500	0.120	0.095	249	391	142	**36**
4	4.500	0.120	0.109	323	583	260	**45**
6	6.625	0.134	0.134	534	1,058	524	**50**
8	8.625	0.148	0.148	771	1,528	757	**50**
10	10.750	0.165	0.187	1,073	2,405	1,332	**55**
12	12.750	0.180	0.250	1,390	3,805	2,415	**63**

TABLE V

CORROSION RESISTANCE - COMPARISONS [10]

Corrosion	Cu-Ni	316 Stainless	Titanium CP, 5, 9, 23
General	Resistant / Susceptible	Resistant	Resistant / Immune
Crevice	Susceptible	Susceptible	Resistant / Immune (<2000 F)
Pitting	Susceptible	Susceptible	Immune
SCC	Susceptible	Susceptible (>1400 F)	Immune (except Gr. 5)
Fatigue	Susceptible	Susceptible	Resistant
Galvanic	Susceptible	Susceptible	Immune
MIC (Microbes)	Susceptible	Susceptible	Immune
Erosion	Susceptible	Susceptible	Resistant
Weld/HAZ	Susceptible	Susceptible	Resistant / Immune

TABLE VI

GENERAL SHOCK RESISTANCE OF ALLOYS [31]

$$\sigma_y / \sqrt{E\rho/386}$$

σ_y = Yield Stress [psi] (actual) [assumed 50,000 psi for the calculation]

$\sqrt{}$ = Square Root

E = Modulus of Elasticity [used 14.9 x 10^6 psi]

ρ = Density @ 0.163 lbs./ in.^{3}

386 = Constant x 1/ sec.^{2}

MATERIAL	SHOCK RESISTANCE [10^3 in. / sec.]
Ti Grade 9 [3Al - 2.5V]	0.95
Ti Grade 2	0.63
Inconel 625 ™	0.55
Monel 400 ™	0.24
316 Stainless Steel	0.21
70-30 Cu-Ni	0.15

TABLE VII

SPECIFICATIONS

TITLE	ASTM	ASME	ASME / ANSI	MSS	COMMENTS
Titanium and Titanium Alloy Welded Pipe	B 862	--			Both Pipe Specifications have significant changes &
Titanium and Titanium Alloy Seamless Pipe	B 861	--			replace ASTM B 337 which has been discontinued
Stainless Steel Pipe			B 16.5		Dimensions only
Welded and Seamless Wrought Steel Pipe		B 36.10M			Dimensions only
Seamless and Welded Titanium and Titanium Alloy Tubes for Condensers and Heat Exchangers	B 338	SB 338			
Titanium and Titanium Alloy Strip / Sheet / Plate	B 265	SB 265			
Pipe Flanges & Flanged Fittings			B 16.5		Dimensions only
Steel Pipeline Flanges				SP - 44	Dimensions only
Factory - Made Wrought Steel Buttwelding Fittings		B 16.9			Dimensions only
Wrought Stainless Steel Butt - Welding Fittings				SP - 43	Dimensions only
Forged Fittings, Socket - Welding and Threaded		B 16.11			Dimensions only
Ferrous Pipe Plugs, Bushings, and Locknuts with Pipe Threads		B 16.14			Dimensions only
Wrought Steel Buttwelding Short Radius Elbows and Returns		B 16.28			Dimensions only

ASTM - American Society for Testing & Materials
ASME - American Society of Mechanical Engineers
ANSI - American National Standards Institute [a Division of ASME]
MSS - Manufacturers Standardization Society

TABLE VIII

APPLICATIONS [4, 10, 23, 24, 25]

SHIPBOARD	OFFSHORE
Ship Service Turbine Generator	Fire Sprinkler Heads, Deluge
Distillation Unit Condensers (S/T) CG 47, DDG 51	Nozzles and Deluge Valves
Distillation Units Heaters CG 47, DDG 51	
Lube Oil Coolers CG 47, DDG 51, CVN	Lube Oil Cooler
Phalanx & LPAC/HPAC Coolers CG 47, DDG 51, CVN	
Aegis Radar Electronics Cooler (S/T) & (P/F)	Compressor Cooler
De-Salination Units (S/T) [27, 28]	Ballast Systems and Valves [29]
Firemain Systems - Piping & Fittings LHA 2, LPD-17	Firemain Systems [30]
Fire Pumps Grades 2 & 5 CG 47, DDG 51	
Service Water Piping	Service Water Piping
Air Conditioning Condenser (S/T)	Central Exchanger (P/F)
HVAC - Air Ventilation Ducting	Discharge Cooler
Distillation unit - Brine Heater and Brine Pre-Heater (P/F) and (S/T)	Direct Low Pressure Crude Oil Service Cooler (S/T)

(S/T) = Shell & Tube (Heat Exchanger)
(P/F) = Plate & Frame (Heat Exchanger)

TABLE VIII cont'd

APPLICATIONS cont'd.

SHIPBOARD	**OFFSHORE**
Engine Jacket Coolers CG 47, DDG 51, CVN TAO oilers (P/F)	Engine Jacket Cooler
Low Pressure Air Compressor Cooler	Quench Water Cooler (S/T)
Exhaust Uptakes Liners (Gr. 9) DDG 51 approx. 9 yrs.	Propane Condenser
Light Boxes	Gas Dehydrator Cooler (S/T)
Oil Waste Systems *	Natural Gas Cooler (S/T)
Magazine Sprinkler Systems *	Glycol Cooler (S/T)
Deck Drainage Systems Urinal Drain Piping LHA 2	Flash Gas Compressor
Bilges *	Intercooler (S/T)
Countermeasure Washdown Piping *	Interstage Oil Cooler (S/T)
Seawater Compensated Fuel Oil Systems *	
Missile Deluge Systems *	
Stanchions *	

* = Applications for Consideration On Board Ship

(S/T) = Shell & Tube (H. E.)
(P/F) = Plate & Frame (H. E.)