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# Wearing moly gets trendy

In pockets, on noses, wrists and ears, even at the end of a dog lead, molybdenum-containing alloys are part of modern life. This article describes their use in objects designed to entertain, connect, inform, alert, identify, or simply make us stand out!

These days, almost everywhere you look, people can be seen with heads down, hands tapping or held to their ears, moving like zombies, talking to invisible beings, some sporting improbable metal accessories pierced through their skin. These scenes incorporate all sorts of portable, useful or decorative, simple or ultra-sophisticated products, often made of alloys in which molybdenum plays an essential role.

## Eyeglasses – robust customizable frames

Eyeglasses are an ideal application for Type 316L stainless steel containing 2–3% molybdenum because it is a tough, corrosion resistant, and hypoallergenic material. Thanks to these characteristics it is used in eyeglass frames, bridges, hinges, and temples. It is easy to manufacture by stamping, a process which avoids welding. It also offers improved mechanical strength compared to other methods, and produces a wide range of shapes and styles.



Stainless steel hinges, bridges and temples offer a wide choice of shapes and styles with high mechanical strength. © Bliss-Eye

## Smartphones, cameras and camcorders – intensive handling

The smartphone must meet demanding specifications for performance, ergonomics, ruggedness, and aesthetics in a small package. Constant use subjects these devices to acids and alkalines contained in skin oils, salty perspiration and both indoor and outdoor atmospheres. They must survive collisions and shocks when they are mishandled or dropped. Their high

visibility requires that they retain their immaculate appearance through all of these travails. As a result, 316L stainless steel is a material of choice for smartphone inner and outer frames. Aesthetics are important to fashion design, so the many surface finishes available on stainless steels make them even more attractive.

Manufacturers of other products also appreciate these stainless attributes. Some smartphone cases and many



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### Cover photo:

Southern Manhattan Island, New York City is one of the world's most important financial centers. Rebuilding post September 11 and new development are leading to a high concentration of stainless steel clad buildings.  
© Outokumpu



The modern human carries molybdenum around every day, mostly in the form of stainless steel, be it in watches, jewelry or electronics. © iStockphoto/LaraBelova

#### **Type 316L passed the transit drop shock test for smartphones**

Recently, a Korean smartphone model was certified compliant with the MIL-STD-810G Method 516.6, Procedure IV Transit Drop shock test, thanks to its molded Type 316L stainless steel case. It survived 26 successive drops from 1.22 meters (4 feet) onto concrete with no deformation or damage on the surface or edges!

portable USB battery chargers have a 316L frame that protects them against premature failure due to wear and tear. For still and video cameras where the competition among plastic, aluminum and stainless steel is ongoing, 316L has an advantage for camera bodies because it has the highest shock and dent resistance.

Other materials are frequently used in these applications. However, the fragility of plastics, the high cost of carbon-fiber composites, and the softness of aluminum make them somewhat less attractive. Often, molybdenum-containing stainless steel is simply the best choice!

#### **Headphones, headsets, earphones and microphones – easy wear and better sound quality**

Headphones, headsets, earphones and microphones allow people to listen to their “tunes” without bothering others and use their phones wherever they go. Molybdenum-containing stainless steel is an important contributor to all of these devices.



High-end headsets use stainless steel wire mesh for excellent sound rendition. © Sennheiser

Headset headbands can be equipped with a flexible, ultra-light Type 316 wire frame covered with foam and enclosed in a removable colored plastic sheath for durability and comfort. In high-end over-the-ear headsets, 316L stainless steel wire mesh reduces acoustic noise from the environment and permits exceptional sound rendition. The one-piece frame of an integrated earphone-microphone unit, equipped with removable plastic covers for access to inner components, can be formed from 316L. A 316L mesh effectively protects the membrane of a handheld microphone from oral spray and provides better resistance to corrosion than alternative materials. An ultrafine (0.1 mm diam.) mesh provides the same protection for a simple earpiece, a microphone connected to an earpiece, or a wireless lapel microphone.

#### **Body piercings – beautiful, hypoallergenic and hygienic**

Humans have worn jewelry for at least 35,000 years. Jewelry is meant to decorate, ascribe power and status, attract attention, and beautify and personalize the wearer. The long-established practice of body piercing has become more

popular in recent years. The fashion industry now offers a wide assortment of studs, rings and other items that pierce the ears, nose, mouth, and other areas of the body. They are produced in a plethora of materials, designs and shapes using a variety of processes. The constant intimate contact of these accessories with the skin or mucous membrane, and the near-surgical act necessary to insert them, creates a significant risk of infection. Thus, these materials must be corrosion resistant, hypoallergenic, sturdy and require a minimal need for maintenance and care.

The molybdenum containing “surgical implant stainless steels” (Types 316, 316L) provide an excellent cost-effective solution to the potential problem of allergic reactions and dermatitis. The inert chromium oxide surface layer on these alloys protects the skin against such reactions. Molybdenum improves localized corrosion resistance, minimizing the release of potential allergens. Other metals (e.g. gold, titanium) can serve as well; however, not only are they expensive,



“Surgical” Type 316 stainless steel is the preferred material for body piercing jewelry.  
© iStockphoto/Kolidzei

but they themselves have occasionally been associated with skin problems. Stainless steels with lower chromium content and without molybdenum should be avoided in these applications because they have a higher probability of causing allergic reactions.

### Watches – ruggedness, elegance and accuracy

Watches are utilitarian and individual objects that may be among the best examples of the combination of metallurgical, mechanical and digital technologies with artistic creativity. From their simplest models to limited-series timepieces, watchmakers use 316 and 316L stainless steels to protect their creations from corrosion and the shocks of daily life.

Hardness, corrosion resistance and hypoallergenic properties are all important factors in selecting materials for watches. Stainless steels provide these characteristics and more. They are suitable for a wide range of manufacturing processes and many different surface finishes can be applied (e.g. gloss, satin, brushed, guilloché, engraved, to name a few). The most common applications are wristbands and cases. High-end watches employ molybdenum-containing specialty alloys for certain parts to avoid

### Molybdenum for wearables

Application	Use	Grades	Benefits
Smartphones	Frames, inner frames, cases	316, 316L (2.00–3.00% Mo)	Corrosion resistance, ruggedness, deformation resistance, aesthetics
Cameras	Bodies		
Headphones, headsets, ear-phones, microphones	Head bands, microphones, ear-phones, ultra-thin noise-cancelling mesh, frames		
Watches	Bracelets, cases, springs, pinions, fasteners	316, 316L	Hardness, corrosion resistance, ruggedness, elegance, machinability, non-magnetic
		440C (<0.75% Mo)	Hardness, ruggedness, less expensive than other corrosion-resistant grades
		904L (4.00–5.00 Mo)	Highly corrosion resistant to chemicals and hydrocarbons
	Springs	SPRON®510 (~10% Mo), SPRON®610	High elasticity, superior resistance to rotating bending fatigue, non-magnetic
Body piercings		316L	Corrosion resistant, hypoallergenic, strong, surgical quality
		316LVM (Low Carbon Vacuum Melt)	Greatly reduced inclusion count allows finer polished finishes and improved resistance to pitting corrosion



Luxury watch cases and bands are often made of Type 316L stainless steel. © Patek Philippe

the effects of magnetic fields on their accuracy. Components close to the crown, where moisture may ingress, are also usually made of 316L stainless steel. Additionally, this grade is especially valued for its superior machinability and cold formability. Cold-formed, work-hardened material is used for internal parts that require a high hardness for wear- and deformation-resistance.

#### Molybdenum guarantees accuracy

The metallic components of a high-precision watch must be protected against magnetic fields that can reduce its accuracy. Molybdenum additions up to 10% play a key role in the very high-strength, non-magnetic cobalt-based Co-Ni-Mo-Fe SPRON® type alloys (see table) found in components such as springs. Molybdenum enhances the alloy's strength and corrosion resistance while preserving its nonmagnetic character. The watch's spring accumulates energy either from manual winding in mechanical watches or from wrist movements in automatic watches, and drives the hands via gearing. The most sophisticated springs can store energy for up to 72 hours without additional winding. Molybdenum-containing alloys are also present in precision parts like pinions, fasteners, and winding stems where hardness is essential.

While Type 440C stainless steel (0.75% max. Mo) is less commonly used in watches, it is still appreciated for its hardness. It is less resistant to seawater and more easily magnetizable than 316 or 316L, but it offers a much less expensive alternative and is often used for inexpensive luxury watch reproductions.

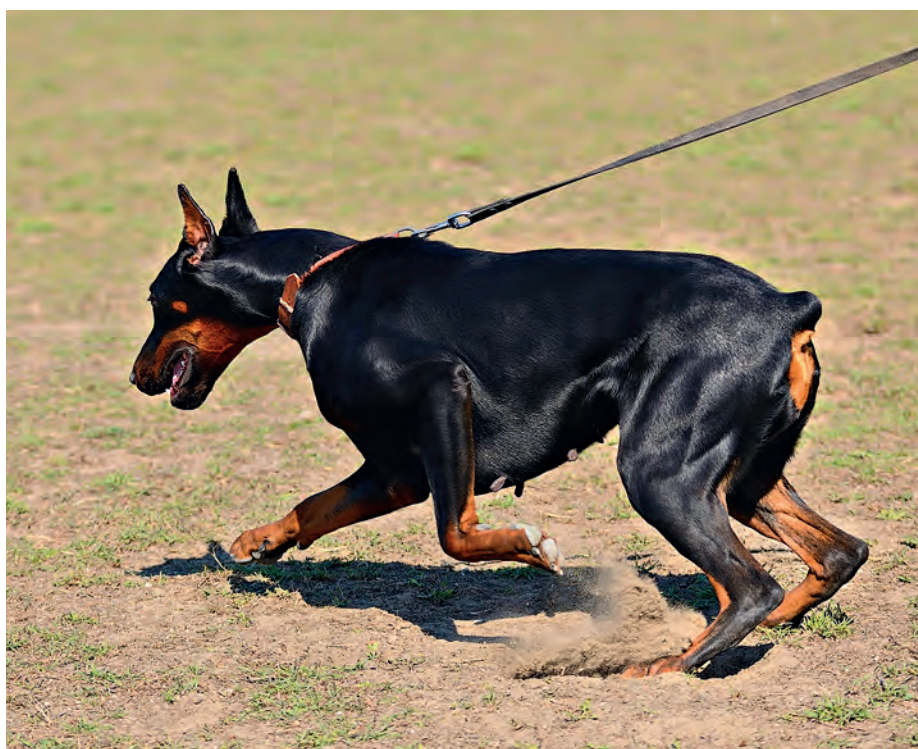
Molybdenum-containing materials have even become design features that are emphasized by marketers. Apple, for example, highlights in its advertisement the use of 316L stainless steel in the

breakthrough Apple Watch®. And Rolex heavily promotes the excellent corrosion resistance of its divers' watches thanks to 904L (4.5% Mo) stainless steel cases and bands. This grade is a highly corrosion-resistant stainless steel commonly found in marine applications and in industrial process equipment.

#### Animal accessories – rugged and corrosion resistant

Even when it comes to pets, stainless steel is essential. Metal collars and identity tags are exposed to the environment and the ring to which the leash is attached has to be strong when Fido suddenly spots a cat. In some cases the collars are a fashion statement and stainless steel contributes to the beautiful design. Like humans, pets can suffer from allergic reactions and need protection. A wide range of accessories is available for them as well as their masters and 316L stainless steel makes up the lion's share!

Molybdenum stainless steels and special alloys are found in the things we wear and carry, no matter whether they are utilitarian or beautiful or both. That is because these materials keep their attractive finish, do not cause allergic reactions and keep sensitive electronic devices safe from damage. They can add beauty and increase longevity and safety to these objects. Molybdenum is an important component in these materials, allowing designers and manufacturers to let their imaginations run free for ever more alluring and useful creations. (TP)



Type 316L stainless steel is strong and durable - necessary to restrain some dogs... © Fotolia/Stieber

# New horizons for London's tigers

**ZSL London Zoo is often noted for its architecture as well as its animals. A revolutionary new enclosure, built from molybdenum-containing stainless steel mesh, maintains the Zoo's proud tradition of innovation. It creates a bespoke environment for Sumatran tigers, meeting all the big cats' needs.**

The Zoo is one of the world's oldest. Founded in 1828 for scientific study, it was eventually opened to the public in 1847. Run by the Zoological Society of London (ZSL), it is part of a charity devoted to the worldwide conservation of animals and their habitats. It currently houses over 700 species.

Many leading architects have contributed to the built environment at the Zoo. Berthold Lubetkin, as an example, designed the world-famous penguin pool. Over the years, the emphasis has shifted from architectural masterpieces to innovative designs which put animal welfare and conservation first. ZSL is firmly committed to creating the best environment for its animals, while giving the public the chance to experience some of the world's most endangered species at close quarters.

This was the brief for the architects commissioned to design 'Tiger Territory', a new £3.6m enclosure for the zoo's Sumatran tigers. Five times the size of the previous compound, the new exhibit was designed with ZSL's team of tiger keepers, conservationists and experts to ensure that it perfectly matched the needs of these magnificent creatures.

## Combining strength with transparency

One of the most important requirements was that the roof of the enclosure covering the 2,500 square meters of exterior habitat be transparent. Tigers in the wild like to observe their terrain from a high vantage point with uninterrupted views to the horizon. Working with structural engineers and specialist subcontractors, the design team was able to realise a concept

incorporating a ground-breaking, virtually transparent 'roof' made from an ultra-strong and super-lightweight material – woven Type 316 stainless steel mesh. The 'roof' reaches 17 meters high in places to accommodate the tall trees and feeding poles, set at a height to encourage natural climbing behaviours.

Sophisticated computer modelling made it possible to provide the required strength while minimizing the dimension of the stainless steel wire and maximizing the mesh size. The resulting product was manufactured from Type 316 stainless steel wires just 3 millimeter in diameter with remarkably large holes. The combination of thin wires and an open gauge results in a mesh that is nearly transparent, yet is immensely strong.

The 'roof' was created by stitching together large pieces of mesh with the same 3 millimeter diameter wire to cover the entire enclosure, held in tension by poles which are anchored in the ground. In some areas, the mesh attaches to viewing galleries where floor-to-ceiling glass windows allow visitors to come face to face with the tigers.

Unlike a standard square mesh, this mesh is able to stretch horizontally and vertically due to its rhombus-shaped weave. The mesh is therefore able to 'drape' around the enclosure and the support poles, creating a flowing organic shape, which fits with the natural environment below.

## A lasting home for conservation

Thanks to the high strength and ductility of the stainless steel wire, the mesh is capable of withstanding both the full impact of a tiger (an average size animal

can exert some 500 kilograms per square centimeter) and the effects of a 1-in-100 year London winter, including the loading weight of significant snowfall. The 2% molybdenum addition in Type 316 stainless steel greatly increases its corrosion resistance, helping to protect it from the effects of city centre pollution for the length of its design life.

Opened in 2013, Tiger Territory is now the central hub for ZSL's tiger conservation work, providing the perfect environment for their specialists to learn more about these elusive animals and apply that learning to conservation projects in the field. Both the European Endangered Species Breeding Programme and the Global Species Management Programme for Sumatran tigers are coordinated from ZSL London Zoo.

It seems that the tigers' new home is conducive to breeding this critically endangered species, with a trio of cubs – Nakal, Budi and Cinta – born to parents Jae Jae and Melati in February 2014. With Sumatran tiger numbers estimated to be as low as 300 in the wild, this was a huge achievement for ZSL London Zoo and the global breeding programs. A further two cubs – as yet unnamed – were born in June 2016.

Molybdenum is found in a surprising number of applications around the world, many of which make a contribution to sustainable development. By playing a part in creating an optimal breeding environment for these tigers, this enclosure is one more example of how molybdenum's unique properties are being harnessed to contribute to a more sustainable future for the planet. (AH)



The superstrong mesh is virtually transparent, allowing tigers to survey their territory all the way to the horizon as they would do in the wild. © ZSL London Zoo

# Stainless steel sparkles in NYC

The iconic New York City skyline is celebrated in movies and photos. But as a global financial, cultural and business center, it is also constantly changing – particularly now. Buildings are rising at a breathtaking pace and many feature sustainable designs. Molybdenum-containing stainless steel is often key to making them not only beautiful, but also resilient and durable, thus reducing their carbon footprint.

Already home to many architectural tourist destinations, the City's list of notable stainless steel projects is expanding rapidly. Residential construction was 65% higher in 2015 than during the previous boom in 2008. The spending on other construction sectors is also substantial, putting NYC in the midst of the largest private construction boom in its history.



Type 316 diamonds sparkle on the new International Gem Tower. © Catherine Houska

## Sustainability drives change

Sustainability is an important design factor in new construction projects as well as in major renovations. New York City has one of the densest concentrations of buildings in the world. There are almost one million in an area of about 800 square kilometers and their operation accounts for about 70% of the City's energy consumption. In 2009, New York became the first US city to mandate monitoring and reduction of building energy use. It has consistently ranked in first place for the number of US Green Building Council (USGBC) LEED<sup>1</sup> certified projects. The Mayor's office has encouraged building code changes, which are focused on reducing carbon footprint and water conservation.

Being coastal and largely built on islands, both the city government and its residents are aware of the potential adverse impact of climate change, particularly after the flooding and damage caused by Hurricane Sandy. This encouraged new initiatives for improving building and infrastructure resiliency in NYC. Now both public and private decision makers expect sustainable and resilient design in new construction and renovation projects.

## Longevity a necessity

Truly sustainable construction requires exterior materials capable of withstanding New York's corrosive environment, because repeated material replacement or major maintenance is expensive

and dramatically increases a building's carbon footprint. The city and the surrounding area are exposed to both coastal and deicing salt. To make things worse, the use of deicing salt has increased and the products employed are increasingly corrosive. So, it must be assumed that all buildings in the city will have some salt exposure with the highest deposits at the lower building levels.

In the first city that used stainless steel in substantial quantities for high profile buildings – the Chrysler and Empire State are now both USGBC LEED® Gold for Existing Buildings – the material's inherent durability and timeless beauty are well known. However, the Type 302 and 304 stainless steels used on many older buildings are not sufficiently corrosion resistant for the current environment. These alloys require regular maintenance cleaning; even then, staining may occur between cleaning intervals.<sup>2</sup>

## Durable stainless construction

For these reasons, molybdenum-containing Type 316L has become the preferred stainless steel for exterior uses, whether the application is a new façade or anchoring masonry during renovation (as in the Empire State and Chrysler Buildings). In the most aggressive applications, where higher corrosion resistance is required, 2205 duplex stainless steel and other more corrosion resistant alloys are increasingly used.



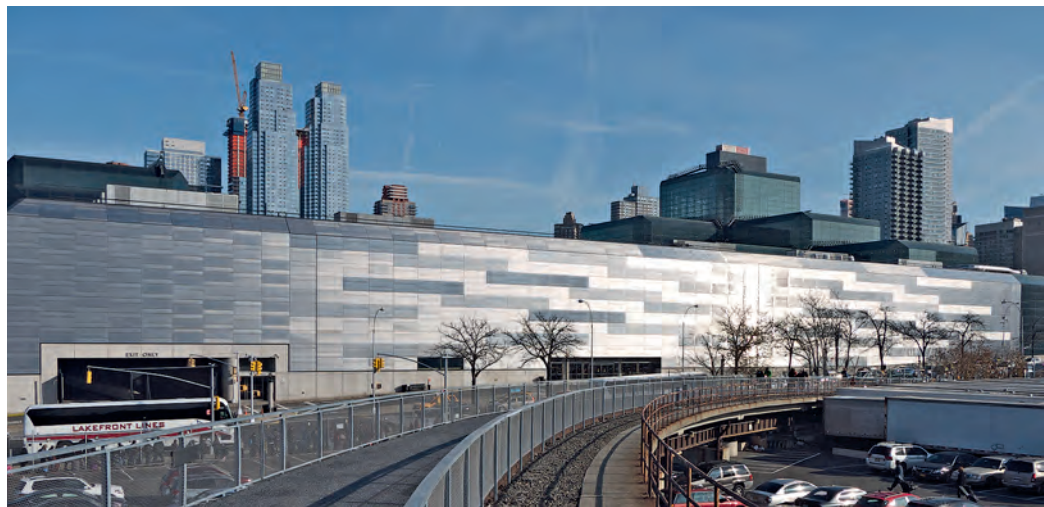
<sup>1</sup> Leadership in Energy and Environmental Design

<sup>2</sup> The highest floors of very tall buildings like the Chrysler and Empire State are well washed during storms with wind levels that approximate power washing. However, lower levels are not uniformly washed and deicing salt deposits can be found at quite high levels on some buildings.

The table below lists some notable recent and current projects with façade and other visible Type 316L stainless steel exterior applications.

### Residential leads the way

Some of the residential buildings use relatively small amounts of stainless steel as jewelry-like design accents. The Jahn-designed 50 West Street, which is nearing completion, uses Type 316L to accent remarkable curved glass panels. A mirror polished Anish Kapoor “mercury drop”-like sculpture will appear to support the new residential ➤



Three different Type 316 finishes add visual interest to Javitz Convention Center. © Nicole Kinsman

Some recent and current Type 316/316L projects by primary application

Building	Year	Architect	Application	Finish	Metric tons
Primarily residential					
245 10 <sup>th</sup> Ave	2010	Della Valle Bernheimer	Façade	Embossed <sup>7</sup>	
HL23	2011	Neil M Denari Architects	Façade	Embossed <sup>7</sup>	
New York by Gehry at 8 Spruce Street	2011	Gehry Partners	Façade	Vibration	270
Via (625 West 57 <sup>th</sup> St)	2016	BIG/SLCE	Façade, structural	Invarimat <sup>9</sup>	196
50 West Street <sup>2</sup>	2016	Jahn	Façade	Scotch brite™ <sup>10</sup>	35
56 Leonard	2016	Anish Kapoor	Sculpture	Mirror	40
Primarily office					
7 World Trade Center	2006	SOM	Façade, grating	Embossed <sup>5</sup>	
Goldman Sachs World Headquarters <sup>1</sup>	2010	PCF	Façade	2M Linen <sup>4</sup>	430
250 West 55 <sup>th</sup> St <sup>1</sup>	2013	SOM	Façade	Raindrop <sup>8</sup>	127
International Gem Tower	2013	SOM	Façade	Starlight <sup>8</sup>	132
1 World Trade Center <sup>1</sup>	2014	SOM	Accent panels, structural, spire	2M Laser <sup>4</sup>	>181
7 Bryant Park <sup>1</sup>	2015	PCF	Façade	2M Linen <sup>4</sup>	120
3 World Trade Center <sup>1</sup>	2018	RSHP	Façade	2M Linen <sup>4</sup>	550
Other building types					
National September 11 Memorial Museum Entry pavilion	2011	SNØHETTA	Façade	#3 & #4 with glass bead <sup>7</sup>	64
Jacob K. Javits Convention Center <sup>3</sup>	2013	FXFowle/Epstein Global	Façade	No. 4 and 2 FL <sup>6</sup> and 6 ON <sup>6</sup>	118.2

1 USGBC Gold LEED  
2 Applied for USGBC LEED Gold  
3 USGBC LEED Silver

4 Outokumpu  
5 Rimex  
6 Rigidized Metals

7 Zahner  
8 Tsukiboshi Art  
9 Contrarian Metal Resources (CMR)

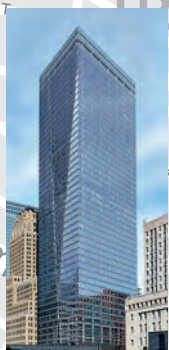
10 Scotch Brite is a registered trademark of 3M



56 Leonard Street



Goldman Sachs World Headquarters



7 World Trade Center



New York by Gehry at 8 Spruce Street



1 World Trade Center



50 West Street



National September 11 Memorial Museum entry pavilion



3 World Trade Center (2018)



Whitehall Ferry station

Stainless steel reconstruction and redevelopment in Southern Manhattan Island New York.

skyscraper by Herzog & de Meuron at 56 Leonard Street. When completed, SHoP's twin American Copper Buildings will have a three-story glass and stainless steel clad bridge suspended 91 meters (300 feet) off the ground. It will be joining the copper-clad buildings creating a design focal point, while emphasizing the beauty of combining natural uncoated metals.

The other high-profile residential buildings on the list use Type 316L stainless steel as a key design element and range from small intimate buildings adjoining the Highline to very large projects. VIA 57 WEST (625 West 57<sup>th</sup> St) is the first building designed by the Danish Architecture firm BIG – Bjarke Ingels Group in North America. It has been shortlisted for the 2016 World Architecture Festival Awards in the Completed Buildings – Housing category. The 709 unit building faces the Hudson River and is nearing completion. Its developer carefully vetted the materials and all aspects of construction with consideration of their impact on the environment. Type 316L stainless steel was selected for both the façade and the custom structural sections that will support the cleaning system. This choice was based on the building's combined coastal and deicing salt exposure adjoining the Joe DiMaggio Highway.

### A glimmering new skyline

The International Gem Tower and 7 Bryant Park are captivating new office buildings, but the largest concentration of stainless steel façades will be around the World Trade Center. As can be seen on the map, Type 316L will visually connect a large concentration of buildings with diverse design styles while making them more sustainable and resilient. They range in size from the small elegant National September 11 Memorial Museum entry pavilion to One World Trade Center, which opened in 2014 and is the tallest building in the Western Hemisphere. Duplex stainless steel was used as a structural design element in the sweeping form of the Calatrava World Trade Center

Transportation Hub and Type 316 was used extensively in the station.

Other high profile residential and office projects featuring stainless steel are under development, including 30 Hudson Yards and Central Park Tower, which will become the tallest building in the Western Hemisphere by roof height in 2019.

Type 316 stainless steel also welcomes visitors to Manhattan Island. It is most visible at Whitehall Ferry station, which was completed in 2005, and on the exterior of the newly-renovated Jacob K. Javits Convention Center. It is an obvious choice for other categories of buildings designed for longevity like the new David H. Koch Center for Cancer Care, museum entrances, municipal service and educational buildings. The new notable projects list is not exhaustive and there are many smaller and existing projects within the city that illustrate the durable beauty of molybdenum-containing stainless steel. (CH)



7 Bryant Park's elegant exterior features Type 316 stainless steel. © Outokumpu



The innovative VIA 57 WEST was designed to be the world's most sustainable residential building. © Contrarian Metal Resources/Gabby Pignanelli

# Molypermalloy sends clear signals

One of the most important innovations in communications history occurred when telegraph cable designers incorporated loops of wire wound around iron cores into their cables. This “simple” innovation evolved into inductors wound around Molypermalloy Powder cores, which are omnipresent in electronic devices on earth and in space.

The Law of Unintended Consequences states that: “actions sometimes produce unexpected outcomes.” While the “law” is usually cited for unexpected negative outcomes, it also applies to unexpected positive outcomes. A good example is the invention and development of the loading coil for electronic circuits. The loading coil owes its existence to a mathematical analysis aimed at understanding why telegraph signals became unintelligible after traveling long distances. Years of research and development in communications theory, circuit design and materials science drove the evolution of loading coils. One result was Molypermalloy Powder (MPP) cores for the coils. Today MPP cores play irreplaceable roles in myriad devices in automobiles, trains, wristwatches, cell phones, computers, and electronic-equipment chargers.

## The Queen illustrates the problem

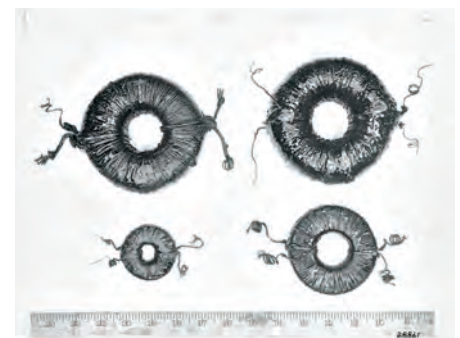
The first successful (and short-lived) transatlantic telegraph cable began operation in 1858. Soon after its commissioning, the UK’s Queen Victoria used it to send US President James Buchanan a 98-word message that took 16 hours to complete. The long transmission time was necessary because the cable distorted the signal when the telegrapher sent more than a few words per hour.

## Heaviside paves the way

When the telephone came on the scene in the mid to late 1800s, communication cables had to carry a spectrum of frequencies instead of just the telegraph’s “dahs” and “dits”. This made transmission fidelity even more important. In 1887,

English electrical genius Oliver Heaviside developed a mathematical expression known as the “Heaviside Condition”. He showed how to greatly increase the clarity of messages transmitted over long cables by coiling each wire pair in the cable around a circular magnetic core at regular intervals. This innovation eliminated time delays and distortions in the signal, permitting much higher transmission rates. The loading coil (so named because the coil “loaded” the circuit with inductance) was born!

In 1899 AT&T engineer George Campbell tested his own mathematical analysis of loading coils. He demonstrated that a telephone transmission line loaded with coils could transmit clear voice signals twice as far as unloaded telephone transmission lines. This led to considerable cost savings over the iron-clad copper wire technology of the day. Around the same time, Columbia University professor Mihajlo (Michael) Pupin received a patent for a similar concept in priority to Campbell’s application. As a result, loading coils became known as “Pupin coils”, and adding coils to transmission

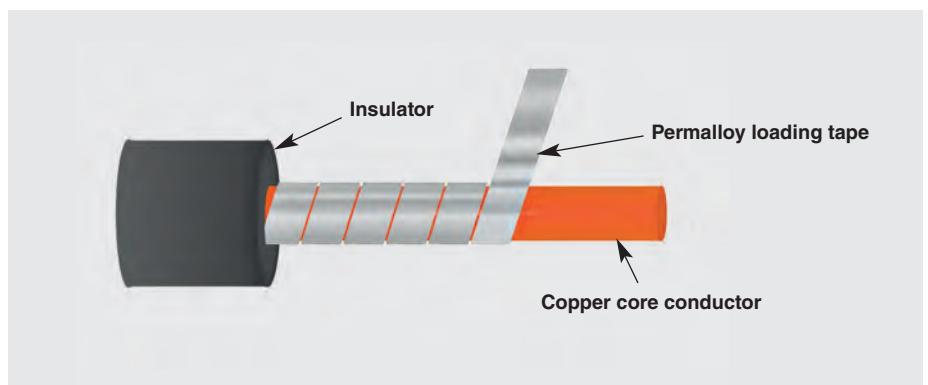


Loading Coils from 1900 (upper right) to 1927 (lower left). © AT&T Archives and History Center CC BY-NC-SA 3.0 ([www.ethw.org/Telephone\\_Transmission](http://www.ethw.org/Telephone_Transmission))

lines was called “Pupinizing” the lines. Ironically, Campbell lost the patent priority battle because he waited to file until after completing his experiments. Pupin himself had neither built coils nor demonstrated the concept as Campbell did.

## Permalloy cable

Other people were also working on improving transmission quality at that ➤



Permalloy-wrapped cable for undersea telecommunications. © SpinningSpark CC BY-SA 3.0 (<https://en.wikipedia.org/wiki/permalloy>)

time. Danish engineer Carl Emil Krarup had the idea to wrap copper cable wire tightly with iron wire (inventing the “Krarup cable”) in order to meet the Heaviside condition. Unfortunately, his design still required loading coils in long transmission lines. AT&T therefore searched for a material with higher magnetic permeability than iron. In 1914, Gustav Elmen discovered Permalloy, a magnetic 80% Ni - 20% Fe alloy. Around 1915, Elman and Bell Laboratories scientists Oliver E. Buckley and H. D. Arnold greatly improved the transmission speed of wrapped submarine cable.

The design was tested in Bermuda in 1923, and the first Permalloy-wrapped telegraph cable was placed in service connecting New York City and Horta (Azores) in 1924. Permalloy wrapping increased the cable's transmission speed from 40 to 400 words per minute.

### Molypermalloy and the MPP core

During the early 20<sup>th</sup> century, loading coils found new applications in power supplies and filters to eliminate current spikes and circuit noise. Designers soon needed new magnetic core materials to optimize the coils' properties for specific applications.

In the 1940s, researchers discovered that adding 2% molybdenum to Permalloy yielded a material with the lowest signal losses available at the time. Over the years it evolved to include alloy variants with as much as 5% Mo. Coils with cores made from “Molypermalloy Powder” (MPP) were higher quality, smaller, lighter, and more tolerant of temperature extremes than coils made with unmodified Permalloy. MPP set the standard for high-quality powder cores, a standard that stands today.

MPP cores have several advantages: They have high stability and high electrical resistance. They have low magnetic hysteresis (i.e. they demagnetize readily when the magnetic field changes), thereby minimizing heating and energy loss. They strongly resist current fluctuations after magnetization, especially when

exposed to high currents. They excel in high-precision applications that must operate under a wide temperature range with minimal loss in properties. They can store large amounts of energy, making them ideal for applications such as chokes that block higher-frequency AC currents in DC circuits and power inductors that maintain a steady current in a circuit that experiences voltage or current fluctuations.

Today MPP is made by both the traditional ingot casting/hot rolling/grinding/screening process and by powder atomization. Cores are compacted from MPP using high pressure. They are then annealed, covered with insulation, and wound with wire to form finished coils. MPP cores are produced in many shapes and sizes dictated by the requirements of specific applications. Toroidal (donut-shaped) cores are the most common; they are available with outside diameters that range from only a few mm to over 160 mm.

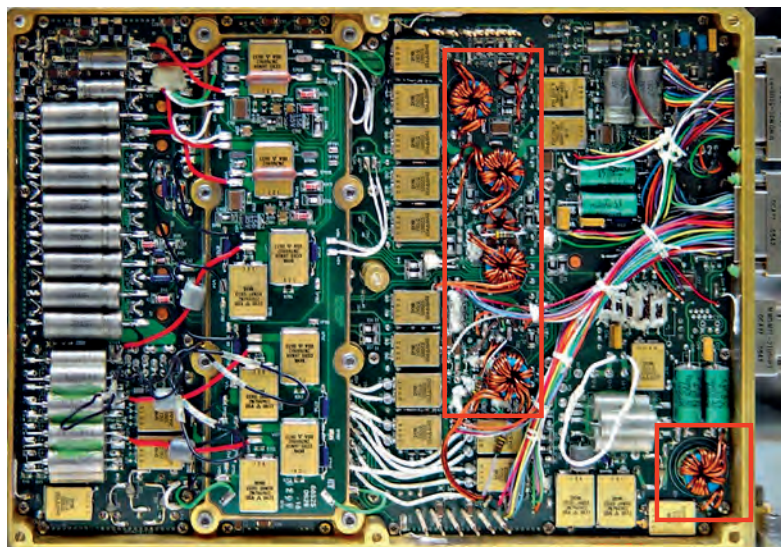
The versatility of coils with MPP cores justifies their higher price; they are found in microelectronic components, inductors, power supplies, transformers and electronic filters. They serve industrial, aerospace, commercial, governmental,

and renewable energy/green technology markets.

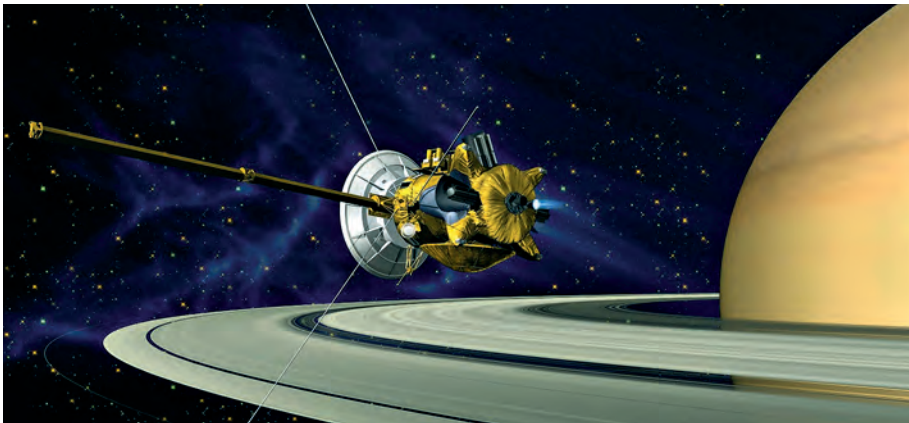
### MPP cores in space

Filters with toroidal cores played an important role in the early stages of space exploration, and still do today. MPP cores replaced much heavier cores in satellite and rocket communications components, reducing both size and weight. These reductions translated to increases in payload capacity and significant cost savings. MPP cores reduced the total core weight in one vehicle from 2.1 kilogram to 0.009 kilogram with an attendant increase in fidelity of communications and data transmission. One early telemetry system employed 23 filters and auxiliary equipment weighing a total of 94 kilogram. Similar equipment using sub-miniature and micro-miniature components, some with MPP cores, reduced the system weight by 99.7% to 315 grams.

Today, NASA engineers trust the well-established reliability and stability of MPP cores for designs that have traveled throughout the solar system. MPP cores have been used on over 40 missions, including those to Jupiter, Saturn and Mars.



Bottom view of the 275 watt power converter developed by Battel Engineering for the SAM instrument on the Mars Curiosity rover. The converter has 15 isolated power outputs for operating the three scientific sensors comprising the instrument. Seven of the seventeen MPP cores used in the power supply are visible on the right half of the picture (boxed). © Battel Engineering



A rendering of the Cassini-Huygens spacecraft as it flies by Saturn.  
© NASA/JPL-Caltech/Space Science Institute

## A spacecraft with superhuman senses!

In one of the most ambitious missions yet to deep space, the NASA/ESA/Italian Space Agency consortium launched the Cassini-Huygens spacecraft in October of 1997. The probe travelled more than 1.6 billion kilometers over a six-year period to study Saturn. Its array of powerful instruments continues to beam accurate scientific data and detailed images to scientists on earth today. The following are two examples of the instrumentation on Cassini.

The Composite Infrared Spectrometer (CIRS) plays a major data-gathering role in the mission. CIRS incorporates MPP cores into the complex electronics of instrumentation that measures Saturn's infrared energy, thermal structure, and composition. The spectrometer performs the same functions for Saturn's moons and rings.

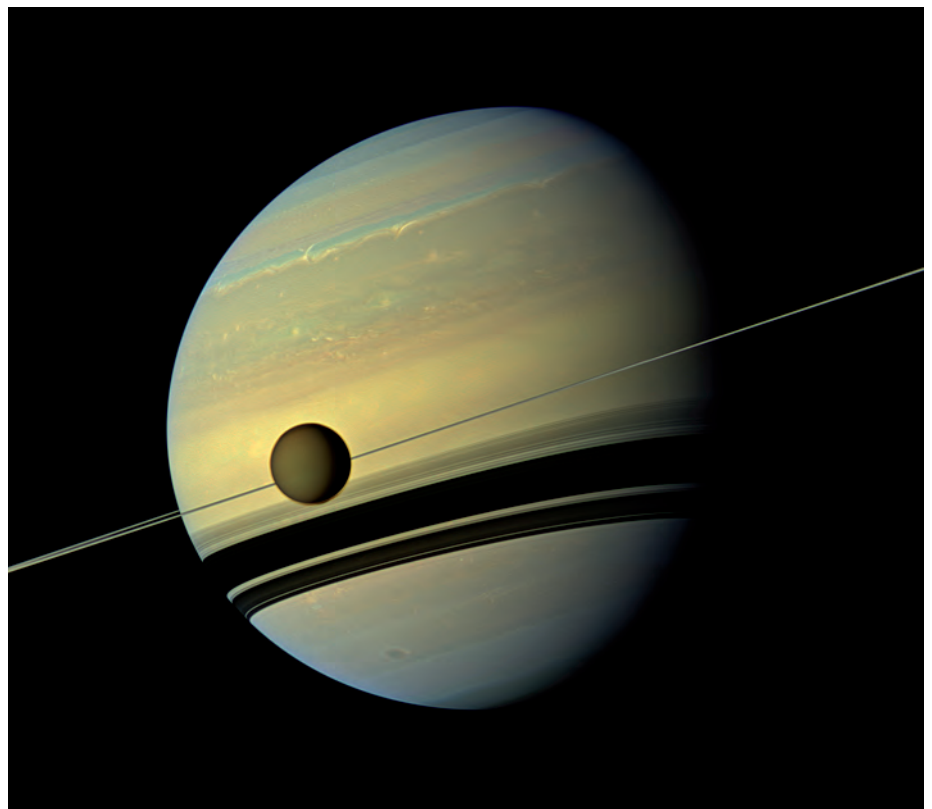
Components with MPP cores also help to power NASA's Ion and Neutral Mass Spectrometer (INMS). INMS measures the density and composition of neutral and ionized gases in the atmospheres of the bodies it passes near. It was built to study the atmospheric composition and structure of Saturn's moon Titan, Titan's atmosphere interaction with Saturn's magnetosphere plasma, and the neutral and plasma environment of Saturn's rings and icy moons. It has already returned groundbreaking information about both

Titan and Saturn's icy moon Enceladus. Scientists hope that the INMS will identify molecular hydrogen present in plumes of Enceladus, which are 90% water vapor. With Cassini's mission extended to 2017, multiple fly-bys of both Titan and Enceladus will occur and even more data will stream back to Earth.

Consortium scientists are now analyzing Cassini's trove of data. So much data is available that many more years will pass before they finish their work. If molecular hydrogen and other complex organic molecules are identified, it might mean life is present on a neighboring planet!

It is a testament to the creativity and perseverance of generations of engineers and technologists that a discovery intended to enhance the quality of telegraph and telephone cable transmissions has helped to take humankind to the far reaches of our solar system. Coils with MPP cores helped to enable this progress because of their unique and versatile combination of properties. MPP cores already touch our lives here on Earth in a multitude of ways, and may help to find life on other planets. (RB, JS)

IMOA gratefully acknowledges the assistance of Mr. Steven Battel, President of Battel Engineering, in ensuring the accuracy of this article's technical and historical aspects.



This photograph taken by the Cassini-Huygens spacecraft on August 29, 2012 shows one of Saturn's moons, Titan, aligning with its rings, which cast a dark shadow on Saturn. © NASA/JPL-Caltech/SSI.

# Guide to high-performance alloys

It can be difficult and time consuming for engineers to find materials properties beyond the basic ones reported in producer data sheets. This is especially true for lesser-used high-performance alloys. The new High-Performance Alloys Database addresses this problem. It contains a large number of materials properties for each of the 100 or so featured alloys, many involving molybdenum.

The database has been developed by a spinoff of Purdue University's Research Foundation. The company's name, CINDAS LLC, derives from Purdue's former Center for Information and Numerical Data Analysis and Synthesis, which was established to provide critically evaluated materials data to engineers. The Center managed a comprehensive research program on the properties and behavior of materials. It produced handbooks and databases, gaining a worldwide reputation for high-quality data among engineers and scientists. Key data volumes included *The Thermophysical Properties of Matter* and *Aerospace Structural Metals Handbook*.

The private company has been formed to disseminate the data collected and analyzed by the Center. It is converting that data to easily accessible digital formats and is adding new information to the database. Its web-based interface ([www.cindasdata.com](http://www.cindasdata.com)) allows users to quickly select and compare the attributes of the alloys they are interested in. These are indispensable tools for engineers working with advanced materials.

The company recently added high-performance alloys to their offerings. The High-Performance Alloys Database (HPAD) was created to address the needs of the oil and gas, chemical processing, power and transportation industries. A survey of materials experts in these fields yielded a list of about 115 alloys to be covered. The inaugural release of the HPAD was in March 2015. It contained about 90 chapters (each chapter covers one alloy) with 10 new chapters planned each year. The HPAD has

the same interactive features as other CINDAS databases; it is web-based and continually updated. Below are some recently added molybdenum-containing alloys:

## **Hastelloy C-22HS (13%Mo):**

An age-hardenable, corrosion resistant, nickel-base alloy that has nearly double the strength of a solid solution strengthened alloy while maintaining good ductility in the aged condition. It has high corrosion resistance in both oxidizing and reducing environments, and high resistance to chloride pitting and crevice corrosion.

## **Stainless steel 22Cr-13Ni-Mn (2.5%Mo):**

An austenitic, nitrogen-strengthened stainless steel with very good corrosion resistance and high strength. It has better corrosion resistance than Type 316 and twice the yield strength.

## **Duplex Stainless steel 2205 (3.2%Mo):**

This is the most widely used grade of duplex stainless steel. Its corrosion resistance lies between austenitic and super austenitic stainless steels.

## **Hastelloy B-3 (28%Mo):**

A member of the nickel-molybdenum family with excellent resistance to hydrochloric acid. It also withstands sulfuric, acetic, formic and phosphoric acids, other non-oxidizing media, and provides excellent resistance to pitting and stress corrosion.

## **20Cb-3 Stainless steel (2.5%Mo):**

A high-nickel fully austenitic stainless with exceptional resistance to general corrosion and stress corrosion cracking in sulfuric acid environments.

## **654 SMO Stainless steel (7.5%Mo):**

An austenitic stainless steel that approaches the performance of some of the highly corrosion resistant nickel-base alloys at a lower cost and much higher useful strength.

Having verified technical information on these alloys readily available will undoubtedly be very useful to engineers and designers. It will help display the great properties of molybdenum-containing materials, prompting materials engineers to use them more frequently. (CK)



Offshore platforms constitute a harsh environment, requiring high performance alloys for many applications. © iStockphoto/Arthurpreston

# IMOA news

## Forecast increase in long-term demand

The Secretary-General of IMOA told delegates at the Argus Metals Week conference in London in March that demand for molybdenum is forecast to

increase by an average of 3.6% per year in the period to 2024.

Mr Outteridge reviewed global molybdenum production and use in 2015, noting that the reduction in use was principally related to a significant fall in demand

from the oil and gas sector. Slower growth in China had also had an impact. However, most other sectors showed only small reductions, with some showing modest increases. Mr Outteridge also outlined a number of sectors expected to generate future demand.

## Reduced conference rates for IMOA members

IMOA is supporting the CRU Ryan's

Notes Ferroalloys 2016 conference in Miami, U.S., 23-25 October 2016. Ryan's Notes is offering a discount of 15% off the regular delegate rate for IMOA

members booking via the following link: <http://bit.ly/29vBuQu> with the discount code 'IMOA15'.

## Keynote address at Chinese Green Building Conference

The contribution made by stainless steel to the development of green buildings was explored during a half-day session at the Twelfth International Conference on Green and Energy Efficient Buildings in China in March. The China Stainless Cooperation Promotion Group (CSCPG), of which IMOA is a co-founder, organized a dedicated session, *Green*

*Building Development and Stainless Steel Application*, at the conference in Beijing.

The session began with a welcome address from the Stainless Steel Council of China (CSSC), followed by the keynote presentation from Dr Gaetano Ronchi, IMOA Greater China Representative, highlighting the impact and benefits of stainless steel use in sustainable building construction projects, with specific

reference to energy-saving sunscreens. The addition of molybdenum makes for exceptional corrosion resistance and very low maintenance and longevity.

"China is an important market for stainless steel," said Dr Ronchi. Ninety delegates representing 65 organizations attended, including architectural companies, design and research institutes, real estate developers and curtain wall fabricators.



Zhang Zhu Ping, CSSC Secretary General, welcoming delegates to CSCPG's session on sustainable stainless steel.

## Research confirms weldability of pipeline steel

Molybdenum in pipeline steel grades increases toughness at low temperatures, particularly attractive to manufacturers making steel for use in Arctic applications. IMOA commissioned Voestalpine to

conduct further research on the weldability of molybdenum-containing pipeline steel. The project, 'HAZ-simulation of modern pipeline steels', demonstrated that molybdenum has no negative effect on the heat-affected zone when welded.

Molybdenum improves the toughness of the coarse grain zone and reduces the likelihood of post-weld heat treatment embrittlement, especially in the presence of increased niobium content, thereby enhancing the alloying limits for weldable low-carbon steels. The results of this research will be published shortly.