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Examining the Business Case for a Titanium Ship

Participants at a workshop exploring the use of titanium structure for ships found that it is not only possible to construct a ship hull from titanium—or Ti, it could be cost effective.

By Edward Lundquist

The workshop was sponsored by the Office of Naval Research and hosted by the University of New Orleans, where an ONR research program on titanium ship structures is being conducted. Representatives of the shipbuilding industry, titanium suppliers, Navy, Coast Guard and Air Force labs, and academia discussed and examined materials, processes and applications.

Most ships today are primarily made from steel. Alternative materials include aluminum and composites. But the consensus of the workshop attendees was that titanium—while more expensive than other materials on a pound for pound basis—has many positive properties that contribute to lower total ownership costs (TOC) throughout the life of the ship. Because titanium has more strength for its weight than steel—Ti offers a 40% weight savings compared to steel—lightweight designs can be achieved that offer increased payload capacity, reduced fuel consumption and reduced carbon emissions. It has a low magnetic signature, which means you can reduce heavy and power-consuming degaussing coils to protect against magnetic influence mines. It has temperature resistance, so it's safer for structures like gas turbine exhaust systems. And Ti is virtually corrosion-free in seawater, so it can be cost effective for sea water piping systems such as cooling water and firemain.

However, more research is needed to develop high-productivity Ti welding processes for ship construction. Although well established, the existing titanium welding processes are too slow for ship hull construction which typically requires miles of welds, according to Dr. Pingsha Dong, a professor at University of New Orleans School of Naval Architecture and Marine Engineering, and director of UNO's Welded Structures Laboratory. Through the UNO investigation, advanced metal inert gas (MIG) welding and friction stir welding showed their potential.

Chris Conrardy, chief technology officer at the Edison Welding Institute (EWI), says there are different techniques for welding titanium, including gas tungsten arc welding, electron beam welding, high-power laser welding, friction stir and hybrids of the different methods. "The optimum approach depends on the structure's configuration, joint design, performance requirements, and economic considerations."

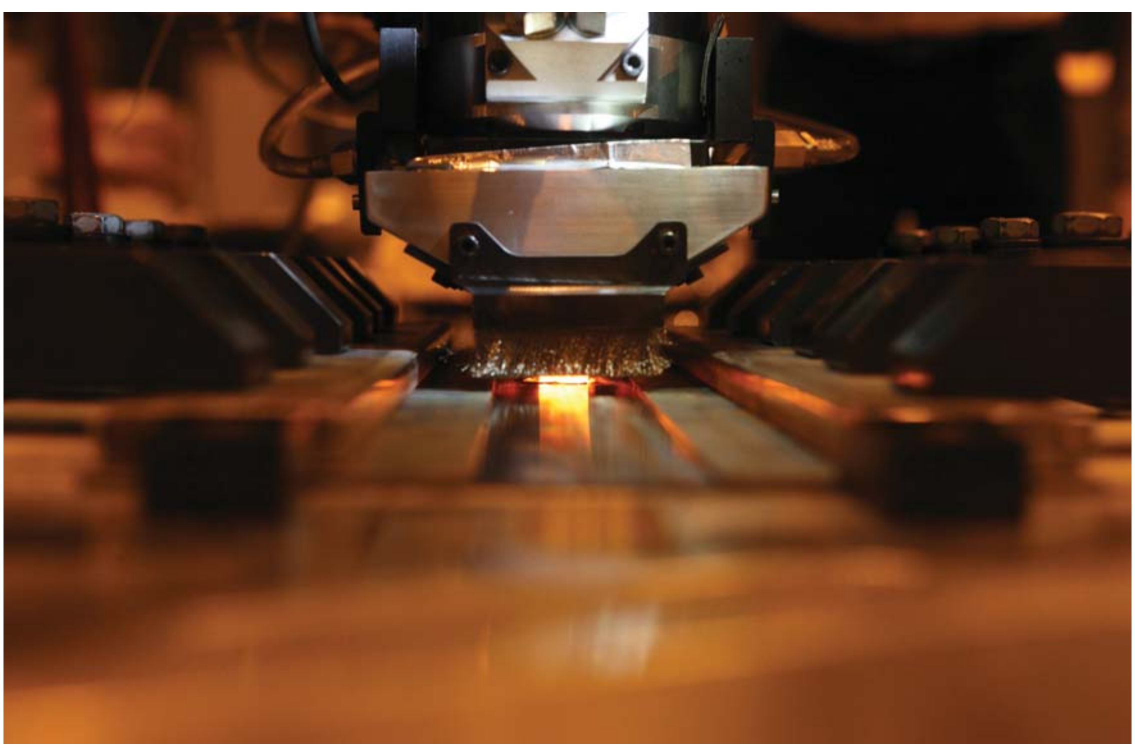
But in each case, quality control is paramount, and inert gas shielding is required to avoid contamination. "Avoidance of contamination is a primary concern with all titanium fusion welding processes," Conrardy says.

"Titanium is highly reactive at elevated temperatures and requires shielding of the molten metal during welding and cooling," says Jennifer Wolk, a materials engineer with Naval Surface Warfare Center (NSWC), Carderock Division specializing in welding and friction stir welding of non-ferrous materials.

"Most steel ships are scrapped because of corrosion of the hull, not problems with the machinery," says Rob Moore at Textron Marine & Land Systems (TM&LS). "TOC is reduced by using a titanium hull."

Aerospace grade titanium used in aircraft is about nine times more expensive than steel. But industry experts predict that "fit-for-purpose" ship hull or marine grades of titanium, as proposed by UNO, could be made less costly—perhaps only three times as expensive as steel —by changing the processing and finishing requirements. When weighed against its positive attributes, titanium may become even more cost effective.

Moore says Ti production is energy dependent and the cost of energy is not going to go down. But, he says, marine grade Ti will likely cost much less than



(UNO-NCAM photo by Dr. Greg Dobson)

Friction stir titanium welding is conducted at the National Center for Advanced Manufacturing at Michoud, Louisiana.

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commercially available aerospace grade Tii.

Marine specific Ti grades have been developed and used for some high strength naval applications, such as piping, but not for general structural applications. The cost of marine grade Ti would depend on the end use and properties needed for the application.

Colen Kennell of the Center for Innovation in Ship Design at NSWC Carderock says Ti offers a potentially ship-scale cost effective alternative to steel structures. "For faster ships, lightweight hulls are a critical enabling technology."

As a further benefit, when a vessel reaches the end of its service life, its scrap value is much higher than a steel ship.

"Old ships are a problem," says Kennell. "Ti scrap retains substantial value even at the end of a 30 or 40 –plus year ship life."

There are other alternatives to steel, such as aluminum and composites for ship structures. "If you want an all-composite ship, then you would need an all-composite shipyard. But Ti could be introduced in a steel yard," says Kennell.

Wolk adds that Ti fabrication currently exists in shipyards, but does require strict controls for fabrication.

There is also the possibility that building ships from titanium would create a demand that would drive the cost up for the metal. There is precedent, when there was an unexpected demand for Ti when Callaway introduced the Big Bertha golf club at about the same time that Boeing announced the start of construction of a new airplane. A spike in the titanium market could also disrupt the aerospace sector.

But suppliers at the conference said that even if the Navy decided to build three or four Ti ships a year, US Titanium capacity is not a constraint. The US has sufficient projected capacity looking at current demand signals, and steps can be taken to mitigate demand spikes.

Such a fabrication facility would require a significant investment, Kennel says, and without additional demand it might be unsustainable. "But there aren't any show-stopper industrial or management issues."

Raymond M. Walker of Keystone Synergistic Enterprises in Port St. Lucie, Fla., says the workshop demonstrated that there are no engineering barriers or obstacles that prevent design or construction of a titanium naval ship. "Challenges, yes; but no barriers."

Walker, an expert in welding and joining of titanium and vessel fabrication, says it was valuable to have representation from many of the key players in the effort to manufacture with titanium: the titanium material providers, titanium processing and joining experts, ship designers, ship fabricators, as well as commercial interests. "It was helpful to get a consensus from this group as to the realities and methods needed for fabricating a titanium vessel."

Vessel life, fuel efficiency, reduced maintenance, and increased range/payload will drive the argument, Walker says. "No new technologies are required, only adaptation of existing titanium practices (primarily from aerospace) to the specifics of vessel design and fabrication."

"The Navy is challenging industry to produce an affordable solution and we all have to take that as an action item to deliver this package as soon as we can back up the numbers and corresponding data," says Booty Cancienne, production superintendent for Textron Marine and Land Systems (TM&LS) in Slidell, La.

Cancienne is production supervisor for the TM&LS shipyard with four decades of experience. He's worked at TM&LS for 35 years, and five more at other yards. He is responsible for all marine construction at TM&LS, including development of all processes, materials and metals used, training of employees and schedule and cost for all programs. He has overseen the construction—and later the refurbishment—of dozens of Navy LCACs (landing craft air cushion). In his job, he makes recommendations for engineering changes to reduce cost and to improve construction fabrication. At the workshop, when it came to welding, his was the voice of experience.

Most recently, he has been involved in the TM&LS proposal for the T-Craft innovative naval prototype being investigated by ONR. TMLS has fabricated a T-Craft side-hull section of aluminum, and will build the same structure from titanium to provide comparison data.

Cancienne says a titanium hull is possible. "We in industry must make the fear of high cost go away. We have to develop some processes to reduce cost and turn everyone's attention to the customers' needs and how to meet commercial and Navy requirements."

The business case

While a number advances have been made in processing, design, and fabrication, the hurdles that the Navy faces regarding the use of titanium are the same hurdles that we faced 10 to 20 years ago. "It all boils down to material and fabrication costs. Until the program offices can overlook the acquisition costs associated with using titanium components and see that the long term benefits outweigh the acquisition costs,

there will still be hurdles to using titanium," says Kim Tran, a materials engineer at NSWC Carderock where she is the non-ferrous welding lead.

Tran says an all titanium ship is not realistic until industry can reduce the cost of material to a more affordable price. "In the past, $4 /lb was the target price for the DARPA low cost titanium initiatives," she says. "With regard to titanium applications, if industry can reduce the current material prices, there may be more opportunities for titanium components on Navy ships. Reduced fabrication costs are also important. Traditional processes for fabricating titanium components are expensive because of the cleanliness requirements for the handling of titanium and complete shielding requirements for arc welding. Technological advances to reduce fabrication costs yet still enable the fabrication (casting, welding, forging) of quality products that meet design and material properties requirements will also enable more opportunities for titanium applications on Navy ships."

To reduce fabrication costs, Tran says more research is needed to reduce the current arc welding shielding requirements. "Complete inert shielding during arc welding is the biggest cost driver associated with welding titanium. In the past, NSWCCD has investigated flux cored arc welding wire and using a flux paste to eliminate the requirement for backside shielding. These were limited studies that should be revisited. Higher productivity welding techniques such as gas metal arc welding (GMAW) and hot wire gas tungsten arc welding (GTAW) should also be researched. GTAW is the primary welding process for welding titanium because it is much cleaner; however it is also a low deposition process requiring more weld passes to complete a joint than GMAW. Using GTAW results in increased fabrication time and cost."

Walker agrees that more study is need to make the business case for a titanium ship, "A credible business case study would be a significant accomplishment to solidify the benefits of titanium vessel fabrication and drive titanium into consideration for new vessel designs."

As an example, Walker points to the aerospace industry, which he says understands lifecycle ownership cost and has justified gas turbine engine investments to achieve thrust and fuel efficiency improvements. "Increased thrust relates to increased payload or passenger capacity. Fuel efficiency benefits rapidly multiply into very large life-cycle cost savings for both military and commercial aircraft. A similar case exists for a titanium vessel in terms of maintenance, corrosion management, reduced painting and coating requirements, lower vessel weight, fewer shipyard visits, longer service life, and so on."

Existing shipyards view titanium as a specialized process that is a cost burden over the state of fabrication for steel, Walker says. "A business case could also be supported by the fact that titanium vessel fabrication should be performed in an aggressively lean environment of a 'small shipyard of the future,' where material handling, welding practices and environments, material flow, and modular construction methods are optimized to titanium to drive down costs and are biased to light metal fabrication (aluminum and titanium). "

Cancienne says the Navy will save a tremendous amount of money with titanium ships just in upkeep of the hulls alone. It's an issue of cost versus longevity.

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"This is the bottom line," he says. "If a hull lasts 50% longer, say 60 years instead of 40, you get the same service life as three conventional hulls for price of two titanium ships. Upgrades in electronics, machinery and propulsion are a lot cheaper than building a new ship."

"Titanium is a common metal, it is easily formable, very weldable, has excellent strength, and is corrosion resistant," Walker says. "A titanium vessel is absolutely possible. There are plenty of pockets of titanium design and fabrication expertise in industry that are producing titanium structures every day. Very little of this expertise resides in traditional shipyards."

BoldMar, Inc. plans to build mega-yachts and commercial vessels at NASA once fabricated shuttle fuel tanks, and the Aries capsule is being built today using state-of-the-art welding techniques. The Michoud facility is also home to the National Center for Advanced Manufacturing, which is leading the way in new materials and welding methods, including friction-stir welding. Friction-stir welding welds mated metal pieces without melting them, causes less damage to the materials, and can be automated with precision results.

BoldMar has embraced friction-stir welding and is able to use one of NCAM's three $20 million friction stir welding machines. "This process will reduce fabrication time by 40% and eliminate a majority of the harmful flash and fumes associated with fusion welding for a cleaner work environment," Bolderson says.

More importantly, friction stir welding could be very advantageous over fusion welding processes for joining thin titanium plates and structural forms from both weld quality and distortion control point of view.

Bold-Mar production of vessels is primarily of aluminum, but has its sights on building vessels from titanium, including offshore patrol and service vessels.

Moving forward with titanium may be what America's shipbuilding industry needs, Bolderson says. "America today is an uncompetitive, third-rate shipbuilding nation, unlike what we were 70 years ago. Building in titanium will leap-frog us ahead of other nations in utilization of Ti as a superior material for shipbuilding; and using automated production technologies will help re-establish America as a competitive and premier shipbuilding nation."

At UNO, Dr. Dong and Larry DeCan are leading an ONR-funded program on "Manufacturability and Structural Performance of a Titanium Mid-Ship Section." This program will advance the science and design/fabrication technologies by constructing a full scale titanium mid-ship hull section. Dong and his team are investigating structural performance assessment techniques and advanced metal fabrication technologies.

"To my best knowledge, this summit is perhaps the first of its kind," says Dong. "The workshop provided a terrific forum for experts of all related disciplines to exchange experiences and ideas on how to make titanium a viable and cost-effective material for ship structure applications. I think we came out of the meeting with a much more optimistic feeling that titanium ship structures will become a reality, sooner than we expected before the meeting. At this Summit, we got to know who is who in all relevant technological areas and major research and development initiatives in industry and academia. More specifically, as the Principal Investigator of the ONR titanium mid-ship program, I'm very much encouraged that our approach and major findings reported at the meeting were validated by leading experts from various technical fields. Furthermore, insights provided by experts on various unresolved technical issues will help us at UNO to devise research plans to attack some of the areas immediately."

Dong agrees there are challenges, including the lack of experience in building large-scale Ti structures and the lack of high-productivity Ti welding processes. He says Ti is also prone to buckling and distortion. But the biggest obstacle is cost. "The key is reasonably priced titanium for ship hull applications. Aerospace grade Ti is not what we need," he says.

The ONR mid-ship section project will focus on advanced fabrication and joining processes, such as high productivity MIG and friction stir welding processes; math-based design-for-fabrication methodologies; creating a database for supporting welding process development and

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structural performance evaluations; development of fit-for-purpose-based definitions of “ship hull” grade titanium or alloys and weld quality acceptance criteria through a test article construction. In addition to UNO, the team includes TM&LS, Keystone Synergistic Enterprises, and MiNO Marine.

“We are using some of the most advanced modeling tools to save time and material costs in researching enabling technologies for building titanium ship structures,” Dong says.

Chris McKesson, a naval engineer with over 20 years of high-speed craft design experiences (currently working on his Ph.D. thesis at UNO) says the ONR-sponsored research at UNO is developing mathematical models for practical problems like welding. “Dr. Pingsha Dong’s math-based approach gives designers insights that had not been explicitly available previously; and provides it early enough and clearly enough to be taken into account early in the design process. It’s not surprising that we are driven to this type of modeling when using an exotic material like titanium, but I look forward to these same design techniques becoming ubiquitous, even in steel and aluminum shipbuilding.”

Attendees noted that developing specifications for marine grade titanium was starting with a “blank sheet of paper.”

Ron Williams of Allegheny Technologies Incorporated (ATI), a company that supplies mission-critical metallics, says ATI’s relatively new ATI 425® Alloy is cold-rollable, a less costly method of making large flat plates that can be used in ship construction.

“Everybody talks about total ownership costs, but the thing that always gets in the way is initial acquisition cost,” Williams says. From a capacity standpoint, Williams says his company is ready to take orders. “We don’t see capacity as an issue today.”

“We’ve got to get Ti down to a more affordable basis,” Williams says. “We need standards, specifications and inspection techniques to be quick to market and keep costs in line.”

Mys-ti-que

According to Bolderson, there is a mystique surrounding titanium vessels and this scares potential buyers. “The established shipyards are the biggest skeptics and this hurts potential development. I can only speak from my own experience in trying to bring a Ti project to reality. The shipbuilding industry is conservative and is reluctant to try new designs or materials,” he says.

Bolderson says the Navy has a preference for “parent” designs. “In most cases, a foreign vessel design is chosen because it represents newer design features than anything available in the USA. In 2007, BoldMar approached Textron Land & Marine Systems to consider a Ti joint venture bid on the new USCG cutter that was eventually awarded to Bollinger Shipyards. BoldMar and Textron both realized prior to the RFP submission that the "parent vessel" issue would negate a Ti vessel being considered.

The economics of inflation also is a factor. Moore’s calculations suggest that the benefit in TOC is reduced, but by no means eliminated, by the effects of inflation. “You pay up front,” Textron’s Moore says. “The value of the money you spend today will not be worth the same as the money you save later.”

According to Wolk, the workshop provided an opportunity to get key people within the Navy and titanium communities to discuss the potential for constructing a demonstration titanium T-craft mid-hull section. “It allowed us to take a look at the current state of the technology and assess limitations hindering the advancement and use of Ti for ship structures. There are still challenges in using Ti for ship structures, primarily in the area of cost and large scale ship yard implementation. Reducing the acquisition cost and total ownership cost is critical for future use of Ti on naval craft.”

Wolk thinks there is much to investigate. “We need to conduct more research in the areas of joining, such as the use of flux for contamination reduction; advancement of friction stir welding for Ti applications; certification of new technologies; large scale quality control within a shipyard to prevent contamination, mishandling, etc.; and taking advantage of Ti properties to reduce the amount of welding/joining necessary for different structures.”

“While we are making progress, there is still a great deal of advance-

Far Left: Edward Lundquist, U.S. Navy (Retired) and Jason Story, U.S. Coast Guard, examine a weld sample as John Alt, UNO-NCAM, explains the weld technique.

At the Universal Weld System #1 (UWS1), visitors watch video samples of the weld system in action.

UNO-NCAM hosted a tour of NCAM for attendees of the Titanium Ship Structure Summit held in New Orleans Nov. 7-9. On the UWS1, L to R: Greg Dobson, Bruce Brailsford, UNO-NCAM; Edward Lundquist, U.S. Navy (Retired) & Contributing Editor of MarineLink.com; Captain Charles Gunzel, U.S. Navy; Lawrence DeCan, UNO; Nicholas Weinhold, U.S. Navy Carderock Division; Erasto Fernandez, UNO; John Pyle, Jeff Bernath, RTI International Metals; Jason Story, U.S. Coast Guard.

ment that we can do and that ONR is currently investing in," she says.

Wolk points to the technical advancements in new Ti grades and technologies from the supplier side that help bring down the cost. "One of the big questions a reader might have is, 'Why haven't we looked at this before and why are we looking at this now?' How has the environment changed? I think a lot of it has to do with a higher level shift in priorities that have moved us to a more mobile, more total ownership cost-conscious Navy. There are existing (and well documented) problems for other materials that lead us to explore Ti."

T-Craft

The Navy has been investing in research on titanium ship structures as part of the Transformable Craft—or T-Craft— Sea Base Enablers - Innovative Naval Prototype (SBE-INP) program.

Because the T-Craft is such a novel ship design, new design models and analytical tools must be developed. New techniques must be explored involving materials such as aluminum, titanium, and composites to be able to make ship components that are lighter, stronger, longer-lasting, and not prohibitively expensive. New power systems need to be tested, such as high-speed generators and permanent magnet motors, to make possible lighter, more efficient drive assemblies for lift fans, air screws, and main propulsion.

Three T-Craft mid-hull sections are being built from different materials—aluminum, composite and titanium—for comparison. "This research can also benefit other classes of Navy ships and systems. The goal is to share this technology to increase capability while simultaneously reducing life-cycle cost," said Capt. Chuck Gunzel, a naval engineer who has been involved in the T-Craft INP. "For example, if it can be shown that a T-Craft can be built economically using titanium, imagine how the costly maintenance packages on other classes of ships could be reduced using similar material choices up front. The goal is to work closely with academia, industry, and the Navy to achieve the art-of-the-possible."

Bolderson found the workshop valuable. "It brought together capable people with the common purpose of examining Ti as a material choice for shipbuilding."

"The capability to construct a Ti vessel is at hand," Bolderson says.

About the Author

Captain Edward Lundquist, USN (Ret.) is a principal science writer with MCR Federal LLC in Arlington, Virginia.

Titanium Welding & Fabrication Facility

Titanium is not new, even for naval ship structures. Aircraft components have been made from Ti for many years because it is stronger and lighter. Several Soviet submarines were built largely of titanium.

The U.S. Navy continues to gain experience with Ti, as well. The Puget Sound Naval Shipyard and Intermediate Maintenance Facility's (PSNS & IMF) in Bremerton, Wash., established a titanium welding and fabrication facility in 2011.

While the Puget Sound yard has more than 400 qualified welders, only 10 are qualified as titanium welders. The new titanium welding facility will help to maintain quality on every job by controlling the temperature and humidity in the work area, and segregating those tools used only on titanium.

"Welding and fabricating titanium requires additional controls, but is not much more difficult than working with other materials," says PSNS & IMF welding engineer Chris Melvin, PSNS & IMF.

Working with titanium requires strict attention to temperature and a clean work area and employment of an "auxiliary" inert gas to prevent contamination by air while welding. The air we breathe contains elements such as carbon, nitrogen, hydrogen and oxygen, all of which can cause the material to lose its desired properties.

"The value to the Navy by using titanium piping systems over copper nickel or other materials is that the titanium systems are designed to last for the life of the ship or submarine instead of being replaced two or three times," says Melvin. "The initial cost of using titanium is higher, but the value is the material's strength and high resistance to cracking and seawater corrosion."

"One way the new facility helps us prevent impurities is by purging the part of pipe to be welded with weld gas, internally and externally," said Melvin. "Specialized equipment of the facility maintains weld quality by using a purge containment glove box that controls and maintains an atmosphere of inert gas to prevent impurity entrapment during welding."