BY: MICHAEL SKILLINGBERG

The 127m ***Benchijigua Express***, built by Austal Ships, is the world's largest aluminum ship

ALUMINUM AT SEA

Speed, endurance and affordability

Marine engineers and naval architects recognize aluminum as an advantageous material in shipbuilding and the fabrication of components in offshore platforms. The lightweight, superior mechanical properties, and corrosion resistance of aluminum alloys has dictated their use in many of these applications. Using aluminum, naval architects can design ships and boats with high-speed capability, long life, high payloads, and low maintenance costs, as well as a high recycle value.

Aluminum in civilian and military vessels has a long history that tracks the development of the aluminum industry itself, beginning in the late 1890's when some of the first all-aluminum marine vessels were built. The introduction of 5xxx (Al-Mg) alloys in the 1920's gave a boost to widespread usage of aluminum by marine architects and engineers. These alloys, much improved since the 1920's, are still used in ship and boat building and more stationary marine applications.

Aluminum alloys used in hull construction of vessels have been primarily 5083, 5086, 5454, and 5456 sheet and plate, but now include 5059 and 5383. These alloys are often used in the annealed condition (O temper), but when higher strength is required, they are used in a work-hardened condition (H temper) such as H116 or H321.

Below and above deck, 6xxx (Al-Mg-Si) alloys in the heat treated condition have been used in extruded and sheet forms along with 5xxx alloy sheet and plate. The 5xxx alloys are less frequently extruded, but some 5xxx alloy extrusions are available for marine applications. Extruded 6xxx alloys of complex cross sectional shapes are widely used in hull stringers and ribs and on decks in crossbars, tracks, rub rails, sailboat masts, hand rails, walkways, stairways, radar towers, and furnishings.

SPEED

The low density of aluminum, combined with high strength, toughness, and corrosion resistance, allow vessel designers to achieve weight savings of 15-20% over steel or composite designs. Weight savings equate to higher speed, increasingly demanded for vessels such as ferries, patrol boats, military craft, hydrofoils, fishing vessels, cargo vessels, leisure craft, and work boats.

The advantages of aluminum in high-speed ships and boats were recognized as early as the late 1800's. In 1895, the Scottish shipyard Yarrow & Co. built a 190 ft. long aluminum torpedo boat, *Sokol*, for the Russian navy that attained a speed record in its day of 32 knots. In September of that same year, the aluminum yacht *Defender* won the America's Cup.

Besides allowing for more streamlined mono-hull designs that help to increase speed, aluminum has prompted many technological advances in multi-hull, submerged-wing, hovercraft, and waterjet-propelled aluminum passenger vessels that are routinely designed for cruising at speeds of up to and over 40 knots.

HIGH-SPEED ALUMINUM CAR FERRIES

Speed equals profits when moving passengers and cargo on ferries, and the use of aluminum in fast ferries for rapid, reliable, and economical transport of vehicles and passengers has escalated in the past 20 years. All-aluminum fast vehicle and cargo ferries, with speeds of 35 to 50 knots and incorporating wave-piercing catamarans, hydrofoils, and mono- and multi-hulled vessels, have revolutionized transport over open water routes, often cutting travel times in half compared with former craft.

About 85 fast ferries are built each year, many in Australia. More than 100 fast ferries are currently operating in Europe. The pioneer in the all-aluminum fast vehicle ferry was Australia's Incat Tasmania. In 1990, it developed the first 74m wave-piercing catamaran with a deadweight of 238 tonnes at its Tasmanian shipyard to carry road vehicles and passengers at speeds in excess of 39 knots. Over the last 17 years, Incat Tasmania has refined its wave-piercer design. Today, its Evolution One 12 has a length of 112m and can carry up to 1,000 tonnes deadweight, with 1,000 passengers and 312 cars at speeds of 40 knots.

In the 1990's competitors such as Austal Ltd., Henderson, Western Australia, Australia, quickly followed suit, developing their own fast vehicle and cargo-carrying multi-hull ferries. In 2005, Austal built the world's largest aluminum ship, the 127m, 1,291 passenger, 340-vehicle *Benchijigua Express*. Operating for Spain's Fred Olsen S.A. in the Canary Islands, the *Benchijigua Express* has a capacity of 1,000 tonnes and can reach speeds of 40 knots at a deadweight of 500 tonnes.

What's perhaps just as significant is that the *Benchijigua Express* is a trimaran or stabilized monohull design. As part of the Bath Iron Works/General Dynamics Team, Austal is leveraging its trimaran design to build the "Flight 0" or prototype seaframe for the U.S. Navy's Littoral Combat Ship. Construction of the 127m vessel is well underway at Austal's U.S. shipyard in Mobile, Ala.

The construction of the LCS follows other Austal successes in the U.S. On June 1, 2004, the 192-ft *Lake Express*, built by Austal USA, Mobile, Ala., became the first commercial fast vehicle ferry to operate within the U.S., making its maiden voyage between Milwaukee, Wis., and Muskegon, Mich. Two weeks later, the 774-passenger, 228-car capacity *Spirit of Ontario I*, built in Australia, made its maiden voyage across Lake Ontario in record time. The Rochester, N.Y., to Toronto service proved

The *Benchijigua Express* has a capacity of 500 dwt at speeds of 40 knots

Ship's funnel under construction

economically untenable and the 86m vessel has since been sold to a German company, Forde Reederei Seetouristik GmbH & Co. KG, for operation in Europe.

Also delivered in 2004 was the Alaska Marine Highway System's fast vehicle ferry, The *Fairweather*, which was built by Derecktor Shipyards Bridgeport in Bridgeport, Conn. The 73m *Fairweather*, carrying 250 passengers and 30 vehicles, was designed to cut travel time between Juneau and Haines, Alaska, in half.

Austal USA is currently building two all-aluminum, megaferries for Hawaii Superferry. At a length of 345 ft, these high-speed catamarans will be able to transport 1,000 passengers and up to 300 vehicles at speeds of 30-40 knots between the islands of Hawaii.

A number of U.S. boatbuilders also construct all-aluminum high-speed passenger-only ferries, water taxis, crewboats and pilots boats. These yards include All American Marine, Bellingham, Wash., Blount Boats, Inc., Warren, R.I., Bollinger Shipyards, Lockport, La., Dakota Creek Industries, Anacortes, Wash., Gladding-Hearn Shipbuilding, Somerset, Mass., Gulf Craft, Inc., Patterson, La., Kvichak Marine Industries, Seattle, Wash., and Nichols Brothers Boat Builders, Whidbey Island, Wash.

In 2005, for example, Kvichak Marine Industries delivered a 40 knot, foil-assisted, waterjet-powered, all-aluminum catamaran called *Swift* for the Virginia Pilot's Association (VPA). The vessel was the first to incorporate the Foil Assisted Ship Technologies (FAST) foil design for pilot duty on the U.S. East Coast. VPA chose the aluminum hydrofoil design for its stability, safety, maneuverability, and wake displacement for operation in the short, steep waters of their Port of Hampton Road route.

HIGH-SPEED MILITARY BOATS

Many high-speed patrol and military boats in service worldwide are built with mono-hulls and topsides of aluminum alloys. In 1954, the Japanese Coast Guard introduced a 49 ft. boat called the *Arakaze* wholly built from aluminum. Soon after its successful debut, the Japanese Maritime Self Defence Force (JMSDF) built three types of 89 ft torpedo boats of the same design in three different materials: aluminum alloy, steel, and wood. Two boats of each material were compared in sea trials, and the superiority of the aluminum alloy hull was confirmed.

This early success with aluminum boats resulted in many future acquisitions by the JMSDF of other high-speed aluminum boats such as the 46-knot PG-823 missile hovercraft from Italy and the 35-knot patrol ship *Bizan*.

Today the Japanese National Guard has several all aluminum patrol boats, including the *Tsurugi*, which is a 164 ft long patrol boat capable of a maximum cruising speed of over 40 knots.

In Australia, Austal is currently building a series of all-aluminum Armidale-class patrol boats for the Royal Australian Navy (RAN) under the A$533 million Sea 1444 project, with contracts for 57 boats to replace the RAN's aging 138 ft Fremantle class patrol boats. The lead ship HAMS Armidable was accepted into service in mid-2005.

The all-aluminum deep-V mono-hull vessels have significantly improved speed and endurance in higher sea states than their predecessors.

Austal had previously launched a series of all-aluminum naval patrol boats, designed with a deep-V semi-displacement hull, for the Republic of Yemen for general police missions in coastal waters, offshore protection and tracking, customs control and anti-terrorist operations at sea, and operations within integrated task forces.

In Europe, RV 160 Wycker Meer, a high-speed inshore/coastal patrol vessel was developed by Netherlands-based Damen Shipyards for the Royal Dutch Military Police. The 66 ft long vessel accommodates a crew of two to ten and has a waterjet propulsion gives it a top speed of 36 knots. The Royal Netherlands Police Force has also put into service its high-speed P49 patrol vessel built by Damen Shipyards (KLPD) with a streamlined aluminum hull designed by Delft Technical University for operation in the Esterschelde River, the Waddenzee, and Dutch seaports.

The U.S. Coast Guard widely employs an aluminum-intensive 47-ft. motor lifeboat (MLB) that was designed as a first response rescue resource in high seas, surf and heavy weather environments. They are built to withstand the most severe conditions at sea and are capable of affecting a rescue at sea even under the most difficult circumstances. The craft are self-bailing, self-righting, virtually unsinkable, and have a long cruising radius for their size. Because of the growing emphasis on Homeland Security missions, these smaller, more agile Coast Guard craft also play an important role in patrolling the inland waterways and shorelines. There are over 115 of these new MLBs currently operational and more are being added each month with a planned fleet of about 200 vessels.

ENDURANCE & FATIGUE

The Japanese Coast Guard's *Arakaze* patrol boat was retired in Oct., 1981, after 27 years of service. At that occasion, test samples were cut from various parts of the ship, and tensile and fatigue tests were conducted together with observation of corrosion appearance. Test results showed that the aluminum materials were in good condition.

The use of tough, weldable, formable, and corrosion resistant aluminum alloys has made them the material class of choice for weight sensitive marine applications such as fast ferries, military patrol craft, and luxury yachts, and to lighten the top-sides of offshore structures and cruise ships. Although endurance of a marine vessel or structure depends very much on material selection, it also depends on design. And while, over the last two decades, the ultimate limit state (ULS) design approach has been widely adopted in the design of aerospace and land-based metallic structures, it is just recently being considered as a basis for the structural design and strength assessment of ships and offshore structures. Practical ULS methods or design codes are available in the aerospace and civil engineering industries, but they are now being developed for use by the marine industry. The durability of aluminum alloys combined with ULS design will make marine vessels and structure even lighter and more efficient.

According to marine design engineer Michael Kasten of Kasten Marine Design, Port Townsend, Wash., an aluminum hull designed for equivalent strength and stiffness to a steel hull would be about 50% thicker but lighter by as much as 50% and would have a 30% greater dent resistance and 13% greater resistance to rupture.

The corrosion resistance of aluminum derives from the thin passive oxide coating that forms on aluminum when it is exposed to the atmosphere. Unlike the oxide coating on conventional steels, the aluminum oxide coating is continuous and resists further oxidation. As protective as it is, the oxide coating on aluminum can be subject to attack or dissolution in highly acidic or alkali media.

For aluminum and other metals, the issue of galvanic corrosion must also be addressed. To preserve the natural corrosion resistance of aluminum electrolysis due to contact with dissimilar metals must be prevented. If aluminum must be joined to steel or other metals, an insulating pad of non-conducting material should be inserted between the two dissimilar metals. Mechanical fasteners with non-conducting surface coatings should be used. With an aluminum hull, a stainless steel propeller should be selected over a bronze propeller.

The use of sacrificial anodes is a common method of mitigating corrosion of metallic structures. These are made of metals such as zinc or magnesium that are electrochemically anodic to aluminum. Zinc anodes are commonly used in the form of streamlined blocks that are bolted into the hull or attached to the propeller shaft.

If a hull is built of steel, building the superstructure from aluminum obviously saves top weight, which is extremely important for stability and handling under extreme conditions. If steel and aluminum are used together in construction of a boat, these dissimilar metals need to be insulated to prevent galvanic attack of the aluminum, which acts as an anode in electrolytic contact with steel. Explosively bonded bimetallic transitions having stainless steel bonded metallurgically to aluminum are also available. These transitions allow steel to be welded to one side and aluminum to the other side, forming a corrosion resistant welded joint.

The aluminum industry has worked

with the marine industry to ensure the strength and corrosion resistance of aluminum through the development of new alloys and also through the development of improved material standards such as ASTM B928 Standard Specification for High Magnesium Aluminum-Alloy Sheet and Plate for Marine Service.

WELDING

An aluminum boat is usually built by cutting metal—sheet, plate, and extrusions—to shape and welding them together to achieve a watertight shell that is reinforced on the inside by aluminum framing, chine bars, and stringers. The deck of the boat needs to be designed to create a watertight seal. So, vents, stanchions, bulwarks (toe nails), winches, cleats, davits, hatches, etc. also made of aluminum can be welded to the deck. Architecture inside the hull can incorporate aluminum floors, cabins, transoms, seating, berths, galley, water and fuel tanks, etc. that are bonded to the hull by welding, mechanical fasteners, or adhesives. In addition, repairs and modifications to the structure can readily be made due to the ease of welding of the aluminum materials.

The two main types of welding utilized in boat construction are gas (oxy-acetylene torch) and electric (TIG, MIG, GMAW) welding. The recently developed friction stir welding (FSW) process has been used to good effect, especially on large vessels. Friction stir welding of aluminum, which does not involve fusion of the metal, produces high quality welds with little or no heat affected zone. Friction stir welding of steel has not yet been successfully commercialized. Cutting of aluminum shapes in preparation for welding can be done by various methods, including laser, waterjet, plasma arc, or mechanical saw. The advances in cutting and welding processes have reduced fit-up and assembly time through reduced distortion and residual stresses. These improvements lower the cost of construction but can also positively impact the vessels endurance.

AFFORDABILITY

Affordability in marine vessels is a function of value: value to the boat or ship builder, value to the boat or ship buyer, value to the boat or ship passengers, and eventual scrap value. Marine vessels in general are manufactured in low volumes, especially when compared with volumes in the automotive industry. Lightweight aluminum sheet and plate, readily available from aluminum mills or distributors, are easily handled and fabricated in low volume assembly operations. At the same time, aluminum extrusions are very cost effective in low volume production, due to low tooling costs and the fact that complex lineal forms can be directly produced on extrusion presses. Basically, aluminum affordability derives from the multifunctional forms that aluminum alloys are capable of – sheet, plate, extrusions, and castings – their ability to be formed and joined by many different processes, and their outstanding properties.

From the perspective of the marine architect, aluminum embraces vessel designs that achieve speed and endurance in the water, thereby creating value through function. Overall, an aluminum hull is stronger and will in most cases cost less than a fiberglass boat, although the cost for accessories is equivalent.

David Ross, president and CEO of Burger Boat Company, a custom yacht builder, has indicated a strong preference for aluminum in the production of yachts 100-150 ft (30-46m) and larger. He has stated that the high strength to weight ratio along with the excellent uniformity and predictability of 5xxx aluminum alloys have been key to the performance of his company's large yachts. The reduced structural weight of the vessels means higher load carrying capacity which translates into more fuel capacity and greater range. The smaller displacement can also lead to higher speeds and greater economy of operation.

Weight savings achieved with aluminum alloys allow for higher speeds or equivalently greater payloads and lower fuel consumption in vessels with a given propulsion system. The old saying "Time is Money" applies on water as well as on land, and the continuing worldwide growth in the market for aluminum intensive high speed car/passenger ferries and commercial vessels proves the affordability of aluminum in ship building.

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