NICKEL MAGAZINE

THE MAGAZINE DEVOTED TO NICKEL AND ITS APPLICATIONS

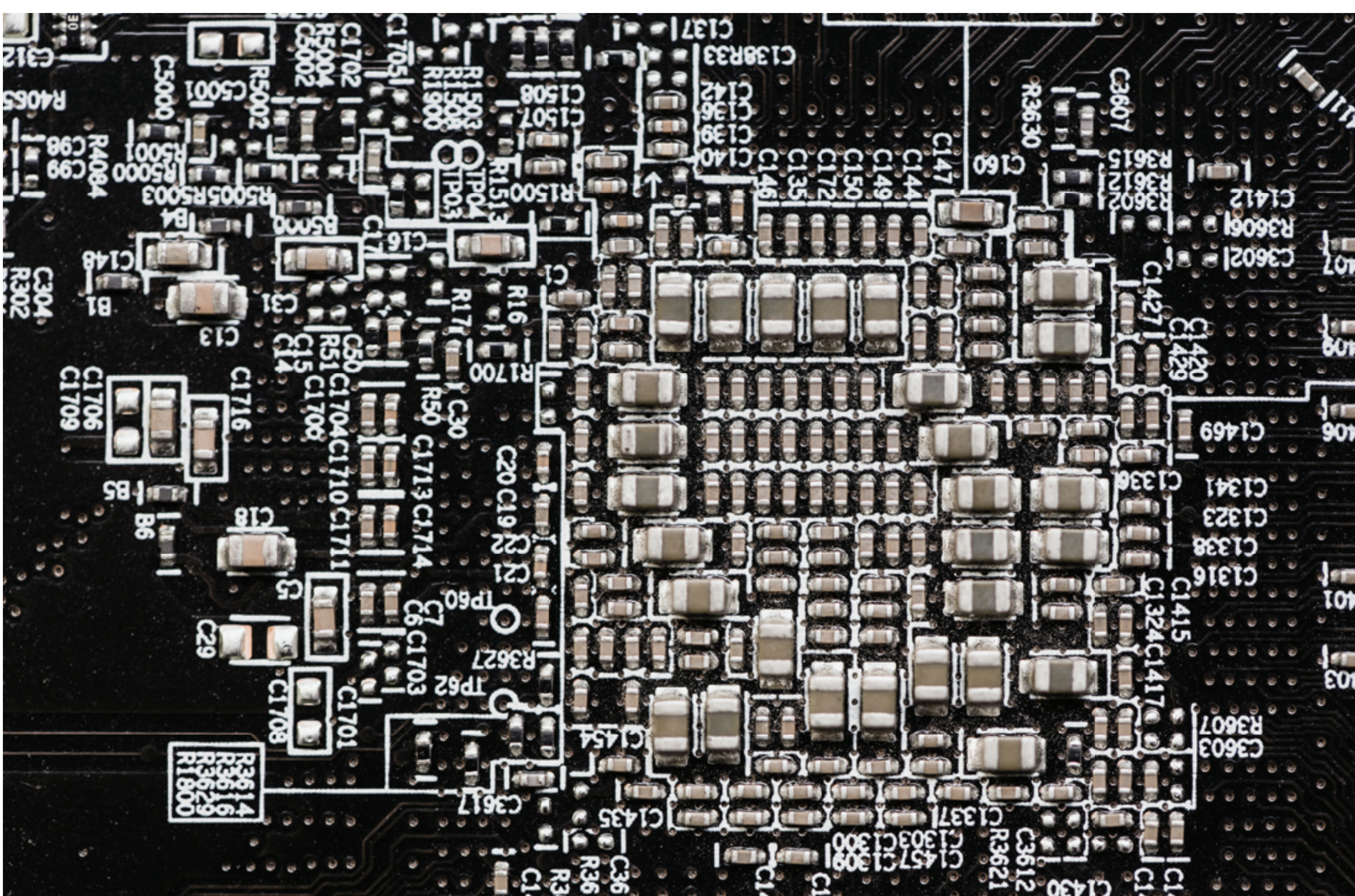
NICKEL, VOL. 36, Nº 3, 2021

Social nickel enabling social life

Mini capacitors keep us connected

Vaccine production contributing to social contact

Sociable nickel plays nicely with others



REMKO DE WAAL EPA-EFE

MX3D

Stainless steel: Arcelor Mittal

Architects: Joris Laarman Lab

Lead Engineers: Arup

Manufacturer: MX3D, a Dutch company focused on large-scale robotic wire arc additive manufacturing (WAAM)

Location: Oudezijds Achterburgwal, one of the oldest and most famous canals in the centre of Amsterdam

Length: 12.2 m

Width: 6.3 m

Height: 2.1 m

Tested under a 17 ton load, 4,500 kg of Type 308LSi stainless steel was used.

Time to print: 6 months

CASE STUDY 23
3D-PRINTED PEDESTRIAN BRIDGE, AMSTERDAM

The world's first 3D-printed stainless steel bridge is open in the Netherlands. The designers took advantage of additive manufacturing which enables almost any design to be rapidly built with little scrap and options for either on-site or factory fabrication. In this case, the 12 m bridge was built off-site.

Made of 4,500 kilograms of Type 308LSi (UNS S30888) stainless steel welding wire, the fabrication relied on four 6-axis industrial robots fitted with welding torches to 3D-print the structure. These machines produce the bridge sections using an intricate layering process resulting in a raw steel finish. Nickel makes 300 series stainless steel weldable, strong and tough, thus highly amenable for 3D-print constructions.

Designers used two methods of 3D-printing—Direct Energy Deposition (DED) and Powder Bed Fusion (PBF). With DED, the printer feeds material, usually in powder or wire form, through a pen-like nozzle, and an intense heat source melts the metal on contact. Similarly, PBF enables higher resolution, allowing the designers more precision to achieve their vision.

A process known as digital laser sintering, was used to weld together the 3D-printed bridge by large robots. It has been fitted out with sensors to collect data that keep track of its performance.

On July 15, 2021, it was officially unveiled by Queen Máxima, assisted by, what else? A ribbon-cutting robot. Ni

EDITORIAL:
SOCIAL NICKEL ENABLING SOCIAL LIFE

Nickel is a social metal. A strange idea, but when you think about it, it is the basis for what makes nickel really useful.

In this edition of *Nickel*, we examine nickel's social character, from its chemical and physical properties to the way it enables applications that help humankind connect.

Nickel readily mixes with most metals. This allows a wide range of heat- and corrosion-resistant, strong, tough, ductile and weldable alloys with varying useful, even critical physical properties to be produced. It also enables metals to work together in finishes on metals and plastics, and all these social skills are solving problems in almost every aspect of our lives.

And what about the applications for nickel which facilitate our own social networking? We look at the role of nickel in miniature capacitors which help power our smart phones – the essential tool for any socialite.

Once those electronics that have kept us connected reach the end of their useful life, what happens to them? We discuss the growing area of nickel in electronic waste and how it is being reclaimed from these applications to serve again. Recovered nickel is often reused in alloys such as stainless steel, where producers can take advantage again of its sociable nature.

We also examine how nickel-containing stainless steel has helped the pharmaceutical sector rise to the challenge of producing the vaccines that are so badly needed to combat diseases like Covid-19, allowing us to socialise once more.

This issue celebrates the numerous and diverse applications that nickel contributes to. Even the tiniest amount of nickel in so many applications, collectively makes a huge difference. And as we start to gather again, we are reminded, it's often the little things that matter!

Clare Richardson
Editor, *Nickel*

Nickel enables applications that help humankind connect, thanks to its chemical and physical properties.

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www.nickelinstitute.org

Dr. Hudson Bates, President
Clare Richardson, Editor

communications@nickelinstitute.org

Contributors: Gary Coates, Jim Fritz, Richard Matheson, Geir Moe, Kim Oakes, Odette Ziezold

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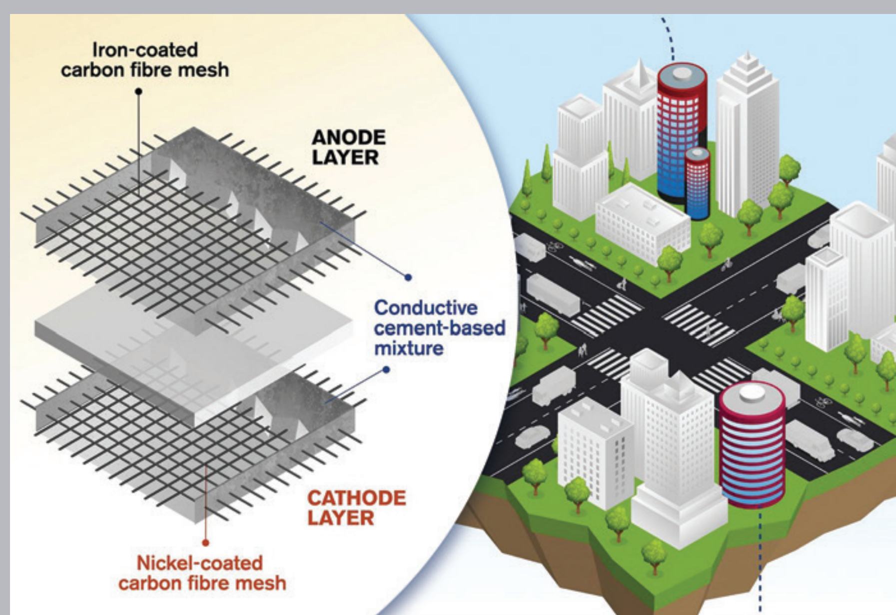
NICKEL NOTABLES

More power to concrete



YEN STRANDQVIST/CHALMERS UNIVERSITY OF TECHNOLOGY

Turn an apartment into a giant battery? Researchers Tang and Zhang at Chalmers University in Sweden have developed a prototype for a rechargeable, cement-based battery. The breakthrough involved embedding a concrete mix with short carbon fibres, an iron-coated mesh of carbon fibre, and mesh coated in nickel, using iron for the anode and nickel for the cathode. Research yielded an average energy density of 7 watt-hours per square meter. Low compared to commercial batteries, but through sheer volume, the technique is capable of storing and delivering a substantial amount of energy. Concrete is the world's most widely used construction material, so when the cement-based battery is incorporated into buildings, bridges, and sidewalks in the future, it could be a construction game-changer towards greater sustainability.

Branching out in China

It's a futuristic forest where whimsical architecture meets technological ingenuity. Located in Nanjing, China and part of the Jiangsu Garden Expo, the Future Garden features 42 stainless steel trees that act as umbrellas supporting the roof. Each tree is the same and they are all connected to one another. The acrylic panel is the top of the lotus leaf, the first of its kind in the world. The area, transformed from reclaimed mines and an abandoned cement plant, is now a delight to the eye, despite its complex ground conditions and construction challenges. It was successfully completed using 1,000 tons of nickel-containing Type 316L (UNS S31603) stainless steel.

CHINA ARCHITECTURE DESIGN & RESEARCH GROUP PHOTO: ZHANG GUANGYUAN

Flying electric

ELECTRICAIR

In a significant step towards greener skies, ElectricAir's founder Gary Freedman recorded the world's longest flight over water by a pure electric plane, making a 40-minute journey across the New Zealand's Cook Strait. Powered by two nickel-containing lithium battery packs to drive the electric motor, they can last up to 90 minutes and be recharged in under an hour. The solo flight came 101 years after the first conventional aircraft flight over the strait that separates New Zealand's two main islands and timed to coincide with the opening of the October 2021 U.N. Climate Summit in Scotland. "The start of radical change." Freedman says, "Bigger, longer-range electric aircraft are on the way and are ideal for short haul routes."

Measuring the sweet in sweat

Scientists from Pennsylvania State University have published the details of an innovative, noninvasive, low-cost sensor that can detect glucose in sweat, in *Biosensors and Bioelectronics*. First constructed with laser-induced graphene (LIG), it was "not sensitive to glucose at all". They then chose nickel because of its "robust glucose sensitivity." Attaching the reusable device to the arm one hour and three hours after a meal, the subject performed a brief workout. While the concentration of glucose in sweat is about 100 times less than in blood, the new device accurately measured the glucose as verified by commercially available monitors. "We want to work to see how we can apply this technology for daily monitoring of a patient," Cheng said.

PENNSYLVANIA STATE UNIVERSITY

NICKEL IN YOUR POCKET
MINIATURE CAPACITORS KEEP US CONNECTED

Nickel has allowed MLCCs to shrink in size by reducing the thickness of the dielectric layer, while maintaining the same capacitance values.

The smartphone in your pocket is a complex electronic system incorporating many different functions that are all powered by the same internal battery. An electronic circuit is composed of individual electronic components, such as resistors, transistors, capacitors, inductors, and diodes, connected by conductive wires or traces through which electric current can flow. The capacitor is a component which has the ability or "capacity" to store energy in the form of an electrical charge, much like a small rechargeable battery.

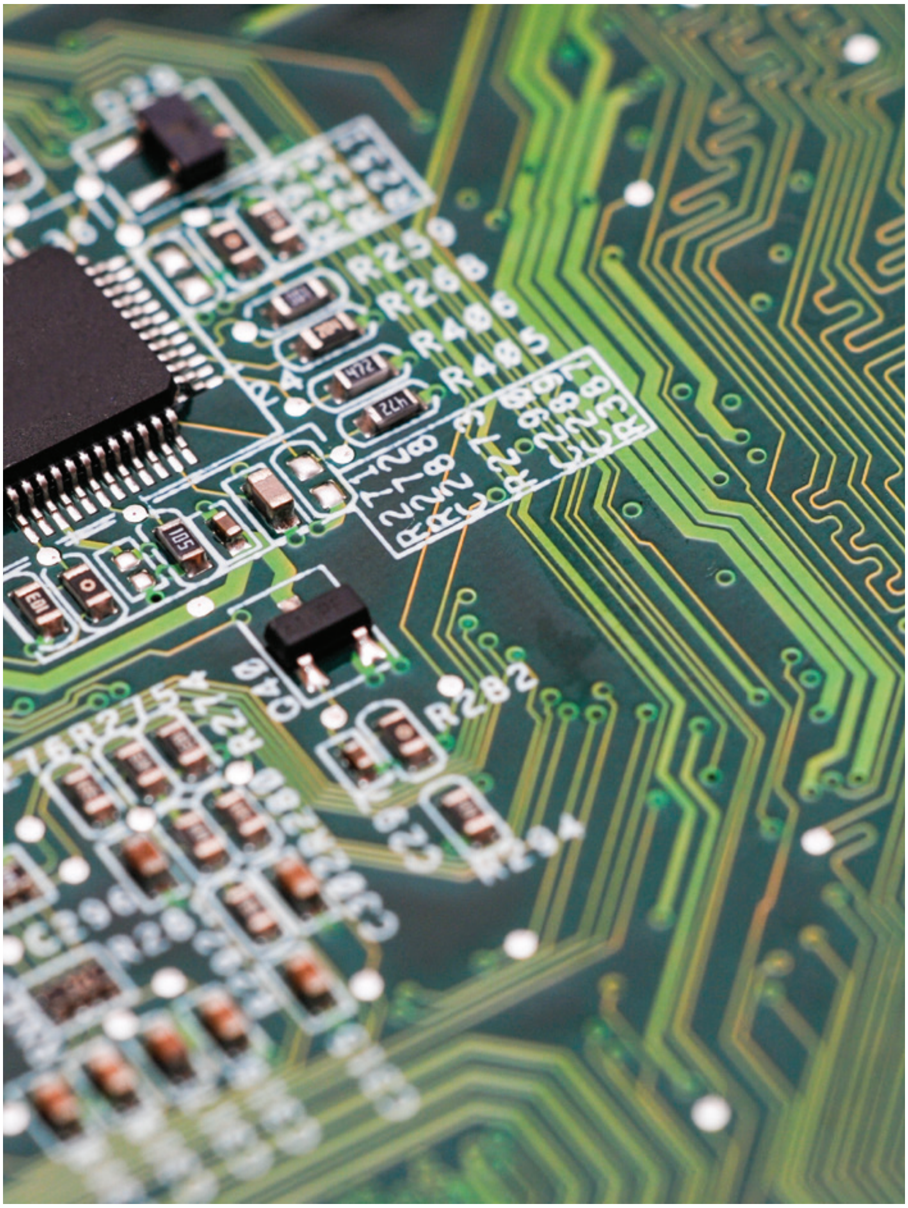
Capacitors are essential for an electronic circuit to function. If power supplies could provide a constant voltage regardless of the current draw and there were no components that produced electrical noise, capacitors would not be required. But fluctuating voltage is a reality and has to be smoothed out. The capacitor provides buffer storage that always makes sure there is enough current for all components and filters out 'noise' to ensure the various electronic subcircuits function as designed.

In consumer electronics, there are often hundreds and in the case of high-end smartphones, such as an iPhone, more than a thousand miniature capacitors. Known as Multi-Layer Ceramic Capacitors (MLCCs), they can be as small as a grain of sand on your favourite vacation beach. Their function is to decouple subcircuits from each other, so they are not affected by inconsistencies in the power supply caused by activity in another subcircuit.

The anatomy of an MLCC

In its basic form, a MLCC consists of two or more parallel metal plates (electrodes) which are electrically separated by an insulating material known as a dielectric. Currently MLCCs can possess 600 parallel electrodes less than one micrometre thick.

MLCCs were first invented more than 40 years ago to replace disc ceramic capacitors. Disc ceramic capacitors have two lone leads which were typically mounted through holes in the printed circuit board. They were neither conducive to rapid installation nor miniaturisation of electronics. The rectangular shape of the MLCC allowed for high-speed surface mounting. MLCCs initially used silver-palladium (Ag-Pd) as the electrode, and were replaced by nickel in the early 2000s. Nickel electrodes offered



TAIYO YUDEN EUROPE GMBH

In 2020, 4,800 tonnes of nickel powder were used to make Multi-Layer Ceramic Capacitors, which can be as small as a grain of sand.

several advantages over Ag-Pd, including:

- Thinner dielectric layers
- Higher capacitance values (better volumetric efficiency)
- Lower cost

Nickel is now the material of choice in the manufacture of MLCCs. It has allowed MLCCs to shrink in size by reducing the thickness of the dielectric layer, while maintaining the same capacitance values. Nickel-containing MLCCs are found in smart phones, wearable electronics such as smart watches and fitness bands, aerospace systems as well as smart cars, particularly cars with Advanced Driver Assistance Systems (ADAS). In fact, you will find MLCCs anywhere there are miniaturised electronics. As many as four trillion MLCCs are manufactured annually of which 40% are used in the assembly of smart phones. In 2020, 4,800 tonnes of nickel were used in the fabrication of MLCCs to create the tiny components that keep us connected and without which our electronic devices would not function.

MINING ELECTRONIC WASTE
A NEW LIFE FOR USED METALS

"Our processes are based on complex lead/copper/nickel metallurgy, using these base metals as collectors for precious metals and other metals, so called "impurities", such as antimony, bismuth, tin, selenium, tellurium and indium."
—Umicore

"E-scrap, including LIB-scrap, is placed in a copper smelting converter after pretreatment. After that, it is separated into crude nickel sulfate by electrolysis and sent to a nickel refinery to become pure nickel sulfate, which is used as a raw material for batteries."
—Sumitomo Metal Mining

"Thanks to the modular structure of our new recycling systems, we are able to react very flexibly to the market and needs and thus return more and more metal-containing materials to the material cycle."
—Aurubis

Think of the largest cruise ship. Then imagine how much it weighs – just over 100,000 tonnes, in fact. Now think about 500 of those ships, and what they weigh. That is the staggering amount of new electronic waste that we generate every year.

Over 53 million tonnes in 2020 alone, according to the Global E-waste Monitor. And every year there will be more, with 74 million tonnes projected for 2030. But today, only about 10 million tonnes of e-waste gets truly recycled, meaning we are recovering the metals and other valuable materials, including nickel. The remaining 43 million tonnes of e-waste, estimated to contain recoverable material worth around US$55 billion, is not recycled, and is landfilled instead. Cellphones, computers, TVs, appliances and other electronic components which we use every day are finding an unsatisfactory end-of-life.

Complex recovery

There is nickel in the e-waste, although the amount depends on the particular electronic components being recycled. Recovery is quite complex, as nickel is a "social metal", mixing well with most other metals. Typically, the nickel content may be between 0.5 and 2% of the total weight of a component, far less than its copper and iron content. Nickel is used in electronics for its key attributes, for example as shown by its use in MLCCs (see page 6). The precious metals – gold, palladium and silver – even if present in much smaller quantities, may have a larger monetary value. But in the circular economy, we need to recover as much as we can, and the Nickel Institute members are doing their part.

Proprietary processing

Each nickel producer involved in recycling has its own and often proprietary processing route for e-waste. It starts with pre-processing, as e-waste contains a large amount of plastics, ceramics and other non-metallic materials that have a separate path – the metallic fraction is what is of prime interest. Even there, steel in appliances can be magnetically separated out and sent to steel mills for direct recycling. Shredding of, for example, circuit boards and even whole cellphones into small pieces can help in the separation process. Some companies will have a separate recycling line for the various types of batteries, the supply of which for recycling is expected to increase rapidly as electric vehicle batteries come to the end of their life.

The processes involved in recovery of the metals, copper, nickel and the precious metals, involve pyrometallurgy (high temperature), hydrometallurgy (dissolution in acids) or both. Some companies can recover other metals used in electronics, such as indium, selenium, bismuth and other metals present in even smaller amounts.

Important raw material

E-waste has been handled by some of our members for over 30 years now. It is an important raw material, and they are willing to process it in greater quantities in the future. This material, now waste, mined many years ago, can be made into new and essential electronic components to be enjoyed by us all. Even though the amount of nickel in e-waste is relatively small, the nickel industry is a valuable partner with society in accomplishing the goal of creating a circular economy. Ni

"Vale traditionally has pyrometallurgically processed recycled materials but is evaluating hydrometallurgical routes as well. We have a robust flowsheet with several options to process this material and will continue to advance our ability to process Black Mass."
—Vale

"Our Rönnskär smelter in northern Sweden is one of the world's largest recyclers of metal from electronic material. The facility also minimises its emissions and generates district heating from electronic material."
—Boliden

"We have recycled more than one million tonnes of electronic scrap since the 1990s."
—Glencore

VITAL NICKEL IN VACCINE PRODUCTION

Tangential flow filtration skid used in vaccine production

COTTER BROTHERS CORP

Although 2020 and 2021 were filled with much bad news and suffering caused by COVID-19, vaccine development was the one bright spot that continues to bring hope that the pandemic may be brought under control. The rapid development of highly effective vaccines by pharmaceutical companies, scientists and governments will certainly be remembered as one of the greatest accomplishments of our time.

With the development of these vaccines, the next challenge is to produce hundreds of millions of doses as quickly as possible, but traditional pharmaceutical vaccine production capacity is not readily available. The construction and approval of a new pharmaceutical plant with bio-reactors and the supporting "water for injection" (WFI) and clean-in-place (CIP) systems can take 18 months or longer to be operational. During a pandemic this timing is just too slow.

To speed up vaccine production the industry has turned to single-use technologies. With this approach, polymer materials are used for the bio-reactors which are sanitised using gamma irradiation and are disposed after one use. This technology does not require the supporting WFI and CIP systems and production can be brought on line in a much shorter time period.

The most widely used material of construction in traditional pharmaceutical plants is nickel-containing Type 316L (UNS S31603) stainless steel and when increased corrosion resistance is needed higher alloyed stainless steels or nickel alloys are selected.

With the single-use approach a polymer bag is used as the bio-reactor. This method employs less stainless steel and other corrosion resistant alloys than traditional production. Although single-use production does displace some stainless steels, the nickel-containing austenitic stainless steels continue to play a vital role in vaccine production. The polymer bio-reactor bags must be placed inside metal containers called "totes" for mechanical support and temperature control. The totes are constructed from polished Type 304L (S30403) stainless steel to maintain hygiene and cleanability of the production environment.

The purification of the vaccine product is an important and necessary step in the production process. With single-use production the purification is achieved using tangential flow filtration (TFF). This technique employs membrane filtration where a feed stream passes parallel to a membrane face. A portion of the stream passes through the membrane, the permeate, and the remainder of the stream, the retentate, is recirculated back to the feed. During vaccine production this process is performed in a purification skid. The structural frame of the skid is constructed of polished Type 304L stainless steel and the tubing, which is in contact with the product, is constructed of electropolished Type 316L stainless steel.

Pharmaceutical equipment is most often built to the ASME BPE (Bioprocessing Equipment) standard. It covers materials, design, fabrication, inspections, testing and certification where high levels of hygiene are required.

The worldwide demand for COVID-19 vaccines will continue for the foreseeable future and large traditional production facilities will eventually be built. Until that is accomplished single-use production will continue to be employed for rapid production of these lifesavers. In either case, nickel-containing alloys will continue to serve as vital materials of construction. Ni

Large rectangular totes used for vaccine production

COTTER BROTHERS CORP

NICKEL THE SOCIABLE METAL

Nickel readily mixes with iron, copper, chromium, molybdenum, titanium, cobalt, and tungsten producing useful and critical engineering alloys.

Remember back to your early days in school when the teacher might include the statement "plays nicely with others" in a report card? This also describes nickel, a versatile element which will alloy with most metals. The breadth of nickel-containing alloys and their applications is unmatched.

Nickel forms binary (two element) alloys with copper, molybdenum, titanium, iron and chromium. It also forms tertiary alloys where iron is the third element either because iron is essential to the alloy's properties, or the presence of iron is not objectionable to the alloy's properties and thus is added to reduce cost.

Then there are multi-element alloys which contain many of the aforementioned elements, in particular the corrosion-resistant stainless steels and nickel-based alloys. The presence of chromium, molybdenum and other elements provide corrosion resistance. But nickel is essential to maintain an austenitic microstructure which gives these alloys their excellent fabrication and welding characteristics. Higher concentrations of nickel are required as the content of these other elements is increased. Thanks to the 'sociability' of nickel, many corrosion-resistant alloys are possible. Without them the production of most of the chemicals used by industry would be more difficult and more expensive using other less satisfactory metals.

	Name	UNS	Composition, wt.%*		Characteristics
			Ni	Other	
Binary element alloys	Alloy 400	N04400	66	32 Cu	Corrosion resistance
	Cu-Ni 70-30	C71500	30	70 Cu	Corrosion resistance
	Alloy B-2	N10665	72	28 Mo	Corrosion resistance
	Nitinol	N01555	55	45 Ti	Shape memory and super elasticity
	Alloy 36	K93600	36	64 Fe	Low expansion
	Nichrome 80-20	N06003	80	20 Cr	Electrical heating elements
Tertiary element alloys	Kovar®	K94610	29	17 Co, 54 Fe	Low expansion
	Alloy 80	N14080	80	5 Mo, 14 Fe	High magnetic permeability
	Alloy 600	N06600	75	15 Cr, 8 Fe	Corrosion resistance
	Alloy 33	R20033	32	33 Cr, 34 Fe	Corrosion resistance
Multi-element alloys	MP35N®	R30035	35	35 Co, 20 Cr, 10 Mo	High strength, corrosion resistance
	Alloy 188	R30188	22	40 Co, 22 Cr, 14 W	High temperature service
	Alloy 617	N06617	54	12.5 Co, 22 Cr, 9 Mo	High temperature service
Corrosion resistant stainless steels and nickel-base alloys	316	S31600	10	16 Cr, 2 Mo, 70 Fe	Corrosion resistance
	6% Mo SS	S31254	18	20 Cr, 6 Mo, 55 Fe	Corrosion resistance
	Alloy 625	N06625	60	21 Cr, 8 Mo, 3.5 Nb, 4 Fe	Corrosion resistance
	Alloy C-276	N10276	58	15 Cr, 16 Mo, 5 Fe, 3.5 W	Corrosion resistance
	Alloy 718	N07718	52	19 Cr, 5 Nb, 3 Mo	High strength, corrosion resistance
	310	S31000	20	25 Cr, 52 Fe	High temperature service
	330	N08330	35	19 Cr, 1.2 Si, 44 Fe	High temperature service

* Approximate composition of significant elements

INVAR – A NOBEL ALLOY

In the temperature range from room temperature up to the maximum temperature of your kitchen oven, about 260 °C (500 °F), steel which is an alloy of iron and carbon expands in size. Generally, this expansion is not noticeable nor large enough to cause a problem, but for some equipment such as precision measuring devices and mechanical clocks, thermal expansion in this temperature range is a significant problem. In 1895, Swiss physicist Charles Edouard Guillaume discovered the uniquely low coefficient of expansion of the iron-nickel alloy with 64% iron and 36% nickel for which he was awarded the Nobel Prize in Physics in 1920. This alloy was named Invar, which comes from the word invariable, referring to its relative lack of expansion or contraction in this temperature range. Between 20 °C to 100 °C (68 °F to 212 °F) the rate of thermal expansion of Invar is about one-tenth that of ordinary steel.

As nickel increases from 36 to 50%, the thermal expansion rate increases. This has led to the development of an entire family of iron-nickel alloys with their rate of thermal expansion optimised for specific temperature ranges, which are collectively known as controlled expansion alloys.

These alloys allow for the tailoring of expansion rates to match those of various glasses and ceramics to produce hermetic glass-to-metal and ceramic-to-metal seals to protect electronics from gases and liquids. Moulds can be produced to manufacture composite materials for aerospace applications to tight tolerances. Bi-metal strips with a low expansion alloy on one side and a high expansion alloy on the other side will function as a thermally activated switch. Invar also retains good strength and toughness at cryogenic temperatures and is used to manufacture membranes for containment of Liquefied Natural Gas (LNG).

This iron-nickel alloy system is critical for producing precision measurement equipment, thermal switches and protecting electronics. Ni

Controlled expansion alloys

		Ni	Fe	Co
Invar 36®	K93600	36	bal	
Kovar®	K94610	29	bal	17
Alloy 42	K94100	41	bal	
Alloy 52	N14052	52	bal	

EMILIO SEGRÈ VISUAL ARCHIVES

Swiss physicist and Nobel Prize winner Charles Edouard Guillaume

Invar® can be used as a membrane layer for LNG ship transport.

ROLAND MOURON CUVE

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 would like to know if buried stainless steel piping needs corrosion protection measures for pipe exterior surfaces (soil side).

A: This is not a simple question because soil types vary in their corrosivity and corrosivity can vary depending upon the time of year. Generally, buried steel pipelines and tanks suffer from corrosion when the soil presents one or more of the following conditions:

- High moisture content
- A pH value less than 4.5
- A resistivity less than 1000 Ω-cm
- Presence of chlorides, sulphides and bacteria
- Presence of stray currents

If the soil is well compacted so oxygen is excluded, then corrosion would be stifled. Free draining soils that lose water content quickly, typically above the water table, are less corrosive than soils that hold moisture for a long time. The presence of chloride in soils in marine areas or adjacent to roadways where de-icing salts are applied can also be problematic. And organic matter or sulphides can provide nutrients for microbial activity which may cause microbiologically influenced corrosion (MIC).

In most circumstances Type 316L (UNS S31603) is a suitable alloy. But if corrosive soil conditions cannot be mitigated by use of well drained backfill or because of the presence of corrosive species, such as chloride, the choices are to use a more corrosion resistant stainless steel, such as 2205 (S32205), 2507 (S32750) or 6Mo Type (S31254) or, wrapping in petrolatum tape. Coatings are not usual because of the probability of mechanical damage.

Useful references that discuss this topic, include:

Soil Corrosion Test for Stainless Steel Pipes – 10-year Burial Test Result Report available for free download from: *www.nickelinstitute.org*

Corrosion Resistance of Stainless Steels in Soils and Concrete by Pierre-Jean Cunat available for free download from: *www.worldstainless.org* Ni

NEW PUBLICATIONS

Two new AISC stainless steel standards published

AISC (American Institute of Steel Construction) has published two new stainless steel standards. **ANSI/AISC 370-21 Specification for Structural Stainless Steel Buildings** and **ANSI/AISC 313-21 Code of Standard Practice for Structural Stainless Steel Buildings** are available to download free of charge at: *www.aisc.org/publications/steel-standards/*

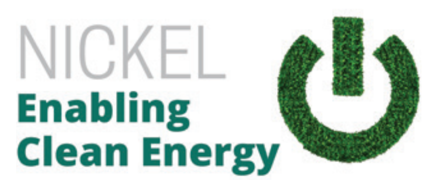
The availability of these eagerly anticipated standards will help engineers, materials specifiers and designers take full advantage of the outstanding properties of stainless steel in building, construction and large infrastructure projects such as bridges. These codes are significant because they are the first US specifications for structural use of heavier gauge hot rolled and welded stainless steel sections. The AISC codes are also used by structural engineers in many other global regions.

Nickel Institute and Team Stainless consultants Nancy Baddoo (Steel Construction Institute, UK) and Catherine Houska, along with steel producers and product manufacturers have worked closely with AISC over the last three years to develop these important new standards. Ni

New Video: Nickel Enabling Clean Energy

The Nickel Institute has created a short, fun and dynamic video showing what nickel contributes to technologies that help combat climate change. The video presents an industry that is taking its responsibilities, acknowledges that more needs to be done and produces a product that has a critical role in clean energy technologies. Available on the Nickel Institute's YouTube channel and website.

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
S30403 pg 11	0.03 max	18.0-20.0	-	bal	2.00 max	-	-	8.0-12.0	0.045 max	0.030 max	1.00 max
S30888 pg 2	0.03 max	19.5-22.0	0.50 max	bal	1.0-2.5	0.75 max		9.0-11.0	0.03 max	0.03 max	0.65 1.00
S31254 pg 14	0.020 max	19.5-20.5	0.50-1.00	bal	1.00 max	6.0-6.5	0.18-0.22	17.5-18.5	0.030 max	0.010 max	0.80 max
S31603 pg 5,10,11,14,16	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 14	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
S32750 pg 14	0.030 max	24.0-26.0	-	bal	1.20 max	3.0-5.0	0.24-0.32	6.0-8.0	0.035 max	0.020 max	0.80 max

© IWAN BAAN

A LUMINOUS ICON **LUMA ARLES TOWER**

© ADRIAN DEWEERDT

The cylindrical base invokes Arles's two-tiered Roman amphitheatre built in 90 AD. The gleaming stainless steel clad upper levels were inspired by Vincent van Gogh's Starry Night, painted in 1889 while he was at the Saint-Paul-de-Mausole asylum.

It's a striking, bold new centrepiece in the French city of Arles, a 56-metre-high tower. Its twisted facade is composed of 11,000 irregularly arranged stainless steel panels, punctuated by protruding glass window boxes, rising from a circular glass drum. Designed by Pritzker Prize-winning architect Frank Gehry, it pays tribute to the surrounding landscape and what was perhaps, in their own time, Arles' most famous residents: the Romans and the artist Vincent van Gogh. The "creative campus" hub is on a former railyard that was left vacant in 1986.

Gehry elaborated on his vision for the Tower, "The façade of the new building takes its inspiration from the limestone peaks of Les Alpilles. The building changes in appearance as one moves around it, as each of the panels reflects light differently. Rendered in stainless steel, the building panels simultaneously reference the tradition of masonry construction of the region and the industrial heritage of its immediate site."

The building is clad in 220 tonnes of Type 316L (UNS S31603) patterned stainless steel. Patterned stainless steel is a cold rolling process where a specific pattern is embossed onto the sheet. The embossing process releases tension from the sheets to achieve ultimate light reflectivity. Ni