ANNUAL REPORT

2017 - 2018

BAOSTEEL-AUSTRALIA

JOINT RESEARCH AND DEVELOPMENT CENTRE

BAOSTEEL | The University of Queensland Australia | UNSW Sydney | University of Wollongong Australia | MONASH University

CONTENTS

Abbreviations

ARC	Australian Research Council
BAJC	Baosteel-Australia Joint Research and Development Centre
CRC	Co-operative Research Centre
UNSW	The University of New South Wales
UOW	University of Wollongong
UQ	The University of Queensland
MU	Monash University

The Baosteel-Australia Joint Research and Development Centre (BAJC) is a world-first partnership between China's largest steel enterprise and four research-intensive Australian universities:
The University of Queensland, The University of New South Wales, Monash University and the University of Wollongong.

Baosteel established the Centre with the universities in 2011 for the purpose of creating an internationally recognised centre of excellence in metals-related research. Following the consolidation and restructuring of Baosteel and Wuhan Iron & Steel to form China Baowu Steel Group Corporation Limited in late 2016, pursuit of this goal continues.

Our research portfolio explores and generates new knowledge to develop technologies that have particular significance to China Baowu's strategic development and business activities in selected areas.

Baosteel and China Baowu have committed more than $28 million since the Centre began, matched by in-kind contributions from the partner universities of almost $38 million.

The Centre is functionally located within The University of Queensland's School of Chemical Engineering, and fosters collaboration between all participating research teams, including academic exchange visits to China Baowu's facilities in China and annual scientific conferences.

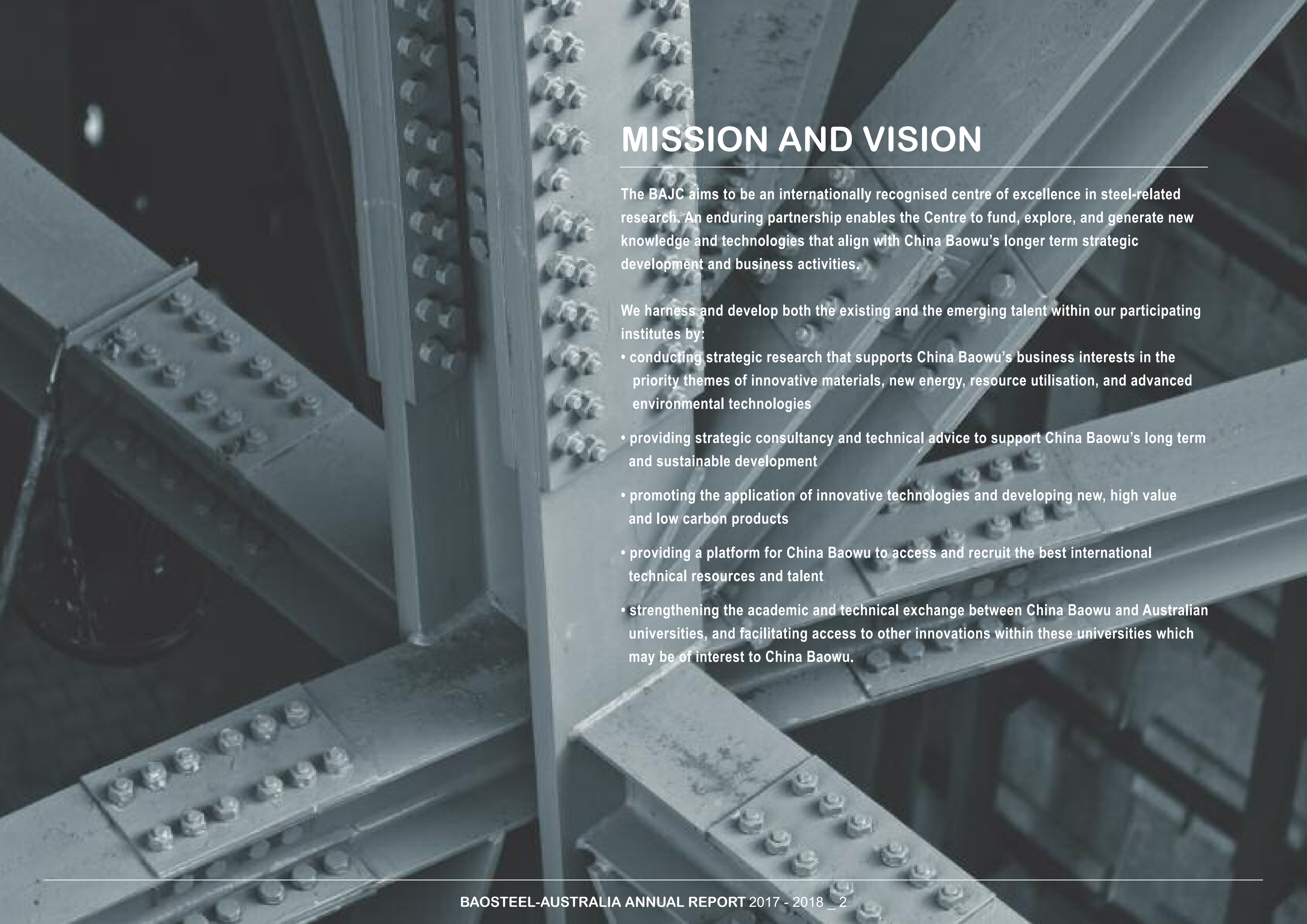
KEY CAPABILITIES

Since 2011, the Baosteel-Australia Joint Research and Development Centre has

- Engaged over 130 eminent researchers based in Australia and China
- Supported 55 innovative research projects
- Disbursed a total of A$18 million in project funding
- Attracted A$40 million in-kind partnership contributions
- Leveraged A$7.7 million in ARC Linkage and CRC grants
- Published and presented more than 300 academic papers
- Filed 18 patents
- Hosted 6 annual conferences

The Centre has access to its partners' world-class technical resources, including:

- High Temperature Confocal Microscope
- Thermal Desorption Spectroscopy
- Two-disk rolling contact tribological test rig
- Laser measurement technology
- Powder metal injection (PIM) laboratory
- Spark plasma sintering laboratory
- EOS selective laser melting machine
- Concept Laser (the largest selective laser melting machine in the southern hemisphere)
- Experimental roll former
- Trumpf direct laser deposition
- Deckel Maho 5-axis milling centre
- Nanopoli-100 Nano-polisher
- NCI High-Performance Computers (National Computational Infrastructure)
- Australian National Fabrication Facility



MISSION AND VISION

The BAJC aims to be an internationally recognised centre of excellence in steel-related research. An enduring partnership enables the Centre to fund, explore, and generate new knowledge and technologies that align with China Baowu's longer term strategic development and business activities.

We harness and develop both the existing and the emerging talent within our participating institutes by:

- conducting strategic research that supports China Baowu's business interests in the priority themes of innovative materials, new energy, resource utilisation, and advanced environmental technologies
- providing strategic consultancy and technical advice to support China Baowu's long term and sustainable development
- promoting the application of innovative technologies and developing new, high value and low carbon products
- providing a platform for China Baowu to access and recruit the best international technical resources and talent
- strengthening the academic and technical exchange between China Baowu and Australian universities, and facilitating access to other innovations within these universities which may be of interest to China Baowu.

FROM THE BOARD CO-CHAIRMEN

"BAJC-sponsored projects have led to over 400 published papers and conference presentations, and have supported more than 40 postgraduate students since 2011, including 24 in the past year."

The Baosteel-Australia Joint Research and Development Centre continues to tackle the major challenges facing the steel industry this century. We are proud to present in this Annual Report highlights of the innovative approaches and new knowledge generated over the past year.

With the merger of our founding partner, Baosteel, with Wuhan Iron & Steel to become China Baowu Steel Group, our scientists and engineers are now progressing the discoveries and processes arising from their research towards commercial outcomes for the second largest steel company in the world.

A key development for the Centre was the official launch of an executive training program through UQ Business School (UQBS). This extension of the partnership between UQ and Baosteel welcomed 10 Baosteel executives to UQBS Executive Education for two weeks in October 2017. The training focused on intellectual property strategy, leadership in current and post-R&D integration as well as cutting-edge technology innovation.

The program included visits to the Queensland Centre for Advanced Technologies and UQ's Sustainable Minerals Institute.

We continued to participate in a number of Research Hubs established by the Australian Government's Industrial Transformation Research Program, including the Australian Research Council (ARC) Research Hub for Computational Particle Technology based at Monash University (MU), with BAJC managing the Queensland node; and the ARC Research Hub for Energy-Efficient Separation (ARC-EESep), also based at MU.

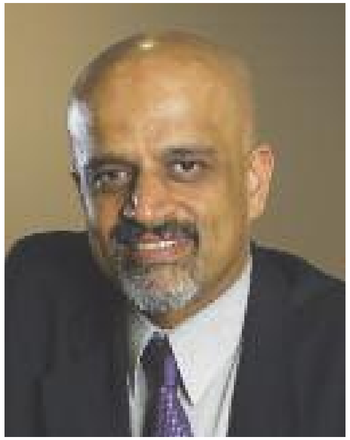
Recent successes for our researchers leveraging BAJC funds to attract additional ARC funding for their work include UQ's Professors Lianzhou Wang (A$389,000) and Han Huang (A$300,000); and UNSW's Professor Liangchi Zhang (A$300,000). We congratulate them all on attracting this prestigious and valuable recognition for their research.

These grants represent another measure of the success for the collaborative model that BAJC has developed over the past eight years and the quality of the research undertaken. BAJC-sponsored projects have led to over 400 published papers and conference presentations, and have supported more than 40 postgraduate students since 2011, including 24 in the past year.

With Professor Frieder Seible concluding his term as Dean of the Faculty Engineering at Monash University, Professor Elizabeth Croft joined the BAJC board to represent MU. We thank Professor Seible for his service and contribution to the Centre's success.

We would also like to thank you for your ongoing interest in the Centre. It is our pleasure to share with you just some of advances in materials science that our researchers have made towards solving the global challenges facing the metals and energy sectors, now and in the future.

PROFESSOR G.Q. MAX LU



PROFESSOR MOHAN KRISHNAMOORTHY

FROM THE CENTRE DIRECTORS

> "Collaboration remains a strong feature of the Centre's approach to tackling the productivity and product quality challenges facing the manufacturing and energy materials industries worldwide."

The Baosteel-Australia Joint Research and Development Centre continues to receive many applications from our partner universities' researchers whose proposals for research translation and innovation development via scientific discovery both intrigue and excite.

With an additional $1.6M investment from Baosteel this year, we funded another round of projects that seek novel solutions for transforming industries relying on steel and other metals. Summaries of these new investigations begin on page 11, and their related published works are captured on pages 18 and 19.

As you can appreciate, with more than 65 projects now supported (including many co-funded by ARC Linkage grants), providing details for them all is not practical; however, you can read about them on the BAJC website. The 'honour roll' of researchers continues to grow, and we acknowledge their contributions on pages 20 and 21.

Collaboration remains a strong feature of the Centre's approach to tackling the productivity and product quality challenges facing the manufacturing and energy materials industries worldwide. Our sixth Annual Conference was held at the University of Wollongong in February 2018, where 27 researchers presented their work to 60 delegates from Baosteel and partner universities.

While a snapshot of other collaboration and knowledge exchange activities is provided on page 5, we would like to highlight the visit from senior Baosteel representatives to The University of Queensland (UQ) in October 2017.

Mr Junsheng ZHU, Director of Baoshan Iron & Steel Co., Ltd (Baosteel) and Deputy Secretary of CPC Committee, and Dr Jun WU, President of Baosteel Central Research Institute (R&D Centre) led the delegation from Baosteel.

As well as attending the opening ceremony of the Baosteel training program at UQ Business School Executive Education, they met senior UQ executives and reviewed Centre activities. They also learned more about the capabilities of our partner universities for addressing Baosteel's research needs; further training opportunities; and research and technology translation. (On this latter point, we are pleased to report that nine patents emerging from BAJC research have progressed to National Phase Entry stage for China, Korea, Japan, and the United States.)

PROFESSOR VICTOR RUDOLPH, CENTRE SENIOR DIRECTOR

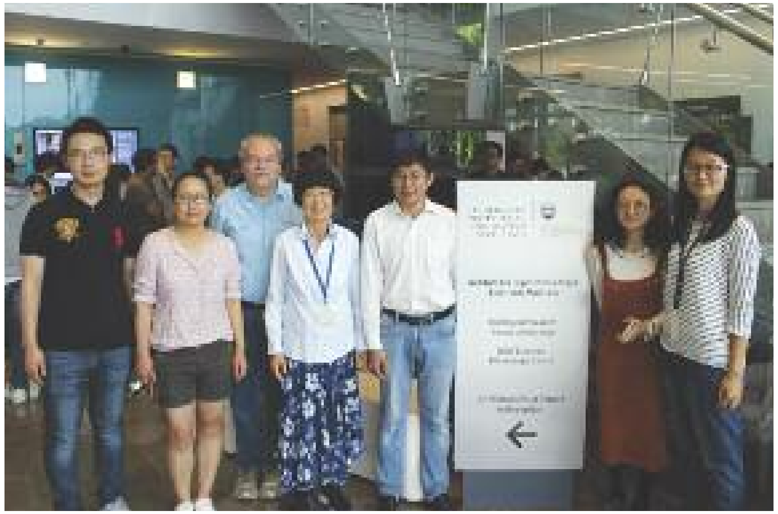
PROFESSOR GEOFF WANG, CENTRE EXECUTIVE DIRECTOR

Coordinating events such as these while ensuring the Centre maintains efficient operations requires dedication and resourcefulness. We acknowledge with thanks the effective administration support received which allows all our researchers to pursue their objectives with confidence and minimal disruption.

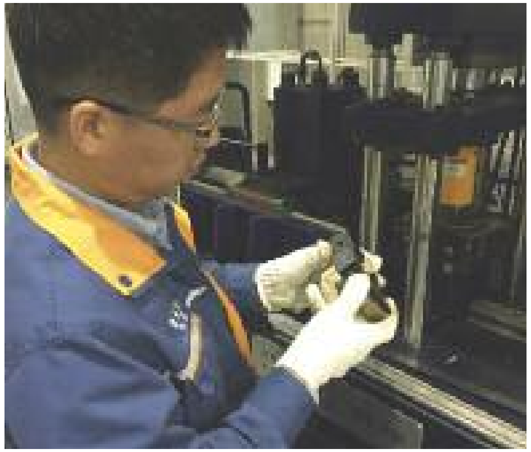
Our appreciation is extended to the Board, Technical Advisory Panel, and Independent Expert Referees for their continued leadership and governance. With their support we are looking forward to seeing more BAJC projects generate valuable new knowledge about eons-old metals and the advanced modern materials that will characterise the future of steel processing technologies.

COLLABORATION & KNOWLEDGE EXCHANGE

UQ Business School Executive Education's inaugural Baosteel Senior Delegation and Executive Education Program participants.



The Baosteel Research Institute visit to UOW.



Baosteel's Mr Chao Niu visited UNSW from November to December 2017, where he carried out the investigation of surface galling in the deep drawing process.

As well as the major collaboration and knowledge exchange milestone of the inaugural executive training program through UQ Business School mentioned in the Board Chairs' message, our partner universities welcomed several other visitors from Baosteel teams throughout the year to meet colleagues and study projects of particular interest.

Dr Jun Wu, President of Baosteel Research Institute, visited the Australian Institute for Bioengineering and Nanotechnology (AIBN) nanomaterials labs at UQ on 24 October 2017. The purpose of this visit was to understand more about the capabilities of AIBN/UQ as the BAJC partner to meet Baosteel's research needs and technology translation.

Dr Zan Yao, also from Baosteel Research Institute, visited UQ for the final two months of 2017. Dr Zongze Huang, Director of Product Research at Baosteel's R&D Centre, spent a week at the end of October at UQ.

UOW hosted four Baosteel visitors from October to December 2017: Dr Sheng Liu from the Department of Hot Rolled Strip; Dr Zhengzheng Li from the Automobile Steel Research Institute; Dr Liangliang Guo from the Special Steel Technology Centre; and Mr Leilei Sun from the Pipe & Tube Technology Centre.

Professor Xiaoming Mao, Director of Baosteel Research Institute's Ironmaking Lab, was welcomed at MU's Simulation and Modelling of Particulate Systems Lab for three days in November 2017. He took this opportunity to attend the ARC Industrial Transformation Research Hub for Computational Particle Technology's Annual Meeting, where he discussed the progress and future planning of blast furnace process modelling projects and other potential research collaborations.

Representing the BAJC, Professor Lianzhou Wang, Professor Geoff Wang, and Professor Max Lu visited Baosteel in August 2017, to further discussions about possible three-party collaborations with Shangdong Chang'an Group relating to lab scale production, small-scale electrode production and battery testing.

IRON & STEEL METALLURGY

Processing iron ore to extract and purify the metal, then mixing it with other elements like carbon to produce alloys such as steel is an ancient science. Contemporary studies of iron and steel metallurgy continue to reveal new knowledge about their physical and chemical behaviour. Advanced technologies allow metallurgy researchers to examine internal structures and properties at nanoscopic levels, to discover what happens when they are put under different pressures. Applying scientific principles to the production and engineering of iron and steel determines how they will perform when used for different purposes in the 21st century.

RESEARCH OVERVIEW

Our iron and steel metallurgy research addresses two key issues for Baosteel to continue competing strongly in the marketplace and meeting sustainability targets: reducing the financial costs and environmental impacts of steelmaking, and increasing the efficiency of processes to optimise the use of resources.

With steel manufacturing emitting over 650 million tons of CO_2 per year, and ironmaking representing more than 80 percent of energy consumption and CO_2 emissions in an integrated steelworks plant, BAJC researchers are investigating ways to help Baosteel save substantially on energy costs. A multiscale computer model to describe the distribution characteristics of flow, heat and mass transfer which aims to optimise the design and control of blast furnace ironmaking, is one example.

A metallurgical and process control strategy for generating new high-strength strip-cast steel grades could see much of the downstream processing eliminated, leading to energy savings of up to 90 percent. Other positive environmental impacts include waste minimisation and negligible atmospheric pollutants such as CO_2 emissions.

The advanced thermodynamic models the researchers are developing can identify the conditions necessary to achieve optimum sinter properties, enabling Baosteel to make informed decisions about purchasing ore, using complex ore mixes, optimising process parameters, and designing sinter blends.

The prospect of cost-efficient technology replacing the need for expensive coke and high-grade coal in the blends, resulting in measurable economic benefits for Baosteel, is another outcome the researchers are pursuing.

Scientifically, the new experimental data and fundamental knowledge emerging from BAJC research are resetting the benchmarks for the physico-chemical properties, behaviours and environmental outcomes that can be achieved in steel refining slag systems.

We are also identifying the critical metallurgical features that influence the performance of advanced high strength steels, such as mould fluxes and hydrogen embrittlement in automotive parts, and heat-affected zones of thick-walled line pipe.

PROJECTS 2011-2018

- BA11009 Ironmaking Process Modelling and Analysis
- BA12002 Cost Efficient Slag Systems
- BA12011 Fluoride-Free Mould Flux for Continuous Casting
- BA12029 Stronger, Tougher, Ductile Steel
- BA12035 Evaluating Centreline Segregation
- BA13037 Auto Steels with Higher He Resistance
- BA14002 Maximising Pipeline Safety and Durability
- BA14009 Iron Ore Sinter Optimisation
- BA14013 Defect-Free Strip-Cast Steel Products
- BA14026 Optimum Control of Raceway Operations
- BA15003 High Performance Spring Steel
- BA15005 New Models for Ferronickel Sintering
- BA16002 3D Model of Efficient Blast Furnace Operations
- BA16006 Low-Reacting Mould Fluxes for High-Al Steel
- BA16008 HAZ-Tough, High-Tensile Oil & Gas Pipes
- BA16010 High Strength Auto Steels with Low Hydrogen Impacts
- BA17010 Defect Reduction in High Nitrogen & Molybdenum Alloy Casting

METAL MANUFACTURING

Metal manufacturing transforms metal structures into components that can be used to create larger machines and structures. It includes smelting and refining iron, rolling steel, and making products from light metals and alloys. These processes produce sheets, bars, plates, ingots, billets, slabs and foils which are then forged, stamped, cut, bent, formed, machined, welded and assembled. Metal manufacturing research focuses on developing market-responsive metal components and reducing environmental and safety impacts of both products and processes.

RESEARCH OVERVIEW

Baosteel operates in a US$1 trillion metallic sheet production market serving the construction, automotive, packaging, aircraft and aerospace industries. The BAJC's metal manufacturing projects are breaking through many of the obstacles currently preventing steel makers from advancing the characterisation of metals and understanding how they will perform in new applications.

Our research also focuses on reducing capital and running costs, improving performance, and generating new products with novel microstructures and properties. The environmental outcomes expected from the projects that are optimising casting and rolling processes include minimising feed material, decreasing greenhouse emissions by up to 80 percent, and stamping a much smaller landscape footprint compared to existing plants.

BAJC projects are contributing to new fundamental knowledge about manufacturing methods. For example, the development of a novel nano-additive water-based lubrication for hot rolling has generated new science. The research adopted advanced testing methods to investigate the mechanism associated with nano-additive water-based lubricants, which had never been done before.

Cold rolled steel, with its more precise dimensions and versatility compared to hot rolled steel, attracts a higher market price. BAJC researchers are leading the development of cold rolling worldwide with, for example, an innovative model for friction and pressure at the rolling gap under mixed lubrication conditions. The model allows engineers to observe production processes in their multi-scale intricacy and customise innovative high performance rolling lubricant and processes.

For the minerals industry, we are addressing a major economic challenge by improving knowledge and applicability of roll-bonding clad steel plates in harsh mining environments.

BAJC's metal manufacturing research is boosting the capability to predict interface behaviours, leading to the development of better quality strip cast and rolled products and greater opportunities for Baosteel to compete favourably on performance, price, and environmental impact.

PROJECTS 2011-2018

BA11001 Optimising Strip Casting Performance
BA12003 Characterising Cold Strip Rolling
BA12045 Maximising Hot Steel Roll Life
BA13012 Environmentally Friendly Mill Lubricants
BA13014 Advanced High Strength Steels for Auto Fuel Efficiency
BA14014 Safer, Ridge-Free Ferritic Stainless Steel Production
BA15001 Assessing Thermodynamics in Lubricant Performance
BA16009 Roll-Bonded Clad Steel Plates in Mining Equipment
BA17001 Predicting Surface Scratching in Sheet Metal Deep-Drawing
BA17004 Eco-Friendly Water-Based Lubricants for Hot Steel Rolling
BA17005 Microporous Membranes for Efficient Wastewater Recycling
BA17012 Corrosion Resistance for Extended Asset Life
BA17013 Better Lightweight Automotive AHSS Products

LIGHT METALS

Light metals have low atomic weight and density, and usually lower toxicity compared to ferrous and other heavy metals. These characteristics and a high strength-to-weight ratio make light metals such as aluminium, magnesium, and titanium commercially valuable – they can be manufactured easily and cheaply into many different shapes and types of products on a mass scale. Light metals research seeks to develop stronger, lighter, more durable and more stable metals which can be produced more economically and with better energy efficiency.

RESEARCH OVERVIEW

Demand for lightweight structural metals has accelerated rapidly this decade, along with the expectation that new materials can be designed in shorter timeframes to match the mass-market pull.

BAJC researchers are working on characterisation and processing options for developing faster, environmentally friendly fabrication methods for low-cost, high-performance titanium, aluminium and magnesium alloy products using novel, cheaper compounds. The research has generated new intellectual assets which are attractive to customers in the aerospace, automotive, marine, defence, chemical processing and mining industries.

Some of these patentable technologies may also support the establishment of successful start-up ventures, such as a new smart titanium manufacturing business in Australia to produce cheaper, high performance powder metallurgy titanium products. Such initiatives could also attract other hi-tech light metal manufacturing businesses to operate and develop in Australia. Importantly, any new business devoted to commercialising products emerging from BAJC research would potentially generate billion-dollar profits for Baosteel each year.

As well as contributing to the international bank of metallurgical and manufacturing knowledge about light metals, our teams have advanced the technology readiness level of many discoveries. A new pass schedule based on a numerical modelling capability for achieving aerospace quality in Ti alloy forging, for example, can be integrated immediately into Baosteel's production system, with the reduced processing steps potentially saving RMB$150,000 per year. Another project investigating the potential of advanced thermomechanical processing of Ti alloys aims to enable Baosteel to produce customer-specified size parts and properties faster.

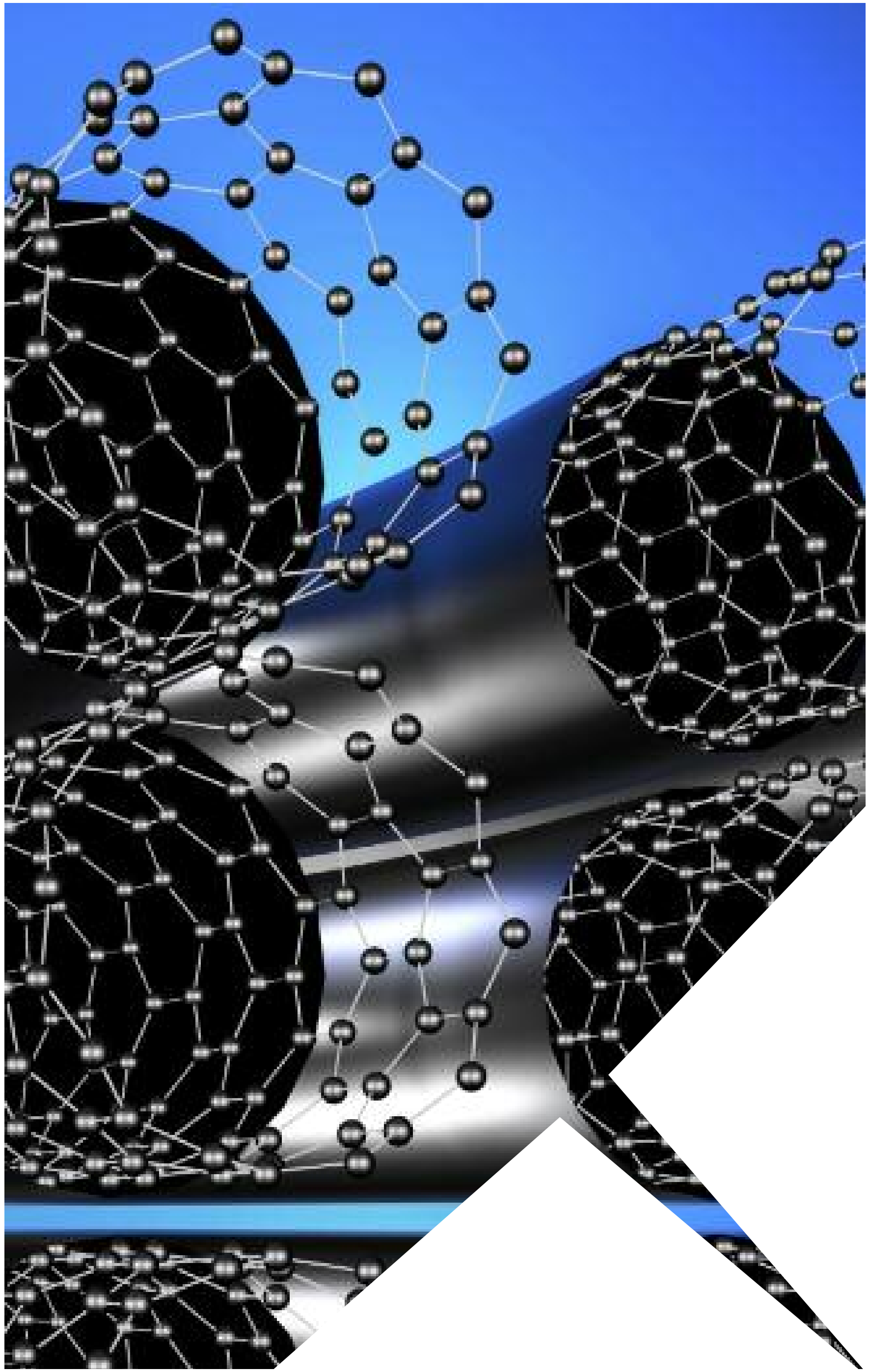
Our light metals research is strategically and commercially important for positioning Baosteel to respond confidently to customer demands for lighter weight alloys with a comprehensive portfolio of high performance materials. The advanced technical solutions our teams are developing will help Baosteel expand and safeguard its market share as lighter metals become the material of choice for many consumer goods. Enabling industry users to produce lightweight metal parts for energy-efficient transportation vehicles at a scale yet to be seen means BAJC research outcomes have powerful potential to significantly transform the light metals market.

PROJECTS 2011-2018

BA11003 Highly Formable Magnesium Sheet
BA11014 Economic Titanium Fabrication
BA11014-RPP Advanced Titanium Manufacturing
BA12014 Next Generation 6XXX Series Aluminium Alloys
BA12031 Next Generation Coatings for Magnesium Alloy
BA14011 New Ti Alloys for The Aerospace Industry
BA14027 High Performance Magnesium Extrusion Alloys
BA15007 Fast Extrusion of Mg Alloys
BA15008 Strong Structural Automotive Aluminium Alloys
BA16003 Advanced Thermomechanical Processing of Ti Alloys

ENERGY MATERIALS

Energy materials support the storage, transmission and supply of renewable and clean power sources, such as photovoltaics, batteries, super-capacitors, fuel cells, hydrogen technologies, thermoelectrics, and photocatalysts. The atomic and microscopic structure and dynamics of modern metallic alloys, novel polymers, and inorganic and organic nanomaterials are studied to understand how their properties – alone and together – might provide power generation industries with lower cost, safer, stronger and sustainable alternatives.



RESEARCH OVERVIEW

Although the energy efficiency of steel manufacturing has improved this century, energy consumption in the iron and steel industry accounts for 15-20 percent of total industrial energy use in China. More than 60 percent of energy produced is wasted in the form of heat. Steelmaking also uses around 3-4.2 cubic metres of freshwater per ton of steel, generating enormous volumes of wastewater.

BAJC researchers are developing innovative and sustainable solutions for reducing Baosteel's carbon footprint. For example, our research into thermoelectric materials that enable heat to be transformed into electrical energy will help to develop new ways of harvesting and recycling waste energy.

The use of electricity generated from renewable sources requires efficient energy storage. Developing new energy storage systems is critical if large-scale solar or wind-based electrical generation is to be practical and able to meet continuous energy demand. Large-scale power storage for electric vehicles and hybrid electric vehicles is also increasingly in demand, with over 720 million electric vehicles expected to be running worldwide by 2030. Chemical energy storage devices (batteries) and supercapacitors are increasingly preferred for this purpose.

Our researchers are working on anode and cathode materials with optimised composition and architecture, and designing the technology for fabricating safer, high performance materials on a large scale. Exploiting the use of these materials will produce a new generation of supercapacitors and advanced Li-ion batteries that combine longevity, high energy and power density; and that can be charged/discharged at an ultrafast speed. Such advanced energy storage devices will be in demand for smart electricity grids, electrical vehicles, and renewable energy storage devices. These efforts will create new business opportunities and position Baosteel and Australia at the forefront of an emerging energy storage market.

The outcomes of BAJC's energy materials research will deliver significant economic and environmental outcomes, such as reduced wastewater treatment costs, decreased fresh water consumption, and effective utilisation of waste heat generated in the steel manufacturing process. Baosteel's uptake of such technology will set an exemplary model for all industries in energy efficiency and environmental protection.

PROJECTS 2011-2018

BA11006 Graphene with High Capacity and Stability for Ultra-Fast Energy Storage
BA11011 Harvesting Waste Energy with Thermoelectric Power
BA12053 Novel Nanocrystalline Alloys for Electric Motors
BA13005 Smart Polymer Hydrogels for Energy Efficiency
BA13051 Low Cost Solar on Steel for Energy Efficient Buildings
BA14006 Optimised Anode Materials for Large Li Batteries
BA14017 Safer, Stable, Powerful Li-S Batteries
BA16011 High Energy-Low Cost Li-Ion Batteries
BA17002 High Performance Practical Aluminium-Ion Battery

PROJECT INDEX BY UNIVERSITY

The University of Queensland Australia

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UNSW Sydney

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BA17001: PREDICTING SURFACE SCRATCHING IN SHEET METAL DEEP-DRAWING

Developing reliable guidelines for manufacturing thin-walled metal components

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OBJECTIVES

The sheet metal forming process of deep-drawing is one of the most important technologies for producing numerous kinds of thin-walled metal components, such as car body panels. However, in a deep-drawing process, the high contact stresses between the die and workpiece surfaces often cause scratching damage to the workpiece surface. The factors that can contribute to this effect include the mechanical properties of dies and workpiece materials; the randomly-distributed surface asperities in die and workpiece surfaces; the possible involvement and properties of the lubricant; and the deep-drawing processing parameters such as the drawing speed, drawing distance/depth, die geometry, etc.

The inability of existing methods to make predictions of acceptable certainty has presented a tremendous challenge for the Baosteel team: to develop assessment criteria for rationalised process design or to provide cost-effective guidelines for clients.

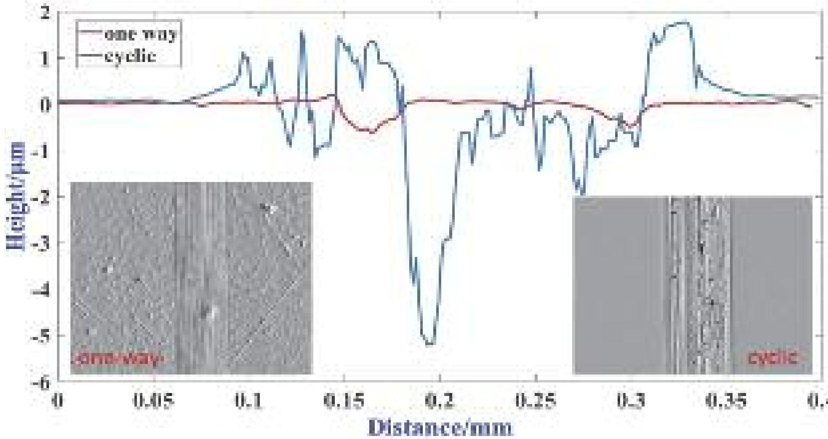
PhD student Wei Li conducting a scratching test.

By taking into account the crucial effects of random asperity distributions and lubricant interaction, this research aims to establish a new predictive assessment of the surface scratching of sheet metals occurring in deep-drawing processes.

POTENTIAL IMPACT

As a major global steel maker and sheet metal supplier, Baosteel needs to provide reliable guidelines for its clients all over the world so they can assess the extent/degree of possible surface scratching of sheet metal workpieces for the design of their deep-drawing processes. This is critical for Baosteel's further development of materials for lightweight vehicles, the quality warranty of products, and market growth.

With the innovation this research will uncover, the surface scratching of sheet metals in deep-drawing processes is expected to be rationally predicted at an acceptable certainty. Such outcomes will progress the aims of Baosteel's technical support team, while contributing significantly the development of future sheet metal forming technologies.



Some experimental results.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Initiated both experimentally and theoretically the fuzzy modelling process by considering the effects of surface hardness, sliding distance, sliding force and die radius on the formation of surface scratching.**
2. **Commenced the development of a statistical, multi-scale method for predicting the surface scratching in deep-drawing, to integrate the plastic deformation of steel plate with the microscale random contact of surface asperities.**
3. **Began characterising three-dimensional surface topography parameters experimentally to identify the critical parameters to surface starching.**
4. **Commenced measurement of the surface hardness of dies and workpieces experimentally, in collaboration with Baowu, to obtain essential data for investigating the surface scratching during deep-drawing.**

BA17002: HIGH PERFORMANCE PRACTICAL ALUMINIUM-ION BATTERY

Exploring high energy and low-cost cathodes to develop a large-scale renewable-based energy storage solution

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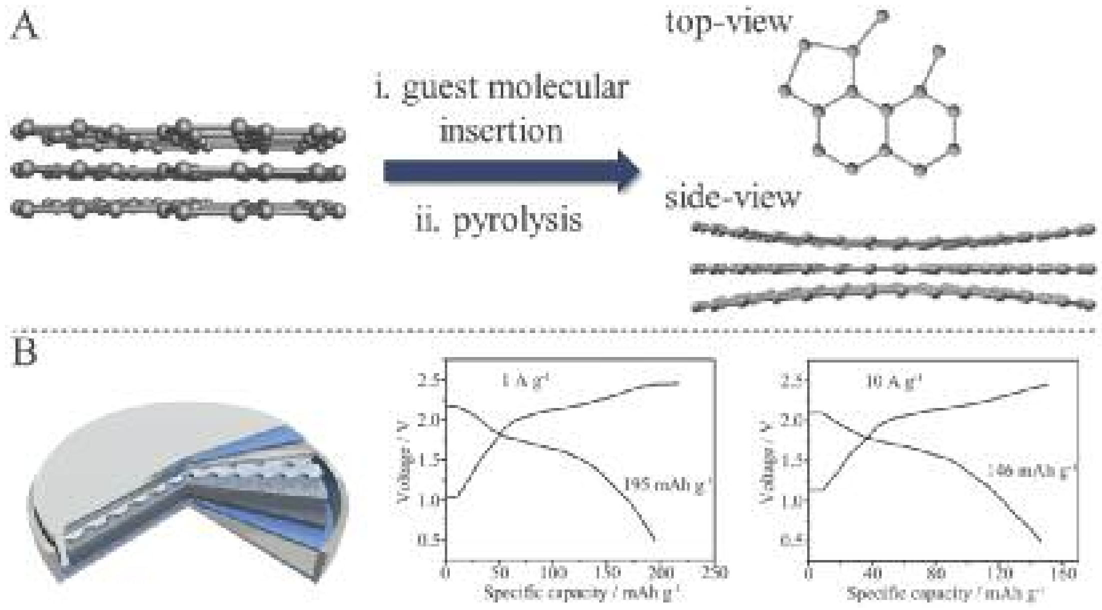
OBJECTIVES

Transitioning from fossil-fuel based energy systems to renewable energies is essential for China's sustainable development. For large-scale renewable-based energy generation to be practical, developing high performance electrical energy storage technologies is critical. Rechargeable batteries represent an exciting opportunity to increase the utilisation of China's renewable energy resources. Aluminium-ion batteries have emerged as a promising new electrical energy storage system, as aluminium is cheap and possesses high gravimetric/volumetric capacities.

Currently, aluminium-ion batteries cannot complete with leading market batteries (e.g. lithium-ion batteries) in terms of energy density. The key element that limits the performance of aluminium-ion batteries is the cathode. State-of-the-art cathode materials using natural pure graphite or graphitic carbon foams suffer from the insufficient capacities, due to their relatively small interplanar spacing (3.4 Å) and rigid lattice structure which restrict the intercalation/de-intercalation of bulky chloroaluminate ions (~5.28 Å diameter).



Schematic illustration of the project's innovations: (A) the material engineering protocol; and (B) the high electrochemical performances.

This project aims to develop practical and high performance aluminium-ion batteries by exploring new high energy density and low-cost cathode materials. These cathodes consist of few-layer exfoliated graphite materials with sp3-carbon rich features and expandable interplanar spacing for high-charge storage capacity.

POTENTIAL IMPACT

The development of advanced aluminium-ion battery technology will place Baosteel and China at the forefront of the rechargeable battery market. New high-profit products and employment opportunities will also benefit Baosteel's strategic plans for market growth.

Commercialised practical, high performance aluminium-ion batteries will also increase the consumption of renewable energy in China and help establish a credible pathway for achieving the government's renewable energy target in the 13th Five-Year Plan.

HIGHLIGHTS AND ACHIEVEMENTS

1. Established a unique material engineering technique for preparing defective exfoliated graphite.

2. Developed a high capacity aluminium-ion battery cathode material with the specific capacity of ~150 mAh/g at 5-10 A/g.

BA17004: ECO-FRIENDLY WATER-BASED LUBRICANTS FOR HOT STEEL ROLLING

Improving product quality and reducing resources utilisation with nanolubricants and related recycling technology

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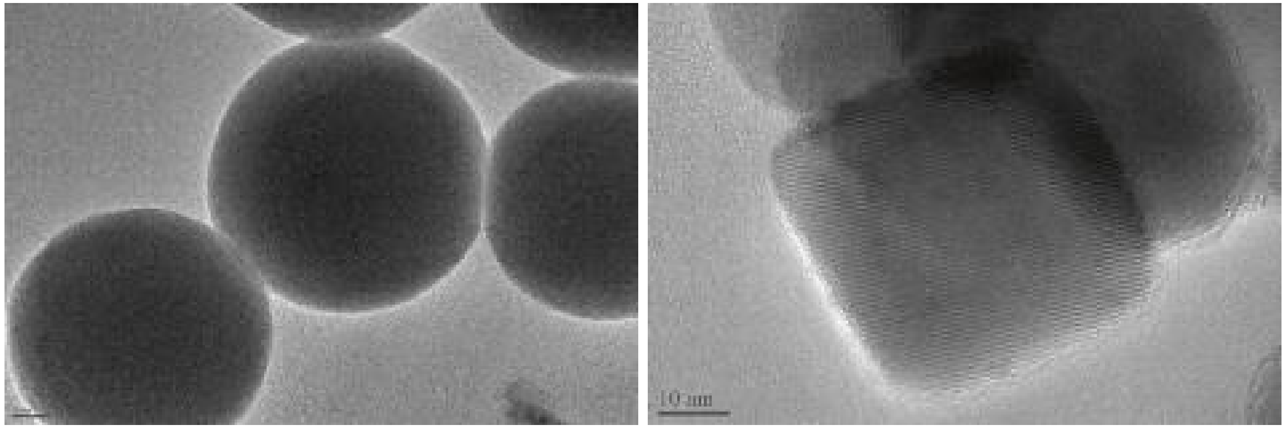
Mr Quansheng Wang (Baosteel)
Mr Jian Liu (Baosteel)

OBJECTIVES

Lubrication significantly affects the surface quality of hot-rolled strips, roll wear, and energy consumption in hot steel rolling processes. The effect of oil-based lubricants currently used in the steel rolling industry is considerably reduced by the high pressure cooling water in the production line, and the waste coolant discharge is of environmental concern.

The researchers aim to improve product quality and reduce resources utilisation, solving a long standing issue for the steel-rolling industry. They are developing eco-friendly water-based lubricants using TiO_2, Al_2O_3 and SiO_2 nanoparticles as additives at a practical production scale that can be applied in hot steel rolling production.

The project will also develop an on-mill supply-to-roll-gap system and recycling technology for large-scale nanolubricants in Heavy Plate Mills.



HR-TEM images of (a) SiO_2 and (b) TiO_2 nanoparticle aqueous suspensions.

POTENTIAL IMPACT

These nano-additive water-based lubricants are expected to have a significant impact on the current Heavy Plate Finishing Mills at Baosteel. For example, the application of nanolubricants would benefit the control of product quality, through reducing the roll wear and oxidation on steel strip surfaces. As progressive deterioration due to corrosion and wear is a major efficiency issue for metal manufacturers worldwide, both operationally and financially, the technological advances from this project will position Baosteel strongly in the supply market for high quality products. Developing a recycling solution for large-scale nanolubricants will reduce reliance on traditional cooling methods and their subsequent environmental impacts, and ensure Baosteel remains at the forefront of sustainable heavy metal manufacturing.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Completed a field study of the heavy plate line at Baosteel to examine the feasibility of implementing the lubricant supply system.**
2. **Designed the nanolubricant supply system.**
3. **Received approval for the implementation field test plan at Baosteel.**
4. **Conducted a systematic investigation of large-scale synthesis of water-based nanolubricants.**
5. **Submitted a patent application to Baosteel for the water-based lubricants using GO/SiO_2-Al_2O_3 nanocomposites as additives.**

BA17010: DEFECT REDUCTION IN HIGH NITROGEN & MOLYBDENUM ALLOY CASTING

Understanding the solidification behaviour of Fe-Ni-Cr stainless steels to reduce cracking and gas pores

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Dr Liangliang Guo (Baosteel)

OBJECTIVES

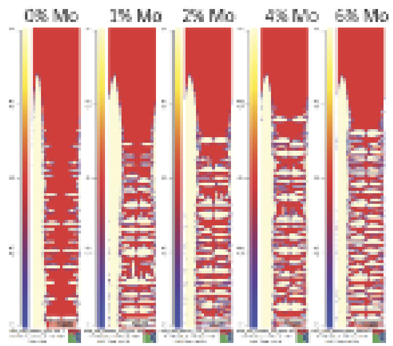
Super-austenitic and Duplex stainless steels are advanced alloys used for demanding applications in the oil and gas, desalination, and hydrometallurgical industries. Baosteel has invested significantly in developing a production capacity to meet China and Australia's growing need for these strategic materials. However, crack formation in Super-austenitic and gas pore formation in Duplex stainless steels have a substantially negative impact on production output.

This project is leveraging the unique combination of experimental and computational facilities at the University of Wollongong with the practical casting expertise at Baosteel to elucidate the underlying cause of defects.

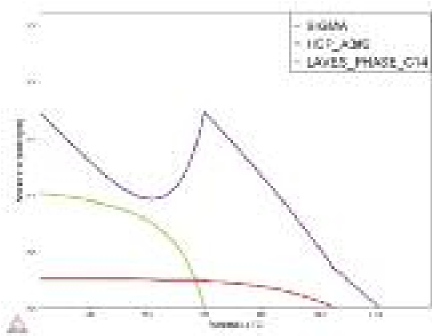
Undertaking a fundamental experimental and modelling study of crack formation in Super-austenitic and gas pore formation in Duplex stainless steels is expected to provide in-situ observations using High Temperature Confocal Microscopy (HTCM) and HTCM-DTA (Differential Thermal Analysis), Differential Scanning Calorimetry (DSC) and advanced characterisation of these steels.

Thermodynamic and kinetics modelling studies using ThermoCalc and Micress respectively will be benchmarked against the experimental data to corelate data between simulations and on-plant phenomena.

To establish casting parameters for optimising product quality in terms of cracking and gas pores for the two steel grades, trials conducted at Baosteel will test hypotheses developed during the course of the project. Samples from these trials will be analysed for defects, segregation patterns, etc. and used to feed back into the modelling framework to further refine understanding of the casting problems.



Simulation



Secondary phase formation of SASS

POTENTIAL IMPACT

Fe-Ni-Cr stainless steels are strategically important to China, and Baosteel is committed to achieving stable production capacity. With the expected research results, Baosteel will be able to define and implement optimised casting and alloy composition parameters, leading to a 10 percent reduction in gas pore/cracking defects in target Baosteel products.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Successfully applied HTCM in both concentric solidification and HTCM-DTA modes to each steel type.**
2. **Observed the peritectic transformation in Super-austenitic steel grades in the concentric solidification mode; and the effects during solidification of delta-ferrite on the subsequent formation of austenite in the duplex stainless steel segregation.**
3. **Established the required experimental settings to provide a basis for generating the data for benchmarking the future thermodynamic and kinetic modelling activities.**
4. **Conducted experimental thermodynamic assessment of solidification using HTCM-DTA for both steel grades.**
5. **Conducted thermodynamic modelling activities to establish the data files required for Micress simulation, including ThermoCalc benchmarking of solidification.**
6. **Completed a Micress study to test model parameters for dendritic solidification.**
7. **Commenced work on establishing the parameters for the benchmarking from concentric solidification experimental work.**
8. **Commenced initial experimental activities in support of the thermodynamic modelling work, including DSC analysis of two steel grades.**
9. **Secured internal funding from UOW to procure a new HTC Microscope.**

BA17012: CORROSION RESISTANCE FOR EXTENDED ASSET LIFE

Developing a novel surface functioning technology for heating and hot rolling carbon steel

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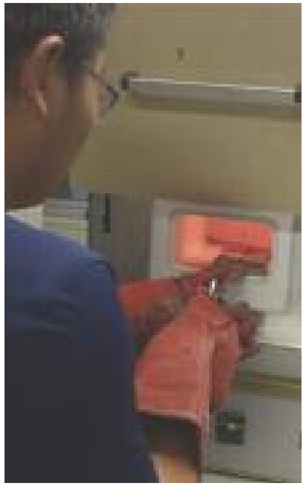
OBJECTIVES

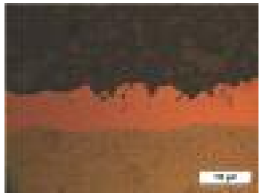
Corrosion is a major cause of structural deterioration in marine and offshore assets for the oil and gas sector and renewable energy plants, such as wind farms. Surface deterioration of steel structures can lead to premature, costly and often sudden failure, resulting in unscheduled downtime and, for oil and gas rigs, the threat of leaks.

Adding expensive alloying elements into bulk steels is not cost effective, as only steel surfaces are exposed to harsh and aggressive sea environments. Understanding how the surface of steels function at high temperatures could lead to improvements in the corrosion resistance of hot rolled steels when manufactured at a lower cost. However, the relevant research and technology platforms to address this problem are still lacking.

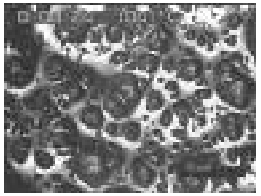
In this project, the researchers are applying in-depth science to the anti-corrosion challenge, and plan to introduce a novel surface functioning technology during heating and hot strip rolling to improve



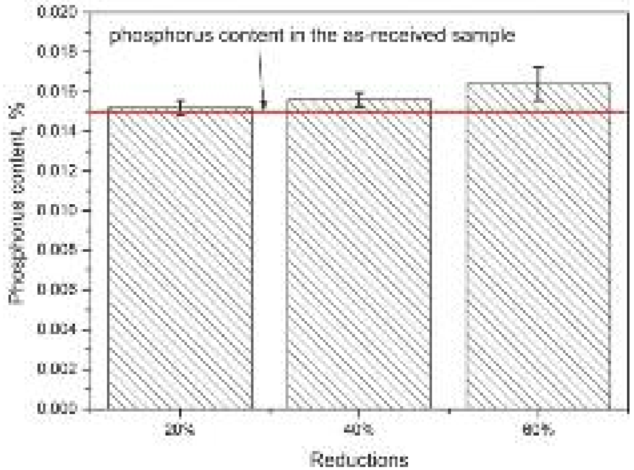
Coating of Cupper on steel sheet surface at a high temperature muffle furnace.



Cupper layer deposited on steel by integrating compounds at high temperature.



In-situ observation of thermal interaction of $Cu+N_i$ compounds by HTLSCM.



Phosphorus content at steel substrate by applying polyphosphate during hot rolling process.

corrosion resistance.

They are investigating the corrosion mechanism and quantifying how new technology will combat corrosion-related problems effectively in practice, to offer long term integrity and life extension to both onshore and offshore assets.

POTENTIAL IMPACT

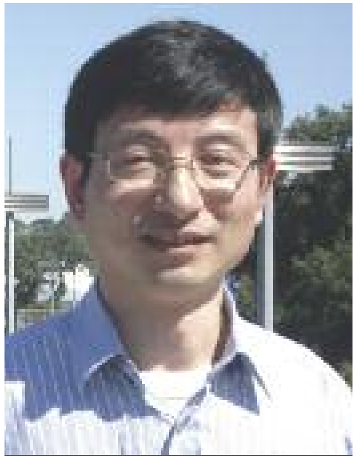
A breakthrough development in surface functioning technology during hot strip rolling would improve the corrosion resistance of key steel products while creating new opportunities for manufacturing corrosion-resistant steels at a lower cost. With the ability to improve the corrosion-resistance of hot rolled steels and their manufacture, Baosteel can bolster its domestic and global competitiveness. For Baosteel clients, the improved structural integrity of their assets will lengthen the production gains cycle and reduce the costs of maintenance.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Conducted a preliminary experiment for surface functioning technology by integrating Cu+Ni+Si+Al compounds at high temperature during re-heating furnace.**
2. **Observed in-situ thermal interaction of composites with hot steel surface by a high-temperature laser-scanning confocal microscopy (HTLSCM) simulating the reheating furnace conditions.**
3. **Conducted a preliminary experiment for surface functioning technology by applying polyphosphate during the hot rolling process.**
4. **Hosted and provided for Dr Sheng Liu from Baosteel.**
5. **Recruited a PhD candidate funded by UOW and Higher Education Commission Pakistan.**

BA17005: MICROPOROUS MEMBRANES FOR EFFICIENT WASTEWATER RECYCLING

Developing advanced membranes to address wastewater treatment challenges in steel manufacturing



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OBJECTIVES

The iron and steel industry consumes a large amount of fresh water and the waste water generated from various processes requires treatment before it is discharged or recycled. Currently, reverse osmosis technology removes various contaminants such as suspended solids, total dissolved solids, and ions from the steel mill wastewater to meet treated water recycling standards. The traditional membrane materials this technology uses suffer from drawbacks such as a trade-off between permeability and selectivity, fouling, degradation, and high operation costs.

The research team is developing a two-dimensional, slit-like microporous channel membrane for ultrafast water permeation and high rejection of contaminants for highly efficient wastewater treatment and recycling.

The project is also utilising waste heat to further increase wastewater treatment productivity, thus reducing fresh water consumption and environmental impact.

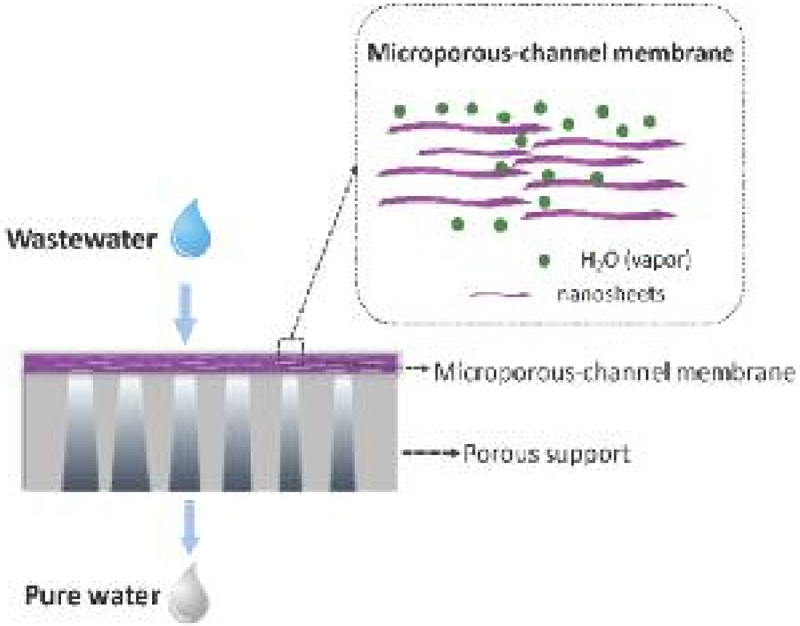

Illustration of microchannel carbon membranes for an ultrafast water transport process.

POTENTIAL IMPACT

When completed, high water flux and rejection, thermal and chemical stability, and outstanding tolerance of surface wetting will make the microchannel membranes highly suitable for treating wastewater from steel making so it can be recycled. The new experimental data on the microchannel structure, pore volume, surface properties, and stability based on the flux will pave the way for scalable membrane design.

By harnessing the waste heat from the steel industry and many other industrial processes, the technique is expected to lead to a scalable membrane with microporous channels for efficient wastewater treatment, producing significant economic, environmental and social benefits.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Recruited a research fellow and a PhD student.**
2. **Investigated parameters for controlling the microstructure of membrane-supported small porous ceramic substrates and identified the surface roughness and pore size of the substrate as the main parameter for affecting membrane quality.**
3. **Designed and assembled a performance evaluation system.**

BA17013: BETTER LIGHTWEIGHT AUTOMOTIVE AHSS PRODUCTS

Investigating residual stresses and product qualities of roll formed compared with Chain-die formed AHSS products

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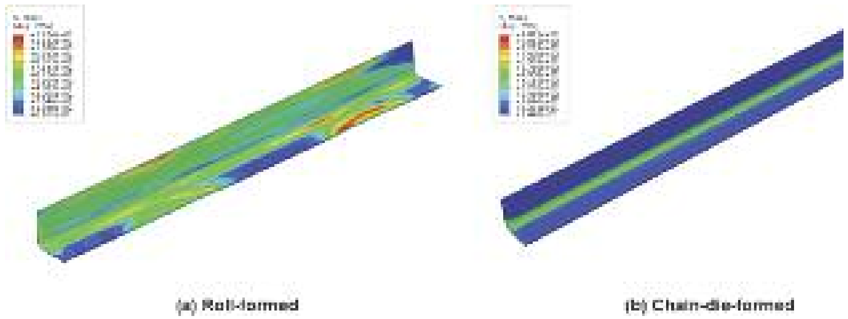
OBJECTIVES

With its high strength and better energy absorption, advanced high strength steel (AHSS) is used extensively in automotive industries. The widespread application of AHSS contributes to the lightweight and low emission requirements of modern vehicles. Residual stress and subsequent strength and elongation play significant roles in determining the product quality of the AHSS products.

Bending-dominated manufacturing processes, such as roll forming and Chain-die forming, are the most efficient sheet metal forming methods for fabricating AHSS products for automotive and related industries. This project is exploring ways to understand and optimise the residual stress and product qualities of elongation and strength in cold bent AHSS products.

This includes developing a bending tester to study the formability of AHSS with a bend moment-curvature diagram. The relationship between the Bauschinger effects of metal sheets and bend moment-curvature diagram will also be studied. The bending tester will then be employed to investigate the as-received residual stress in metallic components of AHSS sheet metals.

Later, the study will explore the predictive modelling of residual stresses of roll-formed and cold-formed AHSS profiles in consideration of Bauschinger effect and as-received residual stress. The expected models will be examined through the neutron diffraction residual stress facility at Australia's Nuclear Science and Technology Organisation (ANSTO). The micro-cracking initiation and propagation of some critical regions of formed AHSS products (such as bend corners) will be investigated and analysed through the microanalysis tools. Subsequently, the remaining effects of strength and elongation will be explored through a small, scaled mechanical properties testing approach.



Comparison of final residual stress distribution of roll formed and Chain-die formed DP980 U-channels.

POTENTIAL IMPACT

Earlier studies have proved that Chain-die forming uses less energy than roll forming, offering cost savings and decreased pollution emissions. This method has also reduced the redundant strain components of AHSS, resulting in low residual stresses in formed products. This research will lead to a better understanding of the formation mechanism of residual stress and the remaining strength and elongation properties of roll-formed and chain-die formed AHSS products.

As well as the bending tests generating new fundamental knowledge about the material behaviour of AHSS during the bending process, which is currently difficult to obtain with a traditional tensile test, the application of this knowledge to Baosteel's manufacturing processes is expected to boost Baosteel's market share, product quality and reputation in Australia. This will ultimately foster Baosteel's competitiveness globally.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Established effective analytical models to predict the residual stress of Chain-die and roll formed AHSS products, generating new knowledge about the formation of residual stress during cold bending processes.**
2. **Established effective numerical models to predict the residual stresses during roll forming and Chain-die forming processes in consideration of as-received residual stresses and Bauschinger effect.**
3. **Performed intensive experimental verification of established models with microanalysis tools, including SEM observation and the neutron diffraction residual stress measurement method.**

PUBLICATIONS AND PATENTS

Since 2011, the Centre's research teams have published and presented 230 journal papers, three book chapters, 126 conference papers, and filed 18 patents.

JOURNAL PAPERS 2017-2018

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CONFERENCE PAPERS AND PRESENTATIONS 2017-2018

Ferry, M. (Plenary). Direct Strip Casting of Steel – Historical Overview, Processes & Properties. *BAOWU International Conference on Near Net Shape Casting*. Wuhan, China, 24-25 April 2018

Lyu, S., Ma, X., Huang, Z., Yao, Z., Wang, G., Zou, J., Lee, H.G., & Zhao, B. Critical Analysis of Non-Metallic Inclusions in Al- and Si- Deoxidized Spring Steels. *7th International Congress on Science and Technology of Steelmaking*. Venice, Italy, 13-15 June 2018

Ma, X., Marl, J., Huang, J., Yao, Z., Lee, H.G., Wang, G., Zou, J., & Zhao, B. (2018). Correlation of Tensile Strength and Hardness, and Effects of Heat Treatment and Alloying of Spring Steels. *7th International Congress on Science and Technology of Steelmaking*, Venice, Italy, 13-15 June 2018

Wu, H., Zhao, J.W., Xia, W.Z., Cheng, X.W., He, A.S., Yun, J.H., Huang, S., Wang, L., Huang, H., Jiao, S.H., Jiang, Z.Y. Tribological behaviour of water-based nanolubricant containing TiO2 on ferritic stainless steel. *International Symposium on Advances in Abrasive Technology*. Okinawa, Japan, 3-6 December 2017

Wu, H., Zhao, J.W., Huang, S., Wang, L., Huang, H., Jiao, S., Jiang, Z.Y. Evaluation of tribological properties of water-based nanolubricant added with TiO2 nanoparticles at elevated temperatures. *SurfCoat Korea*. Seoul, Korea, 28-30 March 2018.

Xu, W. (Keynote). The Characteristics of Strip Casting Steel Microstructures. B*AOWU International Conference on Near Net Shape Casting*. Wuhan, China, 24-25 April 2018

Yang, J., Zhang, J., Ostrovski, O., Zhang, C., & Cai, D. Flux-Steel Reaction of CaO-SiO2 and CaO-Al2O3-based Mold Fluxes with *High-Al Steel. 7th International Congress on Science and Technology of Steelmaking. Venice*, Italy, 13-15 June 2018

PATENTS 2017-2018

Through UniQuest, The University of Queensland's research commercialisation company:

PCT/CN2015/080452	Chalcogenide nanomaterials (UOW)
PCT/CN2015/080464	Aqueous route to metal chalcogenide nanoparticles (UOW)
PCT/CN2015/079243	Nano- and micro-scale engineering of MoS2-based catalyst for conversion of syngas to ethanol (UQ)
PCT/CN2015/076022	Formable magnesium-based sheet alloys (MU)
PCT/CN2015/076023	Strain-induced age strengthening in dilute magnesium sheet alloys (MU)
PCT/CN2015/083421	Mini hot rolling mill for equipping on a thermal-mechanical simulator (UOW)
PCT/CN2015/089698	Low cost innovative powder metallurgy titanium alloys and control of oxygen for improved ductility (UQ)
PCT/CN2015/097227	Mechanically-assisted electrochemical production of electrochemically-derived graphene oxide (EGO) (MU)
PCT/CN2015/089577	Hydrogel-sponge interpenetrating materials as a draw agent for forward osmosis process (MU)
PCT/CN2015/098194	An integrated polymer-based technology for Li-S batteries (UQ)

Through Baosteel

PCT/CN2015/10926259.3	Magnesium alloys sheet rolling and preparation method (MU)
PCT/CN 2015/10926268.2	A graphene composite coating for Mg-Al-based alloys (MU)
PCT/CN 2015/10736990.X	A novel silicon-based anode material in lithium ion battery, including its fabrication method, other silicon included anode materials and batteries (UOW)
PCT/CN 2016/10041265.5	A protective coating system for Mg-Re-based alloys (MU)
PCT/CN 2016/10511299.6	A composite forward osmosis membrane and the method of making (MU)
PCT/CN 2016/10269926.X	Water-based nanolubricants for hot steel rolling (UQ)
PCT/CN 2017/10053977.3	Nano- and micro-fibre ceramics reinforced high-strength and ductile titanium materials (UQ)
PCT/CN 2017/10083337.7	Water-based lubricants using 2D-0D nanocomposites as additives (UQ)

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Mr Zhou Li (RS)	Mr Guoqing Zu (RS)

Key:
CI Chief Investigator
RF Research Fellow
RS PhD Research Student

BOARD

The Board sets priority and strategic research themes; oversees the annual budget; determines funding rules; and approves project funding. It provides guidance and oversight to the Centre's management team.

The Board consists of nine representatives, comprising two Board Chairs appointed by Baosteel and The University of Queensland, four members from Baosteel (including a Board Chair), two members from The University of Queensland (including a Board Chair and the Centre Senior Director), and one member each from the other participating universities. The Centre Executive Director, who serves as the Board Secretary, and the Chair of the Technical Advisory Panel, each have observer status.

MANAGEMENT TEAM

A Senior Director, Executive Director, and Centre Operations and Finance Officer comprise the Management Team. A Baosteel coordinator also participates in the Centre's management. The Management Team is responsible for attracting and collating proposals, project coordination and facilitation, project meetings, reporting, budgetary management and IP management. It provides reporting and secretariat services to the Board, including organising Board meetings and documentation. The Management Team is responsible for ensuring the Technical Advisory Panel and Independent Expert Referees (IERs) are supported in their activities. It also arranges the Centre's annual conference, visits from Baosteel representatives, and communication and promotional activities.

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Professor Victor Rudolph, The University of Queensland

Centre Executive Director
Professor Geoff Wang, The University of Queensland

Centre Operations Officer
Ms Cathy Yuan, The University of Queensland

Baosteel Collaboration Manager
Mr Yongzhu Ma, Baosteel Research Institute (R&D Center), Baoshan Iron and Steel Co. Ltd

Professor G.Q. Max Lu
Board Chairman
President and Vice-Chancellor
University of Surrey

Dr Pijun Zhang
Fellow of Baosteel
Institute (R&D Center)
Baoshan Iron and Steel Co. Ltd

Dr Shiwei Xu
Senior Engineer, (R&D Center)
Baoshan Iron and Steel Co. Ltd

Professor Victor Rudolph
Centre Senior Director
School of Chemical Engineering
The University of Queensland

Professor Judy Raper
Deputy Vice-Chancellor
(Research & Innovation)
University of Wollongong

Dr Warwick Dawson
Director, Research Strategy
& Partnerships
The University of New South Wales

Professor Mohan Krishnamoorthy
Board Co-Chair
Pro-Vice-Chancellor
(Research Partnerships)
The University of Queensland

Dr Haomin Jiang
Vice President of Baosteel
Research Institute (R&D Center)
Baoshan Iron and Steel Co. Ltd

Professor Freider Seible
Dean, Faculty of Engineering
Monash University

Professor Aibing Yu (observer)
Chair of the Technical Advisory Panel (TAP)
Pro Vice-Chancellor & President (Suzhou)
Monash University

Professor Geoff Wang (observer)
Board Secretary & Centre
Executive Director
School of Chemical Engineering
The University of Queensland

TECHNICAL ADVISORY PANEL

The Technical Advisory Panel's Australia-based experts lead, facilitate and advocate for their institutions' projects, to guide interactions with Baosteel.

The Technical Advisory Panel (TAP) comprises internationally recognised Australia-based academics and experts recommended by the participating universities and approved by the Board, plus technical liaison advisors appointed by Baosteel. The Board-approved TAP Chair is jointly nominated by Baosteel and The University of Queensland.

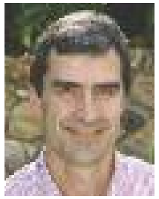
TAP members provide technical leadership, facilitation and advocacy regarding projects from their Institutions; identify and steer project investigators in the selection, preparation and execution of projects; and provide a continuing contact guiding their Institutions' interactions with Baosteel technical area champions. TAP members can lead and/or undertake projects within the Centre; they do not participate in the technical assessment and selection of research proposals to be funded.

INDEPENDENT EXPERT REFEREES

Board-appointed by invitation as required, IERs review, assess and provide commentary on project proposals.
IERs strengthen the proposal selection process by identifying gaps or areas of weakness and by giving feedback on funded project progress and outcomes.
IERs are internationally recognised experts in particular technology areas pertinent to the proposals. They do not lead or undertake Centre projects.

Professor Aibing Yu
Technical Advisory Panel Chair
Monash University

Professor Victor Rudolph
Technical Advisory Panel Co-chair
The University of Queensland



Professor Ian Gentle
The University of Queensland

Professor Mark Hoffman
The University of New South Wales

Professor Huijun Li
University of Wollongong

Dr Pijun Zhang
Baoshan Iron and Steel Co. Ltd

Dr Haomin Jiang
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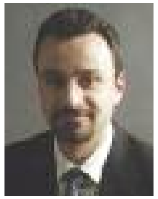
Dr Shiwei Xu
Senior Engineer, (R&D Center)
Baoshan Iron and Steel Co. Ltd



Professor Nick Birbilis
Monash University

FINANCIAL SUMMARY

Financial Statement for the period from 01 July 2017 to 30 June 2018

BAJC Grantors:

Baoshan Iron & Steel Co Ltd (Baosteel)
The University of Queensland
The University of New South Wales
Monash University
University of Wollongong
Australian Research Council (ARC)
Cooperative Research Centres (CRC)

Cash Balance as at 01-07-2017
$2,304,856.18

INCOME (CASH)

Grant and Collaborative Research	
Baosteel R & D Fund	$1,400,000.00
Baosteel - management support	$150,000.00
The University of New South Wales - management support	$50,000.00
Monash University - management support	$50,000.00
University of Wollongong - management support	$50,000.00
The University of Queensland - management support	$100,000.00
Total Cash Income	**$1,800,000.00**
Total Leveraged ARC-Linkage Grant	$1,022,270.66
TOTAL INCOME (EXCLUDING IN-KIND)	**$2,822,270.66**

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Ask of the steel, each strut and wire,
Ask of the searching, purging fire,
That marked their natal hour;
Ask of the mind, the hand, the heart,
Ask of each single, stalwart part,
What gave it force and power.

Joseph B. Strauss

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