MOLYREVIEW
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INTERNATIONAL MOLYBDENUM ASSOCIATION
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Molybdenum challenges the seas

Photo: Rolex Fastnet Race – Rolex/Carlo Bolenghi

Molybdenum stainless steels can be found everywhere, even in the most exotic and exciting applications such as sailboats and racing yachts. Today's modern sailboat designs and advanced materials make sailing enjoyable and safe for many. Molybdenum stainless steels play an important role above and below deck, lending functionality, strength and aesthetic appeal.

Racing a twenty-ton yacht in a wild storm carries inherent risks. A collision or failed gear could be catastrophic. When lives are at stake, a yacht must meet the demands of both its owner and the elements. Molybdenum, as an alloying element in stainless steel, makes an important contribution to yacht integrity and safety.

The danger presented by the sea and the need for dependable equipment are not in question. There is ample evidence of the danger in the history of the Fastnet race, sailed off the southwest coast of England. In 1979, a terrible storm sank dozens of boats and took fifteen lives. Even with subsequent improvements in safety practices, boat design and sailing techniques, another fierce storm in 2007 caused three quarters of the 300-boat fleet to abandon the race, with some boats lost to the sea.

Thousands of yacht races take place around the world every year, and tens of thousands of people enjoy sailing's pleasures every day. At the elite end of the racing spectrum is the prestigious America's Cup race. This race is quite different as it is a competition between just two boats. It is so closely watched and supervised that there is little chance of crew members being lost at sea, but it still entails great danger to both sailor and yacht because the yachts sail at the extreme edge of design, materials, and human endurance.

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Mending the broken heart with a touch of moly

Stents play an important role in preventing heart attacks by avoiding arterial blockage. They have been made of Type 316 stainless steel, containing three percent molybdenum, from the beginning. New improved stents still rely on advanced molybdenum-bearing alloys.

How do you mend a broken heart? No, this is not a self-help article for the lovelorn. As life expectancy increases worldwide, heart disease, and specifically coronary heart disease, has become the leading cause of death, according to the World Health Organization, and one of the most difficult issues to solve in the medical field. While diet and healthy lifestyle choices are the best ways to prevent heart disease, great advances have been made in mending the human heart, with molybdenum playing a key role.

The working of the heart

The heart works hard – harder, perhaps, than any other muscle in the body. An adult heart pumps about 6,000–7,500 liters of blood every day, supplying oxygen and other nutrients to every other organ and muscle in the body. When the body is at rest, the heart pumps around 4 liters of blood every minute. When active – running or playing sports – the heart pumps 27 liters per minute. At less than 0.5% of the total body weight, it must feed 100% of the body to keep it going. It is no surprise that sometimes the heart needs a little help to accomplish this vital task.

When the heart breaks

Coronary heart disease is caused by blockages in the coronary arteries that deliver oxygenated-blood to the heart. These blockages reduce the heart's oxygen supply, making it unable to function at full strength. A heart attack occurs when the artery is completely blocked.

Fixing the heart

Angioplasty – In 1977, Dr. Andreas Gruentzig of Zurich, Switzerland introduced one of the first surgical interventions to tackle this problem. By carefully guiding a deflated balloon to the blocked artery and inflating it, he was able to push the blockage against the artery walls and increase blood flow in the artery. This proved to be a very beneficial first step in the treatment of coronary heart disease, but it did not always solve the problem completely. For a successful outcome, the artery must stay open after removing the balloon. However, often the artery walls, stretched by the balloon, are weakened and close again. The American Heart Association says that 40% of arteries opened with angioplasty alone, close within six months. Something more was needed, and molybdenum became a significant part of the solution.

Stent – Jacques Puel and Ulrich Sigwart of Toulouse, France demonstrated the stent in 1986. They were the first to insert a metal mesh tube, or stent, into a human coronary artery. A stent acts like a scaffold, ➔

Content

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Mo-containing stent alloys – chemical composition (wt %)

Common name	UNS Number	ASTM	Cr	Ni	Co	Pt	Mo	Fe
T316L	S31603	F138	18	14	–	–	2.5	65
T316 LVM	S31673	F138	18	14	–	–	2.9	64
Elgiloy®/Phynox®	R30003	F1058	20	15	40	–	7	16
MP35N®	R30035	F562	20	35	34	–	9.8	1
Pt-Cr Alloy			18	9	–	33	3	37

maintaining the artery's shape and allowing blood to flow through. Stents need to be both strong enough to hold the artery open after angioplasty and flexible enough to be threaded through the vascular system to the blocked artery without causing damage. Four very specific qualities are therefore required of the stent material:

- **bio-compatibility**, so the body will not reject the stent;
- **strength**, to allow a very thin and small stent that will not collapse;
- **corrosion resistance**, so the stent will not corrode or release particles into the body;
- **low production cost**, to allow more patients access to treatment.

Stents were in wide use by 1997. Early stents were made of 316L (UNS S31603) stainless steel, which contains up to 3% molybdenum. Angioplasty combined with stainless steel stent intervention boosted the procedure's success rate to 75% within a few years of its introduction. Moreover, the coronary stent has been the object of improvement and innovation that continues to this day.

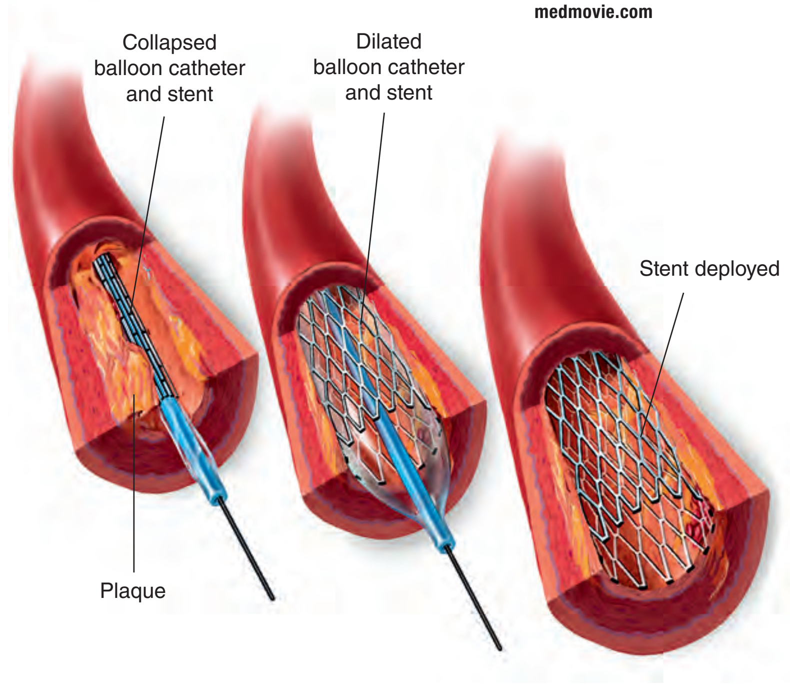
Continued progress with molybdenum

In recent years, stent manufacturers have focused on improving materials and methods of construction, and on incorporating beneficial pharmaceutical coatings on stent surfaces. Materials engineers have focused on increasing strength to reduce the wall thickness of the stent, ductility to minimize fractures, and X-ray visibility to improve the surgeon's ability to properly place the stent. These efforts continue to increase the success rate of surgical intervention.

The most significant developments have been in the use of alloys such as Elgiloy® (7% molybdenum) and MP35N® (10% molybdenum). These alloys meet the requirements for higher strength, retained ductility and improved X-ray visibility due to their higher density. The stent manufacturer can now make the stent smaller or of reduced wall thickness, which allows the stent to be inserted into smaller diameter arteries or deliver a higher flow of blood. These new stronger materials help to reduce the problem of restenosis, the reoccurrence of the blockage. Pt-Cr Alloy is a new, modified Type 316 where platinum replaces much of the iron. Platinum's greater density gives the stent better X-ray visibility.

Stent metal mesh foundation fabricated by micro-machining a precision tube. Photo: istockphoto-faslooff

Doctors are hopeful that these and expected further improvements in stents will reduce mortality rates and improve the quality of life for many millions of people. Such progress will alleviate the world's number one health problem with its many associated economic consequences. So, the hearts may ache if we are unlucky in love; but science, with the help of molybdenum, continues to keep them beating. (AS)



Inserting and deploying of a coronary stent. Illustration: medmovie.com

Continued from page 1

Molybdenum challenges the seas

The yacht mast is a truss structure utilizing a hollow central beam under compression and high strength cables under tension. Photo: Lewmar/Navtec USA

Materials in yacht design and construction

The modern sailing yacht exhibits an amazing degree of performance, dependability, and safety – the result of sophisticated fluid-mechanics and structural modeling in sail and hull design. Such advanced designs require high performance materials, among them molybdenum stainless steels. Yachts sailing in the first Fastnet race in 1925 were built in the traditional way with mahogany, pine, or cedar hulls planked over oak ribs, cotton sails and rope lines and masts from slender hollow spruce tubes. Even in 1925, rigging, the cables supporting the mast, might already have been made of molybdenum stainless steel.

The fiberglass hull, a significant materials development, came in the early fifties. Its low cost, versatility and easy maintenance made yachting accessible to nearly everyone. The extruded aluminium mast followed, another major improvement over wood, as it is lighter and stiffer, improving boat performance. Designers married these materials to stainless steel rigging and deck fittings, and the modern pleasure yacht was born.

Today's designer can choose from materials that provide a variety of strength, durability, cost, and aesthetic options. Many synthetic cloth materials are available for sails. Structural resins and carbon fiber composites are used for extreme-performance racing yachts that require high strength and low weight, and where cost is not a consideration. Whilst other metals are used just as they were 100 years ago, such as bronze on "classic" yachts, molybdenum stainless steels are now by far the most widely used. Type 316 (UNS S31600) with 2% molybdenum is the most common grade, but other grades are used when strength or weight is paramount.

Designing the yacht above deck

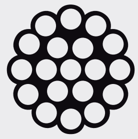
The most important of many above-deck applications are the rigging cables, or shrouds that support the mast. If the shroud fails, the mast fails and all is lost. The mast is essentially a long, slender beam prevented from buckling by triangular trusses, shown in the picture on the left. Thin rigid beams, known as spreaders, separate the shrouds to allow them to better support the mast. The shrouds are under tension, while the spreaders and mast are under compression. Forces on the mast shrouds and spreaders are very high in order to keep the mast perpendicular to the deck under high winds.

Type 316 stainless has been the accepted standard for rigging on yachts of all kinds for many years because it is strong and corrosion resistant. In choosing which shroud material and design to use, the designer must evaluate the options considering the boat type and size, and its anticipated sailing conditions. Shroud options include several Type 316 wire variants (including the number and shape of the wire strands), solid Nitronic 50® rod with 1.5% Mo, and Kevlar® or PBO® carbon fiber. Each has advantages and disadvantages described in the accompanying table. →

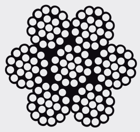
Comparison of shroud materials used for modern yachts (representative values for 12.7 mm (1/2 in.) diameter cable).

Characteristic	Type 316 7 x 19 wire	Type 316 1 x 19 wire	T316 Dyform®	Nitronic®50 rod	Fiber Kevlar®/PBO®
Breaking strength	9,147 kg	11,650 kg	15,240 kg	17,300 kg	17,300 kg
Inspect or replace	6 years	6 years	6 years	6 years	3 years
Stretch	good	good	very good	very good	best
Weight (kg/100 m)	60	80	85	100	35
Wind resistance	fair	good	very good	very good	best
Price	low	low	medium	high	very high

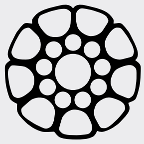
A plethora of deck fittings such as shroud turnbuckles and rail stanchions provide performance and safety for the modern yacht. Photo: Dale Kovach



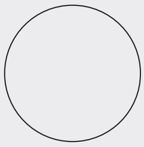
Type 316 – 1 x 19 construction
Provides an efficient combination of strength and cost. Standard configuration for shrouds on cruising and racing yachts.



Type 316 – 7 x 19 construction
Provides greater flexibility but lower strength for a given wire diameter. Useful for backstays and other applications requiring flexibility.



Dynform® special shape wire
Provides more strength and less stretch than equivalent diameter 1 x 19 wire producing a stiffer rig with less wind resistance.

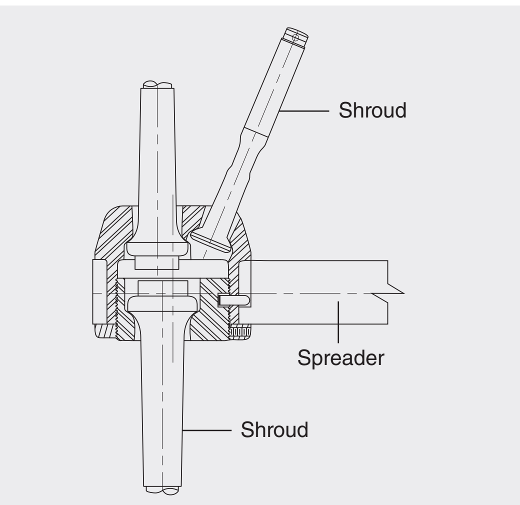


Nitronic® 50 solid rod and bar
Provides maximum strength for a given wire size thus allowing the smallest wire size and least wind resistance.

A variety of shroud cable designs are available offering various performance and cost options. Source: American Rigging Supply, Inc.

Shroud material is not the only design choice, but must be considered as part of a system along with the mast and all of its components. Shipbuilders have many decisions to make, such as mast height, number of spreaders and the appropriate end fittings for the system. End fittings can be very complex, as the illustration shows. They must be strong and hard to minimize galling and fatigue of the shroud connector/spreader joint. A high-strength stainless steel such as Nitronic 50® meets the necessary criteria and is often used.

After completing many design iterations that consider all fittings and attachments to mast and deck, usually with the assistance of computer models, the designer chooses a final rig design. For most applications, ranging from simple day-sailing boats to serious offshore-cruising yachts, the choice for shrouds is 1 x 19-strand Type 316 stainless steel wire. When racing is important, special shaped wire is specified to reduce wind resistance. Solid rod or bar is a higher-cost, higher-performance solution. Nitronic 50® may be specified for even higher performance at increased cost. Carbon fiber gives very good performance, but its short life and high cost limit its application to racing yachts where cost is not a barrier.



Spreader end fitting. Source: American Rigging Supply, Inc.

Designing a yacht on and below deck

There are a variety of fittings required to manage a sailing yacht below the rig. Molybdenum stainless steel is also well represented in this area. A good example is the deck winch used to trim the sails. Even a small sail demands great power to trim it, so the winch must always function, especially during emergencies. Type 316 may be fabricated easily into a winch body in a variety of pleasing finishes, while the shaft and crank may be manufactured from a stronger alloy like 2205 (UNS S31803) duplex stainless steel containing 3% moly. Other examples for stainless steel fittings are clamps, fasteners, cleats, grab rails, hand rails, the pulpit and the swimming ladder.

We can find Type 316 and 2205 stainless steel even at the very bottom of the boat in the vital bolts that fasten the heavy lead keel to the hull. Failure here would be as much a disaster as a rigging failure. From top to bottom, molybdenum stainless steel is essential to the performance and safety of the modern racing yacht. ➔

Sailing to the future

Sailors are an optimistic lot, always looking for the morning to bring sunny weather and a fair breeze that will bring them a win in the next race. One of the smallest, least expensive, and most successful racing sailboats is the Laser™, with over 250,000 built, and sailed worldwide. The boat is only about 4 meters long and does not even require shrouds to support its mast, but stainless steel is aboard from the bow handle to the bracket and hinge supporting its rudder.

The yacht that wins the Fastnet race next year will likely be at least ten times the length of a Laser™ and certainly will carry molybdenum stainless steel in many shapes and forms. The next America's Cup race will match two of the largest and most expensive racing yachts ever built – AV 72 class catamarans having two hulls and wing-type sails. These craft are on the cutting edge of many technologies; they seem more like airplanes than boats. They will also sport their share of molybdenum stainless steel components.

The Laser™ might reach speeds over ten knots when planning down a wave. The America's Cup AC 72 will exceed 40 knots, making it the fastest sailboat ever built. Whilst boat and yacht are very different, both will deliver an exciting ride for their crew, who can be sure that the molybdenum stainless components are doing their part in ensuring a safe, fair sail and a good fast race. (CK)

Yacht CARRANA rounding Fastnet Rock – Daniel Foster. Photo: Rolex Fastnet Race – Rolex/Carlo Bolenghi

Molybdenum: the next semiconductor material?

Molybdenum has long played a role in the development of the electronics industry. It was used to make support wires and grids in the first vacuum tubes and was later employed in the heat sinks that keep chips and integrated circuits cool. A research team has now demonstrated the potential of molybdenum as a semiconductor.

Readers of MolyReview are well acquainted with how molybdenum in its many forms enhances the performance of other materials. It strengthens and toughens carbon steels; it enhances the corrosion resistance of stainless steel; it makes lubricants more effective and able to withstand severe loads and temperatures; it enhances the speed and efficiency of chemical reactions; and it is an integral part of electric power, photovoltaic, flat-panel display and LED lighting technologies. Recent innovative work at the Ecole Polytechnique Fédérale de Lausanne (EPFL) in Switzerland may herald the start of an entirely new application for molybdenum as a semiconductor material that has the potential to revolutionize electronic devices.

All of the myriad electronic gadgets, machines and appliances that have become part of our everyday lives contain integrated circuits, or "chips." At the heart of the integrated circuit is a transistor, which is used to amplify and switch electrical signals. Transistors are very small; a single chip may contain as many as a million transistors. The transistor is made from a material known as a semiconductor, so called because its electrical conductivity lies between that of a conductor and an insulator. By creative processing and circuit design, a semiconductor can be put into conductive or insulating states, which represent the "0" and "1" of the binary number system. This property is fundamental to our modern computers. →

A perpetual goal of the electronics industry is to develop ever more speedy and powerful integrated circuits, to make faster, more efficient computers, cell phones or tablets, which have become so integral to our everyday lives. Smaller, more efficient devices consume less material and consume less energy, thus reducing their impact on the environment.

The computing power of the integrated circuit depends on the number of transistors it contains. The conventional semiconductor material used today is silicon. Integrated circuit manufacturers have so far been able to double the number of transistors on a silicon chip about every two years, in accordance with "Moore's Law" which predicted the trend in 1965. However, there is only so much space available on a chip and barriers to further increases in miniaturization and speed must eventually arise due to the laws of physics.

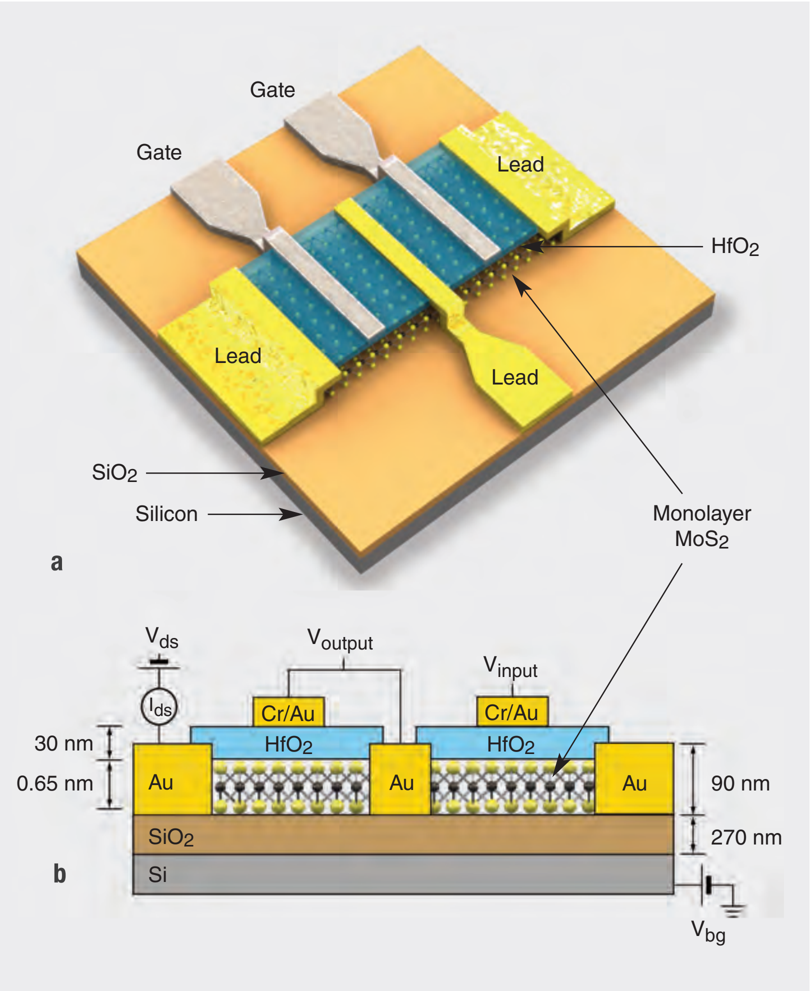
Materials scientists are developing alternative semiconductor materials all over the world. Most work focuses on graphene, a single-layer form of carbon atoms arranged in a hexagonal array. However, Professor Andras Kis of EPFL's Laboratory of Nanoscale Electronics and Structures (LANES) has focused instead on molybdenite, MoS_2. Like graphene, molybdenite can be produced as a single layer. Molybdenite's layered atomic structure helps to provide excellent lubrication under severe conditions in mechanical applications. In the context of integrated circuits however, its electronic properties are most important.

In single-layer form, molybdenite becomes a true semiconductor, just like silicon. However, silicon cannot be manufactured into usable film as thin as molybdenite. This means that it could be possible to make chips three times smaller using molybdenum instead of silicon. Graphene has yet to be produced as a semiconductor, and to create a graphene device that behaves appropriately requires additional costly processing.

Professor Kis' group has produced a small integrated circuit using molybdenite and demonstrated the ability to manufacture such a device[1]. They estimate that molybdenite transistors would reduce standby power demand by a factor of 100,000 compared to current silicon-based technology. This could mean much longer battery life for electronic devices or much reduced battery size, leading to smaller devices.

The diagram shows how this device was constructed. The 0.65nm-thick molybdenite layer (a nanometer is one billionth of a meter) is about 100,000th the diameter of a human hair, or just a little under a third of the thinnest silicon layer that is possible today! This thin layer enables many more transistors to be stacked on top of one another in an integrated circuit, further increasing the transistor density and keeping integrated circuit technology on the path of Moore's Law.

Professor Kis points out other characteristics of molybdenite that make it an attractive choice for a variety of devices. "It can be bent to large angles and can be stretched a lot," he said. This means that it could be used to manufacture computers that could be rolled up or devices that could be affixed to the skin. Molybdenum has great potential as a future semiconductor but at the moment it is still only a promising understudy to silicon and it may be many years before it could be considered a commercial rival. Even so, this research illustrates the unique combination of properties that make it a useful material in a wide range of technologies. (JS)



Schematic of an integrated circuit based on single-layer MoS_2.
(a) A monolayer of MoS_2 is deposited on top of a SiO_2-coated Si chip.
(b) The integrated circuit comprises two transistors defined by a neighboring pair of leads and controlled by local gates with HfO_2 as a gate dielectric.
Source: Ecole Polytechnique Fédérale de Lausanne

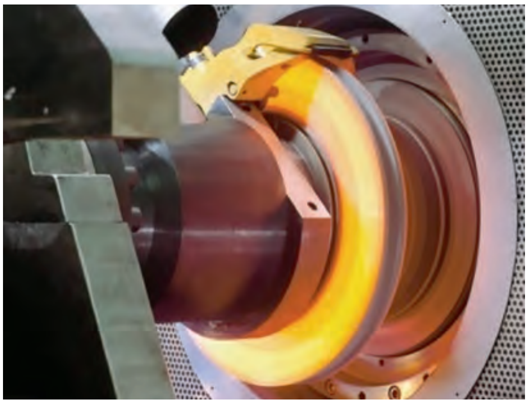
1 Branimir Radisavljevic, Michael Brian Whitwick, and Andras Kis, "Integrated Circuits and Logic Operations Based on Single-Layer MoS_2," *ACS Nano*, 2011, 5 (12), pp 9934–9938.

Brakes with moly take the heat

Molybdenum plays an important role as an alloying element in the grey cast iron used for disc brakes in automobiles. These alloys are highly specialized, and they provide long, quiet, and dependable performance.

It is easy to take brake discs, or rotors, for granted because they are so reliable – we notice them only when we have to pay for replacements. Most drivers don't realize they are finely tuned, sophisticated components. Fixed between the wheel, hub and axle, these quiet, reliable, grey cast iron workhorses help to slow and stop our cars every time we brake.

Braking systems are complex in design and have changed dramatically over the years. The disc brake was a major advance when it first appeared in motorsports during the 1960s. Gradually, disc brakes replaced drum brakes because they virtually eliminated the fade, distortion, accelerated wear, and noise characteristic of the latter. Today, most automobiles are equipped with disc brakes on all wheels; drum brakes are seen only occasionally, and then only at the rear.



Brake disc on test stand simulating heat cycle.

Disc brakes operate by creating friction between the brake pad and the disc. The resulting torque is transferred to the wheel hub on which the disc is mounted, then through the rim and tire to the road. In this way, braking converts the vehicle's kinetic energy into heat on the tire, brake disc and pad surfaces.

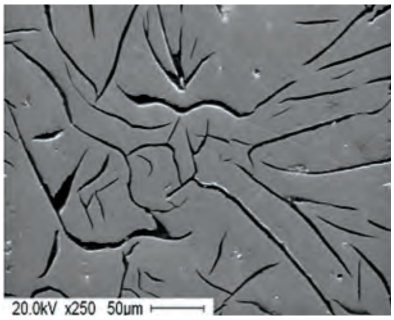
The heat generated is not distributed uniformly – 90% of it ends up in the disc. The pads heat up very little because they are poor conductors, and tire heating is negligible. The discs alone cannot transfer this heat to the surrounding air quickly, so front-wheel discs are frequently ventilated to enhance cooling. Rotation helps to ventilate the disc by moving the hot air radially outwards, but heat is always a threat, especially under severe braking conditions. For example, frequent braking can heat discs to a red-hot 700°C when going downhill.

Besides heat, discs must also withstand a variety of stresses, like those generated by centrifugal and braking forces, and the thermal stresses resulting from the temperature differences within the disc during braking. Thus, strength at high temperature is very important for the disc material.

Meeting these demands is pearlitic grey cast iron – an iron alloy with primary additions of carbon and silicon and alloying elements like molybdenum, chromium, niobium, and vanadium which help form hard, wear-resistant carbides; these carbides increase both strength and resistance to heat.

It's about the graphite

Looking at a polished sample of pearlitic grey iron through a microscope, one can see worm-shaped features dispersed in a matrix. These features are graphite and they play a vital role. The graphite phase is interconnected in three dimensions, so it removes heat efficiently from the contact area and distributes it to the cooler regions of the disc, where it is transferred to the surrounding air. Graphite also dampens vibration, preventing brake squeal. Molybdenum alloying increases the amount of graphite in the material compared to a molybdenum-free alloy, thereby improving its ability to move heat from the friction track formed between disc and brake pad.



Graphite flakes in pearlite matrix.

Pearlite microstructure.

Graphite and more, thanks to moly

Graphite is soft and weak and cannot support high loads. The matrix around the graphite, a mixture of alternating thin plates of iron and iron carbide called pearlite, provides grey iron's strength. Unlike graphite, pearlite is very hard and tough, so it prevents the disc from disintegrating under braking stresses. Molybdenum is commonly added to these irons in amounts of 0.35 to 0.55% to produce a stronger, fully pearlitic matrix. Molybdenum hardens the ferrite phase and refines the pearlite structure, both of which increase strength. It also improves →

the alloy's high temperature strength and increases its stiffness. Molybdenum's multiple benefits produce a superior alloy to meet carmakers' demands.

Summing up moly and brakes

People want brakes that stop smoothly without any irritating noise, and that operate reliably whenever required. Both microstructural constituents in a grey iron disc help to accomplish those goals: graphite conducts heat and dampens vibrations; pearlite provides the strength to keep the disc together under the stresses of braking. Molybdenum enhances the function of both graphite and pearlite, and provides strength of its own – meaning we can all breathe a little easier next time we press the pedal. (HM)

San Diego's new harbor bridge sails onto the skyline

Increasingly, iconic man-made structures near the ocean are being designed from stainless steels containing molybdenum. The city of San Diego's spectacular new pedestrian bridge linking Balboa Park and San Diego Bay is a striking example of that trend. The bridge is the world's second longest pedestrian bridge using stainless steel as a primary structural material.

The city of San Diego, situated in southern California and looking out on the Pacific Ocean, is often cited as one of the world's most livable and beautiful cities, considering the Sierra Nevada Mountains to the east, the beautiful, peaceful ocean to the west, and its semi-tropical climate. Its nautical heritage goes back over 400 years when the Spanish sailed north along the coast to explore and establish missions. The city's beautiful harbor remains very popular with sailors, and it has hosted the America's Cup and other races attracting cutting-edge yachts from around the world. A new soaring bridge, with its unique sail shape inspired by the city's history, is a fitting addition to the harbor.

Designed to last at least a century, San Diego's striking new $26.8-million Harbor Drive Pedestrian Bridge officially opened in March 2011. This landmark structure fulfills the city's 100-year vision of linking the two important regional destinations, Balboa Park and San Diego Bay. It provides pedestrians and bicyclists with a safe elevated means of crossing busy Harbor Drive and the adjoining train and trolley tracks. It also creates a new southern gateway to the downtown area.

The bridge

At 168 meters, this dramatic innovative project is one of the longest self-anchored suspension bridges in the world, and the world's second-longest pedestrian bridge with stainless steel as a primary structural element. The design by Safdie Rabines Architects and structural engineers T.Y. Lin international (TYLi) was the clear community favorite in the selection competition because of its dramatic appearance, cost, suitability for the site, and its transparent profile.

With a main span of 108 meters, the graceful, single-cable self-anchored suspension bridge features a 40-meter tall pylon that is dramatically inclined at a 60º angle over the bridge deck. The elegant streamlined design is very different from traditional suspension bridges, which have very visible bulky suspender and main cables. The smooth, uninterrupted lines of this bridge were created using an innovative design that hides the large main cable.

The 34 suspender cables connect directly from the inside edge of the curved deck to the top of the pylon. The main tension cable is hidden inside the welded 20cm diameter stainless steel pipe above the deck's handrails. This pipe transfers the longitudinal forces of the high-tension cable inside it into the deck and the compression of the pipe by the cable provides a secondary structural support, which increases the load carrying efficiency of the design.

Alternating custom-fabricated stainless steel plate railing posts either support the concrete deck or transfer radial force from the top of the railing to the deck. This balances the forces placed on the deck to prevent torsion. ➔

The bridge mimics a sailboat leaning over to one side before the wind. Photo: Fred Kaplan Photography

The bridge's unique structural design is most easily seen at deck level. Photo: Fred Kaplan Photography

Material of construction – stainless steel
The bridge designers chose stainless steel rather than traditional painted steel for the primary structural supports because of the bridge's close proximity to San Diego Bay's harbor. Several factors went into the stainless steel alloy selection. Since this is an important landmark, corrosion-free performance was expected. Minimal maintenance would be performed and there are local conditions, like regular salt fog and infrequent heavy rain, that made more corrosion-resistant stainless steels necessary. The carbon steel main cable is protected from corrosion inside the welded pipe.

Additionally, the structural loading requirements for the welded pipe and plate railing structure made full use of 2205's greater strength. These factors made 2205 (UNS S31803) duplex stainless steel, containing 3% Mo, the logical choice to support the bridge deck.

The cable support system is composed of 317LMN (UNS S31726) austenitic stainless steel containing 4% Mo, with 2205 duplex connectors. Together with the stainless steel handrails, cables and aircraft cable mesh for the safety screening, the bridge uses moly-containing stainless steel from the deck to the top of the pylon.

A satisfying/successful landmark project
The vision for the Harbor Drive Pedestrian Overcrossing incorporated simple, clean lines that provide unobstructed 360-degree views of San Diego. Pedestrians strolling over the beautiful structure immediately appreciate the bridge's elegant design, but taxpayers will also benefit from its cost-effective, long-lasting, low-maintenance materials and finishes. (CH)

Catalyst project completed – success!

Two years ago, a consortium including IMOA offered funding for research that could lead to new molybdenum applications. The winning project, to develop improved catalysts using molybdenum, was awarded to the University of Michigan. Catalytic compounds based on molybdenum carbides and nitrides were successfully developed and showed potential in chemical processes that produce hydrogen and valuable hydrocarbons. As a result, a patent application has been filed with a view to further development and ultimately, commercialization.

MolyReview readers will remember that the January 2010 issue featured an article describing the initiation of a research project on molybdenum catalyst development. The project resulted from a joint effort by IMOA, CIMAT and COMOTECH[1] to stimulate research involving molybdenum which would lead to market growth. It was selected from over 100 proposals received by the consortium. Professor Levi Thompson led the winning team at the University of Michigan.

A catalyst, in the world of chemistry and engineering, is a material (chemical, molecule or atom) that accelerates a chemical reaction. Molybdenum and molybdenum compounds are already widely used as catalysts in a number of processes. The project goal was to create Mo carbide and Mo nitride compounds, which might have good catalytic properties on their own, and/or as supports for other metal catalysts. The project, now complete, yielded some very encouraging results.

Creating the catalyst
The experimental method utilized molybdenum oxide starting materials which were exposed to carbon or nitrogen containing gases at high temperature. ➔

The desired compounds were the carbides and nitrides, Mo_2C and Mo_2N. Proprietary chemical and thermal procedures were required to produce not only the desired compound, but also compounds with the high surface areas required to improve catalyst efficiency.

Other catalysts were created by supporting the carbide or nitride on alumina, a thermally and structurally stable material, to make Mo_2C/Al_2O_3. Alternative metal catalysts, such as platinum, were then deposited from the appropriate solution onto the support to make, for example, Pt-Mo_2C/Al_2O_3. Gold, iridium and copper were also tested.

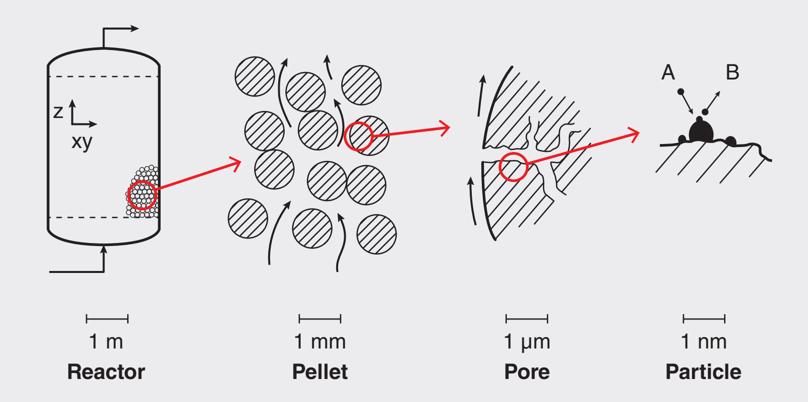
Catalyst evaluation

The project evaluated catalyst effectiveness against well-known, existing catalysts, and evaluated their structural characteristics to build even better catalysts. The evaluations were conducted by measuring conversion rates to desirable products in two very important commercial chemical processes. These were the Fischer-Tropsch Synthesis (FTS) and "water gas shift" (WGS) processes. The processes are used to produce valuable hydrogen and liquid hydrocarbons from inexpensive and abundant starting stocks: water and carbon monoxide. The basic evaluation procedure was to pass the WGS or FTS feed stock gases over the catalysts at various temperatures and then measure the conversion to the desirable end product. Many experiments were run under a variety of environmental test conditions and with various catalyst configurations.

A variety of very sophisticated laboratory instruments and techniques were used for characterization, including X-ray diffraction and high resolution transmission electron microscopy. The characterization included catalyst particle site density estimation, chemical composition, size, shape and atomic structure.

Results

The results were very positive. The Mo_2C and Mo_2N supported catalysts were highly active for the WGS reaction with rates that were superior to those for the commercial benchmark catalyst. Rates were also good for the FTS reaction, but selectivity toward the more valuable hydrocarbon end products was less favorable. A particularly interesting result was the discovery of strong interactions between many of the supported metal and Mo_2C or Mo_2N surfaces. This leads to the formation of metallic, raft-shaped particles on the Mo-based support with very high surface area to volume ratios. By depositing expensive catalytic metals such as platinum on Mo-based surfaces, it may therefore be possible to either reduce the amount of platinum needed, or to further improve the efficiency of the catalyst.



Heterogeneous catalysts, a closer look at various scales: The pellets in the reactor mostly consist of inert catalyst support material with a very large surface area. The active catalyst particles are finely distributed on the pore surfaces of the catalyst support to maximize the surface on which the chemical reactions take place. Substance A turns into substance B through contact with the catalyst particle. [2]

Next steps

The results are of sufficient merit that a patent application has been filed. The next steps will be to introduce the results to industry through technical publications and to overcome the hurdles of scale-up and economic viability. Commercialization may be some way off, but this project, conducted by a group of young scientists and engineers, proves the enduring versatility of molybdenum and suggests that the growing list of applications for this remarkable element is not yet complete. (CK)

1 CIMAT is the Centro para la Investigación Interdisciplinaria Avanzada en Ciencias de los Materiales (Center for Advanced Interdisciplinary Research in Materials Sciences) at the University of Chile in Santiago and COMOTECH S.A. is a Chilean company created by Codelco, Molymet and the University of Chile to promote and support developments of new Molybdenum products and applications.

2 Illustration redrawn after L. D. Schmidt, *The Engineering of Chemical Reactions*, 2nd ed., Oxford, New York, 1998; Page 278 in Chapter 7.

Platinum usually has a globular shape on regular catalyst support (left). On Mo_2C support it spreads more thinly (raft-shaped) so that less of the expensive platinum is needed for the same active surface area.

IMOA News

Molybdenum and sustainability

Molybdenum makes an important contribution to sustainable development as a metal, as an alloying element, and as a constituent of chemical products. A new section on the IMOA website, entitled 'MoRE FOR LESS', highlights the many ways in which molybdenum benefits modern society, the environment and the economy. It explains how the unique properties of molybdenum can and are being used to deliver sustainable advantages in energy production, efficiency, resource conservation and environmental protection. A 'moly in action' section uses three icons – Ecology, Economy and Society – to signpost which of these elements of sustainability apply to real-life examples of molybdenum use.

Sustainable Development presentation given at MEE 2012 Conference

IMOA Secretary General, Tim Outteridge, gave a presentation on molybdenum's contribution to sustainable development to the 'Metals for Energy and the Environment' conference in Las Vegas in June 2012. Entitled 'Molybdenum, Sustainability and the Environment', it was an important opportunity to raise awareness amongst the producers, traders, recyclers, end users and officials who attended.

80% of all stainless steel is recycled at end-of-life. Photo: Nickel Institute

The presentation began with a description of molybdenum and some of its key properties. The challenges to sustainable development arising from global energy demand, industrialization and urbanization were outlined before explaining how the key attributes of moly are used in the development of sustainable practices and technologies.

The presentation highlighted a number of ways in which molybdenum makes a contribution to energy efficiency: in stainless steel sunscreens and building facades, which reduce or eliminate the need for air conditioning; in high-strength steels which 'lightweight' cars and vans, cutting their fuel consumption; and in vehicle engines and power stations which run more efficiently at the higher temperatures enabled by moly-containing alloys.

Next, the role of moly in renewable energy technologies was addressed. In hydroelectric installations, high-strength steel containing moly is used to enable greater water pressure for increased efficiency. In the case of wind energy, most of the powertrain in wind turbines is constructed from moly alloyed engineering steel for durability. In solar energy, moly plays a key role in new thin film photovoltaic cells due to its high electrical conductivity and resistance to high temperature chemical corrosion.

Turning to environmental protection, the presentation highlighted the role of molybdenum in catalysts which are used to produce ultra-low sulfur gasoline and diesel. Moly also increases the corrosion resistance of stainless steels and nickel base alloys in flue gas desulfurization scrubbers at coal-fired power stations. These technologies both help to reduce acid rain in the environment.

Lastly, the presentation outlined the role moly plays in the conservation of resources. Molybdenum's high corrosion resistance prolongs the design life of stainless steel and other corrosion resistant alloys, saving resources. High-strength steels are used to reduce weight in construction projects, saving raw materials and energy. The presentation can be downloaded at:
http://www.imoa.info/media_centre/presentations.php

100 Years of Stainless Steel

During 2012, the International Stainless Steel Forum (ISSF) and members of the Team Stainless network, including IMOA, are celebrating a century since stainless steel was first discovered and commercialized. To mark the occasion, a travelling exhibition had its grand opening in Beijing, China during ISSF's 16th Annual Conference in May.

The exhibition covers the history of the stainless steel industry, the many applications for stainless steel, its alloying elements and its recycling and environmental footprint. A dedicated website provides further information on the centenary and future locations of the exhibition, which can be found at www.stainlesssteelcentenary.info/events.