NICKEL MAGAZINE

THE MAGAZINE DEVOTED TO NICKEL AND ITS APPLICATIONS

NICKEL, VOL. 34, NO. 2, 2019

Today and tomorrow
Nickel in life and science

The future of Carbon Capture and Storage

Detecting cosmic gravitational waves using nickel alloys

New Champlain Bridge 125 years to come

FENDER KATSALIDIS ARCHITECTS

CASE STUDY 16
MERDEKA PNB 118

Vying to be the third tallest building in the world, the 644 metre (2,113 foot) megatall skyscraper, Merdeka PNB 118 (Permodalan Nasional Berhad, a government-backed investment company) is taking shape in Kuala Lumpur. Situated in the historically significant Merdeka site, where Malaysian independence was declared in 1957, the crystalline tower will rise to 118 floors, topped with a 150 metre high spire.

According to Fender Katsalidis Architects, who worked with local architect RSP Architects, and landscape architects Sasaki Associates, "the building's faceted design is reminiscent of those found in traditional Malaysian arts and crafts."

Built to last

A structural steel system comprising six belt truss zones, three outrigger zones, composite floor decks and extensive roof framing make up the main structure. These systems ensure stablity and are designed to resist wind and earthquakes. The superstructure is supported by a 4 metres thick raft foundation slab and 137 cast-in-place bored piles, each 2.2 metres in diameter and extending 60 metres in length.

Plumbed in stainless steel

With 118 storeys to service, stainless steel pipes were chosen for the plumbing. Stainless steel is ideal for the very high pressures encountered in supertall structures as well as facilitating superior drinking water. Over 70 tonnes of stainless will be used for the plumbing system alone. Using Type 304 (UNS S30400) stainless steel, the pipes and fittings are sized from 15–60.5 mm. HOTO Plumbing system (HOTO Stainless Steel Industries), a Malaysian manufacturer of stainless steel tubes, was chosen to supply the cold and flushing water systems and Qudotech Std Bhd will provide the installation. This ambitous project is due for completion in 2021.

HOTO STAINLESS STEEL PLUMBING SYSTEM

EDITORIAL:
NEW NEW, OLD NEW AND EINSTEIN

Our society is fascinated by the new and that's understandable. But we need to be reminded that the materials that got us to where we are, are with us still. That includes nickel.

SPACEX

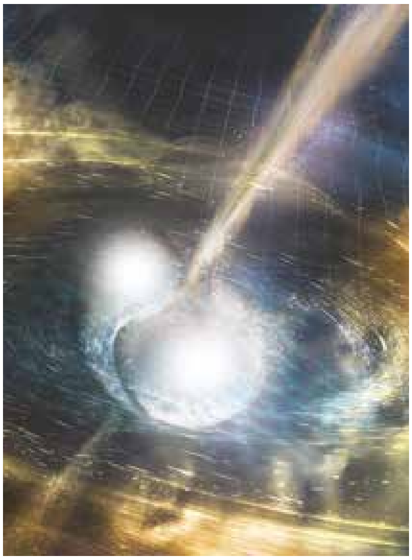
A small example is nickel-containing stainless steel in the vehicles that will take humanity beyond Earth in the future. That is the quest of Elon Musk, CEO of SpaceX. SpaceX is not alone, however, and – especially if its Super Heavy rocket is successful – will be emulated by other space pioneers.

Closer to our everyday reality is infrastructure. A major bridge, opened with great fanfare in 1962, lasted only 50 years. It continued in use until 2019 at a very high cost and inconvenience. Its replacement, the new Champlain Bridge across the St. Lawrence River in Québec, Canada, has a design life of 125 years. A major difference between the failed bridge and the new bridge is the extensive use of nickel-containing stainless steels (*see page 6*). While the consequences of inadequate material selections through the full life cycle of the 1962 structure were very costly, the new bridge reflects the lessons learned.

And Einstein? Increase your knowledge of gravitational waves and find out how nickel-containing alloys made their detection possible (*see page 10*).

Nickel celebrates the continuing contributions of nickel-containing materials to engineering, architecture and science. In various forms, nickel is an essential part of our future. On and off this planet.

Clare Richardson
Editor, *Nickel* Magazine



NSF LIGO SONOMA STATE UNIVERSITY A. SIMONNET

A lot is going on in this artist's impression of a cataclysmic space event: two neutron stars colliding. This is a work of imagination but there is a growing scientific understanding on how physics in the Universe probably works. One example of that is the recent detection and measurement of gravity waves and, yes, nickel is involved. Turn to page 10 *for the story on LIGO and Virgo.*

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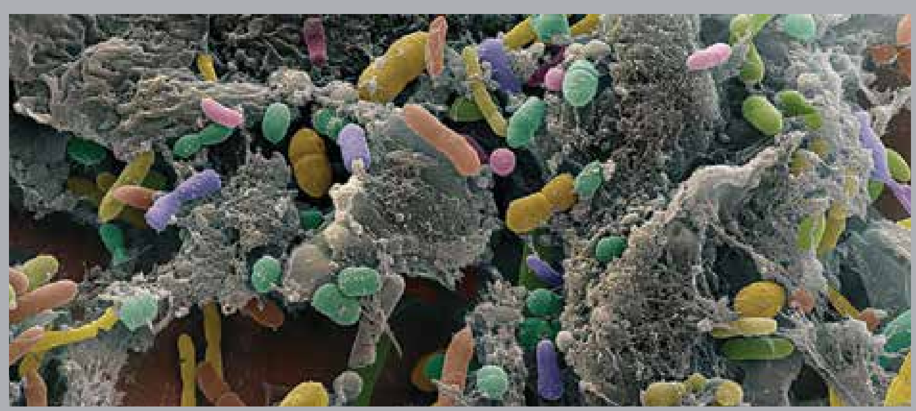
Design: Constructive Communications

ISSN 0829-8351

Printed in Canada on recycled paper by Hayes Print Group

Image credits:
Cover: iStockPhoto©cemagraphics

NICKEL NOTABLES



EYE OF SCIENCE/SCIENCE SOURCE

Bugs in space

Space is hard. It's a stressful and unnatural environment for human beings. When humans arrive in space they carry with them bacteria from Earth. But what is benign or easily managed on Earth, becomes problematic in space.

Prof. Elisabeth Grohmann of Beuth University of Applied Sciences Berlin, author of a new study, has said 'Just as stress hormones leave astronauts vulnerable to infection, the bacteria they carry become hardier – developing thick protective coatings and resistance to antibiotics – and more vigorous, multiplying and metabolising faster'.

A proprietary surface coating of silver and ruthenium has been developed and tested in the toilet area of the International Space Station. Measured bacteria presence after 12 and 19 months was over 80% reduced compared to control surfaces.

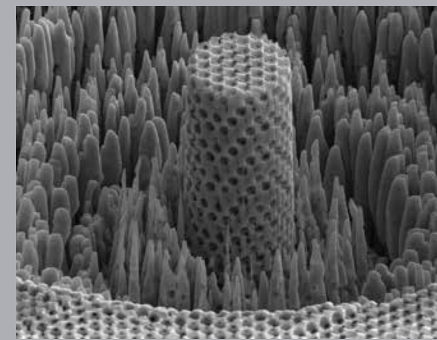
The silver/ruthenium is a surface coating. And the surface it coats is nickel-containing stainless steel Type 304 (UNS S30400), an alloy well known for its ability to accept different surface treatments.

Space will always be hard but nickel-containing materials, in leading and secondary roles, will make it possible to sustain human life.

SPACEEX

Back to the future

Rocket ships were a staple of 1950's science fiction. They were depicted at that time as shiny, fat cigars with windows, fins and legs. The spaceships of the future are now being designed with the prototypes looking very much like the fictional speculative vessels of 70 years ago. And they are being made with nickel-containing stainless steels. SpaceX is developing its Single Stage to Orbit (SSTO) vehicle that will be powered by its Super Heavy (formerly known as BFR) rocket. For a whole host of reasons, Elon Musk, SpaceX CEO, says stainless steel is the best choice for technical, performance and economic reasons, easily beating out aluminium and carbon composite.



UNIVERSITY OF PENNSYLVANIA

Metallic wood

It's as strong as aerospace titanium but lighter than water. While it is called "metallic wood", the material contains no wood whatsoever. Researchers at the University of Pennsylvania, the University of Illinois, and the University of Cambridge have built a sheet of nickel with nanoscale pores that provides the same strength as titanium but is four to five times lighter. The pores make it wood-like, with air spaces in between billions of miniature "struts" of nickel. Magnified thousands of times, the material looks like honeycomb. Next challenge? Figuring out how to produce this material in large quantities. Big slabs could be revolutionary for the building and automotive industries looking for lighter materials able to shoulder heavy loads relative to their weight.

MALVIKA VERMA

A TB treatment that's easier to stomach

A thin coiled wire could provide a big advance in treating tuberculosis (TB), one of the world's deadliest infectious diseases, infecting one-quarter of the population and killing more than one million annually. In rural areas of countries like India, South Africa and China where rates are high, it has been difficult to administer the required six-month course of daily antibiotics. The elastic wire, made of Nitinol (UNS N01555), an alloy of nickel and titanium, is inserted into the patient. It changes shape once it reaches the higher temperatures of the stomach. Up to 600 "pills" of various antibiotics are strung along the wire, and the drugs are released over a one month period. The coiling prevents it from passing further through the digestive system. Ensuring full treatment courses is a global challenge solved here with the help of nickel.

MONTRÉAL'S NEW CHAMPLAIN BRIDGE: **EXTENDED DURABILITY WITH STAINLESS STEEL REINFORCEMENT**

ARUP — INFRASTRUCTURE CANADA

Three possible stainless steel alloys were specified – Types 2304 (UNS S32304), 2101 (S32101) and 304 (S30400). All three alloys would provide substantial corrosion resistance for 125 years as they all include sufficient levels of chromium and nickel. Type 2304 (4% Ni) was used for cost and availability reasons at the time of bidding. The reinforcement was produced and fabricated in North America.

Crossing both the Saint Lawrence River and Saint Lawrence Seaway, the Champlain Bridge is the busiest in Canada carrying over 50 million vehicles annually and about 11 million transit users. It was first opened in 1962 linking Montréal and the South Shore and has served the Québec and eastern Canadian communities for almost 58 years. Now it is slated for demolition.

Replacing it is the new Samuel de Champlain Bridge, inaugurated on 1 July 2019 by Infrastructure Canada. The 3.4 km long bridge is a cable-stayed structure with three separate parallel road decks totalling 60.2 m in width which accommodates six highway lanes, two additional extra-wide shoulder lanes for buses, two mass transit corridor lanes, and a 3.5 m wide multi-use path for pedestrians and cyclists.

The original structure had severely deteriorated mainly due to the corrosive effect of road salt which was not adequately planned for, and some design flaws. Inadequate and faulty drainage caused water ponding and spillage onto critical structural elements. As well, the approach span's concrete pre-stressed/post-tensioned girders, which was a new technology in the late 1950s, deteriorated significantly. In 2013 it was announced that the bridge was to be replaced. Construction started in 2015.

Designers were faced with many service-related challenges. Montréal's environment is extremely harsh with winter temperatures often as low as -25 °C. Seasonal temperatures can vary as much as 60 °C resulting in extreme freeze-thaw cycles. The use of road salt is necessary to keep the bridge open in winter conditions.

As the bridge is an essential economic link to eastern Canada, the owner mandated a 125-year service life for the roadway component of the structure. The extended durability was achieved through design in combination with the selection of appropriate materials. Extensive life cycle cost analyses justified the cost/benefits of using more durable materials in all the core elements. Savings will come over the life of the bridge from avoided repairs and traffic disruption during roadworks.

To ensure that the desired durability and service life would be achieved, the owner stipulated the use of certain "durability-driving" materials

CHRISTINNE MUSCHI/THE GLOBE AND MAIL

ARUP — INFRASTRUCTURE CANADA

rather than take a performance-based specification approach. This included the reinforcement materials (rebar) chosen.

In the Government's assessment, the harsh conditions, the extended service life for the main components of the structure, and the economic importance of this link dictated that the reinforcement steel be stainless. A total of 17,000 tonnes of stainless steel reinforcement was used in the pre-cast and cast-in-place sections of the roadway deck of the entire span of the bridge including the approaches, the abutments and all surfaces around the expansion joints.

The new Samuel de Champlain Bridge combines beauty and utility, with every possible mode of transportation provided for. Thanks to its nickel-containing components, neither climate nor changing transportation patterns will defeat this bridge. Ni

The bottom line is that stainless steel reinforcement is a value-added feature to the design with measurable benefits in terms of long term cost savings and higher utilisation of the network by avoiding roadwork-induced traffic congestion.

FIVE YEARS OF
CARBON CAPTURE AND STORAGE

There are many innovative paths to reduced carbon emissions. One of those is the Boundary Dam carbon capture and storage complex (CCS), also known as Boundary Dam 3 (BD3). After five years of operation, stainless steels such as Type 316L (UNS S31603) as well as nickel alloys such as AL-6XN® (N08367) and 254 SMO® (S31254) continue to perform well in service at what many initially considered to be a demonstration project.

Nickel-containing alloys are performing well in SaskPower's Boundary Dam CCS complex. In the absorber section, AL-6XN® with about 24% nickel is utilised to withstand the corrosiveness of wet flue gas.

SASKPOWER

Meeting power and climatic needs

Boundary Dam is a large coal-fired power generating plant operated by a Canadian provincial utility, Saskatchewan Power Corporation. Operating since 1955, the BD3 turbine unit was retrofitted in 2014 with a carbon capture and storage facility, becoming the first coal-fired power station in the world to utilise Post Combustion Capture.

With a nominal 30-year life, the original design concept was to capture and store up to one million tonnes of carbon dioxide per year from the flue gas, with the added benefit of extending turbine life by decades. With a cost in the order of Cdn $1.5 billion and a reduction of unit power output from 139 MW to net 115 MW, the economics of this facility has not been without controversy even as the technology and materials are proving robust.

SO_2 and CO_2 – a double challenge

For utility-scale power generation, coal is still very widely-used, providing energy for roughly 40% of the world's electricity. Saskatchewan has more than five billion tonnes of lignite coal reserves – sufficient for another 250 years at current rates of consumption.

Sulphur dioxide (SO_2) is a significant combustion product and presents a double challenge for CCS: removal of both SO_2 and CO_2. Upstream, particulate matter is first removed from the flue gas in a precipitator. The particulate, marketed as fly ash – is a fine powder used in concrete, mining, oil wells, road bases, as well as for liquid waste stabilisation. Nitrogen oxide (NOx) is minimised in the flue gas by the use of low-NOx burners, and the limiting of overfired air. The process used to reduce emissions is a solvent-based CO_2 capture technique, coupled with a SO_2 removal process.

First, SO_2 is removed from the flue gas and subsequently CO_2 is captured in the same facility. The SaskPower BD3 CCS unit is capable of removing up to 100% of the SO_2, converting it into marketable sulphuric acid at the rate of 16,000 litres per day.

Up to 90% of the CO_2 can be removed from the flue gas. This gas is compressed to 17.2 MPa (2500 psig) pressure into a supercritical state or dense phase condition. It is then transported via pipelines to geological storage locations: an oil reservoir approximately 1.4 kilometres deep at an enhanced oil recovery operation near Weyburn, Saskatchewan, or a saline aquifer approximately 3.4 kilometres deep. To prove that storing CO_2 deep underground in a layer of brine-filled sandstone is a safe way to reduce greenhouse gas emissions, this geological storage site is subject to measurement, monitoring and verification.

Regular in-service inspections have shown the nickel-containing alloys throughout the unit to be in good condition. Process system components such as vessels, purification and filtration units, piping, compressors, and heat exchangers generally show no signs of pitting and corrosion. In most cases, the metal exposed to the process appears as good as it did when first put in service.

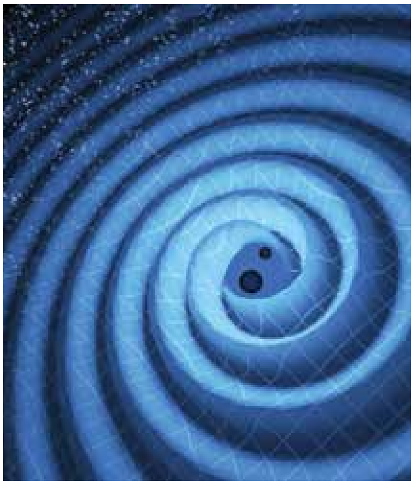
Stainless steel AL-6XN®, a super-austenitic alloy, is known for its high strength, as well as resistance to crevice and pitting corrosion in acidic solutions – just one example of how nickel-containing materials enable innovative technologies in providing paths to a reduced carbon future. Ni

Since 2014, SaskPower's plant performance statistics have shown steady improvement, with approximately 2.6 million tonnes of CO_2 processed to date. In 2018, the CCS facility captured a total of 625,996 tonnes of CO_2, significantly more than 2017. Once external reasons for downtime are excluded, CCS unit availability was 94%.

SASKPOWER

EINSTEIN CORRECT (AGAIN)

PREDICTED GRAVITATIONAL WAVES DETECTED, ENABLED BY NICKEL-CONTAINING ALLOYS



LIGO/T. PYLE

In the above illustration, two black holes are about to merge. Each will have its own rotation and, powered by their mutual gravitational attraction, are spiraling into each other. These black holes were detected on 26 Dec. 2015, and were respectively, 14 and eight times the mass of the sun. The wave-time dimension here is represented by the grid pattern and is being distorted by the gravitational waves generated by the merger. Such events are not trivial even at the scale of the Universe. As LIGO and Virgo are demonstrating, however, they are not rare.

In 1916, Albert Einstein published the paper that predicted gravitational waves – ripples in the fabric of spacetime resulting from the most violent phenomena in our distant universe, such as supernovae explosions or colliding black holes. For more than a century, this prediction has intrigued scientists: could such waves – if they existed – be detected? If so, the implications for fundamental physics – the confidence that Einstein's General Theory of Relativity was indeed a workable theoretical framework – would be profound.

Gravitational-wave astronomy was a theoretical branch of observational astronomy which hoped to use gravitational waves to collect observational data about objects such as neutron stars, black holes and events such as supernovae. But first their existence had to be proven. Scientific and political support for such a search was found and three coordinated efforts, two in the United States (LIGO) and one in the European Union (Virgo) were the result.

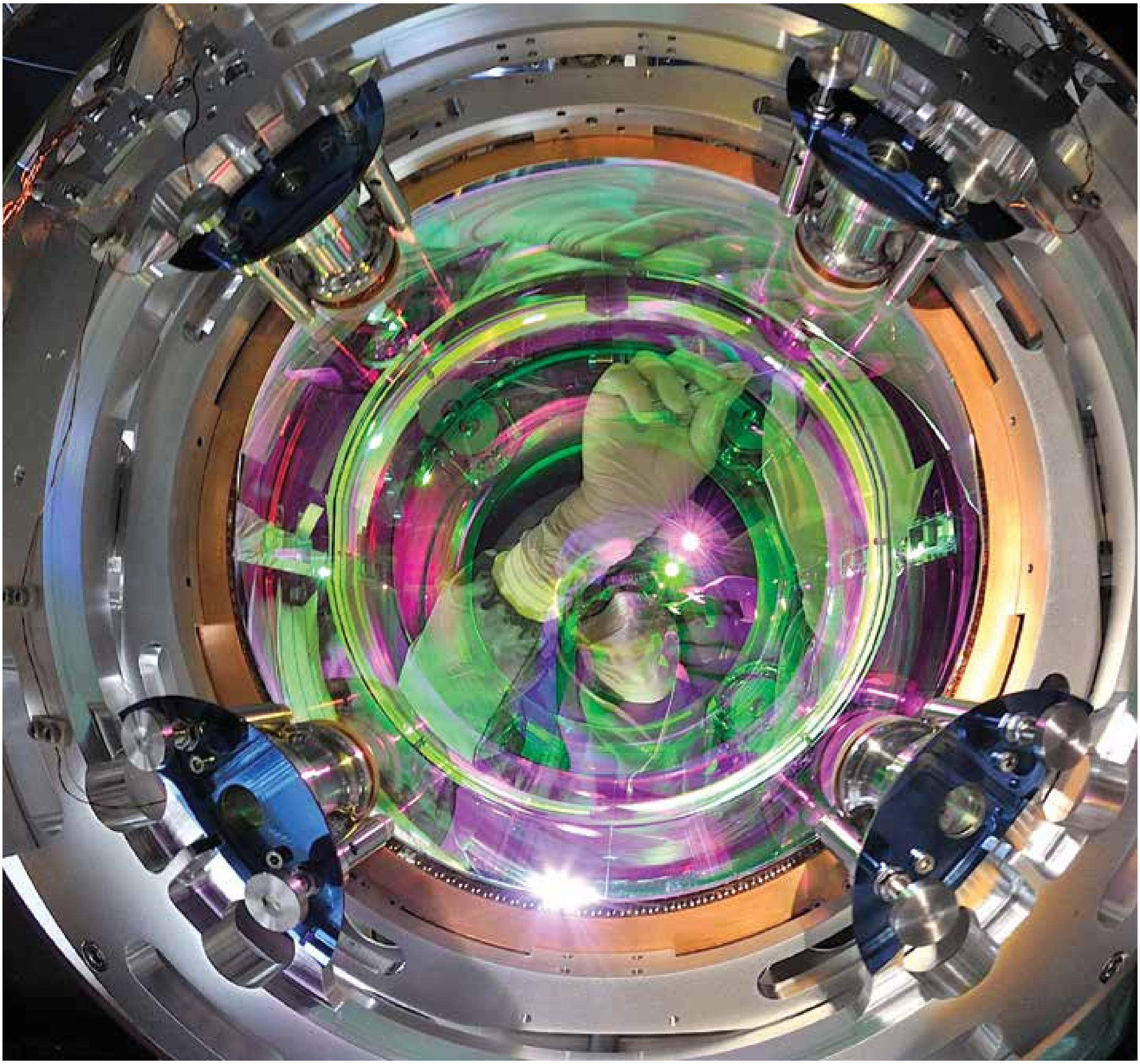
Theoretical no more

The Laser Interferometer Gravitational-Wave Observatory (LIGO) is a large-scale physics experiment and observatory, operated for the U.S. National Science Foundation by Caltech (California Institute of Technology) and MIT (Massachusetts Institute of Technology) to detect cosmic gravitational waves and to develop gravitational-wave observations as an astronomical tool.

Two observatories were built with the aim of detecting gravitational waves by laser interferometry. This is done by comparing the travel time of laser beams sent along two perpendicular paths 4000 metres in length and reflected back from isolated, suspended test bodies.

Initial LIGO operations between 2002 and 2010 did not detect any gravitational waves. In 2008, work commenced to enhance the original LIGO detectors. With upgrades that resulted in a huge increase in sensitivity, the two 4000 metre paths are now continuously compared with a precision of 10^{-19} metre, 1/10,000th the size of a proton.

Achieving this degree of sensitivity requires a remarkable combination of technological innovations in precision lasers, vacuum technology, and advanced optical and mechanical systems. Two LIGO observatories, in the States of Washington and Louisiana, are operated in unison to reject terrestrial disturbances.



EGO/VIRGO COLLABORATION/PERCIBALLI

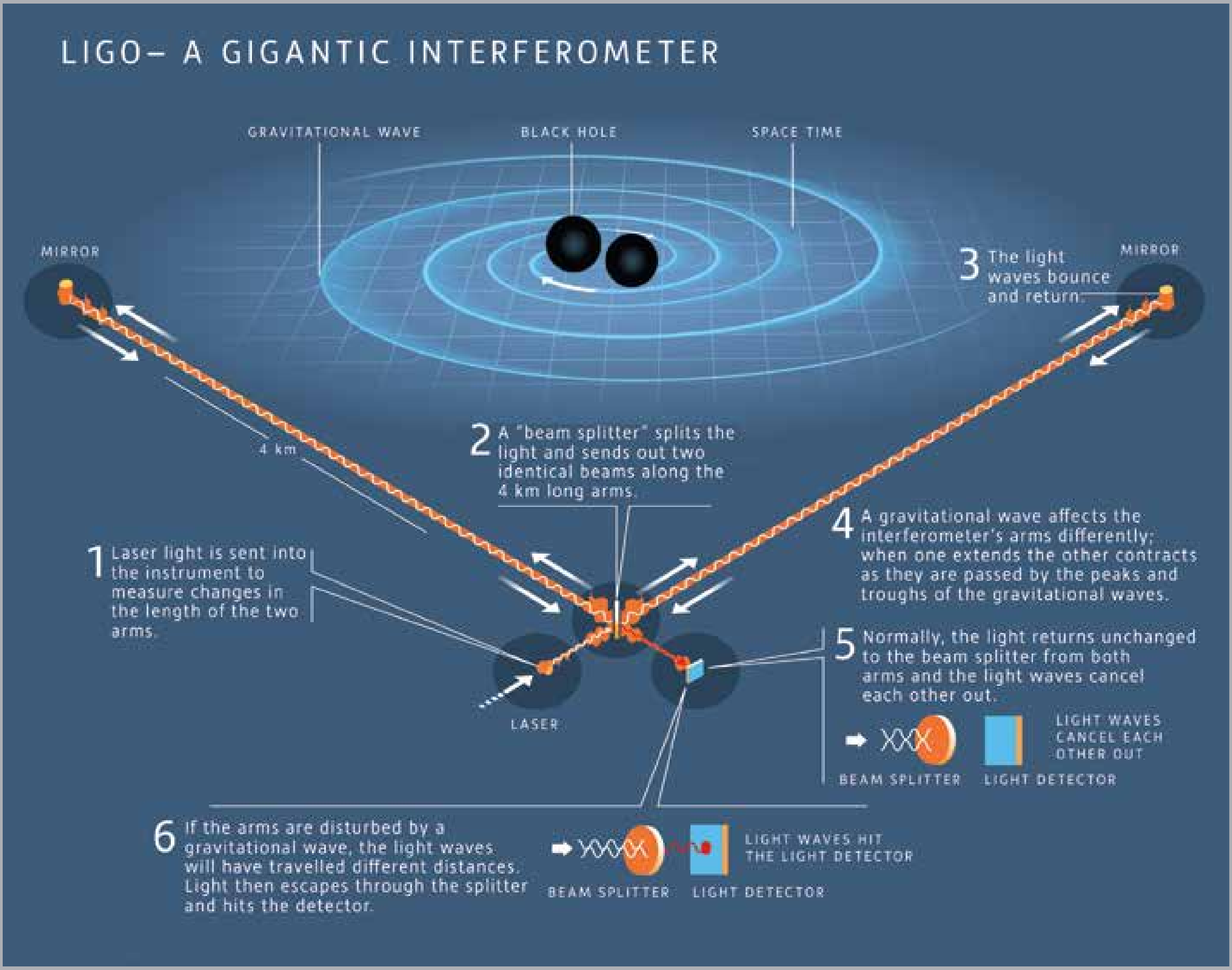
EU too

Virgo, the European equivalent of LIGO, dates back to 2000 when France (Centre nationale de la recherche scientifique/CNRS) and Italy (Istituto Nazionale de Fisica Nucleare/INFC) formed the European Gravitational Observatory (EGO). They were later joined by institutes from the Netherlands, Poland, Hungary and Spain. It had a similar history to LIGO and underwent a similar upgrade.

Eleven gravitational events were detected during the first two observational runs between Sept. 2015 and Jan. 2016 and Nov. 2016 to Aug. 2017. Since the third observational run began in Jan. 2019, there have been an additional 18 detections yet to be confirmed as gravitational events.

Physics does not get more fundamental than this and nickel-containing alloys have again allowed scientists and engineers to push the boundaries. In this case, into another dimension. Ni

LIGO has been upgraded for what is known as the Third Observational Run. Here a technician is working on one aspect of that upgrade. The use and essentiality of nickel-containing materials for strength, machinability, rigidity and thermal stability is apparent.



JOHAN JARNESTAD THE ROYAL SWEDISH ACADEMY OF SCIENCES

CALTECH/MIT/LIGO LAB

"Interferometers merge two or more sources of light to create an interference pattern that can be measured and analysed. They are often used to make very small measurements that are not achievable any other way."

Source: LIGO Caltech

Where's the nickel?

Nickel-containing materials were used in the fabrication of many critical components in the LIGO and Virgo observatories which have similar installations. At the LIGO observatories, to prevent air refraction from disturbing the laser path, each of the LIGO machines is enclosed in one of the largest ultrahigh-vacuum systems on the planet. Each system is comprised of 8000 m of Type 304L (UNS S30403) stainless steel beamtube, 1.2 m in diameter and 3.2 mm thick. Beamtubes at both sites therefore include more than 120 tonnes of nickel; another 15 tonnes or so are included in the vacuum vessels, valves and connecting spools that house and protect the optical systems at the vertex and ends of each system.

Other internal components are fabricated from Type 304 (S30400), 304L and 316 (S31600). Some components are further plated with non-reflective black nickel coatings, to control stray light reflections. Critical high-stress isolation springs and suspension flexures are fabricated from age-hardened Maraging 300 (K93120), which are nickel-plated to resist corrosion during processing and assembly. Ni

NICKEL ON BOARD
ALSTOM'S HYDROGEN TRAINS PROVIDE EMISSION-FREE PASSENGER SERVICE IN LOWER SAXONY

The Coradia iLint, a hydrogen fuel cell train built by Alstom Transport, took its first scheduled trip from the station of Bremervörde in Lower Saxony, Germany on 16 September 2018. The Coradia iLint is the world's first passenger train powered by a hydrogen fuel cell, which generates electric power for traction by combining stored hydrogen with oxygen in the air. The train is quiet and the only emission is water vapour.

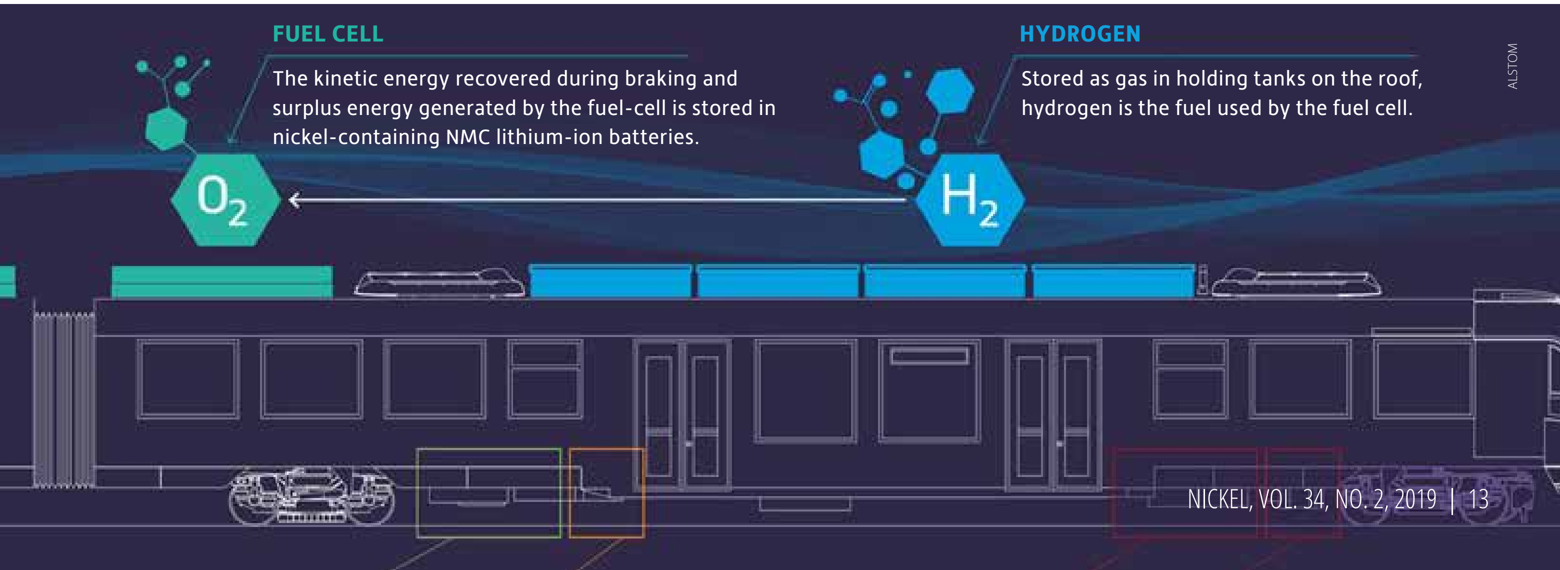
The kinetic energy recovered during braking and surplus energy generated by the fuel-cell is stored in nickel-manganese-cobalt (NMC) lithium-ion batteries. This stored excess energy is available for normal operations, and supplies additional power during the acceleration phases of the train.

The train can carry 150 seated passengers and 150 standing passengers. Its maximum speed is 140 km/h and can travel 600–800 km on a full tank of hydrogen, with the assist of the NMC battery. Dr. Jörg Nikutta, Managing Director for Alstom in Germany and Austria, states, "Our technology is ready for use. It represents an existing environment-friendly alternative for non-electrified or partially electrified lines and offers increased passenger comfort thanks to a significantly quieter train than a conventional diesel multiple unit."

High-strength nickel-containing stainless steel 410L (UNS S40977) is used for the car shells as it is corrosion-resistant and longer lasting than plain carbon steel.

CORADIA ILINT

Two Coradia iLint engines will replace diesel trains on the 100 km route linking the towns of Cuxhaven and Buxtehude, with 14 other hydrogen trains set to be introduced across Lower Saxony by 2021.



ALSTOM

STUNNING DISCOVERY SLIDES
AT JEWEL CHANGI AIRPORT

IMAGE: JEWEL CHANGI AIRPORT

How do you make an airport more inviting? You create the world's first art sculpture and slide combined into one unique attraction. Integral to the airport's strategy to provide an extraordinary visitor experience, the Discovery Slides are part of this multi-dimensional lifestyle destination where nature meets engineering under a beautiful glass and steel dome.

Located in the Canopy Park on the highest level of the new development at Singapore's Changi Airport, four slides of various gradients and heights offer different "wow" experiences; a family slide, a steep drop slide and two glass-covered spiral slides.

The structure incorporates a double curved steel surface, curved glass and fibre optic lights. Plates of Type 316 (UNS S31600) stainless steel were welded, hammered and polished to achieve the smooth mirror finish which forms a continuous and seamless bright steel skin wrapping around the three cones holding up the large access platform. Designed by Carve, the sculpture has over 311 m^2 of stainless steel and weighs a total of 70 tonnes of which 50 tonnes is stainless steel.

It is over 18 m by 16.7 m in area and is 6.5 m high at the highest point.

The project took two years from concept to completion and was built in three different parts of the world before being assembled at Jewel by Playpoint.

The play-sculpture is quickly becoming a hit, a social media favourite and a great reason to book a flight to Changi. As more of these elevated experiences slide into airports in the future, we hope that nickel continues to be along for the ride. Ni

Jewel is a nature-themed entertainment and retail complex at Singapore's Changi Airport. Canopy Park is on the tenth floor and features gardens and leisure facilities.

CARVE

NEW PUBLICATIONS

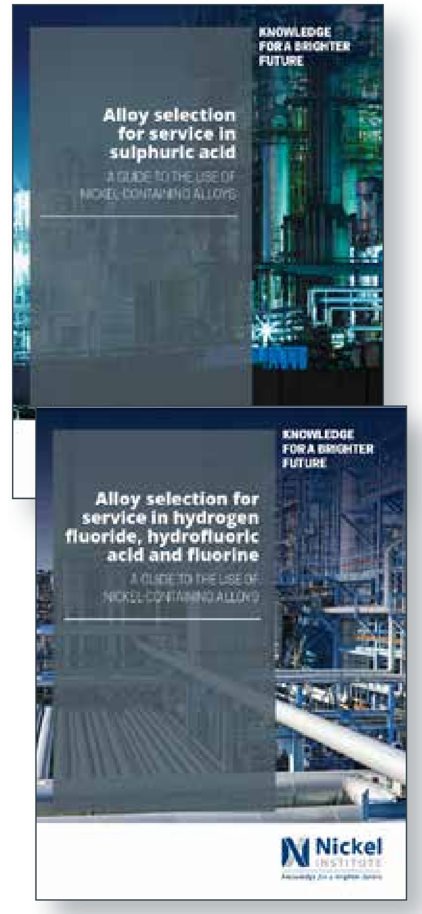
The Nickel Institute has published two new technical guides to assist in the effective use of nickel-containing materials.

Alloy selection for service in sulphuric acid (10057) reviews the corrosive effect of sulphuric acid at all concentrations, and the influence of contaminants on its corrosivity with a range of materials including steels, stainless steels, nickel-base alloys, lead, titanium, zirconium and tantalum under various conditions. It also briefly discusses sulphuric acid manufacture from three possible feedstocks.

Alloy selection for service in hydrogen fluoride, hydrofluoric acid and fluorine (10074) examines the corrosive effect of fluorine, hydrogen fluoride and hydrofluoric acid with a range of materials including steels, stainless steels, nickel-base alloys, copper-base alloys, titanium, zirconium and tantalum under various conditions.

These fully revised technical publications from the Nickel Institute provide a useful guide for materials engineers.

Available to download free from www.nickelinstitute.org Ni



UNS DETAILS

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

UNS	Al	C	Co	Cr	Cu	Fe	H	Mn	Mo	N	Nb	Ni	O	P	S	Si	Ti
K93120 p. 12	0.05-0.15	0.03 max.	8.0-9.5	-	-	bal.	-	0.10 max.	4.6-5.2	-	-	18.0-19.0	-	0.010 max.	0.010 max.	0.10 max.	0.55-0.80
N01555 p. 5	-	0.07 max.	0.05 max.	0.01 max.	0.01 max.	0.05 max.	0.005 max.	-	-	-	0.025 max.	54.0-57.0	0.05 max	-	-	-	bal.
N08367 p. 8	-	0.030 max.	-	20.0-22.0	0.75 max.	bal.	-	2.00 max.	6.0-7.0	0.18-0.25	-	23.5-25.5	-	0.040 max.	0.030 max.	1.00 max.	-
S30400 p. 2,4,6,12	-	0.08 max.	-	18.0-20.0	-	bal.	-	2.00 max.	-	0.10 max.	-	8.0-10.5	-	0.045 max.	0.030 max.	1.00 max.	-
S30403 p. 12	-	0.03 max.	-	18.0-20.0	-	bal.	-	2.00 max.	-	0.10 max.	-	8.0-12.0	-	0.045 max.	0.030 max.	1.00 max.	-
S31254 p. 8	-	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.	-
S31600 p. 12,14	-	0.08 max.	-	16.0-18.0	-	bal.	-	2.00 max.	2.00-3.00	0.10 max.	-	10.0-14.0	-	0.045 max.	0.030 max.	1.00 max.	-
S31603 p. 8	-	0.03 max.	-	16.0-18.0	-	bal.	-	2.00 max.	2.00-3.00	0.10 max.	-	10.0-14.0	-	0.045 max.	0.030 max.	1.00 max.	-
S32101 p. 6	-	0.04 max.	-	21.0-22.0	0.10-0.80	bal.	-	4.00-6.00	0.10-0.80	0.20-0.25	-	1.35-1.70	-	0.040 max.	0.030 max.	1.00 max.	-
S32304 p. 6	-	0.03 max.	-	21.5-24.5	0.05-0.60	bal.	-	2.50 max.	0.05-0.60	0.05-0.20	-	3.0-5.5	-	0.040 max.	0.040 max.	1.00 max.	-
S33207 p. 16	-	0.030 max.	-	29.0-33.0	1.0 max.	bal.	-	1.50 max.	3.0-5.0	0.40-0.60	-	6.0-9.0	-	0.035 max.	0.010 max.	0.80 max.	-
S40977 p. 13	-	0.030 max.	-	10.5-12.5	-	bal.	-	1.50 max.	-	0.030 max.	-	0.30-1.00	-	0.040 max.	0.015 max.	1.00 max.	-

Hyper-duplex steel is 30% stronger than Sandvik's previous strongest stainless steel. It was used to support the fretboard and join it to the guitar body, using an Isotropic Lightweight Structure.

A SMASH HIT!

One of the Top Ten electric guitarists in the world according to TIME magazine, Swedish heavy metal musician Yngwie Malmsteen has smashed over 100 guitars in his career. Sandvik Additive Manufacturing, producers of metal powder for additive manufacturing, decided to challenge him by building the world's first indestructible, 3D printed, all-metal guitar.

"Materials technology, precision machining, additive manufacturing and data-driven production – these are the kinds of processes it takes to create something as complicated and beautiful as a guitar for a master musician," said Kristian Egeberg, president of Sandvik Additive Manufacturing. "But we also wanted to show that we could make it unbreakable."

They selected titanium and SAF 3207 HD™ hyper-duplex (austenitic-ferritic) stainless steel (UNS S33207) containing approximately 7% nickel. Nobody had ever printed a guitar body made of this before. Sandvik's design partner, UK-based guitar designer Andy Holt of Drewman Guitars, had no idea if this was even feasible.

The body was built up using Powder Bed Fusion Laser, an additive technology ideal for printing metal components with extremely complex geometries. Each layer was 50 microns thick (thinner than a human hair).

Confident they had a big hit on their hand, they let Malmsteen take the stage and unleash his smashing skills on it.

In his words? "It is impossible to break. But it breaks other things!" Ni