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Practical guide to using marine fasteners

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Practical Guide To Using Marine Fasteners

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The marine corrosion resistance of copper-, iron-, nickel-, aluminum-, and titanium-based alloy fasteners are reviewed. Coated-steel systems are also included. Several new alloys are characterized as candidate materials. Galvanic compatibility is identified as the most critical consideration for marine fasteners. Guidelines are presented to assist designers in selection of appropriate marine fasteners materials.

Fastener materials can be subjected to five primary conditions or zones in the marine environment: marine atmosphere, splash, tidal, full-immersion, and mud zones. Each of these environments provides different degrees of corrosiveness depending on the material. In addition to these corrosion zones, other seawater conditions affect fastener corrosion resistance: seawater velocity, pollutants (industrial airborne and dissolved gases from decaying organisms), temperature, and hydrogen evolution from electrochemical reactions in the marine environment.

The first fastener failure was apparently documented in 1761. Iron nails corroded from a copper hull sheathing with partial loss of the sheathing from the *H.M.S. Alarm*. This classic example of galvanic corrosion in seawater was one of the first forms of marine corrosion identified.

Today, galvanic corrosion is one of the most important forms of corrosion to consider when designing a fastener system, because by its nature, a fastener system is normally made up of two or more different metals in a metallic couple. One or more of the metals acts as an anode (corrodes), and the other metal acts as a cathode (protected against corrosion).

> *Stress corrosion cracking of improperly heat-treated, stainless-steel valve body bolts has occurred during hot summer months in some plants along the Gulf Coast.*

Galvanic effects are of primary importance in selecting fasteners. The fastener should be cathodic to (more noble than) the base plate material. It should never be the anode (less noble) material. The use of stainless-steel fasteners in aluminum structures is common and follows the galvanic guidelines just mentioned.

However, in aluminum structures exposed in the marine atmosphere, galvanic corrosion of the aluminum causes enlarging of the fastener hole allowing the uncorroded stainless-steel fastener to drop out. The use of copper alloy fasteners in aluminum results in severe pitting and corrosion of the aluminum, and should be avoided.

Using fastener systems of aluminum to aluminum, stainless to stainless, stainless to fiber-reinforced plastics (FRP), and stainless to wood limits the usefulness of these combinations and requires special precautions for satisfactory service. Packing these fastener joints with most greases is not effective, since moisture wicks up between the grease and metal surface, thus increasing crevice attack.

However, there are a few specially compounded greases that adhere to, and displace water from, metallic surfaces. These can be used to prevent crevice corrosion in joints where stainless-steel fasteners are used in aluminum structures, such

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TABLE 1
Bolting Mechanical Properties

Low-Resistant Alloys	UNS Number	ASTM Specification	Yield Strength, ksi	Tensile Strength, ksi	Strength/Wt. Ratio,Inx 100
410[(B)]	S41000	A468	120	175	6.2
416/416Se[(B)]	S41600/41623	A468	120	175	6.2
4140 Steel[(B)]	G41400	A193 B7	100	125	4.4
C Steel[(B)]	G10XXX	A449 Q&T		120	4.2
347	S34700	A468	30[(A)]	75[(A)]	2.6[(A)]
304	S30400	A468	30[(A)]	75[(A)]	2.6[(A)]
303/303SE[(B)]	S30300/30323	A468	30[(A)]	75[(A)]	2.6[(A)]
430[(B)]	S43000	A468	35	70	2.5
C Steel[(B)]	G10XXX	A307		60	2.1

Note: Yield strength measured at 0.2% offset.
[(A)]Tensile/yield strengths of up to 140/95 ksi can be obtained when bolts are machined from strain-hardened, 1.5-in.-diameter bar.
[(B)]Least corrosion resistant.

TABLE 2
Bolting Mechanical Properties

Medium-Resistant Alloys	UNS Number	ASTM Specification	Yield Strength, ksi	Tensile Strength, ksi	Strength/Wt. Ratio, Inx 100
X-750	N07750		122	177	5.9
718	N07718	B637 Type 2	115	170	5.7
A-286 Gr 665	K66286	A453	120	155	5.4
17-4PH(1150)	S17400	A468	105	150	5.4
Nitronic† 60	S21800		112	140	5.1
A-286 Gr 660	K66286	A453	85	130	4.5
316	S31603	A468	30[(A)]	75[(A)]	2.6[(A)]
Al 7075[(B)]	A97075	A468	50	68	6.7
Al 2024	A92024	A468	36	63	6.3
Al 6061	A96061	A468	31	45	4.6

Note: Yield strength measured at 0.2% offset.
[(A)]Tensile/yield strengths of up to 140/95 ksi can be obtained when bolts are machined from strain-hardened, 1.5-in.-diameter bar.
[(B)]Least corrosion resistant.
†Trade name.

TABLE 3
Bolting Mechanical Properties

High-Resistant Alloys	UNS Number	ASTM Specification	Yield Strength, ksi	Tensile Strength, ksi	Strength/Wt. Ratio, Inx 100
MP35N†	R30035	7468[(A)]	230	260	8.6
Alloy K-500	N05500	A468	86	155	5.1
Ti Grade 5	R56400	A1035	125	150	9.4
Alloy 400	N04400	A468	30	100	3.1
254 SMO†	S31254	A276	44	95	3.3
Al Bronze	C61400	A468	35	93	3.3
Si Bronze	C65100	A468	40	73	2.4
Ti Grade 1	R50250	A468	30	52	3.2
Copper	C11000	A468 ETP	10	40	1.2

Note: Yield strength measured at 0.2% offset.
[(A)]AMS specification, no ASTM.
†Trade name.

as Hovercraft† applications.

Strength is another consideration in selecting fasteners for ship hulls, offshore oil platforms, and other structures protected with sacrificial anodes or impressed current. Hydrogen released at the cathodically protected surfaces, including the fasteners, leads to hydrogen embrittlement of the higher-strength fastener materials and to hydriding of titanium. This severely limits the range of fastener materials that can be used in such protected structures.

Stress corrosion cracking of improperly heat-treated, stainless-steel valve body bolts has occurred during hot summer months in some plants along the Gulf Coast. Stress corrosion cracking of copper alloy fasteners due to ammonia in sea gull droppings has also occurred. Dezincification of common brass screws has led to the near sinking of a small craft in heavy seas. High-zinc brasses should never be substituted for copper, silicon bronze, or aluminum bronze fasteners in marine service.

The free-machining stainless steels, namely types 303 (UNS S30300), 303Se (UNS S30323), and 416 (UNS S41600), corrode rapidly in marine service and should be avoided.

An important consideration in material design of marine fastener systems is strength. The density of the alloy (weight of fastener system) is also important in designing marine aircraft components. Tables 1 through 3 compare mechanical strengths and strength/weight ratios for most of the marine fastener materials. Alloy MP35N† (UNS R30035) has the highest strength and a strength/weight ratio very close to that of titanium (UNS R56400). The fastener alloys are listed in order of their tensile strengths. Those materials with poor marine corrosion resistance (and thus difficult to use successfully) are identified in the tables.

Table 4 lists the coatings that are frequently applied to steel fasteners to improve their corrosion

† Trade name.

TABLE 4
Marine Fastener Coatings

- Hot-Dip-Galvanized Zn
- Electrodeposited Zn, Cr, Ni
- Electrodeposited Cd (Baked)
- Al Diffusion, Hot Dip, Silicone
- Fluoroplastic (PTFE)
- Ceramic
- Zn Silicate
- Zn Chromate
- Polysulfide Rubber

TABLE 5
Fastener Selection—Below Water

	C Steel(A)	Aluminum(A)	Copper-Based Alloy(A)	Stainless-Steel Alloy(A)	Alloy 400(A)
Fastener:					
Steel, Zn/Cd	Y	R(B)	R	R	R
Aluminum	R	Y	R	R	R
Copper alloy	G	R	Y	R	R
Type 316 SS	G	R(B)	Y	R	R
Alloy 400	G	R(B)	G	Y	Y
Ni-Cr-Mo	G	R(B)	G	G	Y
MP35N	G	R(B)	G	G	G
Titanium	G	R(B)	G	G	G

(A)Material to be fastened.
(B)Loss of aluminum around fastener is as serious as loss of fastener.
G = Generally satisfactory.
Y = May be satisfactory; detailed information needed.
R = Avoid.

TABLE 6
Fastener Selection—Below Water

	Graphite Composite(A)	Wood(A)	Concrete(A)	FRP(A)	Rubber(A)
Fastener:					
Steel, Zn/Cd	R	R	Y	Y	Y
Aluminum	R	Y	R	R	R
Copper Alloy	R	G	G	G	G
Type 316 SS	R	R	Y(B)	R(C)	R
Alloy 400	R	G	G	G	G
Ni-Cr-Mo	?	G	G	G	G
MP35N	?	G	G	G	G
Titanium	?	G	G	G	G

(A)Material to be fastened.
(B)The alkalinity of concrete provides protection for small areas of type 316 extending beyond the concrete.
(C)Some small boat manufacturers report good performance for type 316 bolting in FRP hulls below waterline when bolts are packed with water-repellent lubricant and recessed in FRP.
G = Generally satisfactory.
Y = May be satisfactory, detailed information needed.
R = Avoid.
? = Very limited information available; suggest caution.

resistance. Both metallic and nonmetallic coatings are used to protect steel fasteners during extended storage and construction periods. None of the coatings adds significantly to the service life of the fasteners after they have been placed in service below the waterline. The coatings are helpful in atmospheric exposures, but they are generally overcoated with the coating system used to protect the structure.

Guidelines for Marine Fastener Selection

Below the Waterline

Tables 5 and 6 offer guidelines for using alloy fasteners below the waterline. Several of the most common fasteners of the family of alloys discussed above are included as examples in this table. Some of the common materials to be fastened or bolted are other metals, such as steel, copper, etc. (Table 5) and various nonmetallics (Table 6). Three basic ratings for the fastened or bolted system are G = generally satisfactory; Y = may be satisfactory, but more detailed information is needed to fully assess the system; and R = the combination of materials should be avoided due to known galvanic problems, crevice corrosion susceptibility, or poor corrosion resistance of the materials.

Below-waterline fasteners, such as bolts in the keel and bilge areas, are an integral part of the safety considerations of all boats and ships at sea. For steel hulls, only aluminum is unsatisfactory because it is anodic to steel. Thus, this fastener combination receives an "R" rating (Table 5). Most of the other fasteners can be safely used in steel base plate because they are all cathodic to steel, and except for titanium, are resistant to damage from hydrogen released at cathodically protected surfaces. Type 316 stainless steel (UNS S31608) and alloy 400 (Monel,† UNS N04000) are protected by steel even in structures that are not cathodically protected by anodes or impressed current systems.

The nonmetallic base plate materials present another challenge to fastener materials. Below the waterline, a fastener used in wood, concrete, plastic, or rubber will not receive any benefit of cathodic protection. The nonmetallic material usually produces a severe crevice condition. Therefore, the alloy fastener's performance depends on the alloy's inherent seawater corrosion resistance. The crevice attack that occurs on fasteners in nonmetallic materials is more damaging to type 316 stainless steel and other common stainless steels than to alloy 400. Alloy 400 has long been used successfully in wood and other nonmetal-

TABLE 7
Fastener Selection—Above Water

	C Steel[A]	Aluminum[A]	Copper-Based Alloy[A]	Stainless-Steel Alloy[A]	Alloy 400[A]
Fastener:					
Steel, Zn/Cd	G	R	R	R	R
Aluminum	Y	Y	R	R	R
Copper Alloy	G	R[B]	Y	R	R
Type 316 SS	G	Y[B]	Y	Y	Y
Alloy 400	G	R[B]	G	G	G
Ni-Cr-Mo	G	Y[B]	G	G	G
MP35N	G	Y[B]	G	G	G
Titanium	G	Y[B]	G	G	G

[A]Material to be fastened.
[B]Loss of aluminum around fastener has caused structural failure in coastal buildings, but stainless-steel fasteners are widely used.
G = Generally satisfactory.
Y = May be satisfactory; detailed information needed.
R = Avoid.

TABLE 8
Fastener Selection—Above Water

	Graphite Composite[A]	Wood[A]	Concrete[A]	FRP[A]	Rubber[A]
Fastener:					
Steel, Zn/Cd	R	Y	G	Y	Y
Aluminum	R	Y	Y	Y	Y
Copper Alloy	R	G	G	G	G
Type 316 SS	R	Y	G	G	G
Alloy 400	R	G	G	G	G
Ni-Cr-Mo	?	G	G	G	G
MP35N	?	G	G	G	G
Titanium	?	G	G	G	G

[A]Material to be fastened.
G = Generally satisfactory.
Y = May be satisfactory; detailed information needed.
R = Avoid.
? = Very limited information available; suggest caution.

lics. The new 6% Mo stainless steels,[1] Ni-Cr-Mo alloys, MP35N, and titanium are more resistant than alloy 400 and are increasingly being considered for these difficult applications.

Some small boat manufacturers have reported good performance for type 316 stainless-steel bolting in fiber glass-reinforced plastic (FRP) hulls. The bolts were used below the waterline. They were packed with water-repellent lubricant and recessed in the FRP. The use of the graphite-free, water-repellent lubricants that fill the bolt hole is good practice for stainess steel and aluminum, both above and below the waterline.

Table 6 presents guidelines for fastener selection in nonmetallic-based materials below the waterline. The "R" rating for most fasteners exposed in graphite warns against the use of any graphite-containing lubricant, packing, or gasket in contact with these materials. The carbon (graphite) galvanic couple with most metals in seawater greatly accelerates corrosion of the less noble metal. This galvanic combination may even be harmful to more noble metals, such as alloy 400, Ni-Cr-Mo alloys, MP35N, and titanium. Considerable caution is advised when using any fastener alloy in graphite composites until more thorough evaluations have been undertaken.

Aluminum and coated steel are not suggested for use in concrete below the waterline. The improved rating for type 316 stainless steel in concrete is based on the fact that the alkalinity of the concrete has been found to protect the stainless steel partially embedded in concrete for several inches beyond the concrete surface.

Above the Waterline

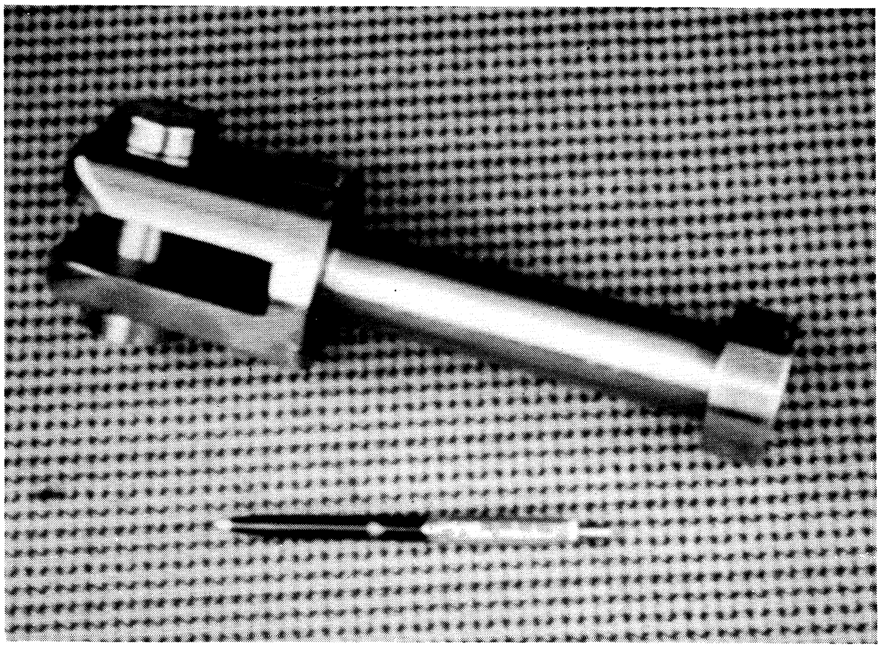
Fasteners are generally not subjected to as critical conditions above the waterline with respect to vessel, platform, or structure safety. Consequently, there is much greater use of coated carbon-steel fasteners. However, the thin coatings do not provide long-term corrosion protection, especially when exposed closer to the seawater. Continual maintenance of the fastener system appears to be more acceptable above the waterline, since it is more accessible and may not be as critical a service condition.

In exposures above the waterline, the galvanic effect is limited to the immediate area of contact and is not spread over the larger, wetted area as it is below the waterline. Local attack can still be severe, as in the case of stainless steels in aluminum, but the attack seldom extends beyond 0.5 in. (1.2 cm) from the point of contact.

Similar to the below-waterline guidelines, alloy 400, Ni-Cr-Mo alloys, MP35N, and titanium fasteners can be used successfully in all of the metal base plates, except aluminum (Table 7). There is still concern for galvanic and crevice corrosion of the other fastener alloys, but to a lesser degree than full immersion. This is especially true where care is taken to pack bolt holes with a water-repellent (graphite-free lubricant) or filler material. This protection method has been used quite successfully with stainless-steel fasteners in the aluminum hull of the large Hovercrafts in ferry service operating across the English Channel.

Copper alloys, type 316 stainless steel, and alloy 400 are the preferred materials for fasteners above the waterline. Type 304 stainless steel (UNS S30408) is also used. The free-machining grades, types 303, 303Se, and the 400 series stainless steels, should be avoided since rapid corrosion may occur in marine environments.

Again, caution is advised in the application of metallic fasteners in graphite composites even above the waterline (Table 8). All of the fastener metals shown in Table 8 have performed well in the various nonmetallic-based materials, but performance is dependent on how close the system is to the seawater environment and how long the fastener is wetted.



Exfoliation of aluminum alloy caused by bolting crevice.

Offshore drilling platform using alloy K-500 bolts in riser clamps.

For example, type 304 stainless steel bolting has survived more than 20 years in a wood jetty just above the tidal zone. However, severe crevice corrosion caused failures of the stainless-steel bolting in the tidal zone. Aluminum bolting has performed well in a concrete bridge above the splash zone for more than 20 years. In addition, alloy 400 bolting has provided indefinite service in wooden structures and steel piling in marine splash and spray environments.

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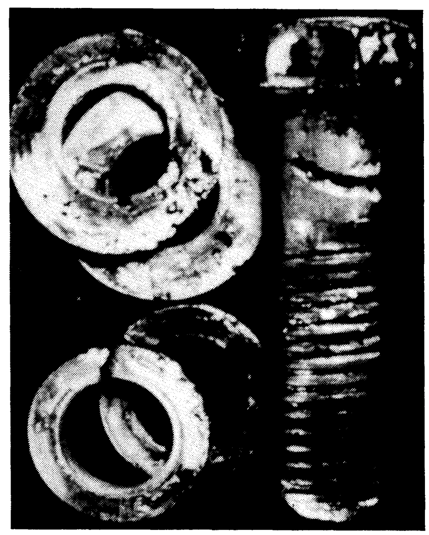
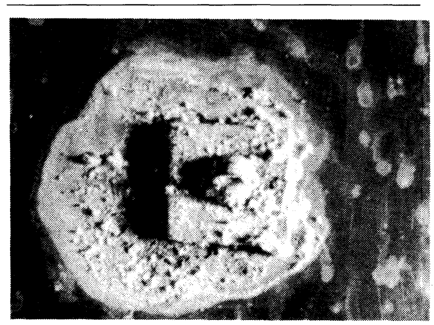
Reference

1. R.M. Davison, J.D. Redmond, Materials Performance 27, 12(1988): p. 39.



Severe crevice corrosion of type 304 stainless steel fasteners in seawater after six months.



Application of alloy 400 boat hull fitting.

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