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Safer rock climbing

Climbing a vertical wall, finding the next crack or jut in the rock face, pushing higher with nothing but the body's strength, are part of the thrill of rock climbing. However, without the aid of safety anchors to catch the climber in the event of a mishap, the sport could be deadly. Both experience and study indicate that molybdenum-alloyed stainless steel anchors play an increasingly important role to protect climbers' lives.

"As soon as I found no further place for my toes or fingers, or to set my anchors, it all came in a flash: the sweat, shaking knees and **fear**. Unbelievably, I was only about ten feet up…[this] turned out to be one of the great experiences of my life – **rock climbing**".

Whether it is to master fear, feel an adrenalin rush, or to enjoy technical and esoteric aspects, people are increasingly turning to extreme sports like mountaineering and rock climbing. The term "rock climbing" covers a wide range of activities from low-level bouldering or scaling indoor, artificial climbing walls, to extreme mountaineering in locations and altitudes such as Yosemite's El Capitan in California and the famous North Face of the Eiger in Switzerland. Here, climbers face challenges that go well beyond the technical difficulty of the rock face. Rock climbing is very popular today because of the increased accessibility to climbing experiences, improved training and support services, and new technologies in equipment. Anchors are a longstanding and critically important part of a climber's gear, but even they are progressing as the sport itself evolves.

Types of rock climbing routes

Traditionally, a climber would scale a 'virgin' route having no previously established path. He or she would use temporary anchors inserted in and removed from cracks in the face as the climber moves over the rock. Now, climbs over a route established by experts and fitted with permanent climbing anchors, or bolts, are becoming popular. These bolted climbing routes are widespread. Sixty thousand have been built in the U.S. alone since the 1980s. More suited to novices or a hiking expedition, are well-established paths fitted with permanent cables or even ladders, which are called 'via ferratas'.

Devotees often argue about whether the use of permanent anchors and devices is environmentally acceptable or philosophically pure, but all agree that they have opened the sport to many more participants. This increase in participation drives a need for better standards for equipment safety and quality, locally and worldwide.

Climbing sport governance

A variety of local and national sporting and industry groups oversee various aspects of climbing around the world. The global organization concerned with safety, sustainability and sport is UIAA (Union Internationale des Associations d'Alpinisme, or International Climbing and Mountaineering Federation). UIAA is active in a broad spectrum of issues in the sport. For example, it grades rock-climbing routes according to increasing difficulty from I to XI. It also has committees focused on ›

Publisher:
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454-458 Chiswick High Road
London W4 5TT, United Kingdom
www.imoa.info
info@imoa.info
+44 20 8747 6120

Editor in Chief:
Nicole Kinsman

Managing Editor:
Curtis Kovach

Contributing Writers:
Geatano Ronchi (GR), Robert Bukk (RB), John Shields (JS), Alan Hughes (AH), Thierry Pierard (TP)

Layout and Design:
circa drei, Martina Helzel

Cover photo:
Stainless steel anchors are an important safety device in rock climbing. © iStockphoto/sezer66

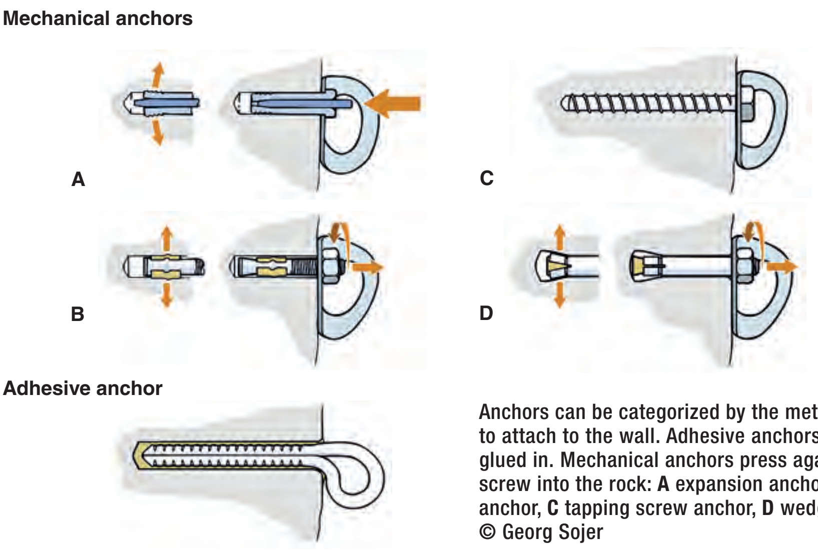
safety standards for helmets, anchors, and other equipment. Individual national clubs contribute in specific areas. For example, the CSMT (Centro Studi Materali e Techniche of the Italian Alpine Club) operates a tower used to test equipment and safety measures.

The permanent climbing anchor

The basic permanent anchor consists of a ring attached to a bolt embedded in the rock face. The placement of permanent anchors is usually carried out by experts, who are well aware of the legal and ethical implications of bolting. They are trained to consider the biophysical impacts on fragile soils, vegetation and wild life, aspects studied by UIAA. The anchors are used in 'belays', where a stationary climber protects an ascending or descending partner, with the help of ropes and breaking devices. Climbers attach the ropes with carabiners and other connections to the ring.

The rope is attached to the anchor with the help of a connection device such as a carbiner. © iStockphoto/Extreme-photographer

Two types of permanent anchors are currently in use. One is a ring, called a 'hanger', attached to a bolt that is mechanically secured in a drilled hole. The other is a one-piece eyebolt inserted and glued in a drilled hole. Anchors were originally made of high carbon steel. However, this material is subject to general corrosion and to galvanic corrosion when in contact with a stainless steel hanger. These older bolts have a life expectancy of only about twenty years, and sometimes much less, which means that hundreds of thousands of permanent anchors installed in the 1980's and 1990's are due or overdue for replacement.



Anchors can be categorized by the method used to attach to the wall. Adhesive anchors are glued in. Mechanical anchors press against or screw into the rock: **A** expansion anchor, **B** sleeve anchor, **C** tapping screw anchor, **D** wedge anchor. © Georg Sojer

In order to increase the life and dependability of these anchors, molybdenum-free Type 304 stainless steel has become common in North America, while Type 316 stainless steel with 2–3% molybdenum is the material of choice in Europe. As the sport grows, more climbing sites are discovered and developed around the world. Some of the most popular are located in corrosive coastal environments that challenge even these materials. Hence the focus on long-term material performance and climber safety grows stronger.

Durability and future of the permanent anchor

This new focus has raised questions about how long a 'permanent' anchor should last and what environmental conditions it should be designed to endure. Late in the last decade, some Type 316 stainless steel anchors failed by chloride stress corrosion cracking. Typically an affected bolt would show little outward sign of distress, before shearing off at the tap of a hammer. ›

Rock climbers are rappelling into a canyon. © iStockphoto/Extreme-photographer

Climbing sites most susceptible to this failure type are those in warm climates with moist coastal environments, for example in Thailand, the Dominican Republic and Greece. Climbers were rightly concerned about this problem because they literally attach their lives to their anchors.

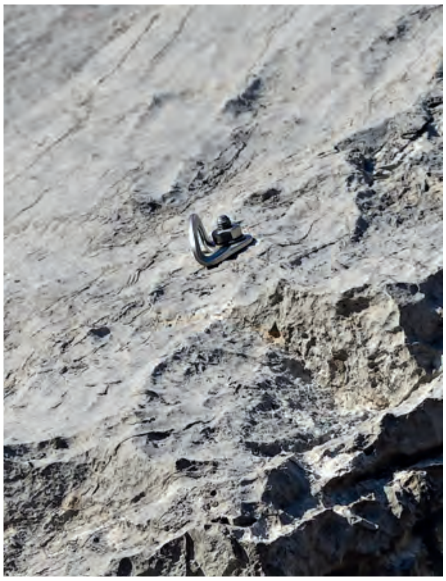
Following the appearance of the problem, UIAA commissioned a working group to study the issue and develop appropriate standards for anchor materials. In June 2016 the UIAA's Safety Commission Working Group issued a draft of an improved standard for anchor safety at an internal meeting in Bergamo, Italy.

The draft standard considered various geographic-environmental conditions and corrosion mechanisms, and made recommendations based on a desired anchor life expectancy of 50 years. It classifies various alloy groups according to their anticipated performance and suitability for particular environments.

In this draft standard, Type 316 stainless steel is suggested for use in non-coastal European locations. A number of high-molybdenum, highly corrosion-resistant (HCR) stainless steels are considered to be resistant to stress-corrosion cracking and localized corrosion in coastal environments throughout the world. These alloys include 2205 (UNS S31803) duplex stainless steel with 3% molybdenum and 904L (UNS N80904) austenitic stainless steel with 4% molybdenum. However, for the most severe warm and humid coastal environments titanium Grade 2 is suggested.

Meanwhile UIAA is sponsoring a long-term testing program on anchor materials, and some suppliers are already introducing HCR alloys into their product offerings. Without a doubt, molybdenum-containing Type 316 and HCR alloys will continue to be a mainstay of the anchors that support and provide safety to rock climbers all around the world. (GR)

New high corrosion-resistant (HCR) anchor made of 904L stainless steel. © Petzl



It is important to minimize permanent damage to the rock and visual impact of safety devices. Stainless steel anchors blend in with their surroundings and have a very long service life, so re-drilling of holes will not be necessary for decades. © Gaetano Ronchi

Moly goes to the races

A race car's skeleton and many of the forged components, that keep its engine running at top speed, are made of chromoly steel. Even though these grades have been around for many decades, and numerous new materials have been developped since, they still are the materials of choice in critical applications. Molybdenum is therefore a vital component to a racing team reaching its ultimate goal – the winner's circle.

Only a few years after the invention of motorized vehicles, the first road race was established. From there car racing quickly turned into an organized sport, moving to dedicated race tracks. Today there are many branches – formula racing, dirt-track racing, drag racing, go-kart racing, and even racing on frozen lakes with nail-studded wheels, to name but a handful. However, it is likely that none of the popular racing forms has such a colorful history as the sport of stock-car racing.

The birth of stock car racing

The origins of stock car racing can be traced back to the Prohibition era in the U.S.. Soon after the law came into force, 'speakeasies' (underground clubs and entertainment venues) came into vogue. Proprietors of the 'speaks' resorted to black-market 'moonshiners' in rural areas of the country, especially the South, to distill their liquor; they then needed 'bootleggers' to transport it.

Many chromoly components, including suspension and steering parts of a race car, keep the car on course and provide for a smooth, stable ride. © Daniel Huerlimann-BEELDE/Shutterstock, Inc.

> **"Moonshiners put more time, energy, thought, and love into their cars than any racer ever will. Lose on the track, and you go home. Lose with a load of whiskey, and you go to jail."** Junior Johnson, NASCAR legend, and one time whiskey runner

Bootleggers developed a distribution network of drivers who used their own vehicles to deliver liquor without the knowledge of authorities. Drivers modified their 'stock' cars to increase speed, improve handling and expand cargo space. The ensuing cat-and-mouse games with police spurred them to continually increase their cars' capabilities, while retaining their outward look, in order to avoid arrest. The great Prohibition experiment ended in 1933, but the passion for speed of the bootleggers found a new outlet in organized races. By 1947, stock car racing had become so popular that the competitors founded a formal governing organization with standardized regulations and an official racing schedule, the National Association for Stock Car Auto Racing (NASCAR). Today, NASCAR racing is one of the most popular spectator sports in America.

Obtaining the competitive edge

Following in the footsteps of their predecessors, today's design engineers constantly work to gain an edge on the track. It doesn't matter whether the object of attention is a top-tier NASCAR, a Formula 1 or even a drag car racing team with local sponsors. All face the same problems and strive to ›

NASCAR teams are making adjustments to their cars.
© Action Sports Photography/Shutterstock, Inc.

solve them in ways that give their team a competitive advantage. They use a myriad of materials to make cars faster, stronger, lighter, more aerodynamic and most importantly, safe!

> **"Auto racing, bull fighting, and mountain climbing are the only real sports ... all others are games."**
>
> Ernest Hemingway

No single material can satisfy all the demands expected of every race car component. However, the AISI (American Iron and Steel Institute) 41xx grades of molybdenum-alloyed steels meet the challenge for many applications with their unique set of properties. They include strength, toughness, weldability, workability and resistance to fatigue, wear, heat, oxidation, and scaling.

Call it chromoly

The chromium and molybdenum additions in the 41xx grades spawned a well recognized name in the industry – chromoly (AKA Chrome-Moly or CrMo). The 4130 grade is most popular. Originally used by the aeronautics industry and bicycle manufacturers, it is also a favorite of race car designers and fabricators. The alloy is used in sheet, forging, and tubing product forms. Chromoly grade 4140 is particularly important for forged applications such as engine and suspension parts because of its excellent tensile strength due to the higher carbon content.

Compositions of chromoly steels by weight

AISI grade	Cr (%)	Mo (%)	C (%)
4130	0.80-1.10	0.15-0.25	0.28-0.33
4140	0.80-1.10	0.15-0.25	0.38-0.43

The chassis is the base

To produce a winning car, design engineers start with the chassis. It must provide the base of support for the motor, transmission and suspension system. In addition to being light and strong, the chassis must resist the incessant vibration and high temperatures generated during a race. Most frames are custom-built using round, oval or square tubing or I-beam shapes for rigidity.

Racing's governing bodies hold frame designers to strict standards. Nearly all frames are fabricated from 4130 chromoly because the alloy offers a better strength-to-weight ratio and higher ductility than carbon steels. It therefore can be used in thinner sections without loss of structural strength, reducing the weight of the car and increasing its speed. Its performance on the track more than compensates for its higher cost.

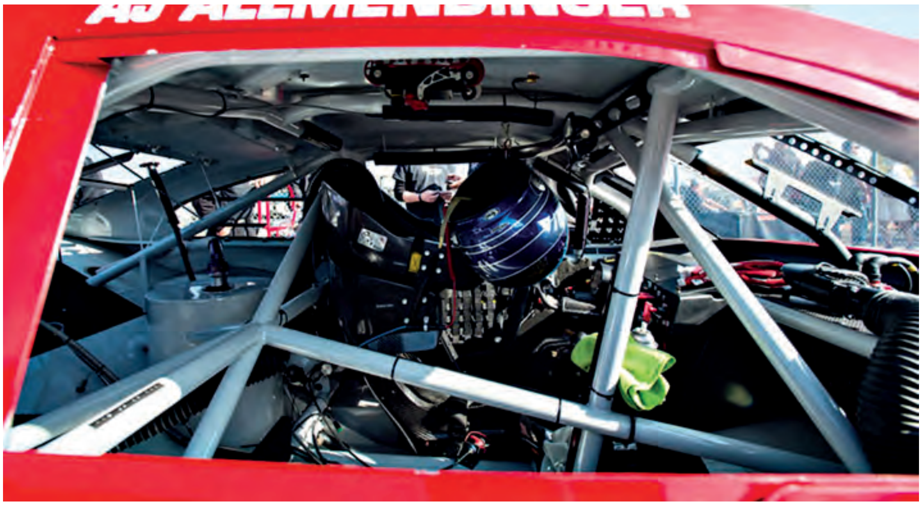
Protecting the driver

Safety is of the utmost importance in the racing industry. Roll bars and roll cages are integrated with the car's frame to protect drivers in case of accidents. They also lend rigidity, strength and stability to the chassis. The materials chosen for such an important structure cannot fail under the extreme impacts that occur in high-speed accidents.

Its superb ductility, flexibility, bendability, and weldability make 4130 chromoly a popular choice also for roll bars and roll cages. The combination of high strength and toughness helps to protect the driver without adding a lot of weight.

Chromoly components keep the car on track

The suspension system must provide stability and good handling while reducing vibration and noise. It keeps the vehicle planted firmly on the track while supporting the car's weight.



The roll cage inside a NASCAR vehicle is designed to protect the driver in case of an accident. © Sean Klingenhoefer

Steering components, tie rods, struts, springs, and linkages are often made from chromoly alloys because of their strength, toughness and wear resistance.

The engine is the heart of the car

A race car's engine produces massive amounts of power that must be maintained for hours over long distances. For example, a Formula 1 engine runs at nearly 20,000 rpm. This generates friction that can produce excessive heat and wear on its moving parts, and ›

Even Formula 1 racing teams rely on chromoly steels for roll bars to protect the drivers from injury. © Natursports/Shutterstock, Inc.

extremely high mechanical stresses on all its components. High-performance engine manufacturers chose chromoly alloys for crankshafts, gears, pistons, and flywheels because of their strength, toughness, and resistance to heat, fatigue and wear.

While no single material meets the host of demands placed on components of high-performance race cars, molybdenum-containing alloys can be found throughout these vehicles. Their broad spectrum of attractive mechanical and physical properties is due in no small part to molybdenum. Even though they have been around since the 1920s, they are still critically important to racing teams today in achieving their ultimate goal – racing straight into the winner's circle! (RB)

Tooling around with moly

Metalworking tools must survive high temperatures, extreme stresses, friction and wear, and still economically produce precision parts from difficult-to-process alloys. In some applications, traditional steel and nickel-alloy tools cannot do the job. Molybdenum metal alloys like TZM and MHC solve this problem, saving material and processing costs, and enabling new and better technologies.

Hot metalworking machines apply thousands of tonnes of force to shape large workpieces. They require dies and tooling made from special alloys that must retain their strength at temperature and resist erosion by the workpiece. Molybdenum has been an important component of tool steels for about a century because it improves hardenability and high-temperature strength. New workpiece alloys capable of higher temperature operation required both higher processing temperatures and improved tooling materials. Eventually, tool steels, nickel alloys, and cobalt alloys were found wanting for some special applications. These applications now use molybdenum where tool temperature can exceed 1100°C. The two examples discussed in this article vary greatly in size, with one using tools weighing only kilograms, the other weighing several tonnes.

The extrusion press – a high-temperature, high-pressure toothpaste tube

The extrusion process is analogous to using a toothpaste tube. Squeeze the tube and out comes a small cylinder of toothpaste. An extrusion press does the same thing, but with a solid metal workpiece called a billet. In hot extrusion, the billet is softer than it is at room temperature, but it still retains significant strength. The press holds the billet in its heat-resistant steel container, and its ram pushes the billet through a die to make a long bar in the shape of the die's opening.

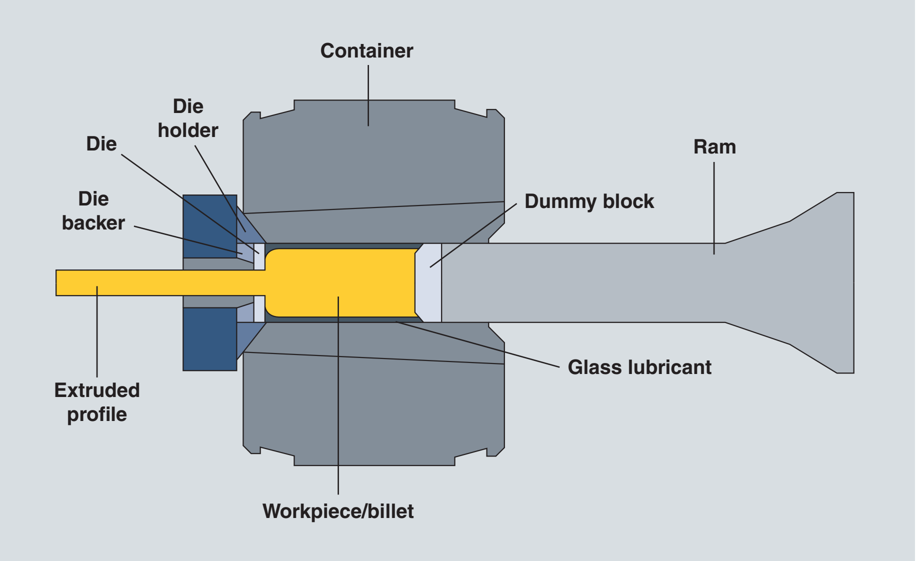
Brass extrusions start with a typical two to three meter-long cast ingot having a diameter of about 250 mm. The 'extrusion constant,' the ingot cross-sectional area divided by the extrusion cross-sectional area, influences the force required to extrude the ingot. The constant of some brass extrusions can be as high as 1600*, demanding high forces and ›

* The cross-sectional area of the billet is 1600 times larger than that of the extrusion. For this extrusion ratio, a 250-mm diameter billet would produce a round bar having a diameter of 6.25 mm.

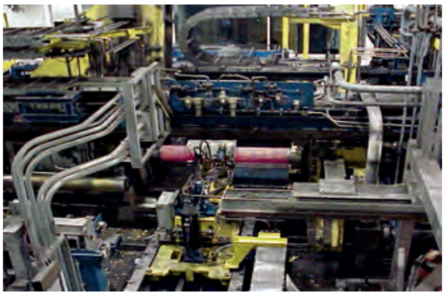
large deformations. Even with pre-heating to 600–1100°C, depending on the alloy, 3,000–4,000 tonnes of force are needed to extrude an ingot of this size.

The process creates high stresses in the die and large amounts of die to workpiece friction. The deformation and friction also create heat that reduces the die material's strength and increases thermal stresses in the die, further challenging the tooling. Production campaigns process many ingots, so dies must also resist fatigue and creep. Die cracks associated with fatigue or overloading create fins in the extrusion that require expensive hand finishing. Dies must resist all these phenomena to make high-quality finished products.

The molybdenum MHC alloy with approx. 1.2 wt. % Hf and 0.08 wt. % C, solves these problems. MHC is nearly 99% molybdenum, so has excellent thermal conductivity and low thermal expansion, both of which reduce thermal stresses. MHC has significantly better strength at extrusion temperatures than standard hot-work tool materials. It resists erosion, extends die life and improves the product's dimensional uniformity. MHC dies have up to ten times the life of dies made from Rexalloy®TM, a competitive extrusion-die alloy. Brass extruders consistently choose MHC over other die materials for these reasons.



Schematic drawing of an extrusion press.



Copper alloy billet in position for extrusion.
© Chase Brass and Copper Co. LLC

Bundles of finished brass bars. © Chase Brass and Copper Co. LLC

Isothermal forging – making waffles with a 40,000-tonne press

Gas-turbine efficiency depends directly on operating temperature. Over many years of engine development, operating temperatures were continuously pushed higher, requiring new materials with ever better high-temperature performance. Because these materials had such high strength at elevated temperatures, the traditional tools to shape and form them were no longer adequate. One such part that threatened to stall progress of turbine efficiency was the turbine disk (see insert p. 10). Only when engineers found a new way to forge IN-100, a heat resistant cast alloy that was not forgeable with traditional methods, could they advance the technology.

A way to forge 'unforgeable' alloys

The key to success was to start with a very fine-grained input material and to 'superplastically' forge it at very slow speeds. This required both the tool and the workpiece to be heated to the forging temperature (1100–1200°C) for long ❯

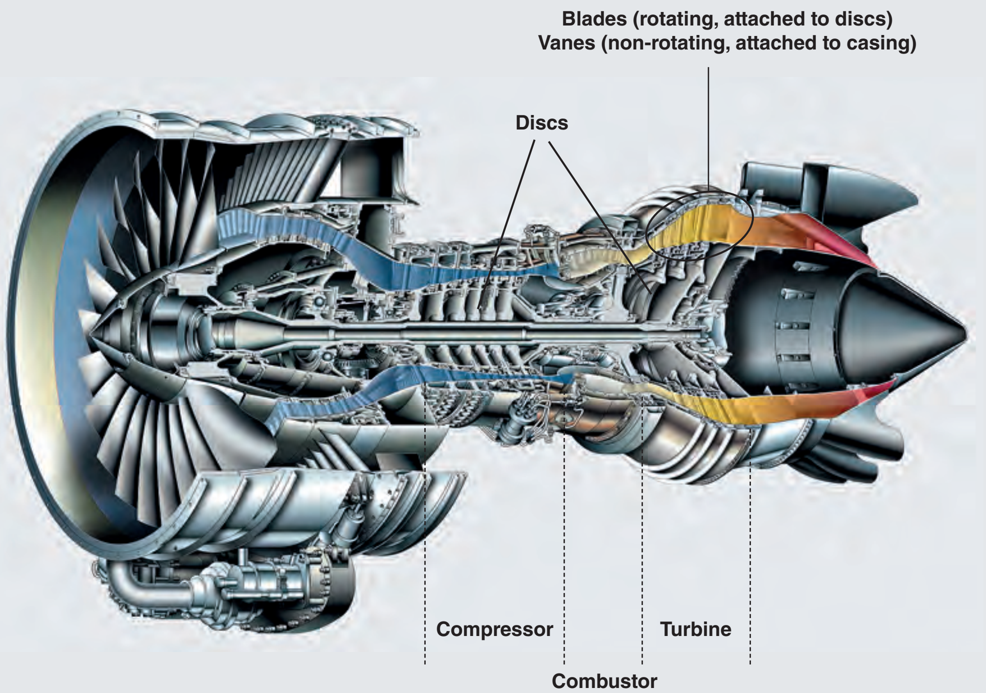
Development of gas turbine engines

Axial-flow turbine engines used in today's aircraft are marvels of design, materials, and manufacturing. They have a compressor section that creates high-pressure air and injects it into a combustor where it burns the engine's fuel. The high-pressure flame enters the turbine's hot section and drives the turbine shaft, then enters the exhaust cone where it expands and propels the aircraft.

In order to maximize power and efficiency while minimizing environmental impact, jet engines must operate at the highest possible temperature. Flame temperatures in today's engines exceed the melting point of the engine's hot-section turbine blades. Only by employing superb mechanical design, unique materials, sophisticated coating technologies, and exceptional manufacturing techniques are manufacturers able to produce turbine blades able to operate in this environment.

A sampling of nickel-based superalloys for jet-engine turbine disks

Alloy	Developer	Decade	Base alloy	Nominal Mo, weight-%
Waspaloy®	United Technologies	1950 – 1960	Ni-Cr-Co	4.3
IN-100	INCO	1960 – 1970	Ni-Co-Cr	3.0
Udimet® 720	Special Metals	1970 – 1980	Ni-Cr-Co	5.0
René™ 95	General Electric	1980 – 1990	Ni-Cr-Co	3.5
N18®	SNECMA	1990 – 2000	Ni-Cr-Co	7.0
Alloy 10	Honeywell	2000 – 2010	Ni-Co-Cr	2.7

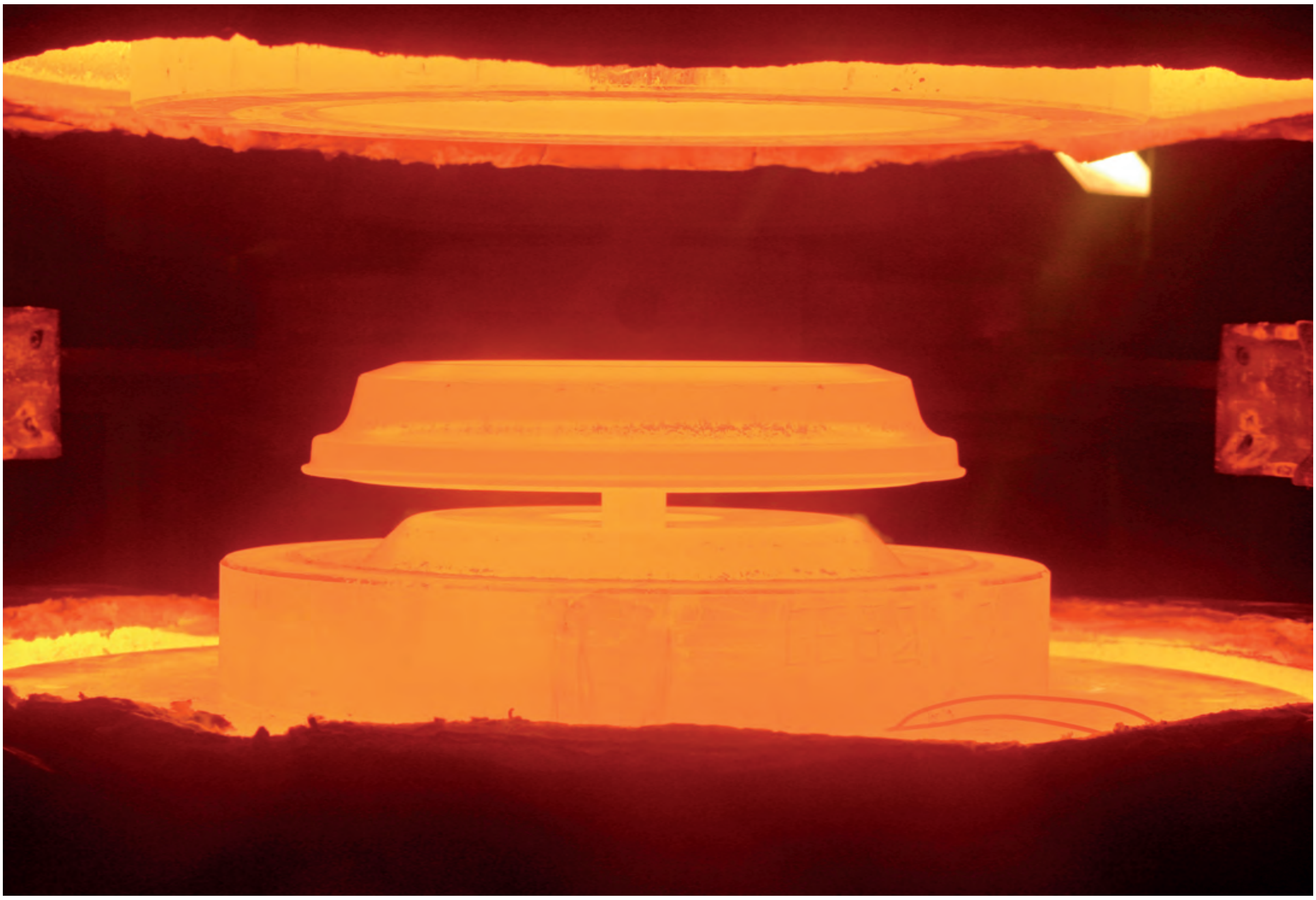


Cutaway drawing of a Pratt & Whitney PW6000 jet engine, showing compressor, combustor, and high-temperature turbine stages. Each stage has rotating disks to which blades are attached. Between the bladed disks are stationary vanes, attached to the turbine case. © 2014 United Technologies Corporation – Pratt & Whitney Division

The turbine disk – holding it together

Turbine disks hold the spinning blades that compress air and extract power from the heated gas. They must endure high stresses, and in the case of hot-section disks, high operating temperatures also. Many disk alloys contain molybdenum because it contributes to high-temperature strength and creep resistance. Until the 1960s, disks were manufactured by standard forging practices; disk alloys could not supply the high-temperature performance of cast blade alloys, which were unforgeable. Steady increases in engine performance eventually pushed hot-section forged disk alloys to their temperature limits, stalling progress.

In a major step forward, Pratt & Whitney engineers devised a unique isothermal forging process to manufacture disk preforms from IN-100, a previously 'unforgeable' blade alloy. The process made forgings about 30% lighter than conventionally forged disks with dimensions much closer to those of the final part, which dramatically reduced input material costs, scrap rates, and machining costs.



Isothermally forged superalloy disk being ejected from Mo-TZM die after forging. © ATI Forged Products

periods while in contact with one another in a protective-atmosphere chamber. Although the disk alloy did not flow quite like wafflebatter at these temperatures, it still moved freely, filling out the die and creating much finer detail than was previously possible. The protective atmosphere minimized scaling of the expensive superalloy, further reducing cost and improving quality.

Finding an appropriate die material was a unique and daunting challenge because no traditional tooling material could survive the process. Enter molybdenum TZM alloy with approx. 0.5 wt. % Ti, 0.08 wt. % Zr and 0.03 wt. % C. Despite its tiny alloy content, TZM has extraordinary strength at the isothermal-forging temperature, so it was perfect for the dies.

Making TZM dies

Today's large TZM die blanks, which can weigh as much as 5,000 kg and measure a meter in diameter and height, are made by standard powder-metallurgy techniques applied on a grand scale. The blank must be forged on a 30–40,000 tonne press (more than enough force to lift a battleship!) at temperatures approaching 1200°C, in order to increase its strength to tackle the job. Installed in its own forging press, a finished pair of dies must produce hundreds of flawless nickel-base superalloy disks that help modern jet engines to fly safely, economically, and with minimal environmental impact.

The world aircraft market continues to grow, and demands for ever-higher engine operating temperatures continue to spur a need for forged superalloy disks in more locations in the engines. Molybdenum will continue to play an important behind-the-scenes role in manufacturing these remarkable power plants.

Molybdenum: an extreme solution

Hot metalworking processes are indeed extreme; they make extraordinary demands on tooling. Molybdenum has long been an important component of traditional tool alloys, but it becomes itself the tool alloy when nothing else works. Whether for relatively small dies used in brass extrusion or for isothermal-forging dies weighing thousands of kilograms, molybdenum metal alloys make advancements in hot metalworking possible. (JS)

Low sulfur on the high seas

Maritime shipping remains one of the most cost-efficient global transport methods, especially compared with air freight. Its rapid growth since the 1970s and the containerisation of cargo have kept pace with the global economy, however this has also increased its environmental impact. New regulations limiting the sulfur content of engine fuel mean that ships must either use cleaner, more expensive fuel, or install equipment to take sulfur out of exhaust gases, a process in which molybdenum plays a key role.

When thinking about air pollution, some familiar sources come to mind – power stations, incinerators, planes, cars and trucks; but what about ships? Some 90% of global trade is carried by sea, with the total volume of freight increasing to nearly 10 billion tonnes in 2014, four times the level recorded in 1970. It is estimated that there are now more than 100,000 transport ships in use around the world.

This steady rise in sea freight means that emissions from shipping continue to increase. A recent study estimated that if nothing changes, emissions from shipping will be the largest single source of air pollution in Europe by 2020.

Ships are usually powered by diesel engines, typically run on heavy fuel oil. Often described as the leftovers from the refining process, this incredibly viscous fuel, which at room temperature has a consistency similar to peanut butter, is inexpensive but very dirty and extremely high in sulfur. It typically contains up to 35,000 parts per million – or 3,500 times the amount in the ultra-low sulfur diesel routinely in use on European roads. It is the reason that maritime shipping accounts for 8% of global emissions of sulfur dioxide (SO_2).

Acid rain and premature deaths

Sulfur dioxide is released when the fuel is burned, dispersing into the atmosphere in the exhaust gases. Depending on environmental conditions, sulfur dioxide will readily react with tiny droplets of water to form sulfuric acid, the cause of acid rain. Acid rain is between 10 and 100 times as acidic as ordinary rain, causing damage to trees, plants and buildings. If it is not dissolved in the atmosphere, it presents a different hazard, as when inhaled, sulfur dioxide is known to cause respiratory problems and is associated with inflammation leading to heart and lung failure. A 2011 Danish study estimated that some 50,000 premature deaths in Europe are linked to air pollution from maritime shipping.

So what is being done about this environmental menace? The International Maritime Organisation develops and implements emission control regulations to reduce pollution by shipping. The MARPOL Annex VI regulations were first adopted in 1997, limiting the main air pollutants in ship exhausts. The latest revisions see the global cap on the sulfur content of fuel reduced from 3.5% to 0.5%, effective from January 2020.

However, an earlier amendment which came into force in January 2015 reduced the limit for sulfur content to 0.1% in the Baltic Sea, North Sea, North American and U.S. Caribbean Emission Control Areas. This means that ships over 400 gross tonnes sailing in these areas must now either use more expensive low-sulfur fuel, or opt to retrofit flue gas desulfurization (FGD) onboard to remove sulfur from exhaust gases and therefore comply with the new regulations.

The scrubber vessel of a marine flue gas desufurisation (FGD) unit ready to be shipped. © CR Ocean Engineering

FGD units on ships typically employ a process called wet scrubbing to remove up to 99% of sulfur dioxide from engine emissions. A liquid is sprayed through columns of exhaust gas, turning the sulfur to sulfuric acid, in a very similar way to how acid rain is formed in the atmosphere.

Where the resulting liquid can be safely discharged (on open seas with moderate to high alkalinity), an open loop system using only seawater to scrub the exhaust gases can be deployed. In waters with low alkalinity such as ports, harbors, lakes and canals, a closed loop system must be used, which does not discharge the scrubbing liquid. These systems use water mixed with sodium hydroxide (caustic soda) to neutralize the sulfuric acid formed and remove the sulfur. In practice, many emission control units use both closed and open loop systems for greater flexibility and efficiency of operation.

The protective role of molybdenum

The environment within parts of the FGD units is extremely aggressive, and it is here that molybdenum plays a crucial role by greatly increasing the corrosion resistance of stainless steel. Several grades of stainless steel are ›

Nearly 10 billion tonnes of freight were moved by sea in 2014. © iStockphoto/dan_prat

A marine FGD scrubber vessel being retrofitted to a cargo ship. © CR Ocean Engineering

typically specified within a FGD unit, depending on the potential for corrosion. Grade 316L is found in closed loop designs which do not use seawater. Open loop and hybrid systems are more corrosive due to the seawater. Therefore, more corrosion resistant, molybdenum-containing duplex, super duplex and super austenitic stainless steels as well as nickel-based alloys are used. These grades, are particularly needed in pumps, valves and the scrubber tower itself, depending on the different manufacturers' specification.

Many recently built ships and those in construction are designed with FGD units built in, or have dual fuel engines to burn cleaner fuels. Older vessels can be relatively easily retrofitted with FGD units, in some cases inside the ship's funnel. The FGD route is cheaper than converting engines to run on alternative fuels (such as gas oil, natural gas or LNG), or switching to low-sulfur fuel, with manufacturers estimating a payback time of around two years. Fears that shortages of low-sulfur fuel could occur when the global 0.5% global cap is applied may also encourage more operators to invest in FGD units ahead of 2020.

Molybdenum already contributes to the protection of the environment in many ways, from playing a key role in renewable energy technologies to making cleaner fuel and more efficient, lighter but safer vehicles. Optimizing the global movement of goods is a key requirement in ensuring that the transport sector can make an overall positive contribution to sustainable development. Shipping has a large part to play in this, and the global reduction of sulfur emissions is a very significant step, one in which molybdenum has a key facilitating role. (AH)

Two-in-one solar panels

This innovative hybrid system combines photovoltaic cells with a molybdenum-containing stainless-steel heat exchanger. It produces both electricity and domestic hot water at the same time, greatly increasing the amount of solar energy extracted per square meter.

A young Marseilles-based startup founded in 2010 by two recent engineering graduates has developed an innovative product that relies on molybdenum-containing stainless steel in an essential role.

Typical commercial silicon-based photovoltaic (PV) panels have a relatively low electrical conversion efficiency of about 15–20%. Because they are heated by the sun, they also trap untapped thermal energy. Unfortunately, existing solar thermal collector designs were incompatible with PV designs, so no product or system combined the two technologies satisfactorily. The engineers' concept was simple: bring together both thermal and PV technologies in a hybrid design. Progress in PV systems has been rapid because of the large number of teams around the world working to increase efficiencies by using advanced concepts like copper-indium-gallium selenide (CIGS) PV cells that use molybdenum as an important component of the cell structure. While offering higher efficiency, these concepts still need to deal with heat build-up, so a hybrid panel approach is useful as well.

A hybrid panel – PV on one side, thermal on the other

The inventors wanted to cool PV cells to capture unexploited heat and produce domestic hot water. To do this, they developed an innovative hybrid panel containing a PV array backed by a heat exchanger. In this design the PV cells themselves become thermal collectors.

The design employs a heat exchanger thermally bonded to the back of a PV panel. The heat exchanger cools the PV cells and stabilizes their temperature. This increases the panel's electrical efficiency by lowering its operating temperature. At the same time it captures heat to produce hot water for the building. The result is a panel with a total combined efficiency of 30–60% instead of the 15% of a typical PV installation.

Heat and electricity for the house thanks to two-in-one panels. © DualSun

Ultra-thin stainless steel heat exchanger

The ultra-thin but rigid heat exchanger is incorporated into the solar panel. It comprises two stainless-steel sheets, one formed to produce a 2-mm-high waffle motif. The “waffled” sheet is welded to a second, flat sheet at its contact points. A glycol/water coolant is pumped through the open volume at low pressure (1.5 bar), reaching a maximum temperature of 75°C during operation. The thickness of the finished hybrid panel is only four centimeters.

Unlike other candidate materials, the mechanical properties of stainless steel are hardly affected by the operating temperature of the heat exchanger. This is one of the reasons stainless steel is widely used for PV panel frames. In this case, designers chose a Type 444 (UNS S44400) ferritic stainless steel containing 1.85% molybdenum. It combines good mechanical properties with excellent corrosion resistance. Molybdenum contributes significantly to pitting and crevice-corrosion resistance in both the water/glycol coolant and the external environment. This grade’s expansion coefficient is similar to that of glass, an important requirement because the heat exchanger is mated to the PV cell assembly. Type 444 has better thermal conductivity than austenitic grades and is easy to form and weld.

The integrated hybrid system uses a conventional inverter to produce electricity, and a heat exchanger/storage tank system for domestic hot water. The system is stationary, silent and thin, and is easily incorporated into any type of roof. The panels produce both domestic hot water and electricity in the space required for the PV panels alone. They provide a space-efficient installation for homeowners or businesses looking for a more sustainable alternative energy solution.

Green from beginning to end

The PV industry recognized the need for recycling in order to preserve precious resources and raw materials at an early stage. It created PVCYCLE, the worldwide not for profit member-based organization supporting the recycling of PV materials. Stainless steel fits perfectly into this philosophy of resource stewardship, since it is completely recyclable. Thus, the heat exchangers that are so important to the efficiency gains in the hybrid system will find a home in new applications and technologies when they reach the end of their lives in about 25 years.

A bright idea becomes a new technology

The young engineers’ idea for a hybrid panel with molybdenum-containing stainless steel has quickly made its mark. It has been certified to European solar energy PV and thermal standards, and already equips corporate headquarters, industrial buildings, apartment buildings, swimming pools and private homes in Europe, the Near-East, North and South America. (TP)

Coolant flows inside the stainless steel heat exchanger just beneath the solar panel, stabilizing its temperature and transferring its heat through another heat exchanger to produce domestic hot water. © DualSun

IMOA news

AGM 2016

Vienna's baroque splendor lent a suitably impressive backdrop to IMOA's 28th Annual General Meeting in September 2016, kindly hosted by Plansee SE. IMOA President Carlos Letelier welcomed some 130 delegates to the Austrian capital for the two day meeting. The speaker program brought a number of experts together to give their insight on a range of very topical subjects designed to be of particular interest to members.

Claus Raidl, President of Oesterreichische Nationalbank, gave a presentation using the latest economic forecasts to deliver his view on the possible consequences of Brexit and the outcomes for the Euro-zone. Independent analyst Jim Lennon used his considerable industry experience to make some predictions on the medium-term prospects in the molybdenum market, while Markus Moll from SMR gave a very entertaining and animated review of the outlook for the market in the longer-term. Bernhard Schretter, from our hosts Plansee, highlighted developments in molybdenum metal powder applications over the last decade, updating a presentation given at IMOA's AGM the last time it was held in Vienna, in 2006.

Delegates also heard presentations on the stainless steel market, the recycling of molybdenum containing materials, the weldability of low carbon steel, molybdenum in heavy plate production and successful uses of structural stainless steel. Nicole Kinsman, IMOA's Technical Director gave an overview of market development and Sandra Carey, IMOA's HSE Executive, presented a summary of HSE activity including product stewardship, regulatory compliance and access to market issues.

IMOA hosted a dinner in the Orangerie at the historic Schönbrunn Palace, once the setting for a famous musical contest between Mozart and the Italian composer Antonio Salieri.

Plansee SE reciprocated on the following evening, kindly hosting a night of traditional Austrian cuisine and wonderful chamber music in the stunning surroundings of the Kunsthistorisches Museum.

Argus Metals Week, London 2017

IMOA is a supporting partner to Argus Metals Week (formerly NiCoMo), taking place in London between 6 and 9 March 2017. IMOA members can register at http://tinyurl.com/argusmetals and are eligible for a 10% discount off the standard delegate rate with the code 'IMOA10'.

AGM 2016: IMOA members enjoying the balmy night before dinner at the Orangerie (left). Bernhard Schretter welcomes the guests to the Plansee dinner at the Kunsthistorisches Museum.

Essentiality brochure published

IMOA published a new brochure in September 2016, exploring how life on earth is supported by molybdenum, which occurs naturally all around us. In common with a handful of other elements, it is also essential – meaning that life cannot be sustained without it.

Following on from a new area on the IMOA website which launched in the summer, 'Molybdenum – Essential for Life' looks at the different ways in which molybdenum sustains life, including the production of vital enzymes in humans, animals and plants. The new brochure is available to download from the 'Molybdenum for Life' section of the IMOA website at http://tinyurl.com/molyforlife.