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Molybdenum at work in the dentist's office

Dental instruments need to be hard for the dentist to work efficiently and precisely, and tough enough not to break during procedures. At the same time they have to be hygienic, corrosion resistant and easily sterilized. The molybdenum-containing hardenable surgical stainless steel Type 440A fits these requirements and new, even harder and tougher grades are on the horizon.

Dentists recommend a semiannual check-up and a visit to the hygienist. Regular flossing and brushing can help slow the accumulation of plaque and tartar, but only dental hygienists can effectively reach small crevices between the teeth and clean near the gum line. To accomplish this and many other tasks, they often use tools made of a hardenable molybdenum-containing stainless steel.

Tools of the trade

Several types of tools are used to clean and care for the teeth, including probes, mirrors, scalers, ball burnishers, and condensers. Mirrors help examine patients' mouths. Scalers remove plaque and tartar by scraping. They come in many angles and tip shapes so the hygienist can comfortably reach all of the tooth's facets. Ball burnishers provide the final polishing of fillings, smoothing scratches left by other tools. Probes are used to find cavities and condensers to place and compact restorative material into a prepared cavity.

Dental tools are available in a variety of materials, including stainless steel, carbon steel, titanium and plastics. Important factors in tool selection include material strength and toughness, weight, balance, ability to hold a sharp edge, and resistance to corrosion.

Strength and toughness prevent tool breakage which might easily lead to puncture wounds. Stainless steel tool tips exhibit excellent toughness. Scalers, curettes and probes need a sharp edge to reduce the pressure exerted by the dentist, helping to avert damage to the patient's teeth or the tool itself. Dull dental tools are more difficult to work with. They reduce control, and with that, the quality and precision of the work. They also require more time for a procedure, increasing fatigue of the practitioner, not to mention that of the patient. Periodic sharpening is therefore an essential part of tool maintenance. The high hardness of surgical stainless steel maximizes tip life between sharpening and reduces the total maintenance time.

As in all medical practices, hygiene is key for safe and successful procedures. Dental tools are sterilized after each use, usually with high-temperature steam under pressure in an autoclave, with dry heat or with chemical vapor. Stainless steel does not corrode in any of these procedures. Its non-reactive surface is easily cleanable and disinfected.

The stainless choice

Stainless steel's superior properties ensure that it is widely used in dentists' offices all over the world. ›

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Huge mobile crane removes scaffolding from Cologne Cathedral.© Liebherr-International Deutschland GmbH

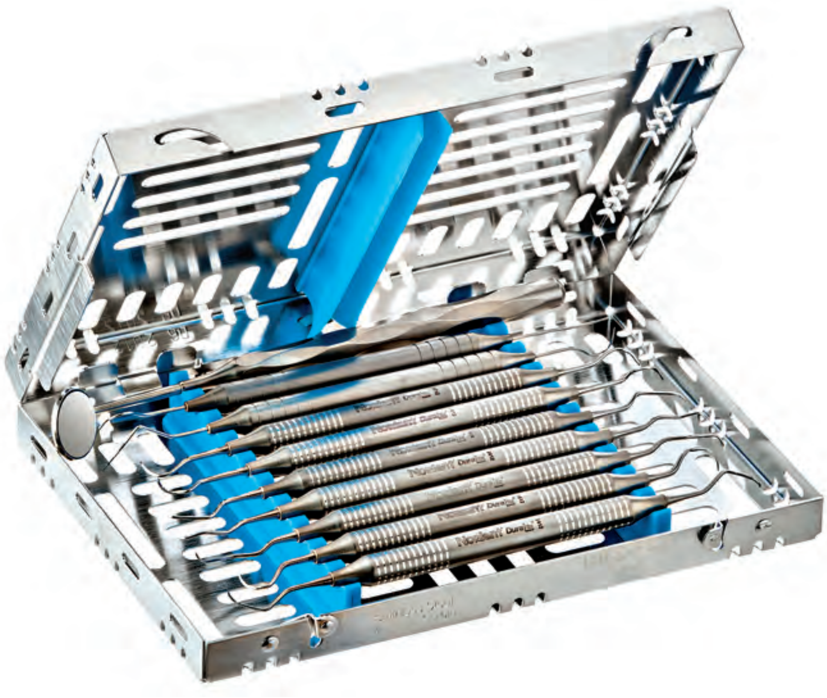
The grade of stainless steel employed depends on the intended use of the tool. One widely used grade for curettes and scalers, instruments used to remove hardened plaque from the tooth surface, is AISI Type 440A. This high-carbon, hardenable stainless steel contains 0.75% molybdenum. A manufacturer in California uses Type 440A to make high-quality dental and surgical instruments. According to their metallurgist, it delivers the best hardness, toughness and wear performance of any stainless steel. Another top US tool producer echoed this assessment and stated that Type 440A stainless steel enables them to manufacture durable, reliable, high-quality instrumentation that allows dentists and hygienists to achieve peak performance and maximize patient care. The alloy's molybdenum addition contributes to the toughness and corrosion resistance.

Regular visits to the dental hygienist help to keep teeth healthy and prevent plaque from accumulating. © Fotolia/Catalin Pop

A maker of dental instruments in Germany makes probes from 3%-molybdenum super duplex stainless steel for its high strength, flexibility, and excellent wear resistance. The latter ensures a long-lasting sharp tip.

But new grades are entering the market. The stainless steel producer Sandvik already offers a range of molybdenum-containing grades for medical and dental instruments. Currently the company is working with high-quality toolmakers to test its newest grade for dental applications, a precipitation hardenable (PH) grade with 4% molybdenum. It can be formed at low hardness and then heat-treated to the final hardness in just one step, offering a considerable advantage over hardenable martensitic grades, which require three or more heat-treating steps. But the key advantage is that the grade is much tougher than the martensitic stainless steels, which can be fragile, especially if dropped.

Dentists can choose among many materials for their instruments. Stainless steels provide just the right properties for every kind of tool. As dentistry advances, the tools and materials must advance with them and there are new developments with even higher molybdenum contents on the horizon. It could be said that Mo-containing dental tools are one of the reasons behind many great smiles! (AW)



"The combination of corrosion resistance, edge retention and tensile strength make Type 440A the perfect material for our product." © Nordent Manufacturing

A breath of fresh air

Clean air is a basic human need for a healthy life. Yet, advances in living standards (electricity on demand, automobiles, and consumer goods) contribute to air pollution in manufacturing, energy production, and the use of products. As scientists began to understand the connections between air pollution and industrialization, engineers developed technologies to minimize the damage. Molybdenum plays a central role in many of them.

Greenhouse gas emissions produced by burning fossil fuels such as coal and oil are today's most pressing air-quality problem. They drive global warming and climate change. However, there still are other serious air pollution challenges, such as acid rain, smog and particulates.

Acid rain

Readers of a certain age will remember when the impact of acid rain first became obvious in the late 1970s. The phrase "acid rain" was seared into the public consciousness by images of bare trees and dying lakes. Large areas of forests were affected, as once-healthy trees became weak and diseased. Acid rain destroys the protective coating on leaves and needles, reducing their ability to support the photosynthesis that trees and plants need to thrive. As the damage progresses, they become more susceptible to cold temperatures, insects and disease. Lakes and streams ironically turned crystal clear but, due to increased acidity of the water, fish populations and plant life suffered. The local ecosystem began to feel the effects as fish were taken out of the food chain and birds and other animals struggled to survive.

Acid rain also damages older buildings by slowly dissolving limestone and marble, speeding up natural erosion and causing the exposed stone to crumble away (see article on Cologne Cathedral in this issue). Indeed, Robert Angus Smith, the UK scientist credited with the first use of the term "acid rain" in the eighteenth century, noticed that stone buildings crumbled more readily in larger towns and cities where more coal was burned.

However, acid rain's effect was more widely felt as industrialization and the need for electric power progressed. It soon became apparent that fossil fuels, which often contain large amounts of sulfur, were at the root of the problem. Scientists have found that fossil-fuel fired power plants are the largest contributors to acid rain. When burned, fossil fuels release sulfur dioxide and various nitrogen oxide gases (NOx) that react with tiny droplets of water in the clouds to form sulfuric and nitric acids. On the pH scale which runs from zero (strongly acidic) to 14 (strongly alkaline), rain naturally has a value between five and six, whereas acidic rain has a pH value of around four. Because the pH scale is logarithmic, rain with a pH of four is ten times as acidic as rain with a pH of five, and 100 times as acidic as rain with a pH of six.

Acid rain caused by sulfurous fossil fuel emissions can wreak havoc on the natural environment, as evidenced by dead and dying forests and lakes. © istockphoto/ThomasTakacs

Smog and particulates

Even before acid rain became an issue, fossil fuels were well known for creating pollution problems. Heavy coal use to heat buildings resulted in the "pea-soup" fogs of Victorian London. This combination of smoke and fog became known as "smog," and it continues to exist in cities around the world today. Unlike Victorian smog, contemporary smog is mostly caused by automotive emissions, though the burning of coal, land and forest fires, and industrial activity can also be contributing factors where regulations are less stringent.

Smog brings with it significant health concerns. The ground-level ozone, sulfur dioxide, nitrogen oxides, and carbon monoxide contained in smog are most harmful to children, senior citizens, and anyone whose health is compromised by bronchitis, emphysema, or asthma. Premature deaths due to cancer and respiratory disease, and increased rates of birth defects and low birth weight have also been correlated with smog exposure.

Smog forms when gaseous emissions react under the influence of sunlight and heat with ammonia, moisture, and other compounds in the air to form the well-known brown haze. Particulates in vehicle exhaust emissions are also regarded › as a health hazard. In fact, the European Union has classified particulate emissions from diesel engines as carcinogenic. The rapidly developing concerns regarding smog and particulate emissions in the 1960s spurred a drive to drastically reduce vehicle emissions even before acid rain emerged as a concern.

Molybdenum, a catalyst for change

Acid rain: Attempts to remove sulfur from the exhaust gases of power stations began in the nineteenth century. But flue gas desulfurization (FGD) units known as scrubbers did not become widespread until the 1980s and 90s. The most widely used FGD system for coal-fired power plants is the wet limestone-gypsum process in which sulfur dioxide and other acidic flue gases are neutralized by calcium carbonate. Scrubbers are very large vessels in which exhaust gases pass upwards through a spray containing the limestone slurry. Scrubber internals must withstand a very corrosive environment, so material choice is an important part of the design process. Highly corrosion-resistant molybdenum-containing alloys are used in modern systems to ensure long service life and prevent frequent costly replacement. Thus, FGD units are built using either molybdenum-containing stainless steel, or carbon steel covered with a molybdenum-containing nickel-based alloy.

Smog and particulates: Today's automotive catalytic converters use precious metals to break down smog-causing compounds. However, the sulfur naturally contained in fuels poisons the catalyst material and renders it ineffective. This means that low-sulfur fuel had to be widely available before carmakers could routinely fit catalytic converters to vehicles. At about the same time, elimination of lead from vehicle fuels required that new processes to boost octane be developed. These processes also used catalysts that were poisoned by sulfur, so desulfurization of vehicle fuels became a critical first step in smog reduction.

Molybdenum plays a crucial role in the hydrodesulfurization process used to produce low-sulfur liquid fuels and natural gas. In this process, fuel vapor flows over catalyst beds composed of molybdenum disulfide and smaller amounts of cobalt, nickel or tungsten. The molybdenum disulfide catalyst promotes a chemical reaction between free hydrogen and sulfur that removes sulfur from the fuel as hydrogen sulfide gas. Hydrogen sulfide is then converted to elemental sulfur, most of which is used to produce sulfuric acid. Today, more sulfur is produced worldwide from hydrodesulfurization than is mined.

Diesel engines present a more complex problem than gasoline engines because they emit a larger variety of pollutants that include many solid particles of soot. Sulfur's detrimental role in diesel fuel is similar to its role in gasoline: it poisons the oxidation catalysts that improve particulate filters by removing gaseous emissions and "burning" fine soot particles that pass through the filters. Low-sulfur diesel fuel therefore makes the technology of converting pollution-causing constituents to harmless gases possible.

Smog is a serious problem in cities that strongly depend on automobiles. Los Angeles, located in a topographical basin that traps emissions, is a classic example. © istockphoto/Daniel Stein

One hundred times cleaner

Even though smog was understood to play a role in health and environmental problems, the dual challenge of needing to reduce smog through the introduction of catalytic converters, but needing low-sulfur fuels to accomplish the goal, was difficult to solve. In the 1970s and 80s, parts of the U.S. legislated the use of reduced-sulfur fuels, spurring development of fuel desulfurization technology. In 1993 the European Commission, in order to improve urban air quality across Europe, required all gasoline and diesel fuel to meet new, cleaner specifications. To gradually reduce the sulfur content of fuels, the EU eventually mandated production of ultra-low sulfur (less than 10 ppm S) gasoline and diesel fuel by 2009.

A lifecycle assessment study analyzing ultra-low sulfur diesel (ULSD) compared the total lifetime environmental impact of a switch from the 2000-ppm diesel fuel of 1993 to today's 10-ppm ULSD in the EU. The study considered a number of environmental metrics relevant ❯

Low-sulfur fuels, catalytic convertors, and diesel particulate filters have contributed to dramatic reductions in smog in cities around the world. Toronto is one city that has benefited greatly from these innovations. © istockphoto/slobo to vehicle use and performance. It calculated the following reductions for the use of ULSD:

- Acidification potential nearly 25% lower.
- Breathable particulates and other inorganic compounds down by 44%.
- Nearly 5% lower potential for smog creation.

In the European continent as a whole, the use of ULSD reduces annual sulfur dioxide emissions by more than three-quarters of a million tonnes (based on diesel consumption in road vehicles in 2011). Furthermore, sulfur dioxide emissions from diesel vehicles are now less than 1% of their 1993 values, despite a doubling of diesel fuel demand in the last 20 years.

In summary

Challenges to our natural world will no doubt continue to increase in line with our living standards and expectations, but the effective elimination of acid rain as an environmental issue and the drastic reduction in automotive emissions in the developed world show that it is not necessary to sacrifice one for the other. Molybdenum has contributed significantly to cleaner air. It has provided highly-corrosion resistant materials for power station FGD equipment. It is also a crucial catalyst used to remove sulfur from liquid and gaseous fuel, a process that enabled the mass introduction of automotive catalytic converters. These accomplishments demonstrate the power of innovation in solving some of the world's biggest problems, and molybdenum's remarkable contribution to those solutions. (AH)

Molybdenum-containing catalysts dramatically reduce the sulfur content of oil-based fuels. © Haldor Topsøe

Moly rescues a lady in distress

Since its dedication in New York harbor on October 28, 1886, The Statue of Liberty has become one of the world's best-known sculptures. However, after nearly 100 years in the aggressive marine environment, galvanic corrosion between the iron framework and the copper skin caused major structural deterioration. Molybdenum-containing stainless steel played a crucial role in restoring this iconic landmark.

The Statue of Liberty was conceived and created by the famous French artist Frédérick Auguste Bartholdi and structurally designed by Gustave Eiffel. It was constructed using some of the most advanced techniques of its time and presented as a gift to the people of the United States from the people of France.

The original structure of the 46-meter statue had a puddled-iron framework of a central pylon, secondary framing and armature bars. The central support pylon had four cross-braced legs with a double-helix staircase rising through its center. The secondary iron framework connected the 1850 puddled-iron armature bars to the pylon. The armature bars supported the copper sheets and allowed movement. About 1,500 U-shaped copper saddles connected the armature to the 73-tonne, 2.4-mm thick copper envelope. This inspired structural design allowed the envelope to flex and expand, and avoid cracking due to heat, cold, and wind.

When dissimilar metals are connected, galvanic corrosion can occur. When such a "galvanic couple" is exposed to an electrolyte, e.g. moisture, salt and pollutants, the more stable metal will be protected and the other metal will corrode at an accelerated rate. The greater the difference in surface area between the two metals, the faster corrosion will occur. Copper is more stable than iron in salt-water environments, so the statue's design harbored potentially serious corrosion problems. ›

Eiffel and his structural engineer Maurice Koechlin understood and anticipated the problem, and electrically isolated the materials using shellac-impregnated asbestos pads. They believed that any corrosion would be apparent upon close inspection, and could be dealt with when found. However, structural and design changes over time allowed more water to enter the structure than anticipated. The interior was therefore painted with coal tar in an attempt to seal the seams. Due to the failure of the asbestos barrier the secondary framework in the arm support structure and much of the sculpture's armature had been replaced by 1938. Over the years leading up to the statue's refurbishment in 1984–1986, its interior was painted at least ten times for cosmetic and protective purposes. Only in 1980, when the statue was inspected carefully after it had been scaled by political protesters, was the extent of the damage to the copper envelope and structural supports discovered requiring extensive rebuilding and repair.

Severe corrosion of the iron armatures had produced rust that expanded (due to its greater volume than the iron) and damaged the copper sheet, requiring replacement of all but a few bars in the foot. Molybdenum-containing Type 316L stainless steel was chosen for this job because of its excellent corrosion resistance in marine air and because there is minimal galvanic corrosion effect with copper in this environment. An additional advantage of this choice was that the coefficients of thermal expansion of Type 316L stainless steel and copper are the same, eliminating mechanical stresses due to temperature variations. Teflon® was used to electrically isolate the metals from one another as an additional measure of protection, even though the risk is low.

There had also been significant deterioration of the secondary framework. The restoration team replaced much of it with a new high-strength secondary framework of highly corrosion resistant, molybdenum-containing duplex stainless steel (UNS S32550). The new framework is attached to the central pylon and supports the Type 316L armature. The sections of the original secondary framework that remained were cleaned and coated with a zinc primer and epoxy topcoat. These layers protect it from corrosion and help to electrically isolate the iron from the stainless steel. Type 316 stainless steel was also used to replace the circular stair treads, for emergency elevator components, and for a redesigned pedestal stairway.

As a result of this remarkable restoration project, Lady Liberty is now well into her second century guarding New York harbor and welcoming those who arrive. Thanks to molybdenum-containing stainless steels, she should continue her greetings well into her third century.
(CH, JS)

The restored Statue of Liberty raises her torch to greet new arrivals to New York City and the United States. © Rudy Norff

Looking up through the central pylon the intricate detail of the unique structure built to support the statue's façade can be seen. © Mike Renlund

Mobile cranes reach higher

Today's global demand to build infrastructure larger, faster and higher challenges crane manufacturers to keep pace by developing more powerful, versatile and cost-effective equipment. Molybdenum-containing high- and ultra-high-strength steels allow them to push performance boundaries to new heights.

Spectators from near and far gathered to watch as three enormous parts of a scaffold that took two years to install were removed in four hours. The Cologne Cathedral, a World Heritage site, attracts approximately 20,000 people a day, making it the most visited landmark in Germany. Its two towers reach 158 meters into the sky, making it the fourth tallest church building in the world.

Weathering, acid rain and other industrial pollutants eroded this gothic masterpiece over its lifetime. Bird droppings also damaged its delicate sandstone façade, though nesting falcons given an aerie in the cathedral have solved this problem. Even so, the cathedral needs constant maintenance and repair, and employs 60 permanent craftsmen for this purpose.

In 1984, a three-meter chunk of stone plummeted 100 meters from the cathedral's north tower during a heavy storm. The ensuing incident investigation found that brass and iron stone anchors had failed. The iron anchors corroded and the resulting rust (occupying a greater volume than iron) put pressure on the stone, cracking and loosening it in places. To avoid similar incidents, stainless steel stone anchors were to be installed in place of the old iron and brass components.

For the stonemasons to access the lofty areas without damaging the façade in the process, intricate scaffolding had to be hand-assembled over the course of two years. It took years to restore the stonework, and then months to disassemble much of the scaffolding. However, the three largest sections of scaffolding remained at a height of 100 meters. Project managers estimated another six months would be needed to extract these last massive sections manually, so a more efficient approach was sought. To do the job quickly and economically, German logistics experts from Wasel GmbH were engaged. Armed with a highly detailed and complex plan, they brought in one of the biggest mobile cranes available, the Liebherr LTM1750-9.1, to perform this delicate operation.

The wonderful world of mobile cranes

Mobile cranes are compact, lightweight and fuel-efficient and can be rapidly set up and taken down. They perform tasks as disparate as unloading the heaviest of shipping containers at an expansive seaport and deftly extracting a large tree from the confines of a residential property. They must be able to travel on highways or over rugged terrain. They must be both light enough to cross highway bridges and small enough to clear underpasses and tight spaces.

Once the crane is at a job site, its boom either unfolds or telescopes to reach the necessary height. Thinner and stronger structural members confer great advantages on mobile cranes. They allow the cranes to be more compact, extend to greater height, and lift larger loads. Crane manufacturers require high- and ultra-high-strength steels to make these thinner and lighter sections. The very high strengths required, combined with the good toughness needed for safe operation, are only achievable by adding molybdenum to the steel. Typically, these molybdenum additions range from as little as 0.1% up to 0.7% for the highest-strength steels. ›

Mobile cranes must be able to navigate standard highways and roads, even in the most demanding circumstances. © Liebherr-International Deutschland GmbH

Mobile crane classification

Mobile cranes are appearing more and more at worksites. They come in varying types, sizes and lifting capacities, and can be categorized as crawler, truck, all-terrain, and rough-terrain cranes.

Crawler cranes have an undercarriage with a set of tracks or crawlers to provide stability and mobility. Manufacturers use high-strength structural steel containing up to 0.7% molybdenum in their designs to reduce weight and increase efficiency.

Crawler cranes are the "heavy lifters" of the crane family, and are widely used for construction projects.© SENNEBOGEN Maschinenfabrik GmbH

These cranes can lift upwards of 6,800 tonnes and maneuver the load with precision. They are ideal for modular construction where large, heavy, pre-fabricated modules need to be positioned. The only disadvantage of the crawler crane is that it moves slowly, so it must be transported to the worksite by truck.

Truck cranes are self-propelled loading and unloading machines mounted on a truck body. They are equipped with rubber tires that allow them to travel on public roads. The crane's working section comprises a rotating turntable and a cantilevered boom. High-strength steels are used in many of the components that make up truck cranes, including the hydraulics that power the boom.

One of the world's largest truck cranes has a lift capacity of 30 tonnes when the boom is extended to nearly five meters, and nine tonnes when extended to 15 meters. Extension booms employ a high-strength structural steel with 0.7% molybdenum.

Some truck cranes are used for lighter-duty work, for instance bridge inspection. These cranes feature a large operating range that allows inspectors access to all parts of the bridge deck. They can also be used for performing light repair work or for taking material samples. Despite the lower loads, they also employ high-strength steels. One leading manufacturer uses steels with up to 960 MPa tensile strength, containing up to 0.7% molybdenum, in their components.

Truck cranes are highly versatile, and are seen in a wide variety of lighter lifting applications such as this tree extraction. © Robert Bukk

All-terrain cranes are a more versatile version of truck cranes. Typically, all-terrain cranes have four to eight large rubber tires, four-wheel drive and all-wheel steering. A single engine powers both the vehicle and the telescoping crane. Their increased mobility makes them ideal for on- and off-road as well as confined work sites and rough terrain. They can travel at speed on public roads and highways. All-terrain cranes use molybdenum-containing steels in their lifting components; these cranes have lifting ranges from 40 tonnes with a maximum boom extension of 35 meters to 400 tonnes with a maximum boom extension to 60 meters. Some all-terrain cranes can hoist loads as large as 1,200 tonnes.

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Rough-terrain cranes are compact cranes with a single cab for both driving and lifting operation and a telescoping boom. All-wheel drive and steering and large rubber tires provide the rough-terrain crane with maneuverability and versatility to work not only on slick, uneven and rough terrain but also in narrow spaces.

Rough-terrain cranes can be used in bridge building, operations in power and chemical plants, refineries, and for large construction projects such as wind farms. Lifting capacities can range from 30 to 135 tonnes. Boom extensions range from 29 to 60 meters for smaller models and higher for larger models.

"Ideal for the job"

Back in Cologne, in July 2013 the 9-axle Liebherr all-terrain mobile crane rolled onto the forecourt of adjacent Cologne Central Station, one of the busiest railway stations in Germany, to remove the remaining scaffolding from the Cologne Cathedral. The best location for the crane to reach the scaffolding would have been the cathedral square. However, the drawings of the parking garage underneath the square were lost when the city archives collapsed in 2009. It was therefore not possible to check whether the ground would hold or to calculate the exact placement of the crane.

Because of the crane's location in front of the busy train station, crews had very little time to assemble the lattice boom, and the constricted space required it to be put together while suspended. The crane's crew worked through the night with the assistance of a smaller mobile crane. By morning the larger crane with its impressive 160-meter boom, built from steels with up to 1300 MPa tensile strength containing around 0.5% molybdenum, was ready to begin the intricate task of removing the scaffolding.

A large number of spectators from all over Germany and the Netherlands gathered to watch as crews detached the seven-meter wide, 33-meter high scaffolds and very slowly lowered them to the ground. To help the crane operator, a crew of guides was secured to the cathedral spires by ropes and climbing harnesses. In some places a mere 15 centimeters separated the scaffold from the cathedral. With delicate coordination between the crane operator and the guides, the scaffold was slowly and precisely moved and deftly deposited in front of the cathedral's main entrance without incident in a little over four hours. Molybdenum-containing high-strength steels played a crucial role in this timesaving drama. (RB)

The Cologne Cathedral's scaffolding is carefully lowered to the ground during its removal following restoration work. © Raimond Spekking/ CC BY-SA 3.0 (via Wikimedia Commons)

A new stainless steel lighthouse

Lighthouses have been beacons for thousands of years, aiding navigation and guiding mariners to safe shores. New Type 316 stainless steel lighthouses are now making their contribution to safety at sea, reducing maintenance and environmental impact.

Lighthouses over the ages

Lights have warned mariners of danger since humans took to the sea. The first lighthouses in the western world were probably built somewhere on the Mediterranean Sea some three thousand years ago. In the Greek myth Leander and Hero, Leander would swim every night across the Hellespont (today's Dardanelles) to meet his lover Hero, guided by a lamp in her tower. As in many stories of ill-fated mariners, a storm arose one night that extinguished Hero's light and Leander lost his way and drowned.

The Eagle Rock lighthouse is located on a wild shoreline, whose breakers have on occasion hurled rocks through the lantern's windows. © Gareth McCormack Photography

The first documented lighthouse was one of the ancient wonders of the world – the Pharos Lighthouse of Alexandria, built by Ptolemy I Soter after he announced himself king in 305 BCE. This huge lighthouse, thought to be 140 meters tall, existed until 1,303 CE when an earthquake destroyed it.

The British Isles experienced a "golden age of lighthouse building" during the 18th and 19th centuries. Hundreds of lighthouses were built to facilitate the rapid expansion of maritime commerce and military sea power driven by the Industrial Revolution. Despite this building frenzy, maritime disasters occurred routinely for many reasons including lack of adequate navigational aids. Lloyds of London estimated that between 1854 and 1879 over 50,000 wrecks were registered.

One of the "golden era" lighthouses was the Roancarrigmore lighthouse built in Ireland in 1847. The light is situated off the low-rising Bere Island, near the town of Castletownbere, and marks the eastern entrance to Berehaven Harbor. This is one of the world's largest natural harbors in Bantry Bay. A remote, unforgiving, but beautiful place, once used strategically by the British Navy, it is now a major fishing port and a harbor of refuge.

Although the Roancarrigmore lighthouse was updated in 1975 with a diesel generator and a sectored electric light flashing every three seconds, the Commissioners of Irish Lights (CIL) decided to replace it in 2011 after it had served reliably for 165 years.

Robert McCabe of CIL said: "Lighthouses are often seen by non mariners as historical or heritage curiosities with little functionality in today's modern world. This could not be further from the truth. Lighthouses have always been at the forefront of the technology of their day and the lighthouse in 2015 is no exception. The modern lighthouse uses energy efficient LED light sources powered by solar charged batteries and is often accompanied by radio aids to navigation such as Automatic Identification Systems (AIS), Radar Beacons (RACONS) or Differential GNSS (DGPS).

The availability of Global Navigation Satellite Services (GNSS) such as GPS, and others has revolutionized marine navigation and made a substantial impact on safety at sea. However, all GNSS services operate on similar frequencies and therefore suffer a common vulnerability to interference, jamming and spoofing. Space weather, local radio interference or intentional jamming can all result in GNSS denial on all systems over a large area. Alternative means of positioning provided by lighthouses such as buoys, beacons and radio aids to navigation are an essential complement and back up to GNSS. Visual aids to navigation are also important for spatial awareness and hazard marking and will be with us for many years to come."

A new lighthouse where stainless steel shines

In 2010 a CIL review of its aids to navigation reclassified Roancarrigmore as a minor light with range reduced to eleven nautical miles, enabling a unique and innovative new design solution that replaced the existing lighthouse with a smaller modern alternative.

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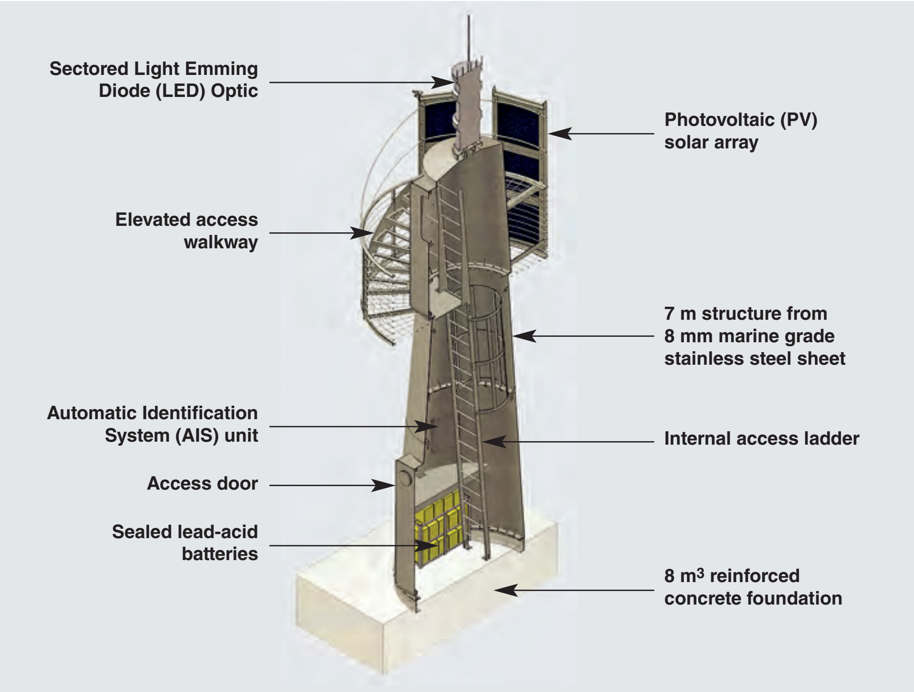
The original lighthouse comprised a stone tower with fully equipped residence, stores and engine room, all of which are expensive to operate and maintain. Requirements for the replacement were for it to generate its own energy, to exhibit its light at the required height while preventing excessive deflection of the optic, to minimise on-going maintenance, to provide basic facilities and shelter for visiting personnel, and to be consistent with the developing e-Navigation concept. The structure had to be strong enough to withstand the anticipated high winds, have sufficient corrosion and erosion resistance to withstand sea spray and any hurled rocks and debris, and be light enough to be lifted by helicopter to the site. The Board approved a final design in December 2010 that was simple, durable, inexpensive to maintain and cost-effective. The new lighthouse is a stand-alone Type 316L (EN 1.4404) stainless-steel structure, having an integrated and elevated photovoltaic solar array, internally located equipment and a flashing sectored LED light mounted on top. It includes an AIS transponder to provide for AIS and remote monitoring.

Due primarily to its higher strength and marine corrosion resistance, Type 316L stainless steel was chosen over aluminum, the only other material considered. The molybdenum content of Type 316L makes it the ideal choice because molybdenum provides high resistance to coastal corrosion. The alloy is also highly resistant to water and particulate erosion. The high-velocity wind and rain cleans the surface, reducing corrosive attack and lowering maintenance costs. The low carbon content of Type 316L makes it easily fabricated and welded.



Cross-section of the new Roancarrigmore lighthouse, showing the location of its internal and external components. © Commissioners of Irish Lights

Fabricating a shell section of the Roancarrigmore lighthouse tower. © Commissioners of Irish Lights

Tower construction

The tower stands on an 8 m^3 stainless-steel-reinforced concrete foundation built by pumping concrete from a mixer on a barge. Twenty-four No. 16 mm A4-70 Type 316 stainless-steel bolts secure the tower to its foundation. Natural circulation ventilates the structure to prevent gas build-up and reduce interior condensation. The tower is naturally lit for maintenance personnel and for building conditioning purposes.

CIL designed the new lighthouse and it was fabricated in three sections to CIL's specifications. The roughly conical main structure is 7 meters high, tapers from 2 meters diameter at its base to 1.2 meters at its top and weighs less than 4 tonnes. Bolted joints between sections incorporate internal rings to strengthen and stiffen the tower. The tower's internal volume provides storage for batteries, equipment and emergency supplies, and shelters personnel during day visits. Upper and lower doors, an internal ladder between floors, and a walkway at the top provide personnel access for maintenance. The walkway also serves to anchor the solar panel array used to generate electrical power.

The Tower's shell is made almost entirely from 8 mm-thick plate, rolled and welded into tapered circular hollow sections. Joints between the sections are sealed to prevent water entry. The internal elements, solar array structural components, balcony and walkways are also constructed from stainless steel. The tower has a matte finish to maximize its corrosion resistance, but it will assume a natural patina with the passage of time.

The tower's roof slopes upwards towards a ventilator and connection flange to which the pedestal for the optic is bolted. An air terminal, or lightning rod, connects to the structure itself and extends above the optics pedestal to become the tower's highest point. The tower is electrically bonded to the rock through ❯

The old Roancarrigmore lighthouse dwarfs the new tower of its replacement during construction. © Commissioners of Irish Lights its conductive concrete foundation, making it, in effect, a Faraday cage. Thus, in a lightning storm the safest place to be on the island is inside the tower.

Navigation aid fit-out

The new LED light is a three-tier sectored design that flashes once every five seconds and has a range of 11 miles white, 9 miles red. The low-voltage power system comprises twelve 50W, 12V solar panels that run the LEDs and charge sealed lead-acid batteries that provide power when the panels cannot. The system requires only an annual maintenance visit, and has significant environmental and cost benefits over the previous generators that burned almost 15,000 liters of diesel annually.

The AIS transponder does double duty, broadcasting its AtoN message and enabling remote monitoring of the facility. This mix of traditional and electronic systems is consistent with the e-Navigation concept that digitally integrates shore AtoN systems with on-board navigation equipment.

Installation

The tower structure was installed in November 2011. The sections were airlifted into place, lowered and oriented onto guides, and bolted to the previously installed section below after applying sealant. The installation, which required almost a year of planning, took the CIL less than three hours to complete.

The mechanical and electrical fit-out of the lighthouse continued for another three weeks, and the new light began to operate in February 2012.

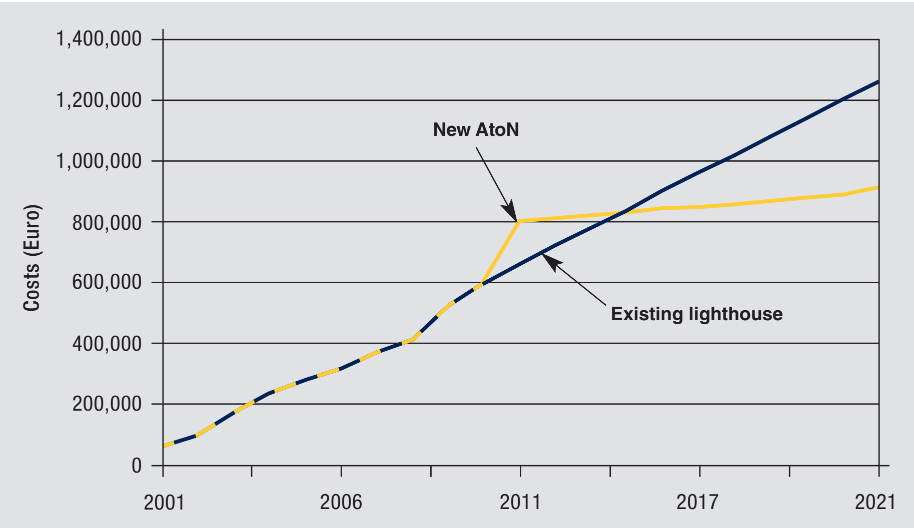
More stainless steel lighthouses

Certainly the most remote lighthouse, situated at the wildest location, is Ireland's Eagle Rock lighthouse, perched atop a 60-meter cliff off Black Rock, Sligo, in the far north of Ireland. This lighthouse is famous for withstanding Ireland's worst storms. In 1861, a storm mounted the cliff and broke the lantern's windows 67 meters above the mean ocean level. In 1894, waves flooded another tower that had been built at the site.

CIL built its second stainless steel AtoN at this storm-tossed site, replacing a 200-year-old lighthouse that had been modernized and automated in 1988. Sadly, the old tower's lantern room and domed roof had reached the end of their working life by that time. The dome, lantern room, large glass lens and mercury bath in which the lens rotated were all removed and replaced with a CIL-designed stainless-steel structure. The new light, which began to operate in November 2013, can be seen for 18 miles from the west with three white flashes every 20 seconds. Another stainless-steel light was installed at Mizzen Head in July of 2013, and plans for a fourth new stainless steel light for Glandore Harbor are complete.

These new lights are steps along a road that will move lighthouses from structures of nearly solid granite to a new molybdenum-containing stainless-steel design that will serve equally well for a hundred years. Their beacons will shine as long as there are mariners at sea. (CK)

The finished Roancarrigmore lighthouse, a new high-technology replacement for its venerable predecessor. © Commissioners of Irish Lights



Cumulative direct costs – existing lighthouse compared to the new aid to navigation (AtoN).
Source: Commissioners of Irish Lights

Acknowledgement:
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IMOA news

New brochure highlights molybdenum's green credentials

A new brochure exploring the contribution molybdenum makes to sustainable development was published in July. 'A Sustainable World with Molybdenum' showcases a range of sustainable applications made possible by its use.

The concept of sustainable development states that the earth's resources should provide for current needs while preserving the environment for future generations. Molybdenum plays a part in achieving this goal in a surprising number of applications spanning many different sectors.

The 28-page brochure brings together these different examples to make a compelling case for the importance of molybdenum's contribution to global sustainable development, including energy efficiency, low carbon generation, environmental protection and resource conservation. The final chapter demonstrates molybdenum's positive impacts on quality of life with a range of applications from medical imaging to desalination plants.

The brochure can be downloaded from the sustainability section of the IMOA website.

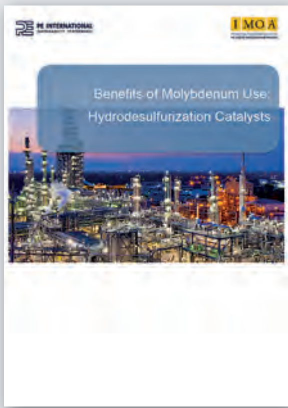
LCA case studies quantify environmental benefits

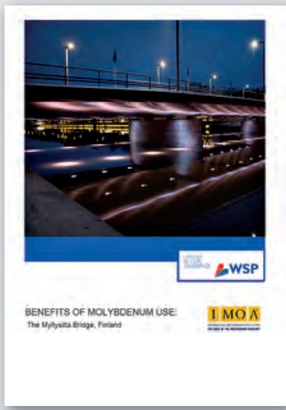
A further two Life Cycle Assessment (LCA) studies were published earlier this year, bringing the total number of case studies in the suite to eleven, three of which are LCA.

The first study compared the use of 2000 ppm diesel (the first EU emission level set in 1993) with today's ULSD containing just 10 ppm, made possible by the improved use of molybdenum-bearing catalysts. The study found that the use of hydrodesulfurization saved the annual emission of more than three quarters of a million tonnes of sulfur dioxide in the European Union, leading to sulfur dioxide emissions at least 100 times lower than 1993 levels.

The second study analyzed the use of molybdenum-containing duplex stainless steel in the construction of the Myllysilta Bridge in Finland. The study showed how the decision to use duplex stainless steel containing 3.1% molybdenum resulted in significant benefits across a range of environmental impacts, including a 62% reduction in global warming potential.

Both studies are available to download in the sustainability section of the website.





Online communications expanded to include social media

IMOA has established a presence on Twitter and LinkedIn to give stakeholders easier access to topical and relevant information. The feed for both pages contains IMOA news, events, and links to publications and research outcomes, all in one place and notified to you whenever a new item is uploaded. The pages also contain reposted content from other users and followers where this is likely to be of interest. Both pages have attracted a broad community of followers from across the mining, metals and related industries, so if you haven't already done so, why not follow IMOA at www.linkedin.com/ company/imoa on LinkedIn and at @IMOA_molybdenum on Twitter.