Forte Spars used titanium ferrules to join the six-piece (for shipping), carbon-fiber battens in the 203-foot schooner Athos.

Photo courtesy of Forte Carbon Fiber Products

The Great Titanium Trickle-down?

The megayacht metal is creeping into the realm of the 99-percenters.

By PATRICK CHILDRESS

Through the commotion of a 30-knot squall, I heard the chainplate pop. It was not an unusually loud pop. The result was impressive, nonetheless. What once was, just a few moments earlier, the tallest part of the mast on our Valiant 40 *Brick House* was now the lowest, scraping the tops of waves in the middle of the South Pacific Ocean. The dispirited look on my wife Rebecca's face made the terrible situation even more depressing. I swore, in rebuilding our rig, we would never again be the victim of the weaknesses stainless steel can hide. We would replace our chain plates, toggle pins, and mast tangs with titanium.

In name alone, the word titanium evokes images of superhuman strength. The metal is aptly named after the Titans, the race of powerful Greek gods, descendants from Gaia and Uranus.

Titanium is whitish in color and the fourth most abundant metallic element in the Earth's crust. Ninety-five percent of mined titanium becomes titanium dioxide. Titanium dioxide is the white pigment added to all types of paints. Titanium dioxide makes paper bright white and is the white paste that some sailors like to smear on their nose on a sunny day to provide a physical barrier against UV radiation. Our white homes and sailboats are resplendent in white titanium.

The new titanium chainplate shines brilliantly among the stainless steel ones it replaced, including the one that broke.

The remaining 5 percent of mined titanium is used to make metal components that must be light, strong, and resistant to heat and corrosion. This five percent, though small, represents a rapidly growing market.

Landing gear of large commercial aircraft, like the 747 and 777, are made of titanium. No other metal has the resiliency to repetitive shock loading and offers the weight savings of titanium. Nearly 80 percent of the structure of the Lockheed SR 71 reconnaissance plane, the highest flying, fastest plane ever built, is made of titanium. From drill bits to eyeglass frames to tennis rackets to artificial heart valves, titanium metal is in our lives every day.

Of particular interest to sailors is titanium's resistance to galvanic corrosion. Only silver, gold, and graphite are more noble than titanium. For titanium to be even slightly affected by sea water, the water must first be heated to over 230 degrees. Cryogenic temperatures will not affect the performance of titanium. It has the highest strength-to-weight ratio of any metal and is non-magnetic. Titanium is up to 20 times more scratch resistant than stainless steels.

The more one considers the physical characteristics of titanium, and how perfectly suited it seems for marine applications, the more one might wonder why we don't see more of it in our boats. Part of the problem is the relative cost of titanium alloys, but a second factor is probably more to blame for titanium's scarcity in the marine market. Titanium fabrication is a highly specialized field that requires specialized equipment. You can't just hire your local welder to go out and build you a titanium arch.

MARINE-GRADE TITANIUM

The performance characteristics of titanium will change greatly with its alloying of other metals for customized work. Commercially pure titanium is typically rated from Grade 1 to Grade 4, with each higher grade corresponding to increasing strength levels. Some of these grades are used to withstand boiling acids; some are used for heat and corrosion-resistant applications such as heat exchangers and chemical processing tanks.

The marine industry standard is Grade 5, Ti-6Al-4V. This alloy is 90 percent titanium, 6 percent aluminum, and 4 percent vanadium. The alloy is so widely used that it represents 75 percent of all titanium alloys produced. Grade 5 has a yield strength over 3½ times greater than 316 stainless steel, yet weighs only 56 percent as much. Yield strength, sometimes called engineering strength, is the amount of pressure or force a material can take before changing shape without returning to its original shape. But titanium is also nearly twice as resilient as steel, so it will flex and return to its original shape under the same loads that might permanently bend a comparable piece of stainless.

Not only is titanium strong, it is highly resistant to chemicals. Being a reactive metal, it spontaneously forms an oxide film whenever there is any amount of water or air in the environment. That oxide film eliminates the possibility of crevice corrosion or stress-corrosion cracking. Titanium is immune to galvanic corrosion when immersed in seawater, but like stainless steel, titanium may encourage electrolysis of a less noble metal it is in contact with. Profurl roller-furling uses titanium screws that pass through the aluminum body of their housings to minimize galvanic corrosion. Still, an isolator like LanoCote (*www.lanacote.com*) or Tef-Gel (*www.tefgel.com*) needs to be applied to the threads of the titanium screws, the same as one would do if stainless-steel screws were used. Above the waterline, Titanium in contact with 316 stainless is of no greater concern than where stainless-steel threaded studs screw into bronze turnbuckles.

Working sheets of titanium into yacht parts requires the same tools that are used for forming stainless steel. Drilling requires sharp cobalt drill bits turning at similar speeds used for stainless steel and plenty of lubricant (olive oil works) for cooling. Sawing and grinding also require sharp tools with good chip removal. Cutting with waterjet and laser is the most effective. But shears that slice through thick 316 stainless steel will stop when forced against equally thick plates of titanium.

When bending titanium, the bend area must first be heated to around 800 degrees, as the yield strength drops to about 40 percent at that temperature. If titanium is overheated to the point where it glows, it can react with air and become oxygen embrittled. For this same reason, cutting titanium with oxyacetylene flame is not recommended.

Welding titanium is not for the inexperienced. Air will contaminate the weld causing discoloration and brittleness. An inert gas like 99.99 percent pure argon must shield the area on both sides of the weld till the material cools below 800 degrees.

The physical properties of titanium are exactly those that are needed in sailboat rigging as it pounds through ocean waves. Unlike stainless steel, titanium will not deteriorate, or crack, or rust, or have an unexpected catastrophic failure. Once installed on a sailboat with titanium fasteners, a properly sized titanium chainplate will never need polishing, although welds should be checked.

So why has the leisure marine industry been slow to use titanium?

The crew of Brick House *waited until morning to begin the tricky process of removing the mainsail after a stainless-steel chaiplate failed, causing the mast to snap.*

Patrick Childress (top left) begins the long process of disassembling the mast. With its mast intact and secured, Brick House *steams toward Majuro in the Marshall Islands (above, top). Majuro atoll is a regular shipping stop (above, bottom)—essential for ordering a new mast. The island offered all the services required for repairing the rig.*

For years, the high cost of titanium made it an aerospace metal for government projects and commercial airplane parts where there was no alternative metal to use. That high cost was an unforeseen result of the protectionist Berry Amendment. The 1941 legislation made it mandatory for the U.S. government to purchase only 100 percent U.S. manufactured goods intended for military use. Titanium was soon added to the list of specialty metals covered under the Berry Amendment. This gave the few largest U.S. titanium makers a lock on the world's largest titanium customer, the U.S. military. This eliminated competition and kept the price of titanium flying high.

This grip on the U.S. titanium market also eliminated any need to streamline the smelting process. But when the U.S. military shifted from a strategic bomber defense to a missile defense, the use of expensive titanium plummeted and some U.S. producers went out of business. The few that remained could only survive by keeping the price of titanium high for their government customers.

According to Christopher Greimes, chief executive officer of Allied Titanium, with the current economic downturn, the U.S. military would like to remove titanium from the specialty metals list as they need more and cheaper titanium, not just for use in aircraft, but for use in armor plating for ground troops. The U.S. titanium producers are strongly lobbying to keep titanium on the specialty metals list. President Barack Obama is allowing an unsigned repeal of titanium from that list to collect dust on his desk. Meanwhile, other countries like China, Japan, and Russia have been ramping up their refined smelting technologies and producing less costly titanium for the world market.

As world production and use in the leisure marine market increases, the price of titanium should continue to fall. One day, titanium will replace stainless steels. The savings to insurance companies that will no longer have to pay for expensive boat losses and the increased safety to sailors will be enormous.

PRACTICAL MATTERS

The problem for an individual boat owner is that the local welding shops do not carry a stock of titanium sheets and to order small lots and fabricate a few parts can be time consuming and ultimately not the price one would hope to pay. There are large outlets for titani-

Myerchin uses the lightweight metal in the body of its new line of folding rigging knives.

Titanium in the Marine Chandlery

A range of marine products already use the metal

Titanium's high price is only one thing that is keeping in the realm of mega-yachts and Cup boats. Some of the essential roles that lightweight metals once played in deck hardware are now being taken by high tech fibers like Spectra or Vectran. Carbon fiber laminates are also taking the place of metal fittings, at a slightly lower cost. Nevertheless many manufacturers see a bright future for titanium. Here is some feedback we got from manufacturers on this topic.

• **John Franta** (*Colligo Marine, www.colligomarine.com*)**:** "Titanium has all the benefits of a metal, machineability, drilling, etc. and no corrosion. Particularly Grade 2 which has about the same yield strength as 316 and is not much more expensive. We make custom chain-plates out of it all the time. Our mast brackets are made from Grade 2 titanium also."

• **Tony De Lima** *(Forte Carbon, www.fortecarbon.com)***:** "Titanium is a specialty material that requires an experienced machinist to cut, and titanium experienced welding shop to stick it together. Here in Ledyard, CT we are next to Electric Boat (the submarine guys) so are spoiled with experienced titanium welders. Most of our custom titanium parts are only machined and so we rely on our regular machine shop for milling. The most common parts we have made of titanium here are milled from strait bar stock and tube these include, joining ferrules and spreader bars."

• **John Myerchin** *(Myerchin Knives, www.myerchin.com)***:** "By using pure titanium handles in our new folding rigging kinves we have reduced the total weight of the knife, added a pocket clip and greatly reduced corrosion problem. . . .Since titanium is not a good choice for blades or marlinspikes, these components are still marine-grade stainless steel."

• **Russell Belben** *(Ronstan, www.ronstan.com)***:** "We used titanium in the 1990s for the cheek plates of our runner blocks, especially for the Americas Cup boats. We rarely use titanium now for the following reasons: many classes now stop the use of titanium due to the high cost ; titanium is notoriously unreliable to weld; and titanium is very expensive relative to conventional alloys. . . . Titanium has been used effectively as a needle bearing on high load blocks making use of the materials strength advantage over the more conventional needle material Torlon."

um fabrication that solve the problem. A company such as Allied Titanium has fabricating outlets in Europe, U.S., and China. A boat owner can log onto the Allied website to view thousands of items such as nuts, bolts and chainplates. If a particular boat part is not listed, it can be fabricated.

We needed 10 new chainplates, all of the same design, and a combination bow roller/chainplate assembly. Since there had been no previous purchase for these items for a Valiant 40, we had options on how to enter the information into the Allied database.

First we logged in and became a customer, creating a user name, and password. We could trace the chainplate outline and bolthole placement onto stiff paper, noting the thickness of the original plate and the desired finish such as sandblasted or polished. However, we thought sending an actual chainplate would be better. Allied then hand drafted our chainplate into its 3D system. We could watch online as the chainplate was received at Allied and made its way through the design process. If a customer supplies design in a 3D CAD file in SolidWorks, Rhino, or 3D Auto CAD, there is no drafting charge at all. If the customer supplies a two-dimensional drawing that is properly dimensioned, with tolerances, finish, etc. and they allow Allied to add their part to the Unique Product Database (UPD), then there is no charge for conversion to a SolidWorks 3D CAD file.

At Allied, the part name, tolerances, finish, titanium grade, etc., are entered into the UPD, creating both an item number and a temporary UPD number. The customer then approves the drawings. When the design process is completed and the customer approves the price, the part design is then transmitted to one of Allied Titanium's factories, some of which are in China.

The immediate hesitation of many boat owners is the idea of having anything made in China. Japan produced a lot of junk after World War II, then learned to do it right and has equaled or outdistanced America in many manufacturing fields. So too, China is refining the quality of its products.

As *Practical Sailor* pointed out in the August 2011 look at mainsails, sails made in China are often rebranded and sold by the top sailmakers in America. Nearly all stainless-steel wire rigging used on yachts now comes from China or Taiwan. When it comes to Chinese titanium, that metal has been strategic in the past, requiring strict quality control by the Chinese military. This means

Some poor sailors still fall victim to the common "stainless-steel" hose clamp with a mild steel screw.

Maintaining Stainless Steel

The marvelous marine metal still requires care.

Stainless steel is exactly what the name says; the steel "stains less." As *PS*'s February 2007 special report "Marine Metals Warning," pointed out, stainless steel is not the maintenance free miracle material many boat owners imagine it to be.

Some stainless steel is more stainless than others. With over 500 different grades of stainless steel, only a few meet the mark for use in the corrosive marine environment. Most marine stainless steel is grade 304 or 316. Stainless steels are made up of metals with a blend of iron, chromium, and nickel. Chromium resists corrosion, and nickel resists acids.

Add a little molybdenum, which looks and feels like graphite, to the 304, and you get the more corrosive-resistant 316 stainless steel. Although 316 is near the top for rust-free steel, it is 85 percent as strong as 304. This is why bolts and screws are made of 304 and will often tarnish before the hardware they secure. Better looking than 316 is 316L. The L stands for low carbon, which is more suitable for welding.

Since 1997, Monitor self-steering vanes have been made of this metal. After many years in a saltwater environment, Monitors still look brilliant with little or no attention from owners. To get that brilliant finish, manufacturers of high-grade marine hardware give their 304 and 316 products an electropolish. Electro polishing is bathing metal in a mild acid with an electric current. It takes away all the impurities and makes the stainless shine. Old stainless-steel hardware can be removed from a boat and electro-polished again.

Some shine is only skin deep. Showing up in marine chandleries is foreign-made hardware that is bright and buff till it is installed in the saltwater environment. Here, the steel becomes "stain-fast." Though not definitive, a magnet can help tell the quality of stainless steel. (Some higher-tensile precipitation hardened components like shackles can have weak magnetic properties.) You will find this true with many hose clamps. The band is of quality 304 or 316 stainless steel but the screw is often of an inferior 400 series and thus attracted to a magnet. The screw will rust which in turn causes the band to rust. Some hose clamps that are marked "all stainless" can't be shaken free of a magnet.

Marine chandleries apparently do not hold their suppliers accountable for labeling. Lack of proper labeling makes it a customer-beware situation. There are manufacturers of hose clamps that get the stainless steel combination right. That quality hardware is well worth the price difference and actually proves less expensive because of its increased working life. A simple hose clamp failure can be catastrophic.

Moisture with little or no oxygen invites rust. Salt, which helps to hold moisture, is a catalyst for the process. This is why rust normally starts at the base of bedded hardware, at longitudinal joins of rolled handrails, or in pitted areas. Welded areas have a higher susceptibility to corrosion due to the heat upsetting the chromium and moving it away from the welded area. For this same reason, it is better to cut stainless steel with a sharp hacksaw, by hand, so it will not heat the metal. Sawing stainless steel with an electric cutting wheel overheats the metal. The stainless steel will rust where it was cut.

Inspecting stainless steel requires skill. What shines on the surface can hide decayed weakness within. Like termites in wood, the most unnoticeable crack can allow moisture to penetrate and rot deep into stainless. Sudden and catastrophic failure of stainless steels is common. Polishing discoloration from stainless steel can actually wipe away evidence of impending doom. Colored dye test kits and a magnifying glass can help to detect defects in stainless steel that lead to failure. But even new stainless steel boat hardware can unexpectedly fail. Stainless steel chainplates and mast tangs are notorious failure points due to cyclical loading and corrosion penetration at minute cracks.

Most of a chainplate is hidden from view by a toggle and where the chainplate lives below deck level. In these areas, de-

that Chinese factories and workers know how to make titanium products properly. The Chinese are now cashing in on the world demand for titanium faster than Obama can sign his name.

According to Allied, "Each time titanium is smelted, re-smelted, or milled, it must have mechanical and chemical tests done on the lot. When a customer requests a 'certs,' the results from the last certification is provided. In most cases, this is the mill certification." However, some U.S. customers of Allied send a sample of their purchase to an independent lab for backup testing. "In all cases, our 6-4 titanium parts have tested above 128,000 psi yield strength. If a customer has an issue with a certain country, we can manufacture their parts in another country (at a different price, of course)," Greimes said.

When the part is complete, it is sent directly from the manufacturing plant to the Allied Titanium Quality Assurance Department in the United States via Fedex, UPS, or DHL. After passing quality assurance, it is shipped directly to the customer.

The street price for one of our chainplates was $260 at the time of this writing. We saved considerably by negotiating a price for all ten to be made at the same time. From the day we mailed our old chainplate to Allied Titanium to the day 10 titanium chainplates arrived in terioration grows undetected. Removing a chainplate from the boat is the only way to properly inspect the piece. If there is any pitting or the slightest cracking, the plate should be replaced, not simply cleaned and reinstalled.

What stainless-steel deck hardware likes best is plenty of fresh water and mild soap to rinse away moisture-retaining salt and grime. On long rainless ocean passages, it can be helpful to scrub down the decks, even with buckets of seawater, to reduce the concentration of salt residue. The stainless hardware can then be followed with a wipe of a rag wet with fresh water. Chlorine is highly corrosive to stainless steel and other metals. Cleaners with chlorine should not be used on deck.

Getting out the shinola kit and buffing stainless steel before it rusts is a good practice. When rust has developed, it is still an easy exercise to buff.

Automotive stores and marine chandleries sell a variety of metal cleaners. The active ingredients of many of these cleaners is phosphoric acid or oxalic acid. These brighteners should be bought in a paste form rather than a runny liquid. A jar runny cleaner with a large lid will most certainly get knocked over on the deck of a boat, and this must be thoroughly rinsed.

When applying a paste cleaner, a tooth brush is a necessity for buffing into tight spots and working into the pores of welds. That agitation is then followed by buffing with a cotton cloth. More advanced rust might need cleaning with a green 3M scrub pad. Continued rusting in welded areas can be a sign of developing failure.

Bringing Back a Silvery Shine

Keeping stainless-steel parts polished can help delay corrosion. However, persistent corrosion stains might indicate impending failure, requiring a thorough inspection or testing using a dye kit. When in doubt, replacing critical components with high-quality, appropriately sized hardware is the safer option.

1. *Corrosion often develops at welds.*

2. *A mild acid cleaner, applied by brush, helps penetrates crevices.*

3. *A 3M scrub pad can help attack stubborn stains (wear gloves when working with acid).*

4. *A fiberglass buffing compound can help restore shine and prevent rust.*

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Applying automotive or fiberglass rubbing compound with a wax component to metal will help protect against corrosion, but in the real world, this protection doesn't last long. A wipe of a light corrosion block oil is only a little more effective.

All this close, hands-on attention not only keeps the stainless looking bright but on some boats has prevented a major failure of the rigging. The close work makes it easier to inspect components, and the cleaning will often uncover cracked turn buckles, wire end fittings and other hardware before failure.

our hands, took 65 days.

We installed all new chainplates, bolts and nuts, clevis pins, mast tangs, and bow roller assembly made of titanium. One immediate problem was the brilliant shine of the chainplates sticking up from the deck. They suddenly made the paint job on our boat look terrible. A sandblasted finish for the chainplates is available, and this might be a good option for the owner of an older boat. Over the past 6 years, the money we have not paid to insurance companies has been reinvested in continually upgrading electronics and safety equipment on our floating home. A new rig with a foundation in titanium will certainly keep us safer and stronger than ever before. I only wish we were wiser and made the titanium upgrades before our rig came down.

Patrick Childress completed his first circumnavigation in 1982 in a souped-up 27-foot Catalina. He and his wife, Rebecca Childress are currently sailing in the Pacific, continuing on their west-about circumnavigation.

CONTACT

ALLIED TITANIUM, 800/725-8143, www.alliedtitanium.com