NICKEL MAGAZINE

THE MAGAZINE DEVOTED TO NICKEL AND ITS APPLICATIONS

NICKEL, VOL. 37, Nº 1, 2022

When strength matters

Building codes
safe buildings and structures

Stainless steel cables
for harsh environments

New San Giorgio Bridge
stronger, safer

CHATTANOOGA BOILER & TANK COMPANY

CASE STUDY 24
WASHINGTON SUBWAY

The Washington Metropolitan Area Transit Authority (WMATA) Metrorail serves more than 600,000 customers a day and is the second busiest in the United States, with 91 stations in Virginia, Maryland, and the District of Columbia. As part of a maintenance programme to replace existing escalators throughout its network, eye-catching stainless steel canopy structures are being installed over uncovered metro entrances to protect exterior escalators from rain, snow and salt during inclement weather, improving escalator reliability and passenger convenience.

The load-bearing elements of the canopy are rectangular, hollow structural sections made from austenitic stainless steel Type 316L which contains 10% nickel.

Providing instantly recognisable entries to the metro rail system, the graceful canopies incorporate stainless steel and glass in a design that is reminiscent of the Metro stations' iconic vaulted and coffered ceilings. Each canopy includes a glazing system supported on a stainless steel torus-shaped frame with main girders located directly above the parapet walls on diagonally tapered struts. The modular design, with large sections of the roof being assembled in the fabrication shop, is transported by road to the site and then bolted together quickly during night-time closures to minimise disruption to the metro operations. The design is modified to meet each site's unique characteristics.

Type 316L (UNS S31603) is ideally suited for structures in transport hubs because of its excellent corrosion resistance, low maintenance requirements and attractive surface finish. Ni

EDITORIAL:
ON THE STRENGTH OF NICKEL

Strength is vital, because when strength is lacking bad things happen. It is one of the key attributes that nickel brings to materials.

> *"The strength of a material is its ability to withstand an applied load without failure or deformation."*

Nickel provides a useful combination of strength, ductility and toughness. This is essential in heavy duty applications like aircraft landing gear which need to withstand repeated shocks. Here, nickel in maraging steel plays a critical role in preventing fatigue and avoiding catastrophic failure.

Nickel in stainless steel enhances corrosion resistance and allows tough, ductile and strong welds which, in turn, ensure that stainless steel can be used in strong and durable structures. Structures like Italy's new San Giorgio Bridge. Designed by Renzo Piano, the use of stainless steel reinforcement guarantees mechanical strength and corrosion resistance. The reinforcement is critical for ensuring the durability of the bridge, which was constructed following the catastrophic failure of its predecessor.

Stainless steel has been used effectively in landmark buildings for over a century. But it is only now that specific stainless steel design codes have been published. These are necessary because the properties of stainless steel differ from carbon steel. The American Institute of Steel Construction's new design standard provides user-friendly and economic design specifications to help designers and structural engineers use stainless steel easily and effectively for strong structural projects.

And stainless steel is also a metaphor for strength. Spanish sculptor, Jordi Dìez says the uniqueness of stainless steel endows his works with power and expressiveness. These attributes are personified to perfection in his recent sculpture of tennis legend Rafael Nadal playing to *his* strengths – his signature left forehand.

Clare Richardson
Editor, *Nickel*

NICOLE KINSMAN

Type 316 (UNS S31600) cables and rods with Type 2205 (S32205) fittings and support arms were used in China's Poly building's stainless steel cable-net curtain wall.

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www.nickelinstitute.org

Dr. Hudson Bates, President
Clare Richardson, Editor

communications@nickelinstitute.org

Contributors: Nancy Baddoo, Gary Coates, Richard Matheson, Geir Moe, Kim Oakes, Benoît Van Hecke, Odette Ziezold

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NICKEL NOTABLES

Super-elastic alloy takes the heat

CITY UNIVERSITY OF HONG KONG

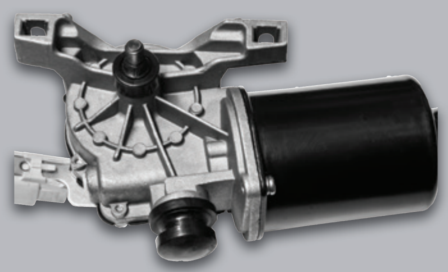
Researchers at City University of Hong Kong (City U) and other collaborators have accidentally discovered a first-of-its-kind super-elastic alloy that retains its stiffness even after being heated to 1,000 K (726.85 °C) or above.

Professor Yang Yong and his team found that Co25Ni25(HfTiZr)50, or “the high-entropy Elvinar alloy”, retains its modulus of elasticity when exposed to a very wide range of temperatures. This means the stiffness of the alloy remains invariant to temperature.

This property is beneficial for devices that are expected to undergo drastic temperature changes. “We know that the temperature ranges from 122 to -232 °C on the surface of the moon. This alloy will remain strong and intact in an extreme environment, and so it would fit very well with future mechanical chronometers operating within a wide range of temperatures during space missions,” said Professor Yang. The work was published in the journal *Nature*.

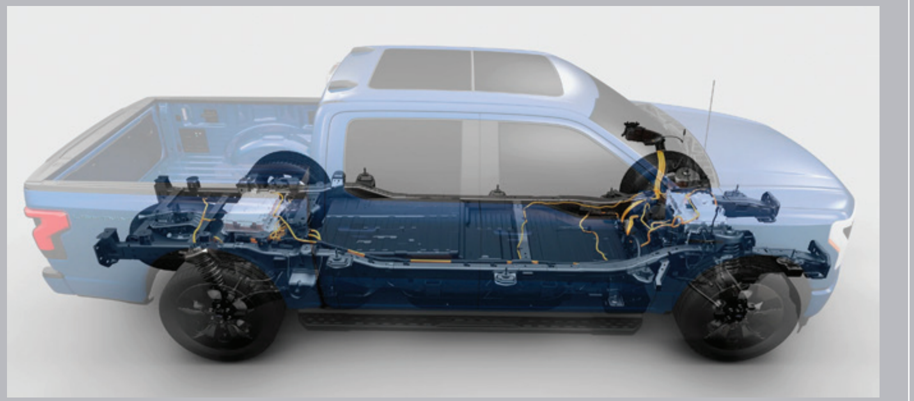
Magnetic first

For the first time in the world, Denso Corporation has succeeded in artificially synthesising iron-nickel superlattice magnetic powder, which has magnetic properties due to the arrangement of iron and nickel atoms. The strong magnetism is equivalent or superior to that of neodymium magnets. To enhance the competitiveness of their key components for electric vehicles, the company plans to apply this less expensive, high performance magnet to small motors as early as five years from now, and in the future to drive motors. The global automotive components manufacturer has started mass production while Aisin, part of the Toyota Group, will establish a global supply system for electric units and other products by 2025.



Riding high

South Korean company, SK On has successfully developed an NCM9 battery, a world first in commercialising the 90 percent nickel content level. NCM (nickel, cobalt, manganese) identifies the three main materials of the battery cathode, while number 9 indicates the proportion of nickel. This award-winning innovation’s high nickel content means higher energy and better battery output, a challenge that required the company to develop advanced technology to ensure the safety of the end product. Tested and installed in Ford’s F-150 Lightning, the first electric version of Ford’s legendary pickup truck, it is ready to roll into the market. With nearly 200,000 vehicles reserved before launch, all eyes will be on this model’s continued high performance and endurance.



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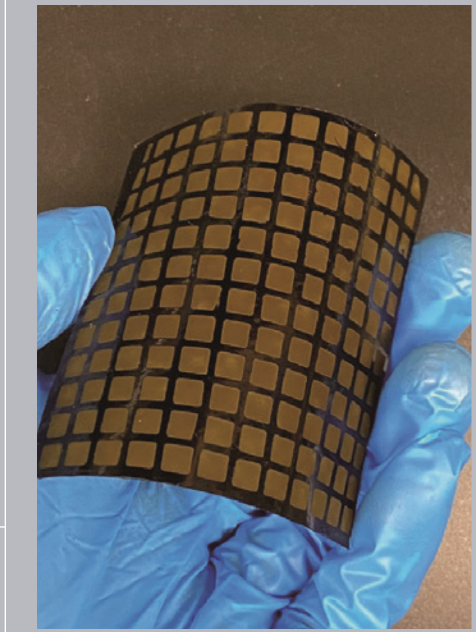
SK On’s NCM9 battery won CES 2022 Innovation awards in two categories: “In-Vehicle Entertainment & Safety”, and “Embedded Technologies”.

Non-toxic detector

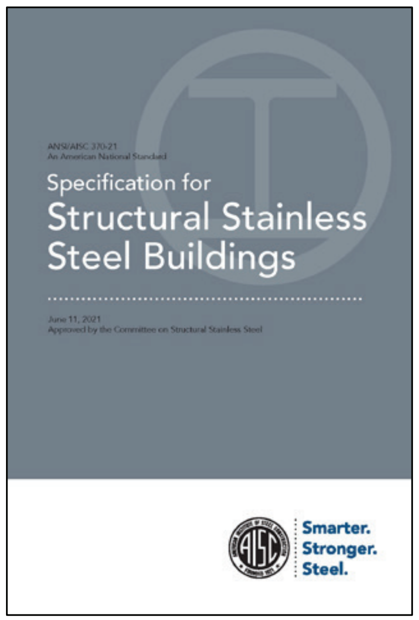


ADAPTED FROM NANO LETTERS 2021, DOI: 10.1021/ACS.NANOLETT.1C02336

When S. Chang, S. Ren and colleagues wanted to create heavy-metal-free metal – organic frameworks (MOF) for a flexible X-ray detector and imager, they looked to nickel for an innovative solution. Traditionally, radiation detectors have contained restricted metals, such as lead and cadmium. The researchers mixed a solution of nickel chloride salt and DABDT, a disulfide-reducing agent. The team sandwiched the MOF, in which nickel linked the DABDT molecules, between gold film electrodes on a flexible plastic surface, using copper wires to transmit current. Placing an aluminium letter “H” on the detector, they irradiated it with X-rays, measuring a much lower current output underneath the H. The researchers say that their proof-of-concept device is a promising advance for the next generation of radiation detection.

BUILDING CODES

SETTING HIGH STANDARDS FOR STRUCTURAL STAINLESS STEEL


ANSI/AISC 370-21
An American National Standard
Specification for Structural Stainless Steel Buildings
June 11, 2021
Approved by the Committee on Structural Stainless Steel
Smarter. Stronger. Steel.

ANSI/AISC 370 – is the first US design specification for structural stainless steel. It was published in 2021.

The sudden failure of a building or bridge is mercifully a rare event, thanks largely to international or national standards: structures are designed in accordance with a design standard, using products conforming to a product standard and manufactured using techniques and to a quality level defined in a construction standard.

Building and construction design standards codify best practices, methods, and technical requirements to create a safe and sustainable built environment for the community. Standards are developed through a process of consensus. In essence, they are the distilled wisdom of people with expertise in their subject matter – material producers, fabricators, manufacturers, designers, researchers, trade associations, users, or regulators.

The requirements in design standards are often hard-fought compromises between economy and ease-of-use. It is also important that design standards are comprehensive and cover the range of structures, materials and loading scenario frequently encountered, and that they are not unduly conservative, resulting in over-design and the waste of valuable finite resources.

In the absence of a standard, time and cost-consuming code exceptions must be obtained from the relevant building authorities and this often cannot be justified by busy designers.

This was the situation in the US until last year for designing structural stainless steel – there was no stainless steel design specification for mainstream structural sections, which are the majority of the market, such as welded, hot rolled or hollow sections. Consequently, it was much easier, cheaper, and faster for engineers and their clients to use other steels, aluminium, wood, FRP, and concrete, which have structural standards and code acceptance. This situation presented a significant barrier to stainless steel's market growth and broad acceptance.

The structural design standards produced by the American Institute of Steel Construction (AISC), or closely related specifications, are used throughout North and South America, as well as in the Middle East and also for about 30% of the projects in China. In 2018, ten years after the stainless steel industry had started discussions with them, AISC finally announced their intention to prepare a full ANSI (American National Standards Institute) design standard for structural stainless steel.

Work began with the establishment of the AISC Committee on Structural Stainless Steel, which included stainless steel fabricators and welding experts, metallurgists, designers, and academics. The Steel Construction Institute in the UK played a leading role in drafting the new design rules. These were based on the significant structural research which had been carried out by universities around the world over the last 30 years or so, and had already been used as the basis for developing the rules in the structural stainless steel Eurocode.

Three years later, the new design standard ANSI/AISC 370-21 *Specification for structural stainless steel buildings* was published. It is expected that the availability of this up-to-date, user-friendly and economic design specification will remove significant long-standing obstacles for structural stainless steel designs and expand global market potential for nickel-containing austenitic and duplex stainless steels.

The benefits of this standards work are not limited to buildings and related structures: it is expected that these stainless steel design rules will be referenced in ANSI/AISC N690, *Specification for safety-related steel structures for nuclear facilities*, which is used globally, and currently does not give any stainless steel structural design information. Additionally, work is starting under the auspices of AASHTO (the American Association of State Highway and Transportation Officials) to modify the rules in ANSI/AISC 370 so that they can be used for the design of duplex stainless steel highway, pedestrian and rail bridges in the US. NI

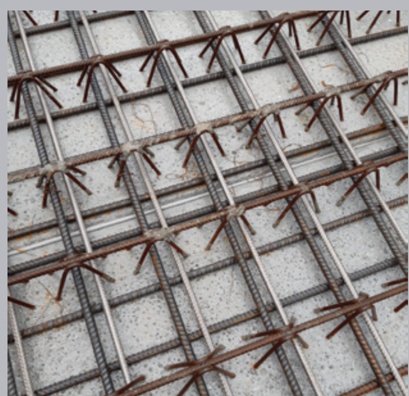
STAINLESS STRUCTURALS

Austenitic stainless steel laser welded I-shape beams and channels

A stainless steel support structure was used for the passive cooling system in the containment structure at the Vogtle Nuclear Power Plant (Units 3 and 4) in Burke County, GA, USA. The tower is 9.1 m (30 ft) tall and 3.4 m (11 ft) square, and made from duplex stainless steel UNS S32101.

PREMIER INDUSTRIAL/WESTINGHOUSE

THE NEW SAN GIORGIO BRIDGE
STRONGER, MORE DURABLE



CENTRO INOX

The combined use of carbon steel and stainless steel, in contact with each other when immersed in concrete, does not lead to an increased risk of corrosion.

CENTRO INOX

After the collapse of Genoa's Ponte Morandi in August 2018, an independent report indicated poor maintenance and flaws in the design and construction of the bridge as the likely causes behind the deadly accident. Corrosion of the cables on the top of the southern stay of one of the towers was cited as the main culprit. Also, regular inspections were said to be insufficient to allow for an adequate level of knowledge on the effective state of degradation of the cables.

Awareness about robustness and durability of bridge design has grown since Morandi's time. The new San Giorgio Bridge (its successor) in Genoa was designed by Renzo Piano and inaugurated in 2020. Unlike the original bridge's cable-stayed design, it uses stainless steel reinforcement, which not only guarantees mechanical strength, but also corrosion resistance.

Stainless steel was specified in the most critical areas at the design stage. For example, stainless steel rebar was chosen for the pedestrian zone of the bridge and positioned next to steel rebar which is located closer to the bridge deck core. When immersed in the concrete, the combined use of carbon steel and stainless steel, in contact with each other as the image shows, does not lead to an increased risk of corrosion of the carbon steel.

Reinforced where it's needed

Stainless steel acts as a protection against corrosion and cracking or spalling of the structure elements most exposed to atmospheric agents; in fact, in very aggressive environmental conditions, such as marine and port structures, it is necessary to use materials with the right characteristics. In the absence of stainless steel, external agents would trigger the corrosion of the carbon steel reinforcement, leading to an increase of its volume, causing the concrete to crack over time and the structure to deteriorate further.

Type 304L (UNS S30403)/1.4307 stainless steel reinforcement of different diameters was positioned at the outer surfaces of the concrete structure, in the sections of the structure which have a thinner concrete cover and are more exposed to the corrosion. Where exposure is not an issue (such as in the bulk of the concrete), carbon steel rebar ensures the structural integrity of the concrete.

Long-term value

The San Giorgio Bridge features 9000 t of carbon steel rebar and an additional 250 t of stainless steel rebar. This ratio of (only) 3% is typical of the 1 to 5% range that characterise reinforced concrete projects exposed to corrosive conditions. Observing such a ratio is also beneficial to the total cost of ownership of infrastructure projects.

When dealing with the challenges of harsh marine environments, stainless steel provides significant savings overall in maintenance costs for bridges, proving to be the most economical solution in the long term. Other important advantages in marine settings include superior mechanical strength, high ductility and excellent energy absorption capacity during seismic events. Ni

The stylish San Giorgio Bridge, shown completed (above) and under construction (left), uses about 250 t of Type 304L stainless steel rebar in critical areas only.

STAINLESS STEEL CABLES
HOLDING UP IN HARSH CONDITIONS

Stainless steel wire rope and cable is used in many industries such as oil and gas, construction, architecture, automotive, pulp and paper, food processing and textiles.

When it comes to hoisting heavy weights and defying gravity, it is critical to get the equipment right. Hardworking metal wire cables and ropes play an everyday role in efficiency and safety in the construction industry, offshore operations, oilfield drilling platforms, architecture, and automotive applications to name a few.

The term wire rope is often used interchangeably with wire cable. However, in general, wire rope refers to diameters larger than 3/8 inch (9.5 mm). Sizes smaller than this are designated as cable.

The industry is divided into stainless steel and galvanised carbon steel. In comparison to galvanised carbon steel, stainless steel wire ropes are more durable and corrosion-resistant in harsh conditions, such as marine and saltwater environments.

Nickel-containing Type 304 (UNS S30400) is the most used stainless steel grade in wire rope and cable. It has about the same strength as galvanised wire rope but is much more corrosion resistant. For highly corrosive environments, Type 316 (S31600) stainless steel wire rope has even better resistance to pitting corrosion and acids. Useful for marine applications, it also performs well in industries where chemicals are predominant such as pulp and paper, food processing, and textiles. Stainless steel wire rope and cable can also be used in temperatures up to 480 °C (900 °F).

Environmental conditions, workload limits (WLL) and tensile strength all play a role in choosing the right stainless steel cable for every project. From oil riggings to bridge barriers, children's playgrounds to yachts, stainless steel cable is a hardwearing material that provides a practical, robust solution as well as contributing aesthetically towards the design. Ni

CRITICAL CONNECTIONS
ADVANTAGES OF STRONGER BOLTS

Bolt failures, arising from overload, fatigue or corrosion, can be very costly; especially when they necessitate the shut-down of key operations whilst repair work is undertaken.

Fasteners come in a variety of steel alloys, so it is important to know the specifics of the application to ensure the correct steel is selected for the intended use to avoid failure. As well as the loads to be carried, issues to consider include accessibility of the connection, environment (temperature, water exposure, corrosivity), and the materials being joined. Reusability and the installation process are also important considerations. To guarantee a trouble-free lifespan and low lifecycle cost, it is essential to select the right grade and properties for the application.

Essential for demanding applications

Stainless steel fasteners are widely used in many demanding industrial applications where carbon steel fasteners would be simply inadequate, such as water treatment, wind energy, chemical process, marine, and also for subsea equipment. They are available in a range of alloys and conditions, offering different strengths, levels of corrosion resistance, and also the ability to operate at both high and low temperatures. As well as being essential for connecting stainless steel members, stainless steel bolts are also suitable for connecting galvanised steel and aluminium members. For example they are used to connect the structural members in aluminium helidecks on offshore platforms.

Long-term cost advantages

Although they are more expensive than their carbon steel equivalents, the savings arising from long life with low maintenace can easily outweigh the initial costs in demanding applications. For example, in 2019 about 6000 duplex and super duplex stainless steel fasteners were used to construct a stainless steel bridge and integral liner to strengthen an old Victorian sewer tunnel in London, UK. Due to the disruption caused by the project and accessibility difficulties, a low-maintenance solution with a 120-year design life was essential. Additionally, the structure was required to be very compact and carry high loads. High strength duplex stainless steel bolts, typically containing between 5 and 7% nickel, were the obvious choice. Utilising the high strength of duplex stainless steel also meant the connections could be downsized, saving materials and cost, and improving constructability on site, with health and safety benefits due to reduced material handling. Ni

Bracing connection in a stainless steel canopy at Porto Airport, Portugal

NANCY BADDOO

MARAGING STEEL
HIGH STRENGTH AND TOUGHNESS

The high strength-to-weight ratio of maraging steels makes them a prime choice for aircraft landing gear.

Demand for high tensile strength steel with good elongation properties led to the development in the late 1950's of maraging steels by C. Bieber of the International Nickel Company (INCO).

The term 'maraging' is a combination of the words 'martensite' and 'ageing'. They are a class of low carbon steels with a martensitic microstructure that are strengthened by a heat treatment process (ageing). This results in the precipitation of various intermetallic particles within the martensite microstructure. There are several variants, but the principal alloying element is ~18% nickel and secondary alloying elements are cobalt, molybdenum, titanium and aluminium. This family is known as the 18Ni maraging steels. There is also a family of cobalt-free maraging steels which are cheaper but not quite as strong. The most common 18Ni maraging grades, with their typical composition and aged mechanical properties, are shown below. They are identified by a number which indicates the approximate tensile strength in thousands of pounds per square inch.

Due to the low carbon content, maraging steels have good machinability. When heat treated, the alloy has very little dimensional change, so it is often machined close to its final dimensions prior to heat treatment.

Maraging steel's high strength, toughness and good ductility are utilised in the following applications:

- Missile and rocket motor cases that are thinner than when made with lower strength steels
- Aircraft – landing gear components, high performance shafting, gears, and fasteners
- Recreational – bicycle frames, golf club heads, fencing blades
- Motorsports – crankshafts, gears, chassis components, torsion bars

Additional info will be available in our new publication *Maraging steels – A review of commercial alloys and their properties.* Ni

Maraging steels – Significant alloying elements and mechanical properties – Aged condition

Grade	UNS No.	Ni	Co	Mo	Ti	Al	Fe	Tensile strength MPa (ksi)	Yield strength MPa (ksi)	Elong. %	Charpy notch impact J(ft-lb)	Hardness HRc
C-200	**K92820**	17.0-19.0	8.0-9.0	3.0-3.5	0.15-0.25	0.05-0.15	bal	1448(210)	1413(205)	12	49(36)	43-48
C-250	**K92890**	17.0-19.0	7.0-8.5	4.6-5.1	0.30-0.50	0.05-0.15	bal	1793(260)	1758(255)	11	27(20)	48-52
C-300	**K93120**	18.0-19.0	8.0-9.5	4.6-5.2	0.55-0.80	0.05-0.15	bal	2035(295)	2000(290)	11	23(17)	50-55
C-350	**K93540**	18.0-19.0	11.5-12.5	4.6-5.2	1.25-1.50	0.05-0.15	bal	2413(350)	2344(340)	7	11(8)	55-60

THE QUEST FOR
USEFUL NEW ALLOYS

Historically, development of new metal alloys was a costly, inefficient, and time-consuming trial and error process. Metallurgical knowledge would be used to formulate new alloy compositions, and determine forming and heat treatment procedures in an attempt to achieve enhanced properties relative to established alloys. A series of trial heats would be melted and tested to fine tune the properties.

Approximately two decades ago, integrated computational materials engineering (ICME) was developed to shift from physical experimentation to virtual simulation. Questek Innovations has applied this methodology to develop several nickel-containing alloys with enhanced properties.

Ferrium takes flight

Questek developed Ferrium S53, a nickel-containing, high-strength, corrosion-resistant steel. It was the first ICME-designed material to receive Aerospace Material Specification (AMS) and Metallic Materials Properties Development and Standardisation (MMPDS) qualifications and fly as a safety-critical landing gear on the US Air Force T-38 training jet. Ferrium S53 is an ultra-high strength steel for structural aerospace and other applications where AISI 4340 is typically used. Ferrium S53 has mechanical properties comparable with these alloys, but with the added benefit of atmospheric corrosion resistance which eliminates the need for cadmium coating.

Another development is nickel-containing Ferrium C64, which is an alternative to high performance gear steels such as AISI 9310. It offers ultra-high strength and high fracture toughness, combined with excellent fatigue and heat resistance. It finds application in critical aerospace and automotive applications such as rotorcraft and race car transmission gears as well as energy applications.

ICME methodology allows for more rapid development of nickel-containing multi-alloys for critical applications. Ni

Typical composition	UNS	C	Cr	Ni	Co	Mo	W	V	Si	Mn	Cu	Fe
Ferrium S53	**S10500**	0.21	10.0	5.5	14.0	2.0	1.0	0.30	-	-	-	bal
Ferrium C64	**K92731**	0.11	3.5	7.5	16.3	1.75	0.2	0.02			-	bal
4340	**G43400**	0.40	0.8	1.8	-	0.25	-	-	0.2	0.7	-	bal
9310	**G93106**	0.10	1.2	3.2	-	0.11	-	-	0.2	0.55	-	bal

Nickel-containing Ferrium 64, with ultra-high strength and high fracture toughness, finds application in transmission gears.

ASK AN EXPERT FAQ FROM THE NICKEL INSTITUTE TECHNICAL ADVICE LINE

Geir Moe P.Eng. is the Technical Inquiry Service Coordinator at the Nickel Institute. Along with other material specialists situated around the world, Geir helps end-users and specifiers of nickel-containing materials seeking technical support. The team is on hand to provide technical advice free of charge on a wide range of applications such as stainless steel, nickel alloys and nickel plating to enable nickel to be used with confidence. https://inquiries.nickelinstitute.org/

Q: I am fabricating a component using a structural steel alloy and painting it. I would like to use stainless steel, but 304L and 316L are not as strong so the plate needed would have to be thicker, and that makes the stainless version very expensive. Are there other more suitable stainless alloys?

A: Types 304/304L (S30400/S30403) and 316/316L (S31600/S31603) are nickel-containing austenitic stainless steels, that in the annealed condition only have a minimum yield strength of 30 ksi (205 MPa). While carbon and high-strength low alloy structural steels can have a minimum yield strength that can range from 36 (250) to 50 ksi (345 MPa).

There is a family of nickel-containing stainless steels known as duplex which possess a microstructure composed of approximately equal quantities of austenite and ferrite microstructure. These duplex stainless steels possess minimum yield strengths about double that of Types 304/304L and 316/316L. These duplex stainless steels have been used in many bridge constructions throughout the world in mountain, urban and seaside locations.

Three duplex grades are shown in the following table in comparison to two steel grades.

Additional information about duplex stainless steels can be found in the Nickel Institute publication *Practical guide to using duplex stainless steels (10044)*. Ni

Common name	UNS	Typical composition,%						Tensile properties ksi (MPa) min.		
		C	Cr	Ni	Mo	Mn	N	Y.S.	T.S.	EL%
Duplex										
	S32101	0.02	21	1.5	0.4	5	0.22	65 (450)	94 (650)	30
2304	S32304	0.02	23	4	0.3	2	0.14	58 (400)	87 (600)	25
2205	S32205	0.02	22	5	3.0	1.5	0.18	65 (450)	95 (655)	25
Carbon steel										
ASTM A36		0.20	-	-	-	1.0	-	36 (250)	58 (400)	23
ASTM A572 Gr 50		0.20	-	-	-s	1.0	-	50 (345)	65 (450)	21

Michael Orry Pearce 1934-2022

Michael Pearce died in his 88th year on 7 January 2022. He had a long career at Falconbridge Nickel Mines and played a key role in establishing the Nickel Institute in 1984 as Executive Director, later serving as President from 1996 to 2000. He was responsible for building international awareness and membership for the organisation where he was fondly known simply as M.O.P. Michael was a metallurgical engineer and graduated in engineering from the University of Toronto in 1957, completing his MA in 1958. He is held in high esteem by former colleagues. He was highly ethical, always respectful, and ever courteous with the ability to bring out the best in others. He is remembered for being a consummate professional as well as a thoughtful mentor and leader. Current Nickel Institute President, Dr. Hudson Bates said, "Michael Pearce's vision for the nickel industry's Institute in 1984 helped create the blueprint on which the Nickel Institute operates today." Ni

NEW PUBLICATIONS

Austenitic chromium-nickel stainless steels – engineering properties at elevated temperatures (2980) is a reprint of the original INCO publication. It provides the material properties for the common austenitic stainless steels up to 1080 °C (2000 °F).

Properties and applications of Ni-Hard alloys (11017) is the newly updated second edition of this informative publication about Ni-Hard castings. Ni-Hard castings are known for their extreme abrasion resistance used in applications such as mining, power, cement, dredging and steel industry.

They are valuable references for engineers, designers, and end users. Download from *www.nickelinstitute.org* Ni

UNS DETAILS

Chemical compositions (% by weight) of the alloys and stainless steels mentioned in this issue of *Nickel*.

UNS	C	Cr	Cu	Fe	Mn	Mo	N	Ni	P	S	Si
S30400 pg 10,14	0.08 max	18.0-20.0	-	bal	2.00 max	-	-	8.0-10.5	0.045 max	0.030 max	1.00 max
S30403 pg 8,9,14	0.03 max	18.0-20.0	-	bal	2.00 max	-	-	8.0-12.0	0.045 max	0.030 max	1.00 max
S31600 pg 3,10,14	0.08 max	16.0-18.0	-	bal	2.00 max	2.00-3.00	-	10.0-14.0	0.045 max	0.030 max	1.00 max
S31603 pg 14,16	0.030 max	16.0-18.0	-	bal	2.00 max	2.00-3.00	-	10.0-14.0	0.045 max	0.030 max	1.00 max
S32205 pg 3	0.030 max	22.0-23.0	-	bal	2.00 max	3.00-3.50	0.14-0.20	4.50-6.50	0.030 max	0.020 max	1.00 max

XAVIER PLADELLORENS

A MONUMENT TO HUMAN STRENGTH

XAVIER PLADELLORENS

Says Nadal, "The statue is spectacular. It's a clean, modern statue and I'm very pleased. It's really difficult to build a statue with that material and be so real as this one is."

With a record 21 grand slam men's singles titles in tennis, the most in history, Rafael Nadal knows how to shine, both on the courts and off.

Unveiled at Roland Garros in 2021, a gleaming statue captures Nadal hitting his signature lefty forehand. It is constructed entirely of nickel-containing Type 316L (UNS S31603) stainless steel. Standing 3 m tall, 4.89 m wide and 2 m deep, it pays tribute to the Spanish player who has won 13 titles on the clay courts in Paris, scoring his first win there in 2005.

The sculptor, Jordi Díez is known for playing with the limits of figurative art. Looking beyond the traditional and studying new techniques, he came to love working with stainless steel.

"As a material it is limitless. It really helps me express the inner energy of the person I am depicting. I wanted to depict Rafael as a synthesis of all his attributes, which I boiled down to one: strength. This sculpture is in fact a monument to human strength."

Getting up at 6:30 am and working 10-to-12-hour days, the sculpture took nearly eight months to complete.

"Stainless steel has some special qualities I respect. It's colourless. It's very light. When you work with it you feel like you are escaping reality. Then there's that magical moment when you finish the work and it takes you by surprise. That gives me strength." Ni