BAOSTEEL-AUSTRALIA

JOINT RESEARCH AND DEVELOPMENT CENTRE

ANNUAL REPORT

2016-2017

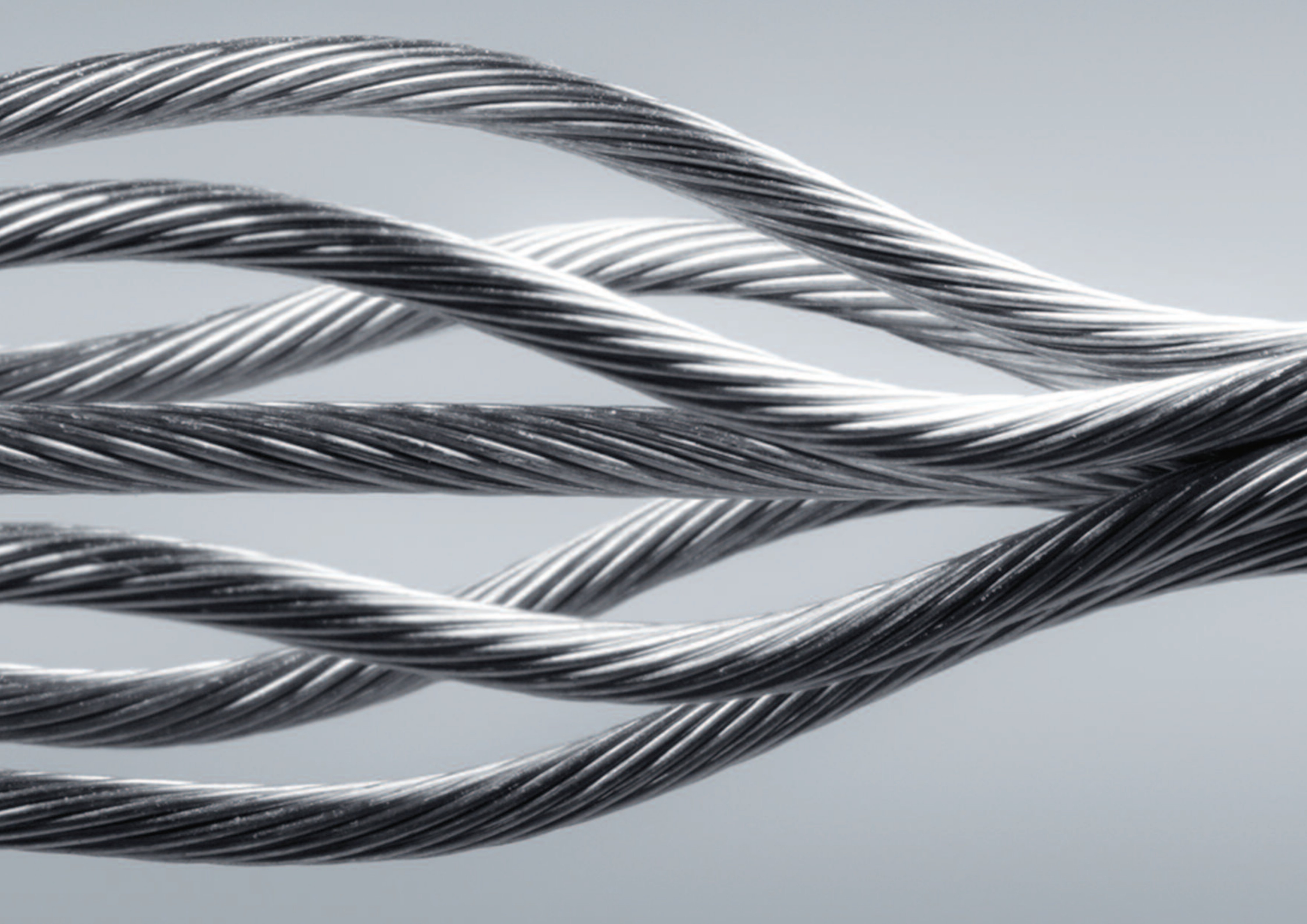
BAOSTEEL

The University of Queensland Australia

UNSW Australia

MONASH University

University of Wollongong



The Baosteel-Australia Joint Research and Development Centre (BAJC) is a world-first partnership between Baosteel – a globally significant steel enterprise based in Shanghai – and four research-intensive Australian universities: The University of Queensland, The University of New South Wales, Monash University and the University of Wollongong.

Our purpose is to create an internationally recognised centre of excellence in metals-related research. We pursue this goal by exploring and generating new knowledge to develop technologies that have particular significance to Baosteel's longer term strategic development and business activities in selected areas.

Baosteel has committed almost $26 million since the Centre was established in 2011, matched by in-kind contributions from the partner universities of more than $34 million.

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

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

CONTENTS

KEY CAPABILITIES

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

- **Engaged over 110 eminent researchers based in Australia and China**
- **Supported 48 innovative research projects**
- **Disbursed a total of A$16 million in project funding**
- **Attracted A$34 million in-kind partnership contributions**
- **Leveraged A$6.9 million in ARC Linkage and CRC grants**
- **Published and presented more than 250 academic papers**
- **Filed 18 patents**
- **Hosted 5 annual conferences**

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

- 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

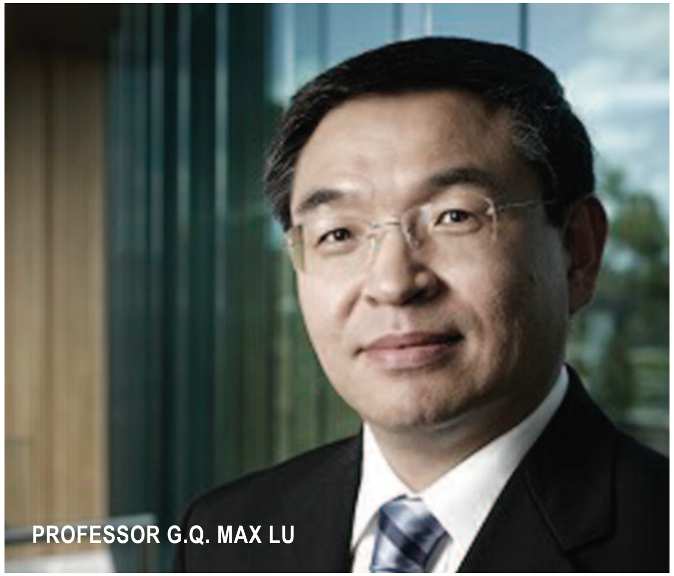
MISSION AND VISION

The BAJC's purpose is to create an internationally recognised centre of excellence in steel-related research. Through an enduring partnership the Centre funds, explores, and generates new knowledge and technologies with particular significance to Baosteel's longer term strategic development and business activities in selected areas.

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

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

FROM THE BOARD CO-CHAIRMEN



Baosteel's confidence in Australia's intellectual capacity is evident in the $26 million it has invested in the four partner universities to generate commercial and scientific outcomes with significant value in the fields of advanced materials and clean, efficient energy.

The Baosteel-Australia Joint Research and Development Centre has enjoyed a very productive year and we are proud to share the highlights in this Annual Report.

2016-2017 saw the unique collaboration between Baosteel and four leading Australian universities enter its second phase, with a stronger emphasis on progressing the discoveries and processes arising from research activities to commercial deployment.

Greater support for student participation has become another point of focus. Since 2011, 30 postgraduate students have contributed to the Centre's 40+ projects, co-authored many of the 300 published papers and conference presentations, and worked on their doctoral theses under the supervision of senior BAJC researchers.

Like the chief investigators they look to for guidance and mentorship, these emerging industry practitioners are forming enduring professional and personal relationships that enhance the experience and outcomes of collaboration while building strong networks. Our postgraduate students also participate in activities arranged to welcome Baosteel researchers visiting Australia for project advancement and knowledge exchange.

Such engagement, for both project leaders and students alike, supports the forming of long term alliances that can respond profitably and effectively to a global market demanding more economical and sustainable solutions.

Baosteel's confidence in Australia's intellectual capacity is evident in the $26 million it has invested for the four partner universities to generate commercial and scientific outcomes with significant value in the fields of advanced materials and clean, efficient energy. The Centre has leveraged this commitment to raise an additional A$6 million (RMB$30 million) from Australian government funding schemes for industry partnerships and discovery programs.

The Centre's relationship with the Australian Research Council (ARC) was strengthened when the BAJC took on the responsibility of managing the ARC Research Hub for Computational Particle Technology, based at Monash University's Clayton campus, and funded by the Australian Government's Industrial Transformation Research Program. The Hub, whose director is the chair of our Technical Advisory Panel (TAP), Professor Abing Yu, also facilitates BAJC researchers connecting with other international organisations, such as Jiangsu Industrial Technology Research Institute, Rio Tinto, and Longking.

This year saw changes to both the Board and the TAP. When Professor Anton Middelberg resigned as a Board co-chair and member in April 2017, UQ nominated Professor Mohan Krishnamoorthy, Pro Vice-Chancellor (Research Partnerships) as his replacement. Baosteel nominated Dr Shiwei Xu, Senior Research Engineer of Baosteel Research Institute to replace Dr Jian Yang as the Baosteel TAP representative and a Board member. We welcomed both esteemed colleagues to the Centre's governance committees with pleasure.

We extend our thanks to Professor Middelberg and Dr Jian Yang for their service and their contributions to the BAJC's success.

We would also like to express our appreciation of your ongoing interest in the Centre. We hope you will enjoy reading about the advances in materials science our researchers are making as they strive to solve critical challenges for the metals and energy sectors, today and in the future.

PROFESSOR G.Q. MAX LU,
BOARD CHAIRMAN

PROFESSOR ANTON MIDDELBERG,
BOARD CO-CHAIRMAN

FROM THE CENTRE DIRECTORS

Our research range, which has grown to 48 projects over the past six years, is on track to deliver transformational outcomes, both commercial and environmental, so that Baosteel can lead the way towards overcoming the challenges facing global manufacturing and energy materials industries.

Every year the Baosteel-Australia Joint Research and Development Centre receives numerous high calibre proposals for novel research that aims to solve real productivity and product quality challenges facing global manufacturing and energy materials industries.

To receive funding and benefit from the BAJC's unique collaborative arrangement, successful projects must align with our four primary interests: metallurgical processing, metal manufacturing, light metals and energy materials.

This report on the Centre's activities over the past 12 months highlights how our research range, which has grown to 48 projects over the past six years, is on track to deliver transformational outcomes, both commercial and environmental, so that Baosteel can lead the way towards overcoming these challenges.

With so many projects in our portfolio now, we have reduced the number that are detailed in the Annual Report to just the most recent round. The initial pages of this document provide the context for a summary of achievements to date on pages 8 to 11 and a selection of Round 6 projects on pages 14 to 20.

If you would like to know more about these projects, please contact the Centre or the chief investigators directly, whose details are included.

BAJC researchers are diligent authors, disseminating their discoveries and methodologies via publishing in renowned scientific journals, presenting at international conferences, and securing patents. This year alone, the output totalled more than 60 items, and these are listed on pages 22 to 24.

Our own annual conference, the fifth since 2011, was held on the Gold Coast on 20 February 2107. Twenty-six researchers presented their work to 80 delegates from Baosteel and our partner universities. Other collaboration and knowledge exchange activities are highlighted on page 7.

At the conclusion of the first year of this second phase of the Centre's operations, we thank all our chief investigators, research fellows and postgraduate research students for their efforts to fulfil the BAJC's mission and achieve ambitious goals, guided by a strong vision and supportive network. An 'honour roll' can be found on page 25.

We also thank the Board, Technical Advisory Panel, and Independent Expert Referees for their leadership and direction. Their governance has enabled us to fund innovative projects that align closely with Baosteel's production functions and business strategy, especially those with an emphasis on more quickly implementing discoveries in the production chain.

We would also like to take this opportunity to express appreciation for the efforts of our efficient administration team which coordinates the Centre's activities across the four partner universities to ensure we continue to maintain high standards of service to all our stakeholders.

**PROFESSOR VICTOR RUDOLPH,
CENTRE SENIOR DIRECTOR**

**PROFESSOR GEOFF WANG,
CENTRE EXECUTIVE DIRECTOR**

Dr Qingfeng Zhang at the Manufacturing Laboratory, UOW

Baosteel Visits to BAJC Facilities

Visitors from several Baosteel teams were welcomed at BAJC facilities throughout the year to meet colleagues and study particular projects.

Mr Qi Wei from the Baosteel Ironmaking team of Baosteel Research Institute spent four months working with Professor Peter Hayes's team at UQ on novel approaches to iron sinter optimisation through microstructural design and the development of new FactSage thermodynamic databases (BA14009).

Other researchers visiting UQ included Dr Zan Yao and Dr Zongze Huang from the Long Products team of Baosteel Research Institute, to assist Professor Baojun Zhao with characterising inclusions and precipitates in high strength spring steel and investigating strengthening mechanisms (BA15003).

Professor Zhengyi Jiang and his team at UOW benefitted from three Baosteel Research Institute Steel team visitors. Dr Xin Zhang assisted with researching improvements to ridging defects through rolling and heat treatment technology (BA14014). Mr Qingfeng Zhang contributed to fundamental research into roll-bonding clad steel plates in mining equipment (BA16009). Ms Li Wang worked on the development of novel nano-additive water based lubrication technology for hot rolling of steels (BA13012).

Dr Bo Yan, Mr Suoquan Zhang, Mr Hui Wu, Mr Anshun He, Prof Zhengyi Jiang, Prof Sihai Jiao, Mr Lingkai Zhang, Mr Lingfeng Zhang and Mr Ran Jin at the Baosteel Research Institute

Mr Hui Wu and Mr Anshun He at Baosteel Research Institute

Dr Yu Zeng from Baosteel Aluminium joined Dr Paul Rometsch's team at MU for three months to work on high strength 6xxx series aluminium alloy sheet for automotive structural applications (BA15008).

A delegation from Baosteel Metal also visited MU for meetings and further discussions about collaborative work between Baosteel and BAJC.

Industrial Transformation Research Hub

BAJC manages the ARC Research Hub for Computational Particle Technology, based at Monash University's Clayton campus in Victoria, funded by the Australian Government's Industrial Transformation Research Program.

BAJC Technical Advisory Panel Chair Professor Aibing Yu heads the $20 million hub, which has started generating new theories, computer models and simulation techniques through close collaboration with leading international companies such as Baosteel.

The Industrial Transformation Research scheme engages Australia's best researchers in tackling the tough issues facing new industrial economies, and enables opportunities to train the future workforce.

The hub at Monash University is one of nine centres supporting collaborative research activity between Australia's higher education sector and industry, to achieve strategic outcomes not independently realisable. Projects arranged through the Monash Clayton hub follow the general principles of BAJC research management, including the IP provisions stated in BAJC Agreement.

METALLURGICAL PROCESSES

Metallurgy is concerned with the physical and chemical behaviour of metals and their mixtures. It involves processing ores to extract the metal they contain, purifying them, and mixing metals, both together and with other elements, to produce alloys. Metallurgy researchers study the internal structures and properties of metals, and what happens when they are put under different pressures. Applying scientific principles to metal production and engineering determines how metal products will perform when used for different purposes.

RESEARCH OVERVIEW

Our metallurgical processing research projects are addressing two key issues for 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.

Steel manufacturing emits over 650 million tons of CO_2 per year, and ironmaking represents more than 80 percent of energy consumption and CO_2 emissions in an integrated steelworks plant. Thus, BAJC researchers are investigating ways to help Baosteel save substantially on energy costs.

A metallurgical and process control strategy for generating new high-strength strip-cast steel grades, for example, 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.

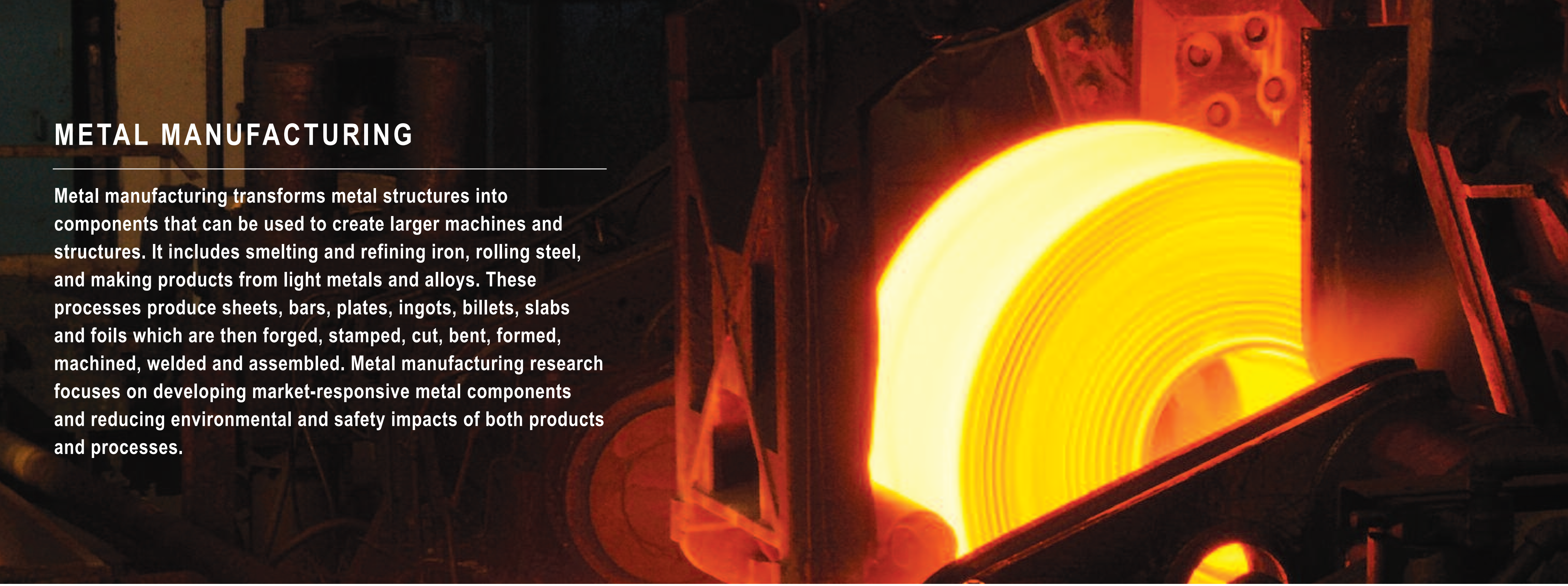
The advanced thermodynamic models the researchers are developing can identify the conditions necessary to achieve optimum sinter properties, enabling Baosteel to make informed decisions about purchasing ore, using complex ore mixes, optimising process parameters, and designing sinter blends.

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.

PROJECTS 2011-2017

- 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 and Gas Pipes
- BA16010 High Strength Auto Steels with Low Hydrogen Impacts



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.

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 2011-2017

- 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

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, 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, could be integrated immediately into Baosteel's production system, with the reduced processing steps potentially saving RMB$150,000 per year.

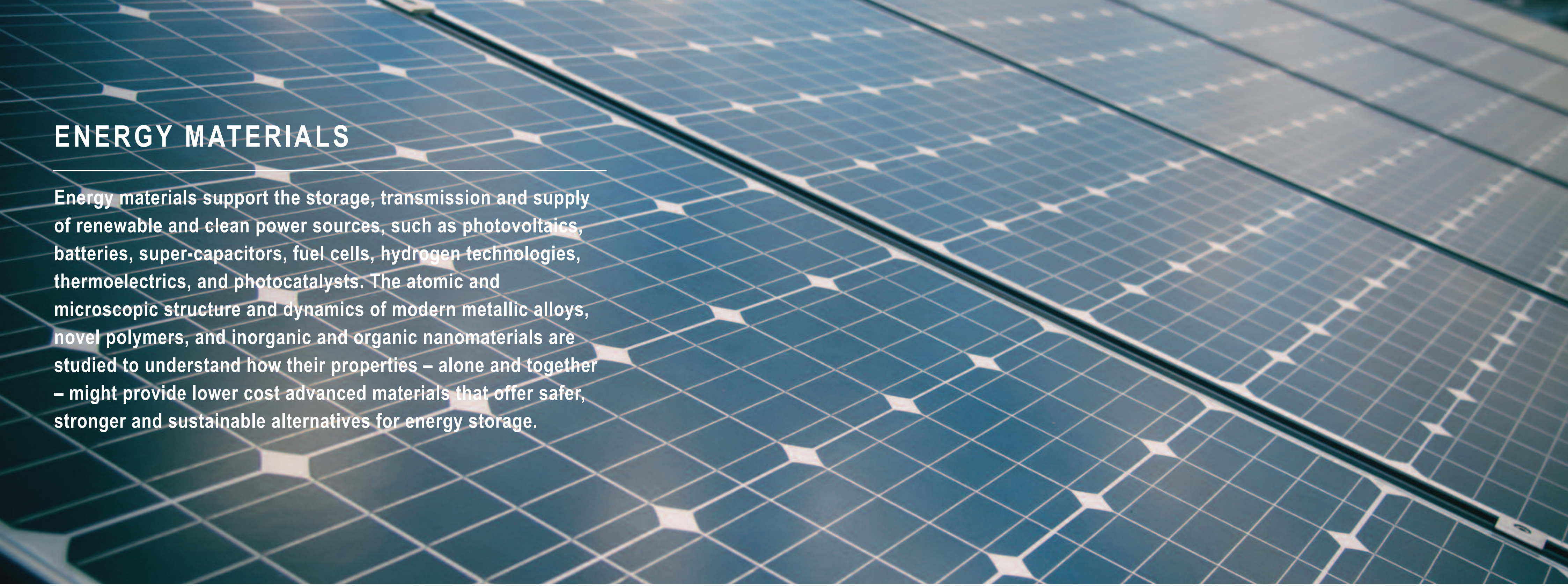
Our light metals research is strategically and commercially important for positioning Baosteel to respond confidently to customer demands for lighter weight alloys with a comprehensive portfolio of high performance materials.

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 2011-2017

- BA 11003 Highly Formable Magnesium Sheet
- BA 11014 Economic Titanium Fabrication
- BA 11014-RPP Advanced Titanium Manufacturing
- BA 12014 Next Generation 6XXX Series Aluminium Alloys
- BA 12031 Next Generation Coatings for Magnesium Alloy
- BA 14011 New Ti Alloys for The Aerospace Industry
- BA 14027 High Performance Magnesium Extrusion Alloys
- BA 15007 Fast Extrusion of Mg Alloys
- BA 15008 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 lower cost advanced materials that offer safer, stronger and sustainable alternatives for energy storage.

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 demands. 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 materials with optimised composition and architecture, and designing the technology for fabricating safer, high performance anode materials on a large scale. Exploiting the use of these materials will produce a new generation of supercapacitors 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 other renewable energy options. These efforts support Baosteel's strategic development of electric vehicles and will 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 2011-2017

- BA 11006 Graphene with High Capacity and Stability for Ultra-Fast Energy Storage
- BA 11011 Harvesting Waste Energy with Thermoelectric Power
- BA 12053 Novel Nanocrystalline Alloys for Electric Motors
- BA 13005 Smart Polymer Hydrogels for Energy Efficiency
- BA 13051 Low Cost Solar on Steel for Energy Efficient Buildings
- BA 14006 Optimised Anode Materials for Large Li Batteries
- BA 14017 Safer, Stable, Powerful Li-S Batteries
- BA16011 High Energy - Low Cost Li-Ion Batteries

PROJECT INDEX BY UNIVERSITY

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

Project ID	Project Name	Research Theme	Page
BA16010	High Strength Auto Steels with Low Hydrogen Impacts	Metallurgical Processes	17
BA16011	High Energy - Low Cost Li-Ion Batteries	Energy Materials	20

UNSW AUSTRALIA

Project ID	Project Name	Research Theme	Page
BA16006	Low-Reacting Mould Fluxes for High-Al Steel	Metallurgical Processes	15

MONASH University

Project ID	Project Name	Research Theme	Page
BA16002	3D Model of Efficient BF Operations	Metallurgical Processes	14
BA16003	Advanced Thermomechanical Processing of Ti Alloys	Light Metal	19

UNIVERSITY OF WOLLONGONG

Project ID	Project Name	Research Theme	Page
BA16008	HAZ-Tough, High-Tensile Oil & Gas Pipes	Metallurgical Processes	16
BA16009	Roll-Bonded Clad Steel Plates in Mining Equipment	Metal Manufacturing	18

3D MODEL OF EFFICIENT BF OPERATIONS BA16002

Model studies of three-dimensional distributions within blast furnaces for reliable and efficient operations

CHIEF INVESTIGATOR

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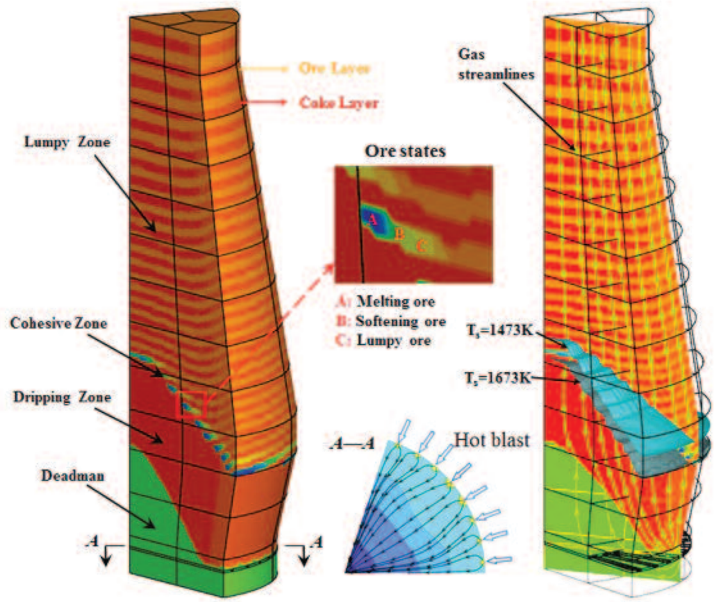
This project is also funded through the ARC Research Hub for Computational Particle Technology.



3D parallel CFD process model considering layered burden structures.

OBJECTIVES

The design and control of blast furnace (BF) ironmaking must be optimised to be competitive and sustainable, particularly under increasingly demanding and tough economic and environmental conditions. Mathematical modelling, often coupled with physical modelling, plays an important role towards achieving such efficiency and reliability.

This project represents the continuing efforts of Monash University's Lab for Simulation and Modelling of Particulate Systems (SIMPAS) in BF process modelling and applications, in collaboration with Baosteel. The researchers are developing a multiscale computer model to fully describe the three-dimensional distribution characteristics of flow, heat and mass transfer within blast furnaces and their impacts on process performance. The project is also quantifying the effects of key variables and formulating strategies for optimum process control under different conditions.

POTENTIAL IMPACT

When completed, this project will provide Baosteel with a world-leading platform to understand 3D in-furnace characteristics of the flow, heat and mass transfer under different conditions, to quantify the effects of pertinent variables. The platform will help achieve accurate control of 3D distribution of in-furnace states, which will ultimately allow the process to function reliably and optimally.

The subsequent and significant environmental and economic benefits include extended BF life campaign, reduced fuel rate, and lower CO_2 emission.

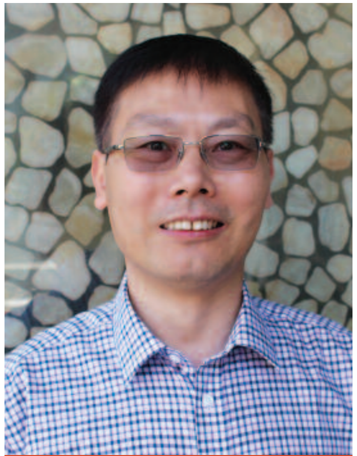
In particular, the insights into the asymmetrical distribution characteristics of in-furnace states, induced by different top and bottom operations, will help identify possible measures to overcome burden descent irregularity (e.g. burden rapidly slips or drops down in some local areas) and channelling flow. These are longstanding operational problems associated with Baosteel No. 1 BF, which represents one quarter of the total pig iron production in the company.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Developed the first 3D BF process which considers the layered burden structures widely encountered in BF practice; it can therefore predict the in-furnace flow, heat and mass transfer and global performance of BFs under very realistic conditions.**
2. **Successfully applied the Message Passing Interface (MPI) parallel technique to the model, which revealed good parallel scalability and efficient simulation of an industrial BF (Baosteel No. 1 BF).**

LOW-REACTING MOULD FLUXES FOR HIGH-AL STEEL BA16006

CaO-Al_2O_3-based mould fluxes for better control and quality of High-Al steel casting



CHIEF INVESTIGATOR

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RESEARCH TEAM

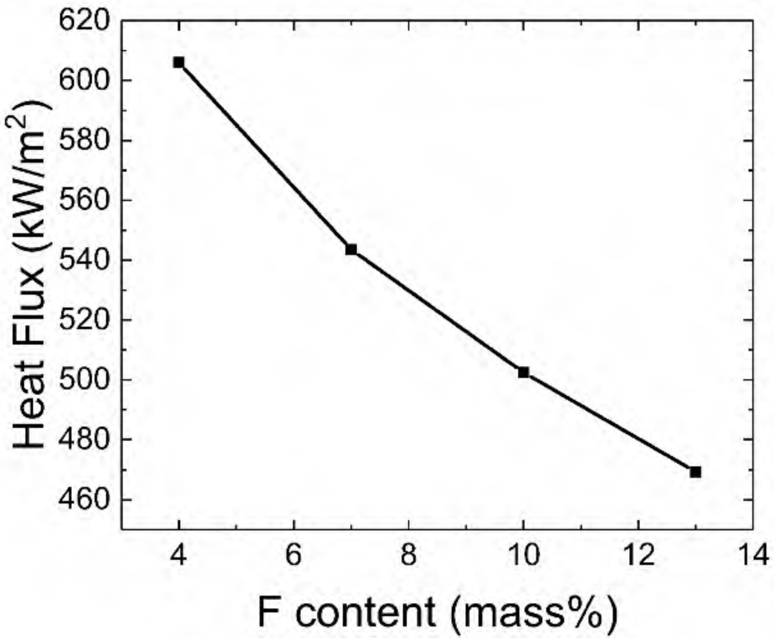
Prof Oleg Ostrovski (UNSW)
Dr Chen Zhang (Baosteel)
Dr Jian Yang (UNSW)
Mr Qi Wang (UNSW)

This project is also funded through the ARC Research Hub for Computational Particle Technology.

OBJECTIVES

High-Al steel has superior mechanical properties and formability, which makes it suitable for automotive industry applications. However, using conventional CaO-SiO_2-based mould fluxes causes Al in the steel to react intensively with SiO_2 in the flux, forming Al_2O_3. This reaction changes the flux chemical composition, resulting in unstable heat transfer and insufficient lubrication of flux. It can incur severe surface defects such as cracks and depressions.

The research team is developing less reactive CaO-Al_2O_3-based mould fluxes for the continuous casting of high-Al steel. They are studying the reaction between CaO-Al_2O_3-based mould fluxes and high-Al steel to examine its feasibility in reducing the reactivity, to avoid abrupt change in chemical composition. Better understanding of the crystallisation behaviour, viscosity, heat transfer and melting properties of mould fluxes will establish a scientific ground for developing mould fluxes that will improve Baosteel's continuous casting of high-Al steel.



Effect of Fluorine Content on Heat Flux across CaO-Al_2O_3 based Mould Flux Disks in IET Experiments.

POTENTIAL IMPACT

The new experimental data on the viscosity, melting property, crystallisation behaviour and reactivity of the CaO-Al_2O_3-based mould fluxes will pave the way for innovative flux design for continuous casting of high-Al steel. Technical benefits are expected to include higher controllability in continuous casting operation. Improving the surface quality of high-Al steel also presents economic benefits to Baosteel, by meeting the urgent demand for high quality TRIP and TWIP steel in automobile industry. The project's findings will also contribute to the theory of metallurgical processes, particularly to the flux chemistry and pyrometallurgy (flux mineralogy, phase transformation in the process of flux crystallisation, thermodynamics, kinetics and mechanisms of flux-steel reactions).

HIGHLIGHTS AND ACHIEVEMENTS

1. Composition design:
- Designed CaO-Al_2O_3-based mould fluxes based on the equilibrium phases calculated through FactSage 7.1.
- Revealed the effect of CaO/Al_2O_3 ratio, B_2O_3 , BaO, Na_2O, Li_2O, CaF_2 and TiO2 on the physicochemical properties of mould fluxes in the chemical composition design.

2. Viscosity:
- Examined the dependency of flux viscosity on chemical composition using a rotating viscometer.
- Studied the relationship between breaking temperature and composition.

3. Heat transfer phenomenon:
- Applied Infrared Emitter Technique (IET) to investigate the effects of Na_2O, TiO_2 and CaF_2 on the heat flux across fluoride-containing mould flux disks and to examine the effects of B_2O_3 and BaO on the heat flux across fluoride-free mould flux disks.

4. Melting properties:
- Measured the melting properties (softening temperature, hemispherical temperature and fluidity temperature) using hot stage microscopy method.
- Revealed the relationship between different oxides, e.g. B_2O_3, Li_2O, and TiO_2 on the melting temperature of mould fluxes.

5. Crystallisation behaviour:
- Investigated the effect of B_2O_3 on the crystallisation behaviour of CaO-Al_2O_3 based mould fluxes using single hot thermocouple technique.
- Revealed the relationship between flux composition and precipitated phases in mould fluxes with different amounts of B_2O_3.

HAZ-TOUGH, HIGH-TENSILE OIL & GAS PIPES BA16008

Improving the weld heat-affected zone toughness of high strength thick-walled line pipe

CHIEF INVESTIGATOR

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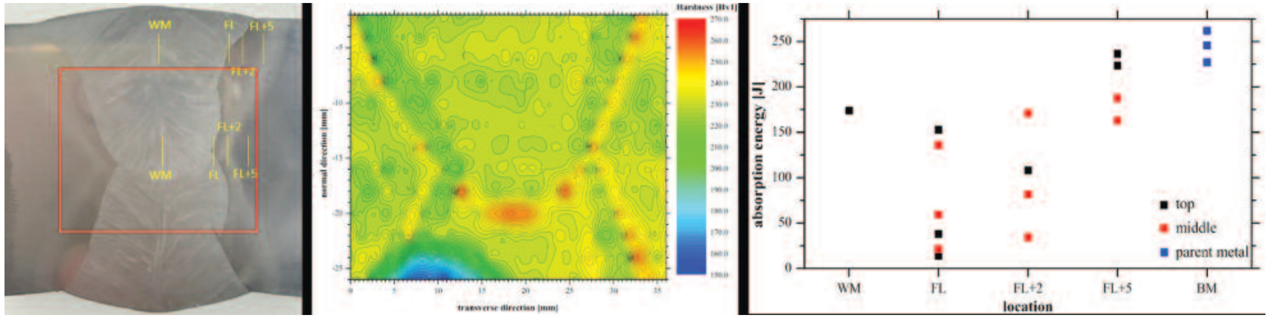


Thick-walled line pipe weld macrograph, hardness distribution, and impact energy at different locations.

OBJECTIVES

The growing worldwide demand for energy, and the subsequent expansion of the oil and gas industry, has increased the use of pipelines to transport hydrocarbons. The transmission of rich resources over long distances places particular demand on pipeline systems in Australia, a key customer for Baosteel. The toughness of the welding in such pipelines is often low in coarse-grained heat-affected zones (CGHAZ), decreasing product quality in a highly competitive market for X65, X70 and X80 pipe. This is especially challenging for heavy wall line pipe steels above 25 mm.

Achieving acceptable low temperature toughness (typically –20°C) in the CGHAZ, and more so in the inter-critically reheated CGHAZ (ICCGHAZ), is very difficult. Data for the HAZ toughness of X70 and above is scarce, including tests of the fusion line.

This project is investigating low temperature HAZ toughness in high heat input seam welds of thick walled X70 and X80 pipe using sophisticated thermomechanical simulation, steel chemistry design evaluation and fitness-for-purpose studies.

POTENTIAL IMPACT

Meeting the standardised high strain-rate Charpy V-notch (CVN) test for toughness in CGHAZ is critical, and currently challenging, to the success of Baosteel's products in Australia. This research has great potential to appreciably improve Baosteel's product quality and reputation, and therefore market share, enhancing Baosteel's competitiveness in the international market.

Studying the microstructure and precipitates with different welding parameters and systematically characterising the effects of alloying elements on advanced alloy design will contribute to the basic knowledge of metallurgical and materials science.

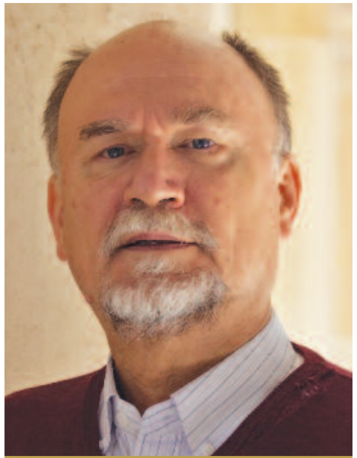
The research outcomes may also be relevant to other high strength thick section applications, such as offshore structures and nuclear and other affiliated industries.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Characterised the microstructure and hardness distribution of the welds of two types of thick walled pipes (28 mm X70 and 33 mm X80) obtained from Baosteel.**
2. **Confirmed that the hardness values across the weld complied with the standard.**
3. **Evaluated the toughness of the weld HAZ, discovering that some values at the fusion line failed to meet the requirements according to the standard.**
4. **Designed thermal simulation of the materials for future testing; the results will guide the setting of welding parameters.**

HIGH STRENGTH AUTO STEELS WITH LOW HYDROGEN IMPACTS BA16010

Identifying critical metallurgical features influencing hydrogen impacts on advanced high strength steels



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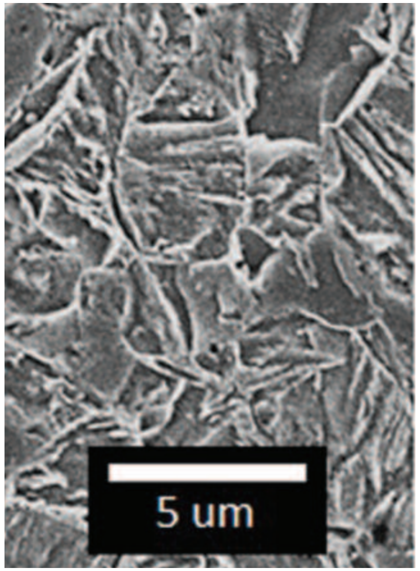
OBJECTIVES

Hydrogen embrittlement (HE) and hydrogen-influenced low-cycle fatigue in high strength steel can cause stressed components to fail catastrophically. Such failure can occur without warning, at a fraction of the load that the component could withstand in the absence of hydrogen. High strength steels developed for car manufacturers wanting to offer motorists the benefits of lighter weight vehicles are possibly prone to this performance risk.

HE and hydrogen-influenced fatigue can emerge at different stages, both in the construction of automotive components and during auto service. Because structural collapse can result in devastating consequences, the risks to the car body over its lifetime influences the car manufacturer's steel supply choices.



Microstructure of martensitic advanced high strength steel.

Building on prior research into how hydrogen interacts with steel, this project seeks to understand how HE and hydrogen-influenced low-cycle fatigue contribute to the strength of Baosteel's newer and stronger steels such as QP1180, MS1700, DP1180, and Medium Mn1180GI. The investigations include identifying important metallurgical features and potential paths to improved automotive steels.

POTENTIAL IMPACT

The research will underpin Baosteel's development of new higher performance advanced high strength steels. The reasons for HE resistance, for example, in other steels with similar metallurgies are not well-understood, so the outcomes of this research will also benefit the steel and energy sectors generally.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Commenced investigations.**
2. **Recruited two Chinese Scholarship Council students to join the research team at UQ.**

ROLL-BONDED CLAD STEEL PLATES IN MINING EQUIPMENT BA16009

Investigating an economic and effective solution for wear and corrosion-resistant applications

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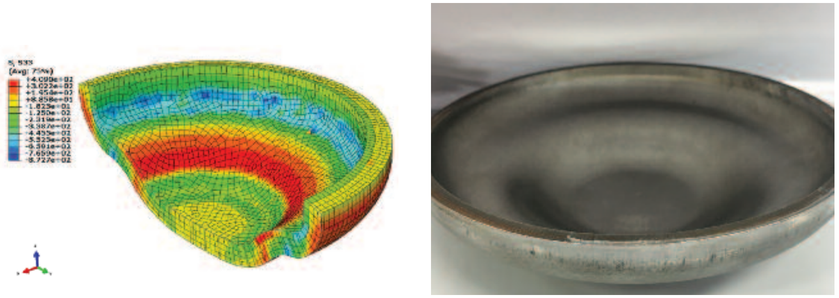
OBJECTIVES

Baosteel's roll-bonding clad steel plates are comprehensively functional, with sufficient strength and the wear resistance that many structural materials require. Other traits, like corrosion resistance at a lower cost to similar products made entirely of the cladding material, also boost their appeal.

However, the lack of suitable product availability and related technical support have delayed interest in clad plates in the minerals industry, especially in Australia's harsh mining environments.

This fundamental and practical research project combines theoretical analysis, numerical simulation, experiments and realistic applications to evaluate the applicability of roll-bonding clad steel plates in mining equipment.



(a) FEM simulation of the forming processes with clad steel plates and (b) Formed bimetal component.

POTENTIAL IMPACT

Baosteel's roll-bonding clad steel plates represent a significant opportunity to solve a major economic problem for mining globally. Targeting the Australian market with products for its tough conditions will increase exports, enhance Baosteel's international footprint, and open up market extension possibilities in other countries for Baosteel's roll-bonding clad steel innovations.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Reviewed the current literature, focusing on the mechanical properties of bonding interface and evaluation of wear-corrosion synergy for clad steel plates.**
2. **Following discussion with Baosteel, designed a detailed research plan to investigate carbon steel AN36 cladding with stainless steel 2205 as the main steel grade.**
3. **Obtained primary simulation results after employing Finite Element Method (FEM) simulation to model the bending and forming process of clad steel plates.**
4. **Based on the quality assessment of bonding interface, conducted tests for mechanical properties and recorded initial data for further analysis.**
5. **Analysed atomic diffusions at the bonding area to evaluate the microstructure of interface.**
6. **Designed tools for stamping tests and conducted practical stamping tests with clad steel plates.**

ADVANCED THERMOMECHANICAL PROCESSING OF Ti ALLOYS BA16003

Identifying optimum forging and heat treatment in ($\alpha+\beta$) and β Ti alloys.

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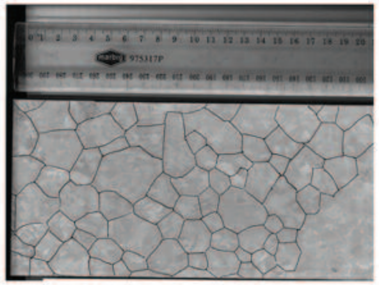
This project is also funded through the ARC Research Hub for Computational Particle Technology.

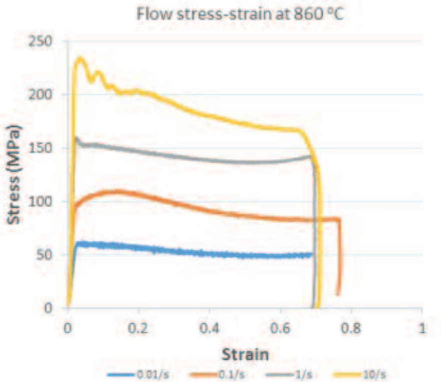
OBJECTIVES

For Baosteel to gain and sustain a strong share of the steadily growing global Ti alloy market, it must overcome the challenges that relate to producing customer-specified size parts and properties within a limited time period.

The researchers are seeking a greater insight into the complexity of forging Ti alloys and a methodology for more routinely identifying the optimum forging and heat treatment parameters in ($\alpha+\beta$) and β Ti alloys. Studying the relationship of strain during processing and its subsequent effect on recrystallisation and further heat treatment will lead to innovative designs for thermomechanical processes that will produce refined β grains and reduce or eliminate the cause of heterogeneities in the processed microstructures of β-forged Ti alloys.



a) The traced out beta grain size of Ti-6Al-4V cast ingot that are 15 to 20 mm in size. These have to be refined to 200 to 400 mm in size.



b) Representative Flow Stress curves for forged TC18 – near β Ti alloy at various strain rates showing flow softening behaviour similar to $\alpha+\beta$ alloy.

The project will also identify desirable mechanical properties by evaluating thermomechanical processing schemes for β grain refinement. Evaluating the mechanical properties will also reveal useful data; for example, of the near-β Ti alloy with different heat treatment processes and with different thermomechanical history concentrating on the influence of prior grain size and structure on subsequent microstructure evolution and development that affects the final properties.

POTENTIAL IMPACT

This research is expected to generate charts relevant to industrial scale processing, to help develop future processing routes for Ti alloys catering to customer specifications. The key know-how and understanding gained will lead to faster identification of optimum forging parameters for near-β and β Ti alloys. This capability will attract increased orders for such materials and boost Baosteel's market share.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Conducted preliminary analysis for the beta grain size of Ti-6Al-4V (TC4).**
2. **Obtained some flow stress curves of near-beta Ti alloy (TC18).**

HIGH ENERGY-LOW COST Li ION BATTERIES BA16011

Introducing Li-rich cathode materials to improve the cost-effectiveness of solar power storage

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OBJECTIVES

Australian households are becoming increasingly conscious of the economic and environmental costs of fossil fuels for powering homes and vehicles. Responding to the growing demand for domestic renewable energy solutions, especially solar energy, this project is developing high energy density and low cost cathode materials for advanced Li-ion batteries that can store solar energy and power the next generation of electric vehicles.

Current Li-rich cathode materials (LRCMs) are prone to significant voltage decay, capacity decline over long-term cycling, and poor rate performance. To develop a high performance solution for a lower cost, the researchers will design battery electrode materials with controlled particle size, preferential surface facet, homogeneously distributed doping species, and a multi-functional surface coating layer.

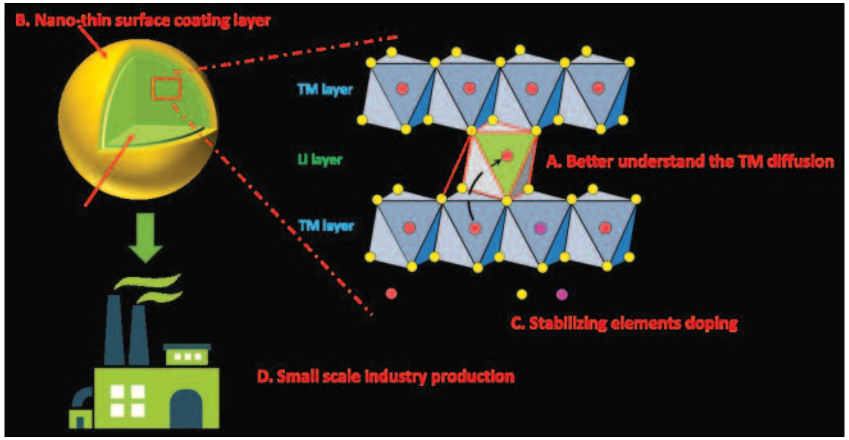

Illustration of the Li-rich cathode project's innovations.

This will involve suppressing or minimising the oxygen loss from the surface lattice and facilitating the Li+ diffusion to improve the rate performance of the LRCMs. These strategies will be considered from two aspects: shortening the Li+ diffusion channel from the bulk to the surface by preparing hierarchical micro-spheres composed of Li-rich nano-particles; and generating a solid-electrolyte interphase that allows highly efficient Li+ diffusion by surface modification.

POTENTIAL IMPACT

The overall synthesis procedure (resulting from this systematic investigation in the lab) should optimise Li-rich materials and scale-up production options. This, in turn, will significantly advance the development of low cost and high performance applications for the energy battery industry.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Appointed and trained a Research Associate and PhD student.**
2. **Prepared chemical and equipment.**
3. **Developed a series of high energy density Li-rich cathode materials with a high specific capacity of 250 mAh/g at low current density.**

PUBLICATIONS AND PATENTS

Since 2011, the Centre's research teams have published and presented 182 journal papers, three book chapters, 124 conference papers, and filed 18 patents.

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

Jiang, Z. Y., et al. (2015). Mini hot rolling mill for equipping on a thermal-mechanical simulator

Konarova, M., el al. (2014). Nano- and micro-scale engineering of MoS2-based catalyst for conversion of syngas to ethanol

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Xu, S. W., et al. (2016). A protective coating system for Mg-Re based alloys

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Mr Junhai Liao (RS)
Ms Yiran Liu (RS)
Mr Peilei Qu (RS)
Ms Lin Wang (RS)
Mr Qi Wang (RS)
Mr Junqi Wei (RS)
Mr Jian Yang (RS)

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

BAJC RESEARCHERS

MONASH University

Prof Nick Birbilis (CI)
Dr Xiaobo Chen (CI)
Prof Chris Davies (CI)
Dr Shibo Kuang (CI)
Prof Dan Li (CI)
Dr Samuel Lim (CI)
Prof Jianfeng Nie (CI)
Dr Paul Rometsch (CI)
Prof Huanting Wang (CI)
Prof Xinhua Wu (CI)
Prof Aibing Yu (CI)

Dr Mingzhe Bian (RF)
Dr Baoyu Guo (RF)
Dr Shravan Kairy (RF)
Dr Seungju Kim (RF)
Dr Shibo Kuang (RF)
Dr Zhe Liu (RF)
Dr Ranwen Ou (RF)
Dr Katharina Pohl (RF)
Dr Wei Song (RF)
Dr Kun Yang (RF)
Dr Yong Zhang (RF)
Dr Yulin Zhong (RF)
Dr Suming Zhu (RF)
Dr Yuman Zhu (RF)

Mr Yuhan Huang (RS)
Ms Lulu Jiao (RS)
Mr Chong Ke (RS)
Mr Xiaojian Xia (RS)
Mr Zhuoran Zeng (RS)
Mr Kai Zhang (RS)

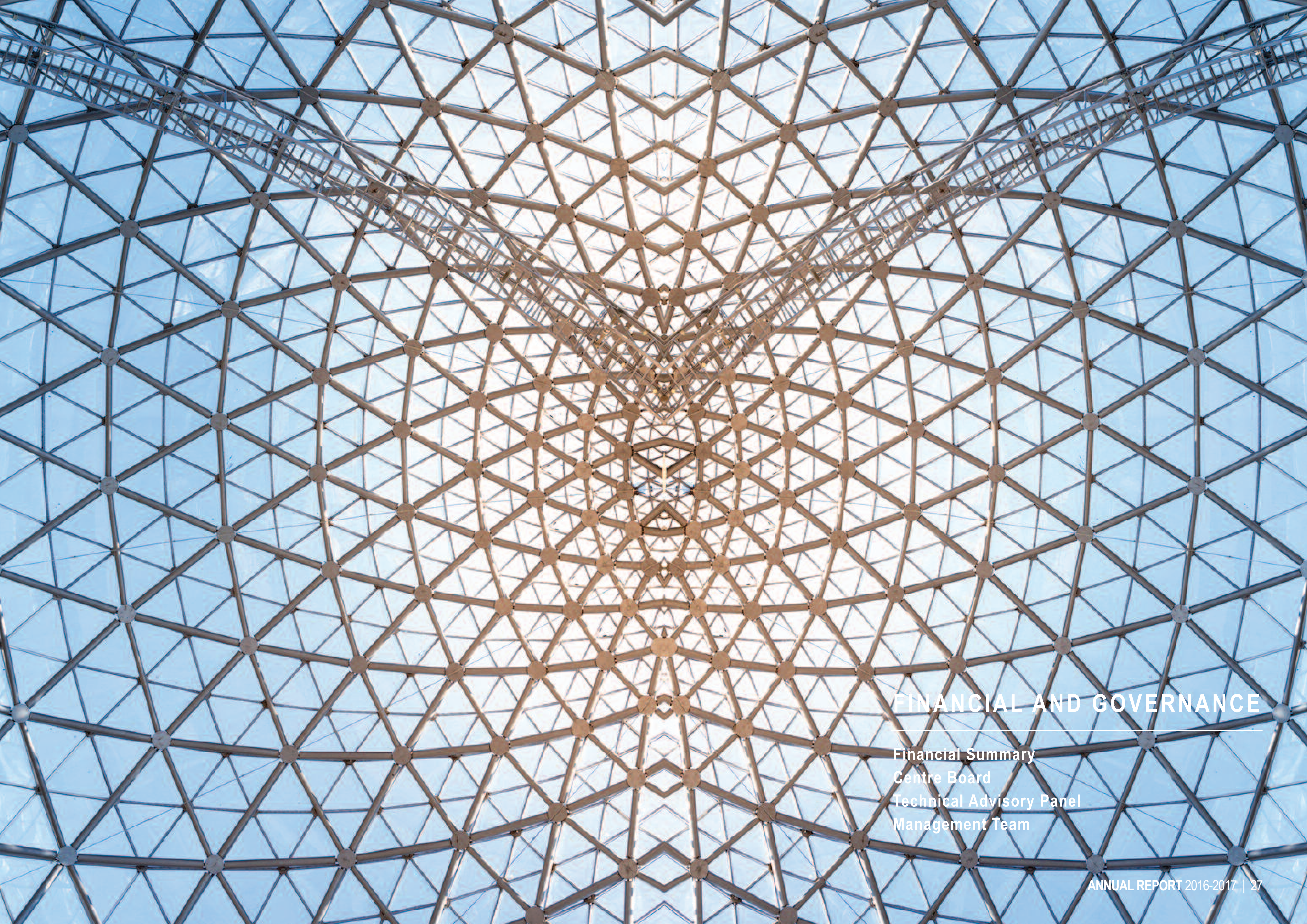
UNIVERSITY OF WOLLONGONG

Prof Shixue Dou (CI)
Prof Zhengyi Jiang (CI)
Prof Huijun Li (CI)
Prof Sean Li (CI)
Prof Huakun Liu (CI)
Prof Cheng Lu (CI)
Prof Kiet Tieu (CI)

Dr Xiawei Cheng (RF)
Dr Shulei Chou (RS)
Dr Guanyu Deng (RF)
Dr Jian Han (RF)
Dr Kosta Konstantinov (RF)
Dr Chen Shen (RF)
Dr Lihong Su (RF)
Dr Yunxiao Wang (RF)
Dr Wenzhen Xia (RF)
Dr Sima Yamini (RF)
Dr Jingwei Zhao (RF)
Dr Qiang Zhu (RF)

Mr Leigh Fletcher (RS)
Mr Haipen Guo (RS)
Ms Liang Hao (RS)
Mr Jaewoo Lee (RS)
Mr Jintao Li (RS)
Mr Zhou Li (RS)
Ms Yajie Liu (RS)
Ms Yao Lu (RS)
Mr Xiaoguang Ma (RS)
Ms Hui Wu (RS)
Mr Lei Zhang (RS)
Mr Guoqing Zu (RS)

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



FINANCIAL AND GOVERNANCE

FINANCIAL SUMMARY

Financial Statement for the period from 01 July 2016 to 30 June 2017

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)
The Cooperative Research Centres (CRC)

Cash Balance as at 01-07-2016
$2,675,902.53

BAOSTEEL-AUSTRALIA
JOINT RESEARCH AND DEVELOPMENT CENTRE

INCOME (CASH)

Grant and Collaborative Research	
Baosteel R & D Fund (Round 6 - Year 1)	$700,000.00
Baosteel R & D Fund (Round 5 - Year 2)	$300,000.00
Baosteel R & D Fund (Round 4 - Year 3)	$300,000.00
Baosteel - management support	$49,881.47
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	**$1,749,881.47**
Total Leveraged ARC-Linkage Grant	$1,011,917.00
Total Leveraged CRC Grant	$12,000.00
TOTAL INCOME (EXCLUDING IN-KIND)	**$2,773,798.47**

EXPENDITURES

Grant and Collaborative Research	
Payment in cash to collaborative approved projects[1]	$1,654,672.00
Allocated ARC Linkage Grant	$1,011,917.00
Allocated CRC Grant	$12,000.00
Total Grant and Collaborative Research Expenditures	**$2,678,589.00**

Baosteel Centre – Management	
Personnel - Salaries	$374,555.15
Staff Development	$5,684.44
General Operating (consumables, stationery, telcommunications)	$12,241.71
Services (professional consultancy)	$20,692.03
Equipment for Office	$2,110.00
Travel	$39,716.23
Hospitality	$10,374.37
Other expenses	$881.89
Total Centre Management Expenditures	**$466,255.82**
TOTAL EXPENDITURES (INCLUDING GRANT & RESEARCH FUND ALLOCATION)	**$3,144,844.82**
Operating Result Cash Balance as at 30 June 2017	**$2,304,856.18**

*Note: [1] Travel and hospitality include partial costs associated with TAP and Board meetings.

BAOSTEEL CASH FUNDING DISTRIBUTION ($K)

	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6	Total
Monash University	$1,802	$870	$400	$550	$700	$650	$4,972
University of Wollongong	$1,131	$700	$ 250	$650	$ -	$400	$3,131
The University of Queensland	$1,028	$1,180	$950	$375	$550	$400	$4,483
The University of New South Wales	$1,389	$1,000	$500	$325	$300	$150	$3,664
Total	**$5,350**	**$3,750**	**$2,100**	**$1,900**	**$850**	**$1,600**	**$16,250**

PARTNERSHIP IN-KIND CONTRIBUTION ($K) (BASED ON PROJECT SCOPE)

	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6	Total
Baosteel	$2,532	$1,588	$1,033	$1,603	$1,390	$1,070	$9,216
Monash University	$2,748	$1,161	$371	$839	$1,329	$1,765	$8,213
University of Wollongong	$1,516	$1,528	$194	$903	$ -	$1,048	$5,189
The University of Queensland	$3,481	$1,493	$2,083	$1,823	$2,126	$1,129	$12,135
The University of New South Wales	$2,205	$1,355	$788	$2,832	$549	$602	$8,331
Total	**$12,482**	**$7,125**	**$4,469**	**$8,000**	**$5,394**	**$5,614**	**$43,084**

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.

BAOSTEEL-AUSTRALIA
JOINT RESEARCH AND DEVELOPMENT CENTRE

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

Dr Pijun Zhang
President of Baosteel Research 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 Anton Middelberg
Board Co-Chair
Pro-Vice-Chancellor
(Research & International)
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.

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
Baoshan Iron and Steel Co. Ltd

Dr Jian Yang
Baoshan Iron and Steel Co. Ltd
(Resigned from BAJC Board in January 2016)

Professor Nick Birbilis
Monash University

Dr Shiwei Xu
Baosteel Research Institute (R&D Center)

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.

Centre Senior Director
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

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.

AUSTRALIAN PARTNER UNIVERSITIES

The University of Queensland
www.uq.edu.au
St Lucia, Brisbane, Queensland 4072
Telephone: +61 7 3365 1111

The University of New South Wales
www.unsw.edu.au
Kensington, Sydney, New South Wales 2033
Telephone: +61 2 9385 1000

Monash University
www.monash.edu
Clayton, Melbourne, Victoria 3168
Telephone: +61 3 9902 6000

University of Wollongong
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Wollongong, New South Wales 2522
Telephone: +61 2 4221 3555

BAOSTEEL-AUSTRALIA
JOINT RESEARCH AND DEVELOPMENT CENTRE

CONTACT DETAILS

Senior Director:	Professor Victor Rudolph
Executive Director:	Professor Geoff Wang

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