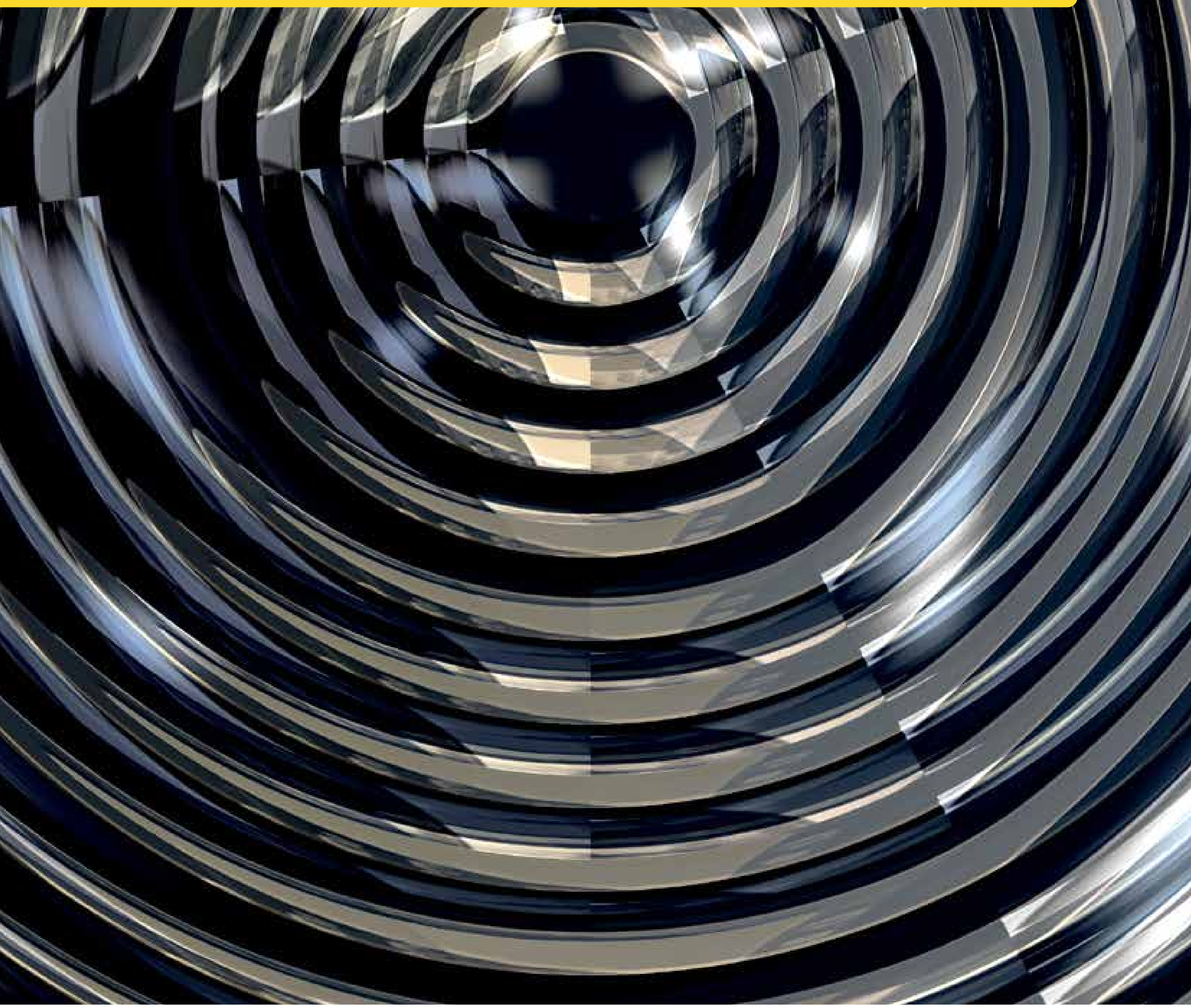
THE VALUE CHAIN OF ADVANCED MANUFACTURING

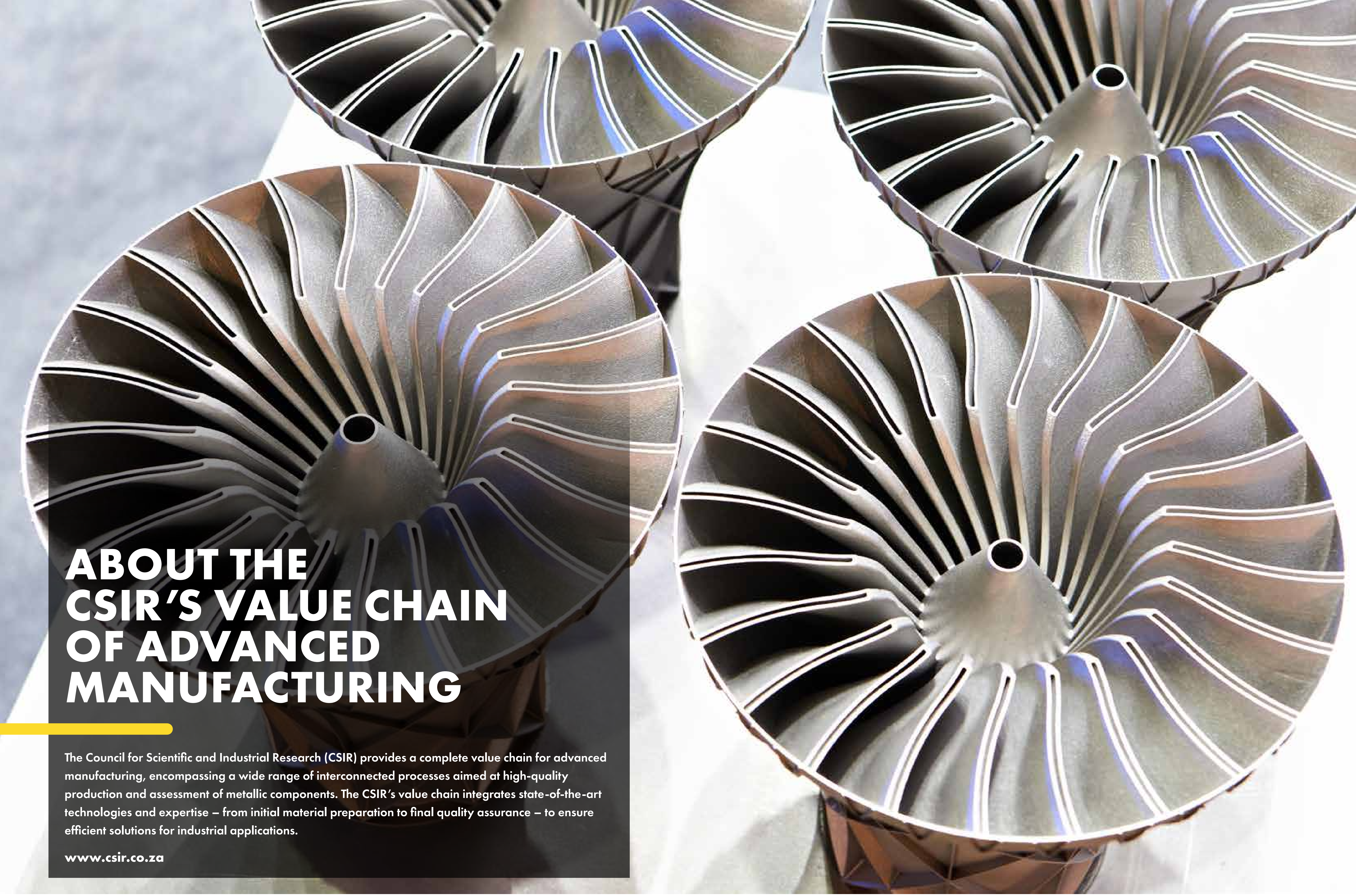


science, technology & innovation

Department:
Science, Technology and Innovation
REPUBLIC OF SOUTH AFRICA

CSIR

Touching lives through innovation



ABOUT THE CSIR'S VALUE CHAIN OF ADVANCED MANUFACTURING

The Council for Scientific and Industrial Research (CSIR) provides a complete value chain for advanced manufacturing, encompassing a wide range of interconnected processes aimed at high-quality production and assessment of metallic components. The CSIR's value chain integrates state-of-the-art technologies and expertise – from initial material preparation to final quality assurance – to ensure efficient solutions for industrial applications.

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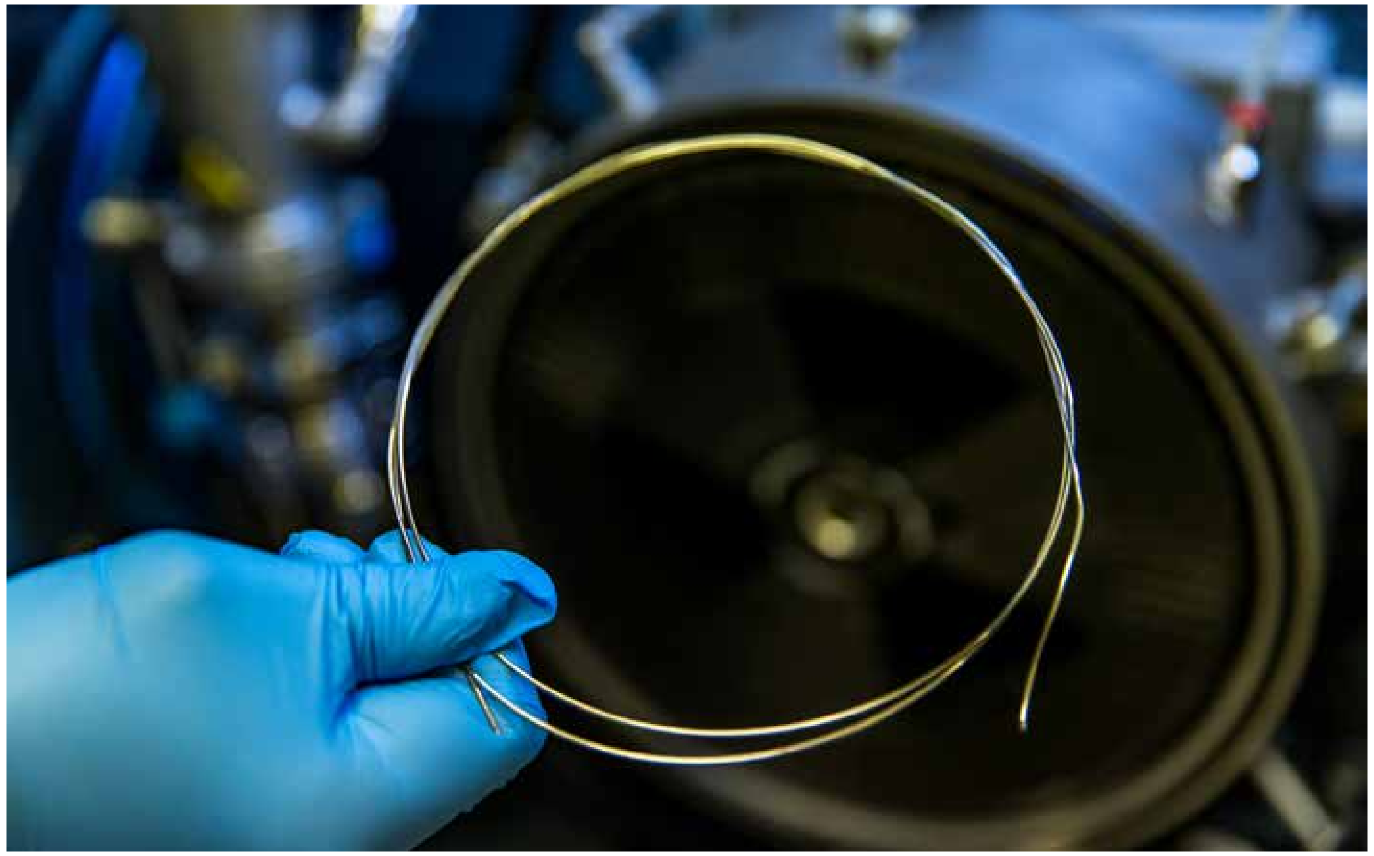
ULTRASONIC **POWDER ATOMISATION**



The CSIR Powder Atomisation has a modern, compact ultrasonic atomiser designed to create spherical powders from metal wires and rods. This facility aims to replace imported spherical metal powders, which currently face issues with high costs and long lead times.

The facility is set to produce high-quality metal powders to support:

- Research and development at research councils and South African universities; and
- Local industries that utilise advanced manufacturing techniques such as additive manufacturing (AM), metal injection moulding (MIM), hot isostatic pressing (HIP), spark plasma sintering (SPS), cold spray additive manufacturing (CSAM), and metal powder coating processes like thermal spraying.

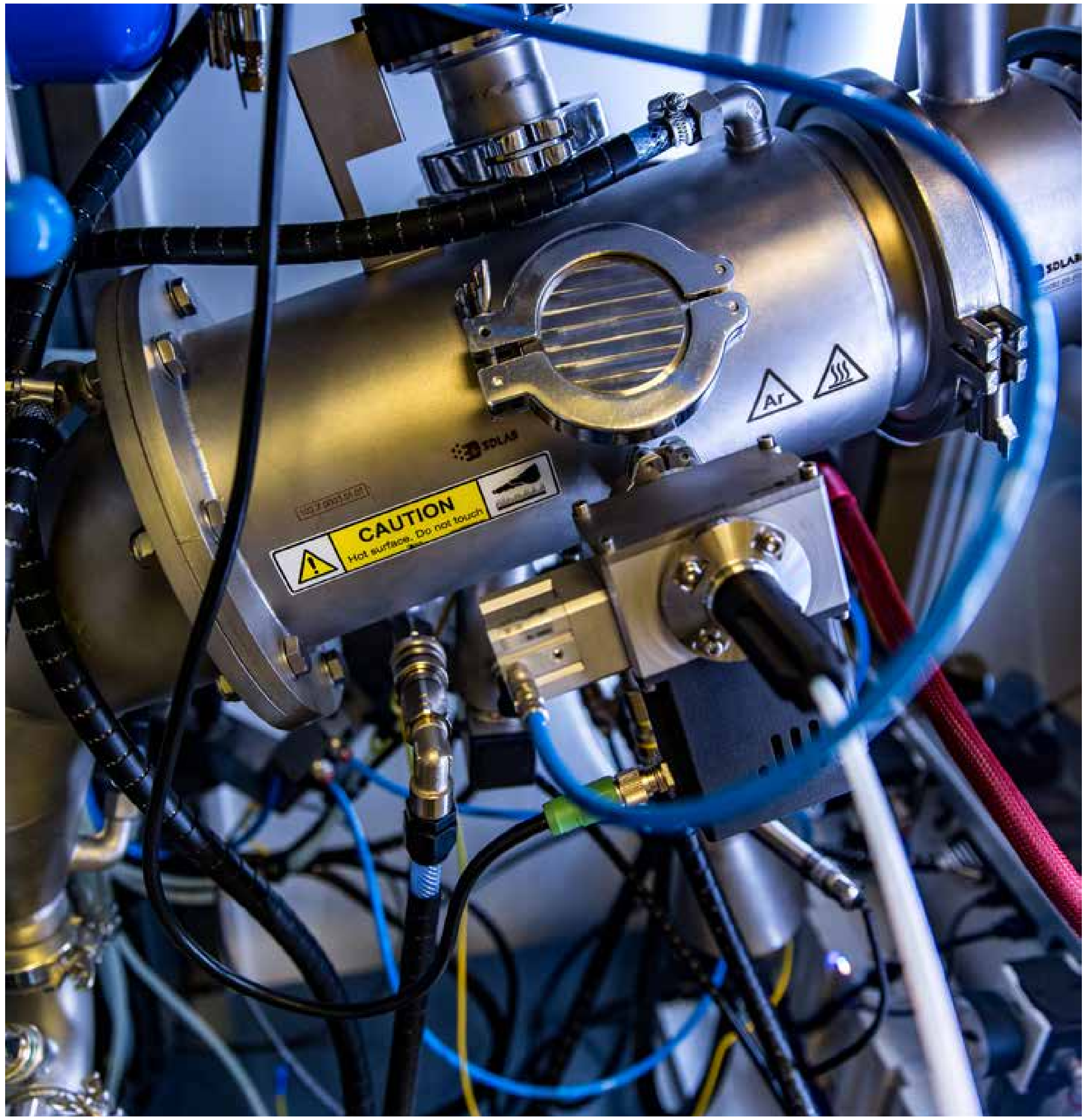
The facility is capable of atomising:

- Non-reactive alloys, including all types of steels (304, 316, 409, 410 and 17-4PH stainless steels);
- Reactive alloys like aluminium alloys (AlSi10Mg, AlSi12), titanium alloys (CP Ti, Ti6Al4V), titanium aluminides (TiAl), shape memory alloys (nitinol, NiTi), and nickel-based super alloys;
- Refractory alloys, like niobium- and tantalum-based alloys;
- Exotic alloys like high entropy alloys; and
- Precious metals and related alloys, including platinum group metals.

During the atomisation process, metallic wires and rods are melted using an electric arc and the molten metal is converted to metal droplets by ultrasonic vibration. The metal droplets are carried away using an inert gas, and in the process, cool down to form powders. The powders produced have high purity and have especially low oxygen (<10ppm) content. The powders possess high sphericity and high flowability and are without any satellites, which is important for applications in MIM, SPS, HIP, and AM.

CAPABILITY OF METAL POWDER ATOMISATION FACILITY AND CHARACTERISTICS OF METAL POWDERS

CHARACTERISTIC/CAPABILITY	INDICATORS
Processable metals	**Non-reactive alloys:** Steels and copper alloys **Reactive metal alloys:** Aluminium alloys, magnesium alloys, titanium alloys, nickel alloys **Refractory alloys:** Niobium alloys, tantalum alloys. **Precious metal alloys (PGMs):** Gold-, iridium-, platinum-, and ruthenium-based
Input material	Wire: Θ 0.8 – 2.2 mm Rod: Θ up to 10mm
Oxygen level during processing	<10ppm
Ultrasonic frequency	35kHz & 52kHz
System throughput	Up to 300ml per hour (mass throughput to be established after commissioning
Powder quality	• High purity powders • Highly spherical particles with high flowability • Narrow particle size and distribution • Low oxygen content



POWDER CHARACTERISATION

The CSIR Powder Characterisation facility is ISO17025:2017 South African National Accreditation System (SANAS) T0381 accredited. The facility goes through a rigorous assessment process from SANAS to ensure that it maintains compliance to ensure the validity of analysis results.

Powder characterisation entails the analysis and measurement of powders' physical and functional properties. This process involves multiple techniques to grasp the qualities of powders essential for anticipating their behaviour, performance, and interactions. Within the CSIR manufacturing cluster research, development, and innovation projects, powder characterisation predominantly concerns metal powders used in additive manufacturing, metal injection moulding, and conventional powder metallurgy methods.

PHYSICAL PROPERTIES

The following list of physical properties can be measured:

- Particle size and distribution;
- Shape and morphology;
- Surface area and porosity;
- Density (true density, bulk density, tap density);
- Flowability;
- Rheological behaviour;
- Oxygen, nitrogen and hydrogen content; and
- Carbon and sulphur content.

FUNCTIONAL PROPERTIES

Flowability and rheology affect powder handling, as well as the manufacturing process.

METAL INJECTION MOULDING

The CSIR Metal Injection Moulding (MIM) facility is the only facility of its kind in South Africa having the capability of mass-producing complex near-net-shaped, components from metal powder feedstocks cost-effectively. This technology has the ability to overcome the geometrical and productivity limitations of traditional production methods. In line with the national mineral beneficiation strategy, the facility was established in preparation for the creation of a new downstream titanium industry in South Africa.

Complex precision components can be conceived, designed and manufactured through the expertise and equipment housed in this one-stop facility. The facility specialises in the design and manufacturing of tooling for miniature metal parts, as well as the mass production of small parts. The manufacturing capabilities generally include injection moulding, chemical debinding, as well as thermal debinding and sintering of the parts.

Products made via MIM have high dimensional accuracy and replication fidelity on a nearly unlimited choice of materials, through powder metallurgy. Existing small, medium and micro enterprises in the metals and manufacturing industry are already benefiting from the facility's competencies. The MIM facility is funded primarily through the Department of Science and Innovation's Advanced Metals Initiative and the Advanced Materials and Manufacturing Programmes.

MIM MACHINERY AND SPECIFICATIONS

The MIM facility houses an automated 40-ton ARBURG ALLROUNDER 270U 400-70 injection moulding machine with the following specifications.

METAL INJECTION MOULDING MACHINE - SPECIFICATIONS

Injection unit with screw diameter	mm	18
Effective screw length	L/D	24.5
Clamping force	kN	400
Weight	Kg	2500
Material throughput	Ma.kg/h PS max	4,1
Shot weight	Max. g PS	21
Injection pressure	Max. bar	2500
Screw torque	Max. Nm	90
Heating capacity | zones	kW	4,1|4
Feeder hopper	litres	25

INVESTMENT CASTING

Investment casting is an industrial manufacturing process that has a very long history, dating back 4000 years. Since then, significant advances have been achieved in wax and shell materials and vacuum casting technologies to enable intricate and high-integrity castings to be produced for the most demanding of applications.

The investment casting process is based on the 'lost wax' method, in which a ceramic mould is formed around a wax assembly containing wax models of the required components. The wax is subsequently removed by melting to leave a hollow cavity with the desired shapes into which liquid metal is then poured. After cooling, the ceramic shell is removed and the individual components cut off the assembly. Investment casting is valued for its ability to produce components with intricate shapes, thin walls and an excellent surface finish. The casting is also net-shape, meaning that only minimal machining will be required after the casting process. There is a wide range of metals that can be investment cast such as titanium alloys, steel, stainless steel, copper alloys, aluminium, magnesium, nickel-base superalloys and so forth.

The CSIR does research and development in investment casting technologies including titanium, nickel-based alloys, high strength ferrous alloys, magnesium and thin-walled complex shaped aluminium for exploitation by the South African manufacturing industry. The aim is not to compete with the four existing investment casting foundries but to develop capabilities that could enhance the offerings to local and international customers.

The CSIR Investment Casting facility is an industrial scale casting research facility which encompasses wax injection moulding, dipping/mould production, dewaxing, melting and casting capability. It is the only foundry in South Africa with a production-level vacuum casting capability. The foundry was founded on the ability to produce single crystal nickel-based super alloy turbine blades for gas turbine engines and has more recently established the niche capability to investment cast titanium alloys. The casting capability is however not limited to vacuum casting. In recent years the aluminium mould manufacturing capability has been established.

Since its inception in 1984, the foundry has contributed to a number of technological development and industry support activities which include but are not limited to:

- Single crystal nickel-based superalloy turbine blades for the South African Air Force
- Casting and qualification of a 9mm pistol for the South African Police Force in collaboration with Hausler Scientific.
- Supporting designers and manufacturers with prototype development.
- Developing and optimising casting process for industry.

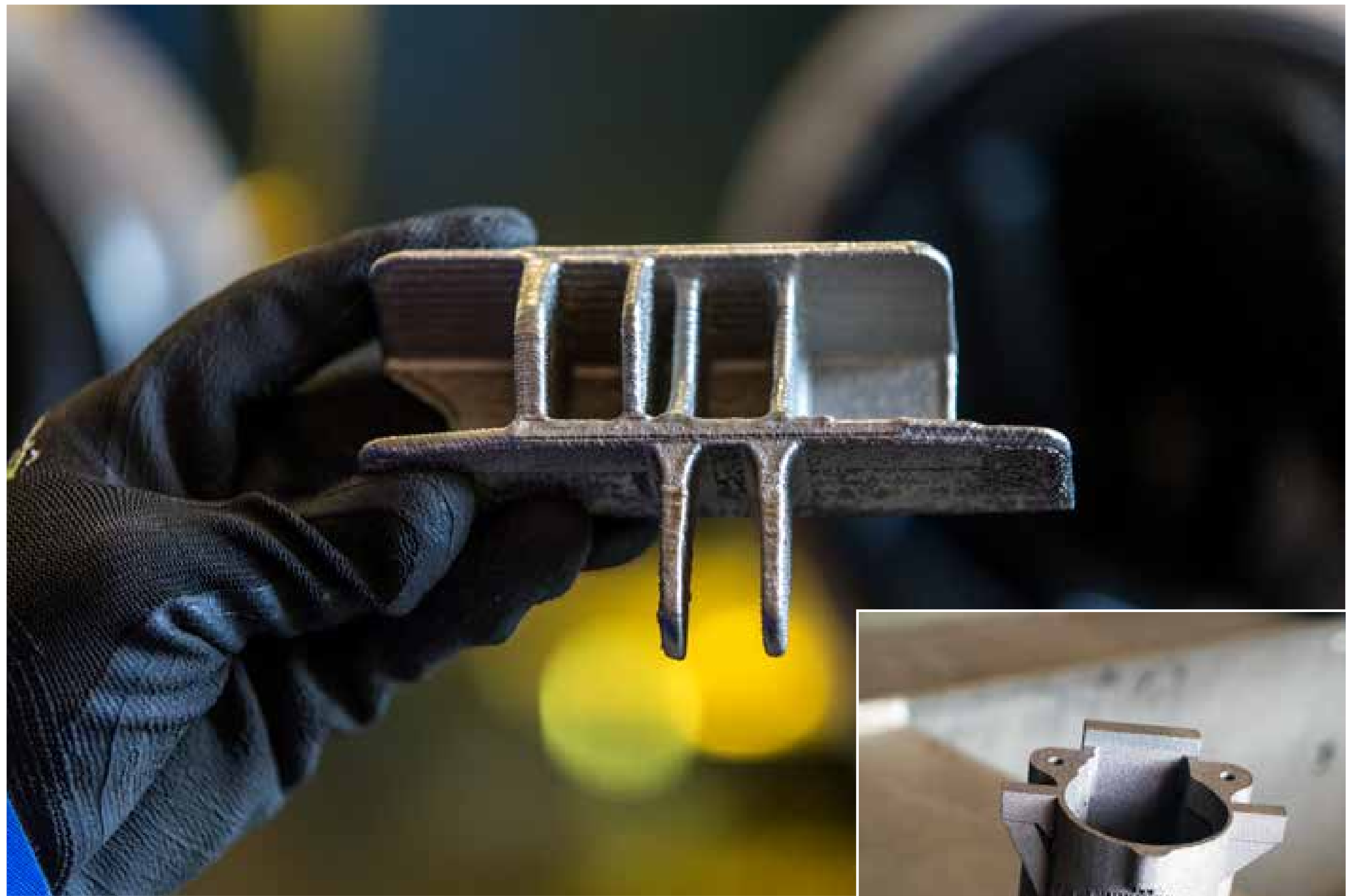
The investment casting foundry at the CSIR is available to industry to perform R&D, proof of concept/product development and localisation of manufacturing.

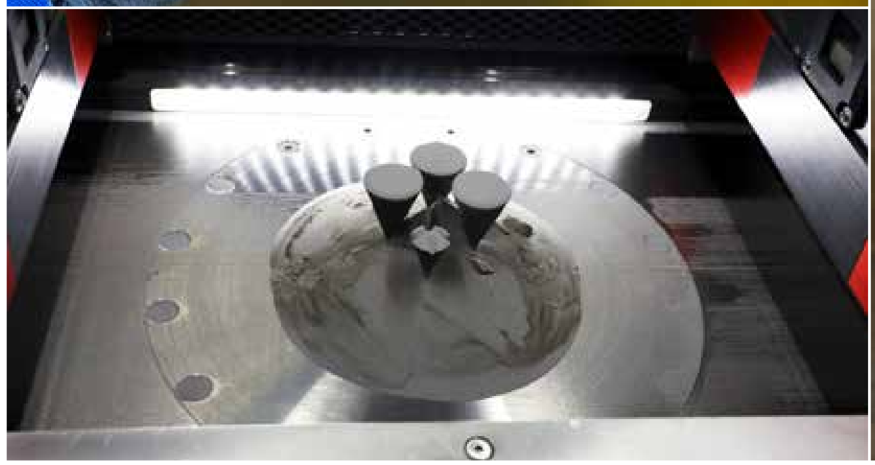
METAL ADDITIVE MANUFACTURING

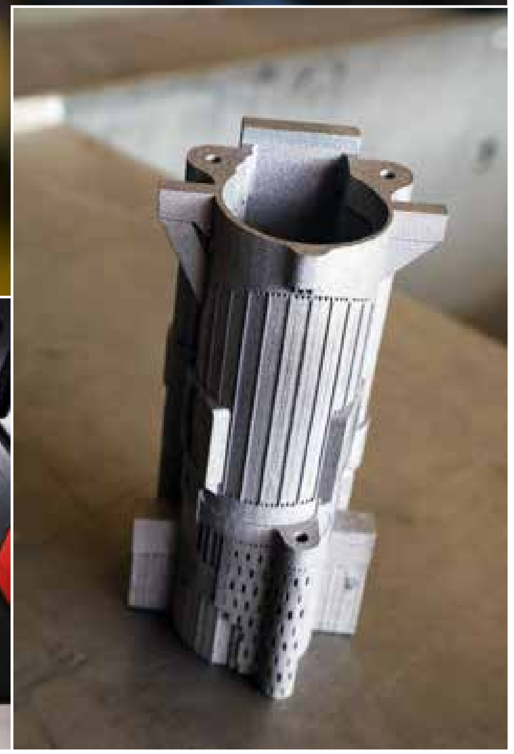
The CSIR established a high-speed, large-area laser-based additive manufacturing platform called Aeroswift, which is one of the largest laser-based three-dimensional (3D) printers for metal components in the manufacturing industry.

The system allows the printing of components up to 2 m long, 600 mm wide and 600 mm high. It also utilises a hot and inert processing environment, which ensures that the components produced comply with strict aerospace manufacturing standards.

Aeroswift is based on the processes of selective laser melting, in which an object is produced from powder arranged in layers and fused by a high-power laser. In general, Aeroswift lends itself to the development of unique components from a range of materials. The CSIR is in the process of manufacturing commercially available metal 3D printers.







LASER-BASED SURFACE ENGINEERING

The CSIR has a diverse and specialised portfolio of laser-based technologies to support various industries such as manufacturing, mining, defence, transport, energy and so forth. By designing novel technologies and enhanced processing approaches, these services typically reduce costs, save time by limiting downtime, reducing wastage and improving performance.

LASER CLADDING

This is a laser refurbishment process used to restore worn, damaged or faulty components. Applications of laser cladding involve repairing various items such as moulds, shafts, compressor screws, turbine blades, continuous casting rolls and sealing cracks, among others.

3D LASER CUTTING AND 3D PIPE CUTTING

The 5-axis, 5 kW CO_2 laser system is designed for cutting 3D parts and tubes. Its applications encompass a variety of tasks, including the laser cutting of welding preparations on tubes, the precise cutting of square tubes, the shaping of formed body parts and the fabrication of automotive body components.

LASER HARDENING

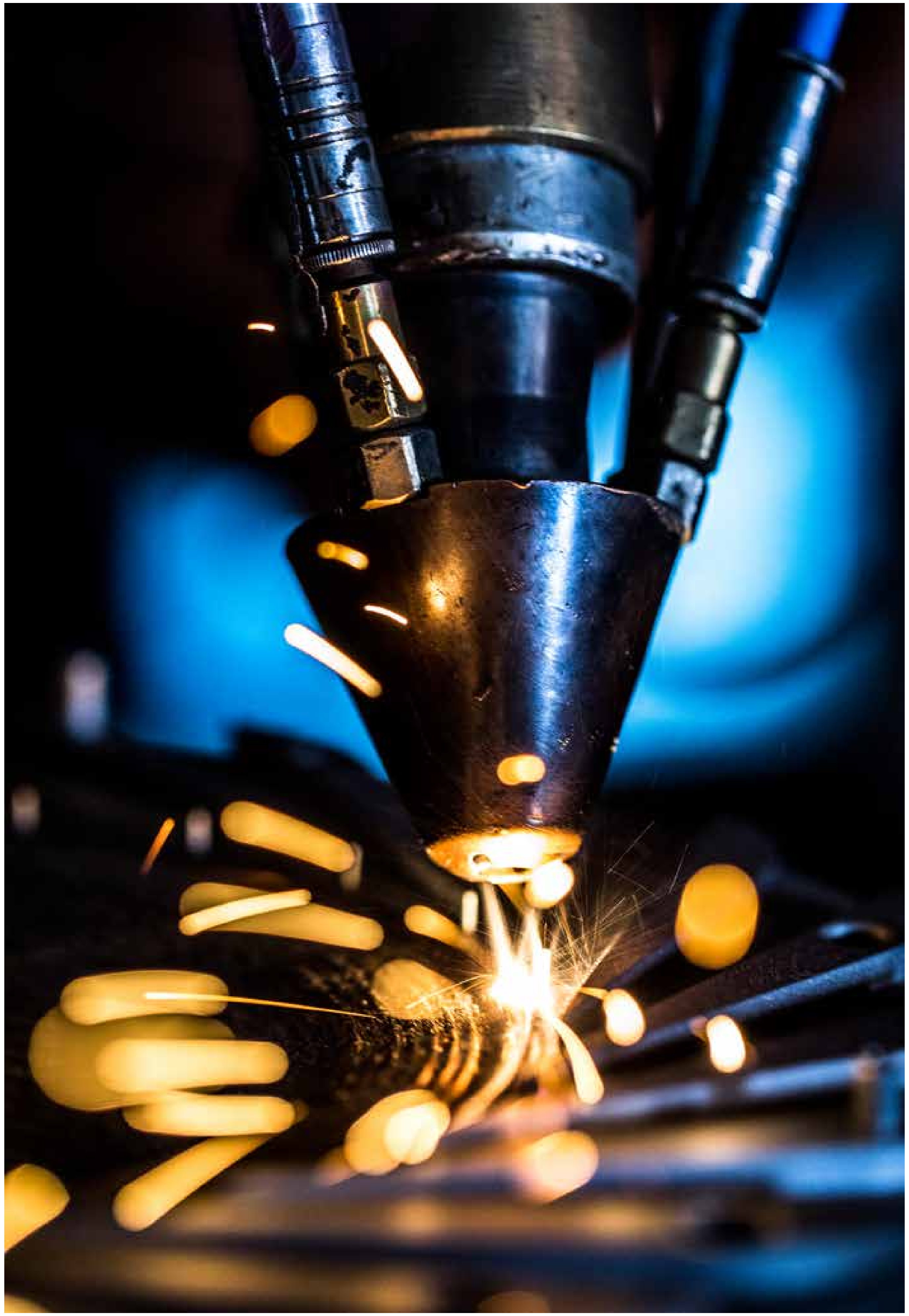
Laser transformation hardening is used on carbon steels that contain between 0.3% and 1.5% carbon, including cast iron. This technique finds applications in various areas such as repairing gears, press tools, components in automotive steering pumps, forming tools and moulds, piston ring grooves in heavy-duty engines and turbine blades, among others.

LASER WELDING

Laser welding involves joining components by utilising a laser source, which may or may not require additional filler material. This technique is applied in various areas, such as welding automotive body panels, creating lightweight structures, manufacturing stainless steel tubing and fixing gears to shafts, among others.

MOBILE LASER-BASED REFURBISHMENT SYSTEM

The CSIR has developed a strong competence in laser-based refurbishment, based on laser cladding technology. The system was designed for on-site welding. This capability is invaluable for the refurbishment of large and high-value components, offering faster response times and significant cost savings to industry.



HOT ISOSTATIC PRESS

The CSIR Hot Isostatic Press (HIP) facility is a newly established facility designed for advanced post-processing and heat treatment. HIP capability is essential for advancing manufacturing technology to higher readiness levels, paving the way for industrialisation and commercialisation while meeting industry demands, including in export markets. The facility enables the production of high-value metallic components, aligning with our mission to add value to South Africa's minerals and metals, positively impacting the local economy.

THIS STATE-OF-THE-ART FACILITY IS IDEAL FOR:

- Castings;
- Additive manufactured parts;
- Powdered metallurgical parts;
- Metal injection moulded parts; and
- Introducing compressive residual stresses in parts to improve fatigue performance.
- Improving fatigue resistance by inducing compressive residual stresses across parts. The HIP facility ensures 100% density by using advanced high-temperature and high-pressure processes.

SPECIFICATIONS:

- Max. operating pressure: 207 MPa
- Design pressure: 228 MPa
- Pressure vessel volume: 242 dm^3
- Maximum operating temperature: 1 400 °C
- Maximum height of workload: 890 mm
- Maximum diameter of workload: 300 mm
- Maximum weight of workload (incl. weight of load basket): 350 kg
- Temperature control: ± 8 °C
- Number of heating zones: 3 pcs
- Number of furnace thermocouples per heating zone, type B: 2 pcs
- High quench capability for in situ heat treatment.

NON-DESTRUCTIVE EVALUATION

Testing services play a key role in supporting the competitiveness of local industries, particularly in so far as risk mitigation is concerned and to support quality assurance in the product design and development process. Very few companies have in-house testing facilities since they are costly to install, maintain and update. Reliance on contractors to perform tests can be risky since it is not always possible to oversee or provide input on the chosen test techniques and equipment, as well as to do quality control.

As South Africa's leading science and technology organisation, the CSIR is relied upon for support by companies of various sizes for expert advice, evaluation and testing, as well as providing access to world-class facilities and equipment.

Non-destructive testing is one of the services offered by the Advanced Casting Technologies group as part of the CSIR Advanced Materials Engineering impact area. The group comprises mechanical and metallurgical engineers, scientists and technicians who work in a range of research facilities and casting technologies. Their overarching objective is to provide industry support across the product development and manufacturing process such as primary castings, secondary castings and fabrication, as well as testing and evaluation.

EQUIPMENT AND FACILITIES

- Infrared thermographic testing equipment: used for detecting sub-surface flaws in composite panels;
- Eddy current flaw detector: NORTEC 600 used for detecting surface and sub-surface cracks, conductivity, coating thickness and sorting metals;
- Digital ultrasonic flaw detector: the Karl Deutch ECHOGRAPH 1090;
- Ultrasonic phase array: M2M GEKKO 170 Flaw Detector;
- Digital ultrasonic thickness gauge: CYGNUS 4; and
- X-ray radiography: basic two-dimensional microfocus X-ray radiography.

OTHER TESTING SERVICES

The structural analysis capabilities are based on finite element analysis. The work done includes technology research and local and international contracting. Tools include a range of analysis software, pre- and post-processing analysis tools and different approaches such as static or dynamic, implicit or explicit, etc.

These capabilities are supported by computational fluid dynamics for load determination, as well as ongoing research at the CSIR in areas such as adhesive bonding, composite failure criteria, composite micromechanics and composite fracture mechanisms. The corrosion testing laboratory houses immersion corrosion testing facilities. Corrosion testing is used by the automotive industry to test components as part of the test requirements for localisation of manufacture. Forensic investigation is undertaken by performing a metallurgical failure analysis of structures. It is used by clients in, for example, the insurance industry to investigate products and in the packaging industry for quality control and assurance

All material test capabilities are supported by the following facilities:

- Metallographic laboratory;
- Scanning electron microscope; and
- Micro-focus X-ray radiography system.

MECHANICAL TESTING

The CSIR Mechanical Test facility (MTF) is ISO 17025:2017 accredited and consists of facilities such as specimen preparation areas, load frames, test jigs for composite materials, impact drop testing, creep testing of metals, and rotating beam testing facilities, as well as data collection and analysis software.

The MTF is extensively used by local industry, state-owned enterprises (SOEs), science councils and universities, including international clients for testing and qualification of materials and components.

KEY TESTING SERVICES OFFERED ARE:

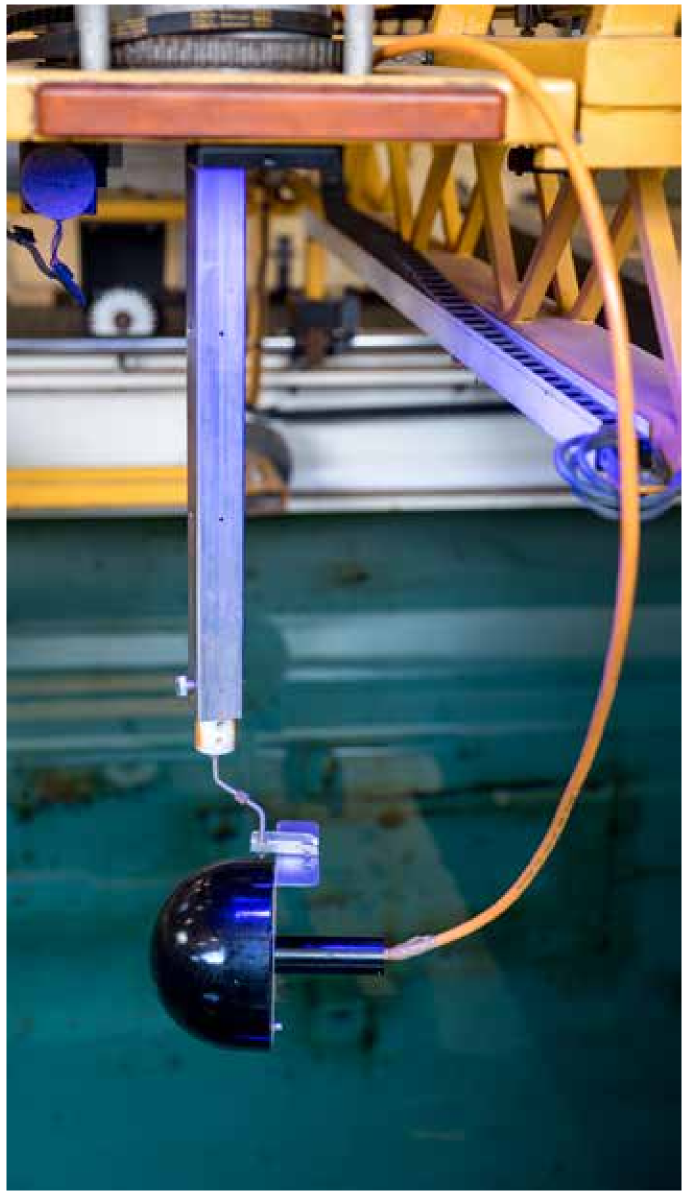
- Tensile and compression testing (to 1000 kN)
- Fatigue testing up to 800 kN
- Low and high cycle fatigue testing
- High temperature fatigue and tensile (0 °C to 800 °C)
- Fracture toughness testing
- Crack growth rates, threshold stress intensity,
- S-N curves
- Creep testing up to 1000 °C

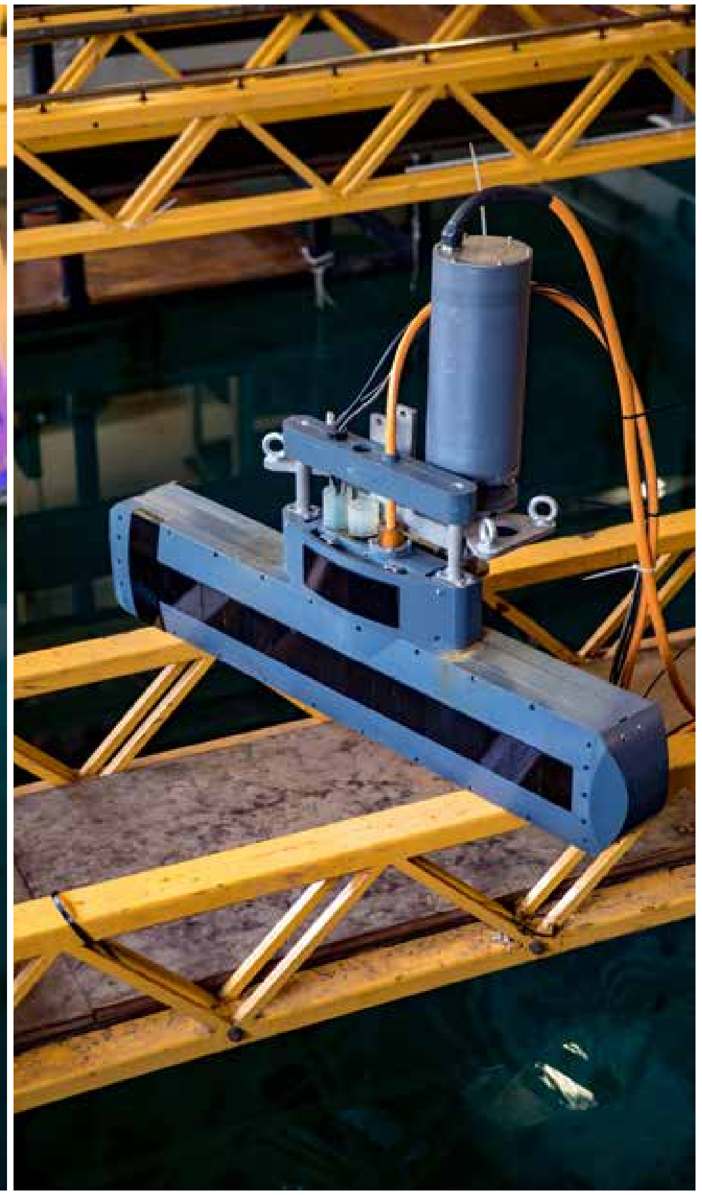
Typical testing standards followed are:

- ASTM E466 constant amplitude axial fatigue
- ASTM E606 strain controlled fatigue testing
- ASTM E647 fatigue crack growth rates
- ASTM E399 K1c plane strain fracture toughness
- ASTM E813 JIc testing
- ASTM E1820 fracture toughness (metallics)
- ASTM E561 R-curve determination
- ASTM E1290 crack tip opening displacement

Testing of manufactured rebar, multi-strand wire cabling and composites testing for local aerospace manufacturing companies. Some large projects include materials testing for construction of the SKA Antenna Reflector, wire rope for Nelson Mandela Bridge, 2010 Soccer World Cup stadia and Eskom power stations. Collaboration with other test facilities is ongoing, including private companies and the South African Bureau of Standards.

UNDERWATER TESTING FACILITY





The CSIR has a strong capability in developing technology and products, especially in the field of sensors. The organisation is well-equipped to create custom products and has earned important certifications like ISO 9001 and ISO 13485, and innovative facilities.

The electro-acoustic underwater test facility at the CSIR is key to testing underwater sonar transmitters, receivers and arrays in respect of their acoustic sensitivity, acoustic beam-patterns and electrical properties.

The electro-acoustic underwater test facility was originally established by the South African Navy (SAN) and is mostly funded through the CSIR, with support from Armscor. The facility permits the local characterisation of newly manufactured or refurbished transducers, providing significant cost and time savings. It permits acoustic testing, electrical testing, as well as high pressure (depth) testing.

The facility has been upgraded with new instrumentation, automation technologies and testing software. It has been used in all sonar development projects undertaken by the CSIR for the SAN and to characterise all of the wet-end sonar transducers deployed on the SAN's current submarines and Corvettes (surface vessels).

The facility can test underwater transducers from 3 to 500 kHz and simulate depths of up to 650 m. The CSIR team is always available to discuss industry's underwater development and testing requirements with a view to locally developing or localising technologies and products and to conduct small-volume manufacturing runs on acoustic or ultrasonic devices.

RAMAN MICROSCOPY

The CSIR offers Raman Microscopy services, which play a crucial role in various scientific and industrial applications. One of these is chemical mapping and chemical identification. This process involves using Raman Microscopy to analyse substances at a molecular level. This becomes incredibly useful in research and quality control, enabling precise understanding and monitoring of pharmaceutical products or water for example.

Another significant capability of Raman Microscopy is mineral content evaluation. This technique allows us to determine the types and quantities of minerals present in a sample. This information is vital in fields such as geology, environmental science and even agriculture, where understanding the mineral composition can guide decisions and development.

Raman Microscopy is also instrumental in degradation, soil and stain analysis. This service helps in examining how materials break down over time. For soils, it assists in understanding the composition and health of the soil, which is crucial for agriculture and environmental conservation. When it comes to stain analysis, we can identify the substances present in stains, which is particularly helpful in forensic science, where identifying unknown substances can be critical.

Furthermore, Raman Microscopy services include surface characterisation and 3D imaging. This involves examining the surface properties of materials and creating detailed 3D images. This capability is important in material science and engineering, as it helps in understanding how materials will perform in real world conditions, ensuring that they meet necessary safety and quality standards.

ROBOTICS AND INDUSTRIAL ARTIFICIAL INTELLIGENCE

The fourth industrial revolution, or 4IR, is changing the way industries operate and it holds great promise for the South African manufacturing sector. One of the main benefits of 4IR technologies is that they can help manufacturers produce goods locally and reduce the need to rely on international supply chains. This can make production more efficient and cost-effective.

The CSIR has developed expertise in several key areas that are central to 4IR, such as industrial robotics and sensors. These technologies can automate repetitive tasks, increase precision, and improve safety within manufacturing plants. Automation through robotics can also help the workforce focus on more complex tasks, enhancing overall productivity.

The organisation also has a strong foundation in industrial artificial intelligence (AI). AI can analyse large amounts of data to make informed decisions quickly. This capability can lead to smarter manufacturing processes, where machines can predict failures before they happen or optimise production schedules to save time and resources.

Augmented reality (AR) is another area where the CSIR is making great progress. With AR, workers can receive real-time guidance and information overlaid on their physical environment. This can make training faster and provide ongoing support for workers, leading to greater efficiency and fewer errors in production processes.

HEALTH AND MEDICAL DEVICES

The CSIR can help local companies, big and small, improve the production of health products. With expertise in designing of product development processes and managing the entire production lifecycle, the CSIR offers support in creating prototypes and helps companies get their products certified, making them more competitive internationally.

An example of this work is the creation of the CSIR L.I.F.E CPAP ventilator during the pandemic in 2020. This was achieved through a rapid digital manufacturing approach. The CSIR also partnered with the Technology Innovation Agency under the Medical Device and Diagnostic Innovation Cluster programme to offer support and training to small, medium enterprises (SMEs) entering the medical device sector. This will ensure that they meet all legal and safety standards. The CSIR team provides guidance on preparing data packs and obtaining licenses from the South African Health Products Regulatory Authority, which is the health products regulatory authority. This step is crucial for legally selling their products on the market. More than 18 SMEs have benefited from this programme since its inception.

The CSIR is also investigating how ultrasonics can enhance primary healthcare, which can positively impact human health and society. Furthermore, the CSIR is developing point-of-care diagnostic devices that use optical methods to quickly detect various illnesses. The CSIR team is currently developing a novel application that can be used on a smartphone to diagnose conditions including tuberculosis, Human Immunodeficiency Virus, Covid-19, and other non-communicable diseases.

VISIT THE CSIR

www.csir.co.za

CONTACTS

DR LUYOLO MABHALI
T: 012 841 4997
E: csirmanufacturing@csir.co.za

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Touching lives through innovation