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Securing molybdenum-99 supply

The molybdenum isotope molybdenum-99 and its decay cousin technetium-99m are extremely helpful and widely used in medical procedures, for example in the diagnosis of cancer. Current production methods for ^{99}Mo are in question because of aging reactors and the use of weapons-grade uranium. Fortunately, some new methods for producing ^{99}Mo are under development and show great promise. If they are successful, molybdenum can continue to play its life-saving role.

Recent articles in MolyReview discussed the basic components of the molybdenum atom (January 2012 issue) and the extreme importance of the ^{99}Mo isotope for medical use (July 2010 issue). Atoms are composed of a nucleus, made of positively charged protons and uncharged neutrons, surrounded by negatively charged electrons. In a neutral atom, the number of electrons and protons is the same, and this number is called the atomic number of the element, which for molybdenum is 42. However, atoms of the same element can have different numbers of neutrons in their nuclei. These are called isotopes of the element. There are 33 known isotopes of molybdenum, but only six are stable – the others decaying radioactively.

The ^{99}Mo isotope, with 42 protons and 57 neutrons, is uniquely suited for use in medical diagnostic procedures. It is radio-active with a half-life of about 2.75 days, meaning that half the atoms, on average, decay in that time. It decays to technetium-99m (^{99m}Tc), the metastable isotope of technetium, the element to the right of Mo in the periodic table. The short half-life of ^{99}Mo is ideal, as it is sufficiently stable to be transported to its place of use, while its radioactivity is short lived.

The ^{99m}Tc isotope is the one used in medical procedures. It decays with a half-life of only six hours, emitting a 140 keV gamma ray, similar in energy to that from X-ray machines. The radiation is thus detectable using standard "gamma cameras". This short half-life means that the medical procedure can happen rapidly and the radioactivity will leave the patient quickly.

^{99m}Tc can be chemically bound to different pharmacological agents that concentrate the isotope in different parts of the body, for example the heart, brain, and kidneys, among others. The gamma rays from the decaying ^{99m}Tc atoms produce a picture of the target area, which is vital for the diagnosis of different medical conditions. ^{99m}Tc is the most widely used medical isotope with over 55,000 procedures performed every day in the US alone.

The problem is that a few aging reactors are producing nearly all the world's supply of ^{99}Mo, and they use highly enriched (weapons-grade) uranium (HEU) in the process. So there is an intense effort by governments and private companies to find alternative methods of producing ^{99}Mo to secure its supply, and to reduce the use of HEU and the risk of proliferation.

One of the newer methods is similar to the traditional, but uses low enriched uranium (LEU) in the reactor. Unlike HEU, LEU cannot be used to make nuclear weapons. The SAFARI-1 reactor in South Africa, for example, has operated using LEU fuel since June 2009 and other operators have followed suit, or are working on similar ways to reduce the use of HEU in the world.

Two of the newer processes under development do not use a reactor or enriched uranium at all. These methods use a particle accelerator. For one process, the Government of Canada awarded $15 million in 2011 to the Canadian ›

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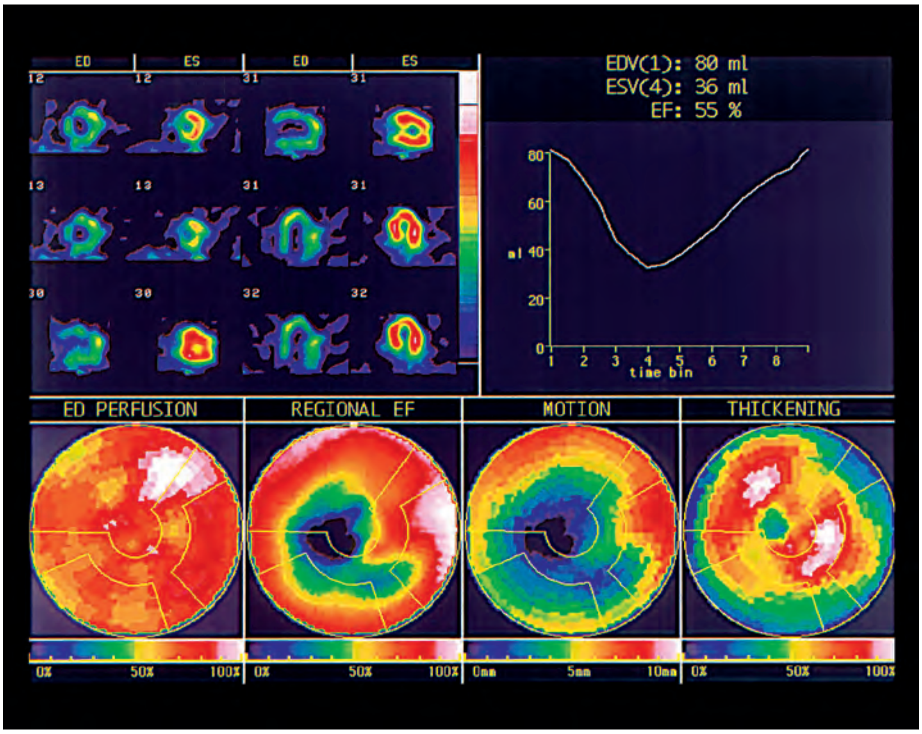
Light Source, a 2.9 GeV electron accelerator facility. They are investigating the production of ^{99}Mo by bombarding another molybdenum isotope, ^{100}Mo, with high-energy gamma rays. In a similar effort, the US Government has awarded a $22.2 million matching grant to Northstar Medical Radioisotopes to build a multiple linear accelerator complex to make ^{99}Mo, also from ^{100}Mo. Northstar believes it could be producing 50% of the US need for ^{99}Mo by the end of 2014.

For the second process, the University of Wisconsin received a $20 million grant for the design of an accelerator-based neutron generator. In this route, the neutrons would strike a sub-critical solution of uranium, producing the desired ^{99}Mo isotope.

It is hoped that one or both of these methods will provide a reliable source of the much needed molybdenum isotope in the near future. This would maintain our vital supplies of ^{99} Mo without the use of weapons-grade uranium. (TF)



Technetium-99m is used as tracer in diagnostic procedures to visualize organs. Here blood was labelled with ^{99m}Tc. The scans are showing blood uptake by the heart muscle (red-adequate, blue-inadequate). © Zephyr/SPL

Stainless steel weaves its web

Stainless steel wire and rod are used to manufacture a wide variety of woven steel mesh products. They are used in many applications ranging from the eye-catching and spectacular to the unobtrusive and utilitarian. Molybdenum contributes to their growing popularity and success by improving corrosion resistance.

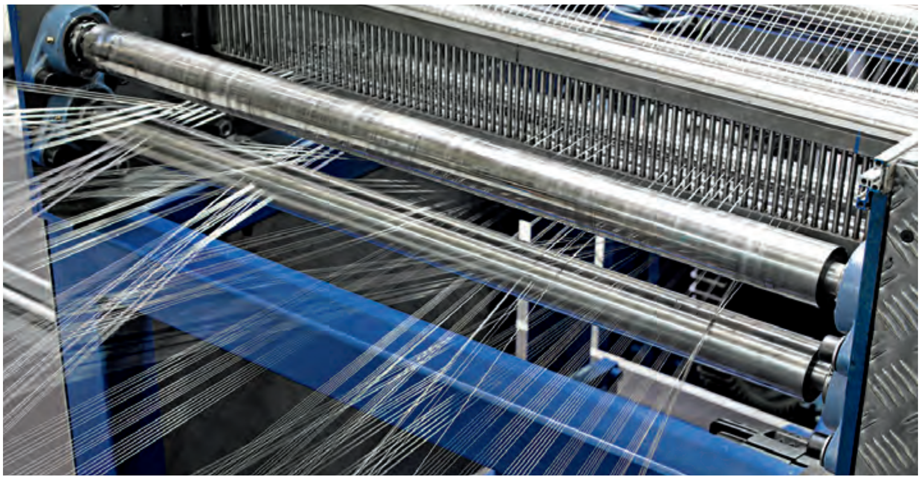
Weaving is one of the oldest of human inventions. Over time, it evolved from manual craft methods to highly advanced, automated processes. The materials used have also evolved – from natural textiles such as fibers of plant and animal origin to synthetic polymers and even metals. In this context, it isn't surprising that stainless steel wire has made its way into current weaving processes. It is found in many mesh applications, both spectacular and inconspicuous, but all essential to everyday life. The many crevices formed by overlapping wires in mesh products are ideal sites for crevice corrosion even in relatively mild environments. It is therefore also no surprise that molybdenum-containing stainless steel is the standard material for such applications since moly improves resistance to corrosion, especially crevice corrosion.

Stainless steel mesh is traditionally used for filtering and screening in a wide range of industries from mining to processing, all the way to high-technology sectors. Architectural applications have emerged more recently but are growing strongly, because stainless steel mesh offers both aesthetic and functional benefits. The common molybdenum grades, Types 316 and 316L are the workhorses, but higher molybdenum grades such as 904L or nickel-based alloys are also used in more aggressive environments.

Weaving techniques borrowed from the textile industry

The weaving of metallic mesh has employed the techniques and vocabulary of the textile industry. Fully automated looms for metal, like cloth looms, employ shuttles, bobbins, and reels. Just as in cloth looms, wires running along the length of the mesh are called the warp; they wrap around stiffer cross wires or rods that are called the weft. ›

The architect was able to transform a rectangular building with stainless steel mesh and give it a striking facade. Maison Folie, Lille. © Paul Raftery



A loom for weaving of stainless steel mesh. © GKD

Modern looms can weave single fibers less than one micron thick, tufts or strands composed of several braided fibers, cables, or solid wire of various shapes with thicknesses up to 5 mm. Such looms can produce mesh up to 20 meters long and 8 meters wide. Woven mesh is available as flat sheets or in rolls, in either stiff or supple form, depending upon the dimensions of the wire used to manufacture the mesh and the details of the mesh design.

Architectural applications

Stainless steel has long been used in architecture because of its aesthetic appeal and longevity. More recently stainless steel mesh made a strong entry into the market because of its remarkable mix of properties. Mesh products can play multiple roles, providing shading while allowing natural light to enter, ventilation while protecting from the elements, and safety while maintaining a pleasing appearance. Mesh offers the designer countless options for customization of buildings, structures and spaces. In many instances it is selected not only for its visual appeal but also for its contribution to energy-saving and sustainable design. The article on energy-saving stainless steel facades in the January 2012 issue of MolyReview gives more detail on this subject.

A second "skin" to encase buildings – A growing trend in modern architecture is to surround buildings in metal mesh to form a "second skin". The mesh may be applied as rigid flat panels, following the contour of the building, or as flexible mesh modifying its shape. In some cases the "skin" can be used to dramatic effect, for example, in the Maison Folie of Lille, in northern France, where the spiral mesh takes on the appearance of a light veil. But, at the same time, the mesh has the practical purpose of thermal insulation, reducing solar gain and wind cooling, and therefore cutting the building's energy requirements, while providing a measure of privacy for the tenants.

The specific finish of the mesh (glossy or satin, darker or lighter color) and the ever-changing play of clouds and sun, reflected by the stainless steel mesh, make a building come alive. At night, illumination can generate a transparent, colored or light-dimming effect. The mesh can also be fitted with an integrated micro-LED lighting system to create programmed lighting effects used, for example, for advertising or for the screening of a movie. Molybdenum containing stainless steel is nearly maintenance-free in these applications due to its high corrosion resistance.

In high-rise parking garages – Mesh allows escape of automotive exhaust gases, and allows sunlight to supplement interior lighting, all the while securing the garage against intrusion and the elements, without leaving a closed-in feeling. Furthermore, woven metal sheets are easy to install. They are simply secured along the perimeter, while solid sheet metal partitions require support and fixing substructures. Carefully thought-out screening on a garage facade can transform the purely utilitarian and generally unsightly aspect of this type of structure to something visually pleasing.

Indoors – mesh from floor to ceiling – A tight weave that comes in rolls offers a wear-resistant and unusually aesthetic floor covering. Metal mesh partitions ❯

Integrated micro-LED lighting systems can create programmed lighting effects for advertising. New York. © GKD/David Joseph

Semi-transparent mesh underlines the airy design of this walkway while providing protection from the elements to pedestrians. Arganzuela bridge, Madrid. @ IMOA

divide spaces and provide a sense of privacy without completely closing them off. Decorative and ornamental meshes can blend steel wires and cables with built-in lighting or exotic materials to create specific ambiences that are highly appreciated by hotel and restaurant designers. On the ceiling, stretched sheets provide good sound insulation and add an interesting decorative element. The fire resistance of stainless steel mesh is another strong point in its favor for architectural use, particularly in public and commercial buildings.

Infrastructure applications –
The Arganzuela walkway, spanning the Manzaranes River in Madrid, designed by French architect Dominique Perrault, uses stainless steel mesh over the length of its double helix structure, serving as guardrails and a screen to protect walkers from the strong summer sun. In addition to these safety and protection functions the mesh's semi-transparency preserves the elegant design's airiness. In Norway stainless steel mesh protects users of the Holmenkollen ski-jump featured on the front cover. Over 7,000 m^2 of Type 316L stainless steel mesh shroud the spectacular flight of steel to protect athletes from the wind and reduce the effects of the cold. By day, the sun's rays play on the metal mesh, while at night illumination creates an impressive ramp of light.

Industrial applications

Architectural applications of stainless steel screening and mesh are only the newest, and perhaps in some ways the most exciting uses of these products. However, mesh has long been used behind the scenes in industrial applications that have underwritten our great technological progress of the last century or more.

Screening, filtering, and sieving –
These processes separate or remove wet, humid or dry particles from their environment and are widely used in many industries. A perfect illustration of their importance is in molybdenum mining, to use a close-to-home example. Winning molybdenite (MoS_2) from the ore in which it is entrapped requires converting hundreds of millions of tons of large rocks into micron-sized particles. They then have to be further treated to liberate and purify molybdenite so that it can be used in all the products that support our society today. The process requires many crushing and grinding steps, each of which must also have a screening step to separate smaller particles that can go on to the next step of processing from larger ones that have to go through additional crushing and grinding. The screens used in these steps require materials having high strength, stability to maintain the proper opening size, and in some steps resistance to corrosion from aggressive liquids.

Food, agricultural, pharmaceutical, metallurgical, pulp and paper, chemical and petrochemical processing are other industries that depend on metal filters and screens as do cars, trucks, airplanes ›

A range of Industrial filters with different stainless steel weaves. © GKD and power plants. The wire material depends mainly on the corrosivity of the process. Materials include the austenitic stainless steels Type 316, Type 904L and 6% Mo grades, and the nickel-based alloys Alloy 22 and Alloy 59, the latter for the most corrosive fluids. There are many filter and sieve designs utilizing many different kinds of mesh. Filters can be cylindrical (structured packs), flat, curved or folded. Fine applications such as dye and ink production may employ wire diameters and opening widths as small as 0.02 mm. Coarse screens used in the mining industry can have wire diameters up to 5 mm with opening widths as large as 18 mm. Large or small, industrial screens, filters and sieves rely on moly-grade alloys because of their mechanical strength and their corrosion and abrasion resistance.

Belt conveyers – Metal belt conveyers are used in many industrial processes. For instance, they are used for the removal of liquids and moisture from solid waste prior to burning in waste-to-energy plants. These belts must carry heavy loads at elevated temperatures, and be resistant to attack from the cocktail of fluids contained in such waste streams.

At the other end of the spectrum lie the stainless steel mesh belts used in food processing. The food industry uses these belts extensively because they are easily cleaned, are resistant to aggressive sanitizing, and they work well in high and low temperatures. Food processing belts are used to bake or toast foods at temperatures reaching 200°C; they are also found in liquid-nitrogen spray-freezing tunnels that operate at temperatures as low as -196°C.

Screen-printing mesh – from soda bottles to semiconductors –
Metal mesh is frequently used for screen-printing because mechanical strength and abrasion resistance are essential properties for mesh materials in this process. The mesh must support high tensile stresses arising from the fast passage of the squeegee as it forces the high-viscosity ink through the mesh. For this type of application, Type 316 wires having a diameter of 15 microns are commonly used for the screen's wefts. Type 316 stainless steel resists the corrosive inks and cleaning solvents that are entrapped in the crevices where warp and weft wires cross. Screen-printing applications range from conventional labeling for pharmaceutical and food bottles to advanced applications required by the semiconductor industry. Here, ultrafine woven metal meshes, for which dimensional accuracy and printing sharpness are imperative, are used to print the masks of printed circuits and mark liquid crystal displays and photovoltaic solar panels. Molybdenum-containing stainless steel micromeshes are present in ink jet cartridges where they ensure the fluidity and proper distribution of inks ahead of the jets. Micromeshes made with wire having diameters smaller than one micron may constitute the lower dimensional limit that can be achieved in stainless steel wire meshes.

Summary

Just as woven fabrics evolved from simple natural fibers woven by hand to produce simple items, woven metal mesh has evolved from simple products using common materials to highly engineered designs that require sophisticated materials solutions for their successful use. Molybdenum-containing stainless steel and other moly-containing alloys solve the problems posed by applications for such new woven products, whether the need is high strength, corrosion resistance, aesthetic properties, or heat resistance. We can expect to see more uses of these sophisticated materials systems as engineers and architects tackle ever more challenging problems and turn to molybdenum containing materials for assistance. (TP)

A stainless steel belt conveyor runs these bread rolls through the oven and also serves to cool them after. © iStockphoto.com/mujdatuzel

Chemical composition and applications of stainless steel and nickel-based alloy grades used as mesh

Grade	% C	% N	% Cr	% Ni	% Mo	others	Applications of mesh
AISI 316L	0.02	0.1	17	11	2	–	Architecture, interior design, screen printing
AISI 904L	0.01	–	20	25	4.3	Cu	Architecture, interior design (salt atmosphere)
6% Mo	0.02	0.2	20	18	6.2	Cu	Industrial processes (solvent, corrosive)
Alloy 22	0.01	–	21	Bal.	13	W-Cr	Screening, filtering, sieving, process belts (higher resistance to solvents, acids and chlorine)
Alloy 59	0.01	–	23	Bal.	16	Al	Screening, filtering, sieving, process belts (higher resistance to hydrochloric acids)

High-strength steel – sustainable and money saving

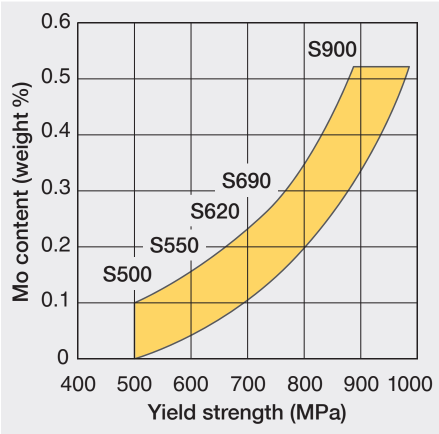
Molybdenum's unique properties are often used to deliver sustainability advantages in energy production, energy efficiency, resource conservation and environmental protection. The newly-constructed Friends Arena in Solna Municipality, Stockholm, is a great example of how "a little moly goes a long way" in reducing the environmental impact of a new building and saving cost at the same time.

Steel is part of the fabric of our modern world, but the iron and steel industry has one of the largest carbon footprints of all industrial sectors, contributing 4% to global man-made emissions[1]. If there were a way of using less steel to build the same structure, CO_2 emissions would be reduced and natural resources conserved. With moly-containing high-strength steel (HSS), that's exactly what happens. Because the steel is so much stronger, less is needed to build the same structure and the overall environmental impact is reduced.

The Friends Arena, the second largest indoor stadium in Europe, was designed utilizing this approach: the roof trusses supporting the retractable roof are partially constructed from molybdenum-containing HSS. The structural engineers optimized the design by using different grades of HSS in the various structural elements within the roof truss. The result is a very light roof for a stadium of its size. This is particularly noteworthy because designers in Sweden have to take much higher snow loads into consideration than in other parts of the world.

Moly for light-weighting

Known as "light-weighting", the use of HSS to achieve weight savings is becoming increasingly important in the manufacture of trucks, cars and pipelines, as well as in large construction projects like the Friends Arena. There are many ways to increase the strength of steel. For example, by simply adding more carbon the strength goes up, but this can have a detrimental effect on both the weldability and ductility of steel. By adding molybdenum to the steel instead, it is made stronger without compromising its weldability. Depending on the required strength level and the plate thickness, the molybdenum content in HSS can range from 0.1% to 0.5% (see figure above).



Yield strength of 20 mm thick plate for various HSS grades with increasing Mo content.

The Friends Arena opened in 2012 and holds up to 65,000 spectators. © Sweden Arena Management

Savings all round

HSS grades S460, S690 and S900 make up nearly one third of the weight of the arena's 4000 tonnes roof:

- S460 (no Mo): 904 tonnes
- S690 (0.2% Mo): 265 tonnes
- S900 (0.5% Mo): 44 tonnes
- S355 (no Mo): balance of roof

The use of HSS led to a reduction of 584 tonnes[2] or 13% of the total weight of the roof compared to a roof constructed from conventional S355 steel. Although HSS is slightly more expensive than ›

High-strength steel trusses supporting the retractable roof.
© Sweden Arena Management

conventional structural steels, the reduced tonnage led to an overall cost saving. The cost of the roof structure was € 2.2 million or 15% less than a traditional design using all conventional steel, largely due to the reduced tonnage of steel and the resulting lower requirement for welding.

In life cycle terms, the greatest reduction in environmental impact also came from the lower amount of steel used. Taking into account the additional effect of transport savings and steel recyclability at end of life, the HSS design achieved an environmental saving of nearly 900,000 kg of CO_2 equivalent or 17%, compared to construction with all conventional steel. This saving is comparable to the CO_2 absorbed by about 80 hectares of pine forest in a year.

A sustainable "win win"

The Friends Arena is a very visible reminder of how the addition of a small amount of moly can make a big difference. High-strength steel is just one example of how the properties of molybdenum can be harnessed to bring significant, cost-effective sustainable benefits to a project. (LH)

1 2009 EAA report No. 9. Greenhouse gas emission trends and projections in Europe 2009. Annex: Additional information on greenhouse gas emission trends and projections.
2 Cederfeld, L. and Sperle, J-O: High Strength Steel in the Roof of Swedbank Arena Savings in Weight, Cost and Environmental Impact. Nordic Steel Construction Conference 2012, Oslo Norway.

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.

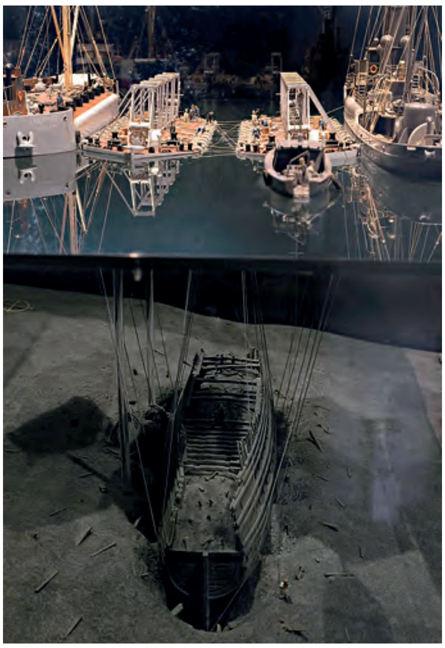
Though it failed as a ship and scuttled Sweden's geopolitical aims, the Vasa is now one of the most celebrated ships worldwide after being heroically raised in the 1950s and put on display for the world to see at the Vasa Museum in Stockholm. Spending 300 years at the bottom of the sea can wreak havoc 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.



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

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


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.

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. (DK)

Acknowledgement – The author thanks the staff of the Vasa Museum and the technical staff at Sandvik Materials Technology for their cooperation and help with this article.

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

Preserving Acropolis artifacts

The thoughts of Socrates and his ancient Greek contemporaries are a foundation of western civilization. The Acropolis and its most famous building, the Parthenon, are physical reminders of our debt to these philosophers. Moly helps to sustain the legacy of these sites in the beautiful new Acropolis Museum, which contains many components made of moly-containing Type 316 stainless steel. The longevity of stainless steel ensures the museum will serve its purpose well for years to come.

High above the city of Athens, bathed in Mediterranean sunlight by day and floodlit by night, the Acropolis represents one of antiquity's greatest achievements. The Parthenon, crown jewel of the Acropolis, was built between 447 and 432 BCE during Socrates' lifetime (469-399 BCE). This revered temple attracts millions of visitors every year. Dedicated to the city's patron goddess, Athena Parthenos, it originally featured a grand roof, Doric columns, an inner room, and fine sculptures and friezes. It remained well preserved until 1687, when a gunpowder magazine located inside the temple exploded during a cannon bombardment of the city. In tribute to its immeasurable historical and cultural value, the Acropolis is today a UNESCO World Heritage Site.

A new museum

The rich historical legacy of classical Athens is being preserved at the new Acropolis Museum which holds a stunning collection of sculptures and artifacts found at the Acropolis. The museum is connected to the Acropolis by the Dionysios Areopagitou, a pleasant, marble-paved pedestrian street featuring excellent views of the many nearby archaeological sites.

The principal architect for the museum was Bernard Tschumi Architects of New York & Paris. Every day thousands of visitors come to see the displays in the €130-million structure which opened to the public in 2009. With over 14,000 square meters of exhibition space, the museum offers a comprehensive picture of human presence at the Acropolis from pre-historic times to late antiquity. It houses a 200-seat auditorium with projection facilities, two gift shops, a café, and a large second-floor restaurant that opens onto a public terrace with a splendid view of the Acropolis.

The new Acropolis Museum in the foreground has a splendid view of the Parthenon on top of the hill. © Peter Mauss/Esto

Modern materials used throughout

Structural steel and reinforced concrete make up its core structure, but the museum also contains large amounts of glass and stainless steel. It presents a wonderful modern monument that maintains strong ties with the fabled past of the site. Upon entering the exhibition space, visitors find themselves in a beautiful gallery lined with display cases and a gently sloping floor of heat-strengthened, laminated safety glass panels. These transparent panels allow visitors to see marvelous ruins from the 4th to 7th centuries BCE, which have been left intact and protected beneath the building. The glass panels are set in corrosion-resistant Type 316 stainless steel frames. The top floor of the museum houses the spectacular Parthenon Gallery, which reconstructs, in full size, the layout of the preserved friezes taken from the famous temple. All 46 of the replica's columns are made of Type 316L stainless steel with a semi-bright surface finish, offering visitors an excellent look at the Parthenon's famous depiction of the Panathenaic Procession.

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The Parthenon Gallery in the museum displays a mixture of the original frieze blocks and reproductions. It has the same 39 m x 84 m footprint as the actual site. © Peter Mauss/Esto

The museum's exterior facade is distinguished by large Type 316 stainless steel fins made from corrugated sheet cladding. By selecting molybdenum-bearing Type 316 and 316L stainless steels, each alloy containing 2% Mo, the architects, designers, and engineers of the Acropolis Museum have chosen materials of construction that will provide corrosion resistance, strength, durability, and low maintenance for many decades to come. Though it would be nearly impossible to duplicate the splendor of the Acropolis in its heyday, the new museum provides a worthy companion to the Parthenon's famous profile in the renowned Athens' skyline. We know of Socrates because his legacy was preserved by Plato's writings. Should we be so bold as to say that moly will play the role of Plato and help preserve and sustain this new worthy addition to the legacy of the Acropolis for another 2000 years?   (FS)

IMOA news

Molybdate research papers published in peer-reviewed journal

The REACH Molybdenum Consortium (www.molybdenumconsortium.org), an initiative of IMOA, recently concluded a multi-million dollar, four-year research program into environmental, human health and physico-chemical aspects of molybdenum and eleven of its compounds. The data was used to generate hazard identification and risk assessment dossiers on the 12 substances. The results are publicly available via the European Chemicals Agency on http://echa.europa.eu/web/guest/information-on-chemicals/registered-substances.

IMOA is now publishing its research; three papers are featured in 'Science of the Total Environment'. Publication in a peer-reviewed journal is critically important because it means the science has been independently and rigorously cross-examined. This, in turn, is the most effective way to achieve IMOA's objective that the data be taken into account by global regulatory authorities, many of whom will only consider peer-reviewed and published data. So the three publications as summarized below are an important milestone for IMOA/MoCon.

The chronic toxicity of molybdate to marine organisms (Heijerick et al). The REACH process identified significant gaps in marine ecotoxicological data about molybdate. This paper summarizes the multiple research projects undertaken to generate the necessary chronic effects data for the marine environment. Abstract: http://bit.ly/OpzVIV.

The toxicity of molybdate to freshwater and marine organisms (Heijerick et al) explains how the chronic effects data for both the freshwater and marine environments are used to calculate the Predicted No Effect Concentration (PNEC). The PNEC is a safe level of molybdate that does not adversely impact organisms living in a specific environmental compartment. PNECs of 12.7 mg Mo/L and 1.9 mg Mo/L were derived for freshwater and marine respectively, using the most scientifically robust and rigorous methodology currently available, known as Species Sensitivity Distribution (SSD). Abstract: http://bit.ly/OGAHgo.

The bio-concentration and bio-accumulation factors for molybdenum …. (Regoli et al) summarizes research projects designed to learn more about whether molybdenum bio-concentrates or bio-accumulates in fish. This is important to assess any potential risk of secondary poisoning in the food chain. The research indicated that molybdenum does not bio-concentrate or bio-accumulate in fish, up to the PNEC value of 12.7 mg Mo/L. It also demonstrated how the homeostasis mechanism in fish, that enables internal regulation of essential trace element concentrations such as molybdenum, was not overwhelmed even at the high PNEC value of 12.7 mg Mo/L. Abstract: http://bit.ly/QNK4Zn. (SC)

Blue mussels (Mytilus edulis) was one of the studied species. © Alexander Semenov/SPL

2nd Symposium on Mo and Nb Alloying in High Performance Steels, April 25–26, 2013, Jeju Island, South Korea

IMOA, CBMM and hosting partners Korean Institute of Metals and Materials (KIM), Posco and Hyundai Steel, are organizing this international symposium. High performance steels are the key to lighter, more durable and more sustainable vehicles, machines, structures and pipelines. The program will focus on alloy design, processing and properties of high performance steels. Speakers are some of the world's leading steel experts. The event is for steel producers as well as users. More information at www.nbmosymposium.com/site/.