

Super duplex to keep the Vasa safe

A major historic preservation project is currently under way in Stockholm. Molybdenum is a key alloying element in the high-strength, corrosion-resistant super duplex stainless steel bolts that will hold the great ship Vasa together.

On August 10, 1628, Sweden launched the great warship Vasa into Stockholm Harbor; she sank almost immediately on her maiden voyage! This event had a major impact on the era's balance of power. It dashed Sweden's hopes to become a major sea power and was in its time as significant as many startling news events we witness today.

Though it failed as a ship and scuttled Sweden's geopolitical aims, the Vasa is now one of the most celebrated ships worldwide after being heroically raised in the 1950s and put on display for the world to see at the Vasa Museum in Stockholm. Spending 300 years at the bottom of the sea can wreak havoc on a ship's wood and the bolts that hold it together. It takes a lot of skill and care to restore such a splendid historical artifact. The museum is now carrying out an updated conservation program intended to preserve the ship for another thousand years. Molybdenum-containing duplex stainless steel is making it possible to achieve that goal.

Sinking of the Vasa

Commissioned by King Gustavus Adolphus, the Vasa was the first of a series of ships intended to be the core of the new Swedish navy. The Vasa and her four sister ships, referred to as "regalskepp" or "royal ships", were among the biggest and most magnificent of their day. The Vasa was designed to carry 300 soldiers and 64 guns. It was to fire over 227 kg of shot at once from just one side. Unfortunately, the ship's grand scale would ultimately prove to be its undoing.

At the time the Vasa was built, shipbuilding was more art than science. Designers

relied on intuition and experience (and the King's orders!) rather than engineering principles. Improper weight distribution can be very dangerous to a ship in a storm. The ship's center of gravity must be sufficiently low to prevent the ship from capsizing in a strong wind. All boats therefore carry ballast (weight at the bottom of the hull) to assure stability. The Vasa's ballast consisted of 120 tonnes of stones. Even though this is a considerable amount of ballast, she still would have capsized in even a light storm because the enormous load of cannon on her upper decks made her top-heavy.

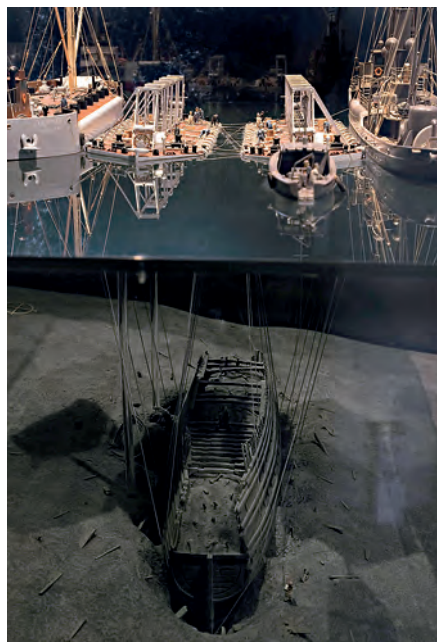
On the day of her launch, thousands of Stockholm's citizens gathered along the harbor. As Captain Söfring Hansson

pulled out, he ordered the gun ports opened to fire a salute. Then the wind began to blow, causing the Vasa to pitch suddenly to port. Though she righted herself, another breeze soon struck causing the lower gun ports to dip below the water line, allowing water to enter the ship. As the Vasa began to flood, she began to heel even further to port, and eventually was unable to right herself. She sank to the bottom of Stockholm harbor scarcely two kilometers from her launching site. The captain was immediately arrested, but then released. In the end, no one was officially blamed for the catastrophe.

Raising the Vasa

Attempts to salvage the wrecked ship were made as soon as three days after her disastrous maiden voyage, but the limited technology available made it a futile endeavor. The Vasa lay forgotten and undisturbed until marine technician and amateur archaeologist Andres Franzén began searching in the 1950s. Franzén made several unsuccessful attempts to locate the wreck, but in 1956 he discovered an anomaly in the harbor floor's topography. The anomaly turned out to be a massive wooden object. The Vasa had been found.

Swedish Navy divers dug tunnels underneath the wreck, ran cables through the tunnels, and attached the cables to a set of pontoons. This arrangement allowed the ship to be floated to the surface gently, in stages, over the course of two years. On April 24, 1961, the Vasa saw the light of day for the first time in three centuries. She was then towed to a dry dock at Beckholmen where she was placed on a concrete pontoon on which she still



A model in the Vasa Museum showing Vasa's salvage. © Anneli Karlsson, the Swedish National Maritime Museums



The Vasa is the only complete ship in the world preserved from the early 17th century.
© Åke E:son Lindman



Over 5,000 bolts were positioned in the Vasa after the ship had been salvaged 1961. They were all fixed in the ship's existing bolt holes, where the original bolts had rusted away.
© Anneli Karlsson, the Swedish National Maritime Museums.

rests today. She is now located at her permanent home at the Vasa Museum in Galärvarvet, near Stockholm.

A race against time

The raising of the Vasa was a monumental achievement. The important task was to keep her in good condition for the museum's visitors, which number over a million each year, and for future generations. Fortunately, Stockholm harbor's cold, brackish water protected the Vasa's wood from the Naval Shipworm (*Teredo navalis*), a species of saltwater clam that burrows through submerged wood and causes extensive damage. The most significant problem facing her is related to her lengthy submersion. The wood was waterlogged and drying would have caused it to shrink and crack. Restorers solved this problem by supporting the hull and replacing the water in the wood cells with polyethylene glycol (PEG) to provide internal support and to seal and protect the wood. They sprayed the entire ship with PEG, inside and out, over a period of 17 years so that the wood could slowly absorb it, preventing cracking and shrinking. This was followed by nine years of slow drying.

Over the fifty years that the Vasa has been exposed to oxygen and humidity,

chemical and biological degradation processes have taken place. Sulfur compounds from the dirty harbor water and several tons of iron compounds from cannonballs and iron bolts had been absorbed by the wood while it was underwater. The combination of iron and sulfur in the wood with oxygen and humidity in the air eventually lead to the formation of sulfuric acid in the wood. The pH measured has been below 3 and even as low as 1 in a number of cases. Neutralizing and cleansing the wood has helped, and stabilizing the temperature and the humidity in the museum through a sophisticated climate control system further contributes to the protection of the ship.



The old rusting mild steel bolts are replaced one by one with new super duplex stainless steel bolts.
© Anneli Karlsson, the Swedish National Maritime Museums

Moly keeps it together

Two years after the Vasa was raised she received a new set of 5,500 galvanized or epoxy-coated mild steel bolts. These bolts proved to be insufficiently corrosion-resistant for the acidic environment and they started to rust and to leach more iron into the wood.

To counter this, the Vasa staff has begun to replace these bolts again. A material was needed that would not react with the acidic wood and that would resist natural corrosion processes, with a design life of at least 100 years.

The bolts also had to be strong and flexible enough to support Vasa's 900 tonnes hull, as she is settling under her own weight at a rate of about 1 mm per year. The braces supporting the gigantic ship are beginning to press into the old oak hull. As she settles, she also twists bow to stern very slightly increasing the pressure on her braces.

The Vasa Museum staff considered a wide array of bolt materials for the project, but ultimately chose molybdenum-containing super duplex stainless steels. They are more than twice as strong as standard austenitic stainless steel and their corrosion resistance is far superior. Another important aspect was their ease of use. Two grades were selected, Sandvik SAF 2507™ and Sandvik SAF 2707 HD™ containing 4% and 4.8% Mo, respectively.

A floating laboratory

Each bolt comprises seven or eight pieces, and can vary in size from 0.3 to 2 meters in length. The new spring adjusted hollow bolt can move with the movement of the wood, reducing the stress on the wood. Replacing the solid bolt with a lighter tube was possible because of the much higher strength of duplex stainless steel. SAF 2707 HD™ with its higher corrosion resistance is used for the tube that is in contact with the acidic wood along its whole length. The other parts, mostly SAF 2507™, are exposed to less severe conditions. ➤

The replacement process requires a special tool to extract the corroded iron bolts and insert the new bolts after cleaning the bolt hole. A maximum of six bolts are changed every day, with only three of those allowed to be in any one area. Work began in autumn of 2011, and the schedule calls for a replacement of 1,000 bolts per year. The team has now stopped for one year after the 1,000th bolt has been replaced. This is to measure the Vasa's movement in its cradle with the new bolts in place and allows curators to determine the success of the new bolts in arresting or alleviating the ship's twisting.

This project is beneficial not only to the Vasa though. The selection of moly stainless steels for this project also gives metallurgists a unique opportunity to measure the performance of the materials carefully over time in a well-controlled environment. Nearly every environmental parameter of the Vasa Museum's gallery is meticulously controlled and monitored to keep the Vasa as safe as possible. The gallery is kept at a relative humidity of 51–59% and at temperatures between 18°C and 20°C. Lighting is intentionally dim to minimize photochemical damage to the ship. Both, the conditions of the gallery, and the long-term supervised nature of the project, allow the Vasa to become a floating laboratory to evaluate the bolt materials on a scale impossible to attain in any other setting.

The Vasa's old bolts weigh roughly 16 tonnes. The newly designed high-strength stainless steel hollow bolts could reduce this figure by as much as 5 tonnes. It is hoped that this "slimming down" of the Vasa will ease her settling by reducing the pressure of the ship on her cradle.

1,000 more years

Though the Vasa faces several complex challenges, she is safe with moly stainless steels. These alloys provide a unique solution to the problem of preserving a 300-year old national treasure like the Vasa. The restoration project helps the museum attain its goal to preserve the splendid ship for many more

millions of visitors to enjoy, and it will provide the added benefit of an excellent experimental setting to learn more about moly-containing stainless steels. (Douglas Kulchar)

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Varying hole sizes and amounts of corrosion demand that individual attention be given to each bolt. © Anneli Karlsson, the Swedish National Maritime Museums



Each stainless steel bolt is made up of seven or eight separate items, including tube, bar, nuts, washers and springs. © AB Sandvik Materials Technology

Chemical composition of Sandvik SAF 2507™ and Sandvik SAF 2707 HD™

Alloy	UNS No.	C max.	Si max.	Mn max.	P max.	S max.	Cr	Ni	Mo	N	Co
2507	S32750	0.03	0.8	1.2	0.035	0.015	25	7	4	0.3	–
2707 HD	S32707	0.03	0.5	1.5	0.035	0.01	27	6.5	4.8	0.4	1