BAOSTEEL-AUSTRALIA
JOINT RESEARCH AND DEVELOPMENT CENTRE

ANNUAL REPORT

2015 -2016

BAOSTEEL

MONASH University

UNSW AUSTRALIA

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

UNIVERSITY OF WOLLONGONG

CONTENTS

Abbreviations:

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

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 $21 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.

KEY CAPABILITIES

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

- **Engaged over 100 eminent researchers based in Australia and China**
- **Supported 40 innovative research projects**
- **Disbursed a total of A$13.3 million in project funding**
- **Attracted A$29.7 million in-kind partnership contributions**
- **Leveraged A$6 million in ARC Linkage and CRC grants**
- **Published and presented more than 200 academic papers**
- **Filed 15 patents**
- **Hosted 4 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

The renewed commitment brings Baosteel's investment in the Centre to almost $26 million since 2011 and highlights the confidence that Boasteel and the partner universities have in the ability of our researchers to generate commercial and scientific outcomes with significant value.

We are proud to introduce the Baosteel-Australia Joint Research and Development Centre 2016 annual report.

This trail-blazing collaboration between one of the world's largest steel companies and some of Australia's leading university-based research teams was intensified in March when the Centre Agreement was extended for another five years (2016-2021).

The renewed commitment brings Baosteel's investment in the Centre to almost $26 million since 2011 and highlights the confidence that Boasteel and the partner universities have in the ability of our researchers to generate commercial and scientific outcomes with significant value.

The projects co-ordinated by the Centre continue to build important and long term alliances, with more than 100 Australian academics and PhD students visiting Baosteel in China and several dozen Baosteel researchers visiting Australia for collaboration, project advancement and knowledge exchange. These interactions fulfill the Centre's key goals of affording Australian researchers critical industry connections and opportunities to develop innovations for a global market demanding more economical and sustainable solutions; and connecting Baosteel into a broad and international network of academic research.

Over the next five years the Centre will initiate new arrangements for internships and student exchange into Baosteel research and production facilities.

This will build on increasing interest from postgraduate student members of our project teams to carry research through to industrial practice; and attract high performing senior undergraduates into careers in this industry sector.

Through this kind of participation and international engagement, these students will develop their own leadership, inspired by projects receiving national recognition and support for their ideas, like BAJC's Dr Xiaojing Hao and Professor Martin Green who are working on a BAJC-ARC Linkage project, building kesterite solar cell-coated a rchitectural stainless steels; and Professor Huanting Wang whose BAJC-ARC Linkage project advances the use of smart polymer hydrogels to transform waste heat and waste water usage in sustainable manufacturing.

Your ongoing interest in the Centre is greatly appreciated. We hope you find compelling the following updates on the Centre's projects and you are as impressed as we are with the advances our researchers are making in the field of materials science.

PROFESSOR G.Q. MAX LU,
BOARD CHAIRMAN

PROFESSOR ANTON MIDDELBERG,
BOARD CO-CHAIRMAN

FROM THE CENTRE DIRECTORS

The collaborative spirit energising the Baosteel-Australia Joint Research and Development Centre continues to manifest as innovations that will transform industries relying on the performance of metal.

Our portfolio has grown to 40 projects associated with the Centre since 2011. This report on the Centre's activities over the past year highlights their outcomes. Our key outputs to date are summarised on page 1, with the majority of the report dedicated to snapshots of research advances in our four primary interests: metallurgical processing, metal manufacturing, light metals and energy materials.

The discoveries and developments made through these projects underpin Baosteel's business interests and strengthen the company's positon as a global steel industry leader. In turn, exciting new knowledge and intellectual assets have been generated, disseminated via publications, conference papers, and patents. This year's publishing output is listed on pages 47-49.

If you would like to know more about any of the research described in this report, please contact the Centre or the chief investigators directly – their details are included with each project.

The Centre began a new five-year cycle with $10 million in cash commitments from Baosteel for projects, plus an additional $4 million as in-kind support. A key focus for the Centre over the next five years will be to progress the discoveries and processes arising from the research activities to commercial deployment, presenting a new phase for the strong working relationships that have been fostered between the various Australian teams and their Baosteel counterparts. Nevertheless, mechanisms are also in place to bring new ideas, projects, and research groups forward for funding consideration.


PROFESSOR GEOFF WANG


PROFESSOR VICTOR RUDOLPH


PROFESSOR AIBING YU

At the BAJC annual conference, this year held in Hobart in February, 30 researchers presented their work. Additional opportunities for further knowledge exchange occurred during visits to BAJC from international colleagues representing Baosteel Metal, Neusoft Co. Ltd, and Wuhan University of Science and Technology.

That the Centre is resourced to continue for another five years is a testament not only to the quality of the science undertaken but also to the efficient coordination of our activities. We acknowledge with thanks the modest but effective administration team that supports all our researchers in their pursuit of the ambitious goals described in this report.

PROFESSOR VICTOR RUDOLPH,
CENTRE SENIOR DIRECTOR

PROFESSOR GEOFF WANG,
CENTRE EXECUTIVE DIRECTOR

FROM THE TECHNICAL ADVISORY PANEL (TAP)

Every year, the Centre receives numerous project proposals which are both novel and intriguing.

Deciding which projects to recommend for funding is always a challenge! This year saw a number of key changes introduced for how projects are assessed, selected and reviewed.

The name of the group assigned to select and review projects was changed to more appropriately reflect the group's revised function, from a committee to a panel providing technical leadership and guiding each member's institution's interactions with Baosteel technical area champions. The members of the new TAP, representing all parties of the BAJC partnership, are listed on page 55.

The responsibility for reviewing, assessing, commenting on gaps or areas of weakness in project proposals and recommending their selection for funding has shifted to Independent Expert Referees (IERs), who cannot themselves participate in Centre projects. IERs, approved by the BAJC Board, are internationally recognised experts in particular technology areas pertinent to the proposals.

The Panel recommended five new projects for Round 5 funding in 2016, and at the time of this report's publication, eight more proposals have been selected for Round 6, commencing in 2017. These projects reflect a trend of being more closely aligned with Baosteel's production functions and business strategy.

All rounds of ongoing projects were reviewed during the year: eight projects from Round 1, nine from Round 2, five from Round 3 and nine from Round 4. A key metric is the progress and advancement of the project technology readiness level, in line with the emphasis on more quickly implementing discoveries into the production chain.

It is exciting to see the large number of BAJC projects that successfully attract additional competitive funding, through the ARC Linkage scheme, CRCs and other agencies – a clear validation of the leading edge research that is being conducted.

We look forward to seeing all the BAJC projects continue to challenge existing knowledge about the properties, performance and application of ancient and modern materials, metals and processing technologies.

PROFESSOR AIBING YU,
TAP CHAIRMAN

PROFESSOR VICTOR RUDOLPH,
TAP CO-CHAIRMAN

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MONASH University

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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.

NEW MODELS FOR FERRONICKEL SINTERING BA15005

Combining experimental and thermodynamic modelling studies to optimise ferronickel making

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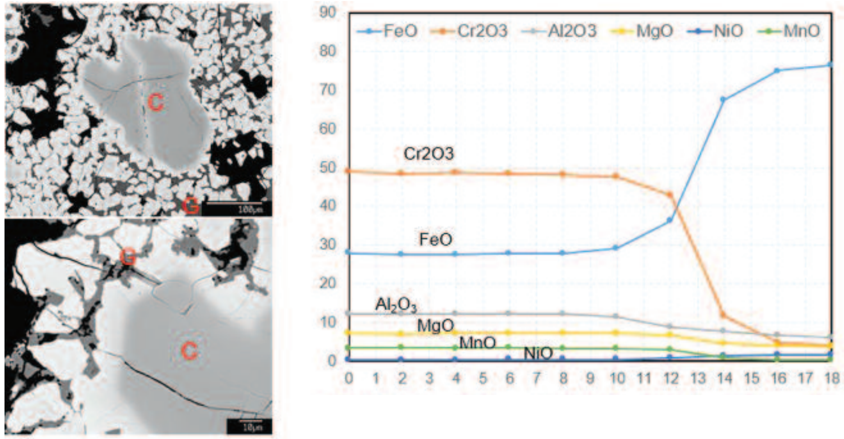
OBJECTIVES

An ongoing challenge for iron makers is to be able to utilise low cost, low grade ores while simultaneously maintaining or improving the energy efficiency of the process. Iron ore sinter blends, consisting of low cost materials from a variety of sources, are typically used to produce synthetic iron-containing feedstock for the iron blast furnace.

The researchers are using state-of-the-art techniques and methodologies developed at PYROSEARCH to identify the optimum process conditions for limonitic nickel sinter-making. This includes investigating the reaction phase chemistry of nickel extraction from high Mg and Si laterite ore using the Oheyama Process, and high temperature phase equilibria on a multicomponent chemical system (NiO-$Cr2O_3$-FeO-Fe_2O_3-Al_2O_3-CaO-MgO-SiO_2) for using slag from a rotary kiln electric furnace (RKEF).



Assimilation of chromite into the laterite sinter matrix.

POTENTIAL IMPACT

This research will provide fundamental information to address critical technical issues currently facing ferro-nickel production at Baosteel's Desheng Stainless Steel plant and help guide strategic development.

With advanced thermodynamic models to identify which process conditions are necessary to achieve optimum sinter properties, the outcomes will directly support process development and innovation capabilities in Baosteel's core business.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Systematically characterised plant samples, including nickel laterite (limonite), limonite sinter and sinter return, collected from Baosteel's Desheng Stainless Steel plant.**

2. **Discovered the high return rate of limonite sinter to be most likely due to the poor strength of bonding phase formed and the poor assimilation of the added chromite phase.**

3. **Using FACTSAGE to predict Limonite sinter phase equilibria, determined that the reaction chemistry during sintering process is highly complex; and that the composition and proportion of the phases formed strongly depend on the peak bed temperature, raw material composition and coke rate.**

OPTIMUM CONTROL OF RACEWAY OPERATIONS BA14026 ARC LP150100112

Investigating multiphase flow and thermochemical behaviours in the lower part of blast furnace ironmaking

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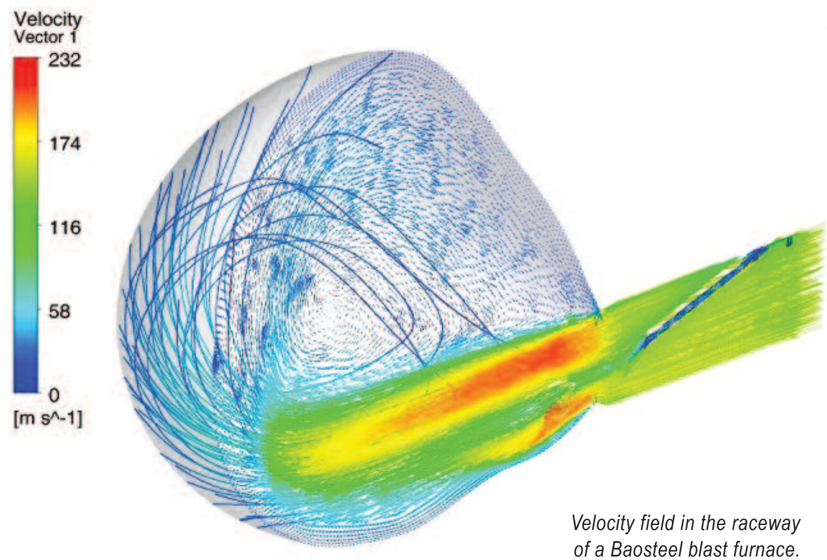
This project also receives leverage funding from an ARC Linkage Project.

OBJECTIVES

Understanding the fundamentals governing multiphase flow and thermochemical behaviours at the lower part of ironmaking blast furnace, and identifying optimal control strategies for raceway operations, will lead to improved process stability, lower costs and fewer CO_2 emissions. This research team is working with Baosteel on advanced modelling techniques, detailed process analysis, and plant tests to quantify the effects of key operational variables (e.g., raw materials, operational and geometrical conditions) on raceway operations for improving blast furnace performance. The project is also studying practical scenarios to formulate and test optimum design and control strategies for Baosteel's blast furnace operations.



Velocity field in the raceway of a Baosteel blast furnace.

POTENTIAL IMPACT

To maintain a competitive blast furnace ironmaking cost position, Baosteel needs to reduce energy consumption and CO_2 emissions. Raceway control, particularly pulverized coal injection (PCI) technology, supports this objective, but even minor adjustments at the lower part of a blast operation and PCI operation can affect furnace stability and cost efficiency significantly. Developing optimum control strategies requires a detailed understanding of the complex multiphase flow and thermochemical behaviour in this region under various conditions. Computer modelling, supported by lab or plant experiments, can reveal information that other types of investigations cannot adequately provide, such as in-situ measurements, experimental studies. With steel manufacture 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, the outcomes of this research could help Baosteel save substantially on energy costs.

Also of significant value is the prospect of cost-efficient PCI technology replacing the need for expensive coke and high-grade coal in the blends, resulting in measurable economic benefits.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Refined the existing PCI model with new features, to reliably describe the multiphase flow and thermochemical behaviours associated with PCI operations.**
2. **Developed a raceway model to reliably describe the multiphase flow and thermochemical behaviours associated with raceway formation.**
3. **Collected and analysed data from Baosteel's ironmaking plant to determine and test simulation conditions.**

HIGH PERFORMANCE SPRING STEEL BA15003

Characterising optimum inclusions and precipitates in high strength spring steel

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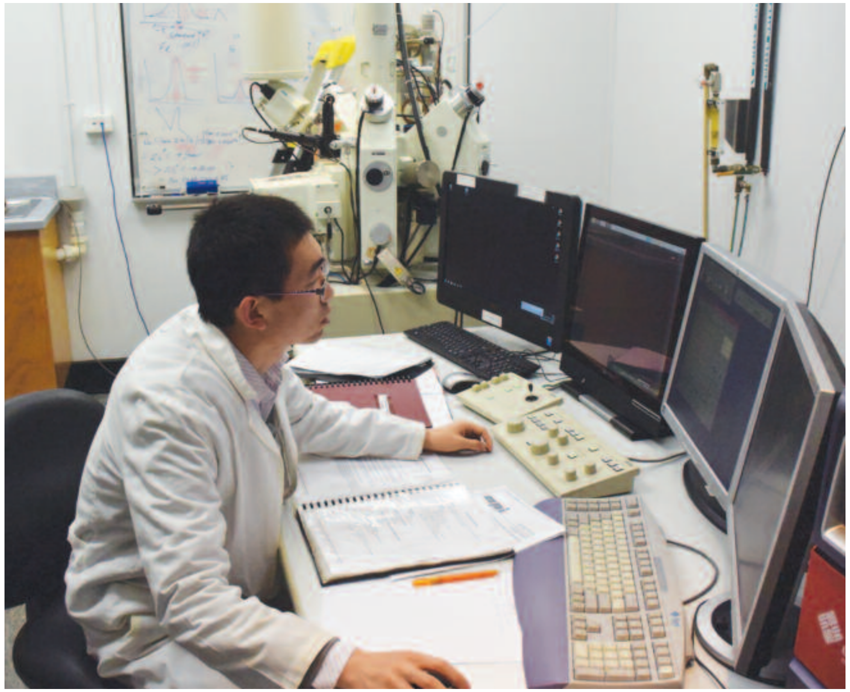
OBJECTIVES

Spring is an important shock absorption and functional unit widely used to produce suspension spring, valve spring and torsion-bar spring in the automobile industry. Light-weight automobiles require higher strength spring steels. However, the large size inclusions present in current spring steels are detrimental to the mechanical properties and therefore impede performance.

This project seeks to know how to better control inclusions at optimum chemical compositions, as well as strengthen mechanisms of micro-alloyed spring steels. The researchers are systematically investigating the effects of smelting process; quenching and tempering; and the number and size distribution of precipitates on steel strength with the addition of V, Nb and Ti. They are also theoretically analysing the effects of refining slag composition and the deoxidation process.



Dr Xiaodong Ma (postdoctoral fellow) conducting electron probe microanalysis on spring steel samples.

POTENTIAL IMPACT

Scientifically, new experimental data will provide new fundamental benchmarks (thermodynamics and viscosity) for the physico-chemical properties and behaviours of the CaO-MgO-Al_2O_3-SiO_2 systems related to steel refining slags and inclusions.

For Baosteel, the outcomes will lead to an improved refining process for better control of the oxide inclusions in the molten spring steels, through which the fine inclusions will be less harmful or even beneficial to the mechanical properties of final products. With a deeper understanding of the mechanisms to increase tensile strength, Baosteel could develop 2100 or 2200 MPa spring steel, a high value-added product for light-weight automobile manufacturing.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Systematically analysed the inclusions of as-received Baosteel samples and identified the formation mechanisms of the inclusions.**
2. **Discovered the impact of reducing additional Nb on as-received Baosteel samples micro-alloying with V and Nb.**
3. **Commenced high temperature experiments (a) on the optimum addition of individual or combination of micro-alloying elements; and (b) for the effect of optimum refining slag composition on the inclusion formation.**

MAXIMISING PIPELINE SAFETY AND DURABILITY BA14002

Examining strain ageing in fusion-bonded epoxy-coated pipeline steel for better strength and safety

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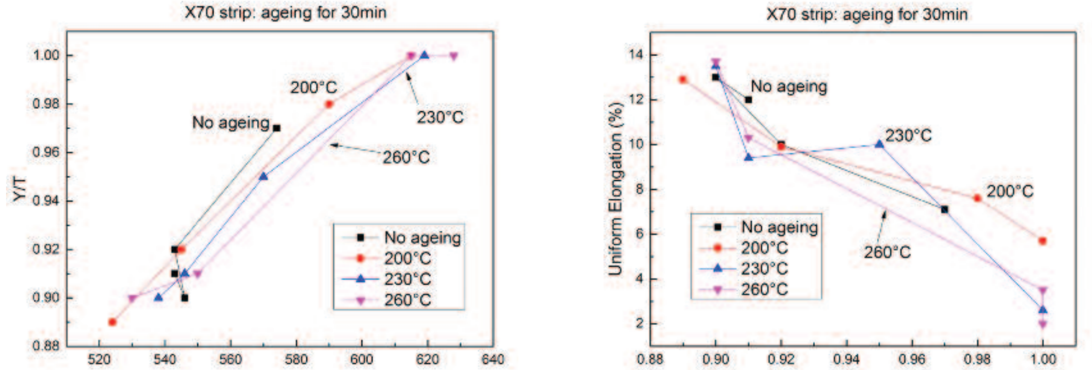

Relationship of Y/T vs. yield strength and Y/T vs. uniform elongation for pre-strain plus aged X70 strip.

OBJECTIVES

Demand for steel pipelines carrying richer mixtures of oil and gas to be operated at higher pressures continues to rise. Fusion-bonded epoxy (FBE) coating is widely used in pipeline construction to protect the steel line pipe from corrosion. During the coating process, the pipe is usually heated to a certain temperature, which changes the mechanical properties of pipeline steels - it increases the yield strength and the ratio of yield stress to ultimate tensile stress (Y/T).

This phenomenon, known as strain ageing, results in ductility loss, hardening, and greater potential for fractures. When these pipelines fail, the subsequent damage to life, property, reputation and revenue can be catastrophic. This has become an in-creasing concern in pipeline design and the purchaser's specification of pipeline steels.

This project involves novel research to understand and optimise strain ageing effects and their structural consequences in pipeline steels. Investigations are covering strain ageing in low carbon and low nitrogen pipeline steels with strong carbon and carbonitride alloys; mechanical property changes; the effect of coating process parameters on mechanical property; the influence of strain ageing on pipeline fracture control; and limits to the Y/T ratio for coated pipes to control pipeline fracture.

POTENTIAL IMPACT

The study of strain ageing mechanics will also contribute substantially to metallurgical science. Until now, a quantitative analysis of carbon and/or nitrogen interstitial atom concentrations in line pipe steels has not been reported. Understanding and optimising strain ageing effects and their structural consequences will help to boost Baosteel's market share, product quality and reputation in Australia through technology development, which will ultimately enhance Baosteel's competitiveness in the international market.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Discovered that the combination of pre-straining and ageing did increase the yield strength and hence the Y/T ratio of the steel plates.**
2. **Demonstrated that the use of Y/T ratio to represent uniform elongation is not correct - at a high Y/T ratio of 0.96, larger than 6% uniform elongation still occurs.**
3. **Designed full scale hydrostatic burst tests, which are scheduled for Baosteel's plant in China.**

DEFECT-FREE STRIP-CAST STEEL PRODUCTS BA14013

Developing a metallurgical and process control strategy for generating new high-strength strip-cast steel grades

PROJECT LEADER

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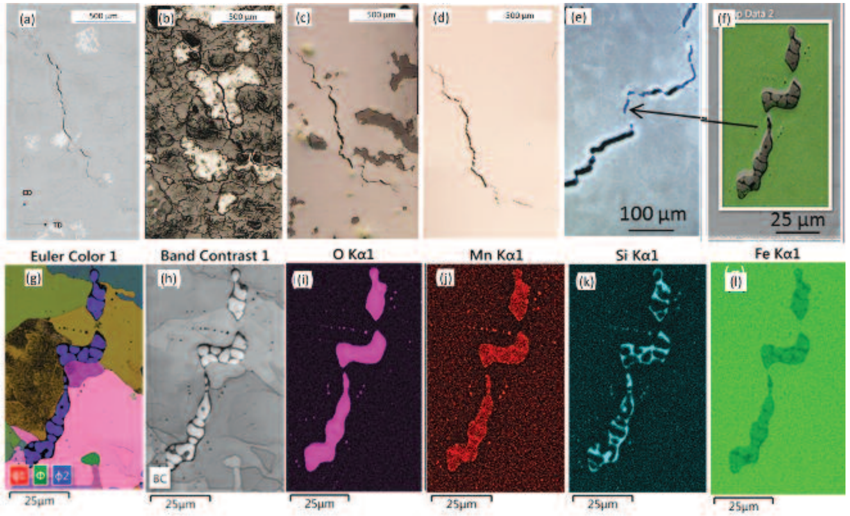
OBJECTIVES

A critical factor that determines the success or failure of a twin roll casting (TRC) processing plant is the ability to consistently produce high quality steel sheet products with minimal casting defects. The highly complex TRC process involves extremely rapid solidification rates, which makes it difficult to ensure high quality strip-cast products are produced with minimal defects. Systematically altering critical plant variables to understand the microstructures that form defects is also a challenge.

Using a novel substrate immersion (dip testing) technique, the research team is designing a strategic suite of strip-cast steel grades based on low-cost alloying additions. The alloys will be trialled in Baosteel's TRC plant in Ningbo, China. The project is also addressing the need for reliable production of strip-cast steel sheet with minimal internal and surface defects.



True 3-D macro/micro-structures and crystallography of a small crack formed on the surface of 2 mm thick low carbon steel strip, produced by TRC in nitrogen + 3-5% air atmosphere, revealed by a series of consecutive polishing along ND (4-5 µm polished away each polishing).

The researchers are studying the mechanisms that form strip casting defects (such as cracking) to provide metallurgical and engineering solutions that will eliminate these defects.

POTENTIAL IMPACT

TRC offers many advantages over the conventional processing of steel sheet products – i.e. the continuous casting of thick slabs followed by several secondary processing stages. These include a substantial reduction in initial infrastructure capital investment; huge process simplification with one compact continuous caster replacing downstream processing; minimal scale losses; improved yields; the use of recycled scrap; and environmentally friendly iron making processes.

Eliminating much of the downstream processing can lead to energy savings of up to 90 percent. Other positive environmental impacts include waste minimisation and negligible atmospheric pollutants such as CO_2 emissions. Optimising the processing parameters will help Baosteel's TRC plant compete strongly in the marketplace and contribute to its sustainability targets.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Determined useful steel compositions (e.g. Si+Mn+Nb microalloyed low carbon steel) and the type of casting defects (e.g. longitudinal surface cracks parallel to the strip casting direction).**

2. **Continued formulating the mechanisms of critical defect formation and investigating the dip-cast structure and mechanical properties of low carbon TRIP steels.**

3. **Progressed initial investigations into the structure and hardness of as-cast strips.**

IRON ORE SINTER OPTIMISATION BA14009

Designing microstructures and developing advanced thermodynamic databases to enhance blast furnace performance

PROJECT LEADER

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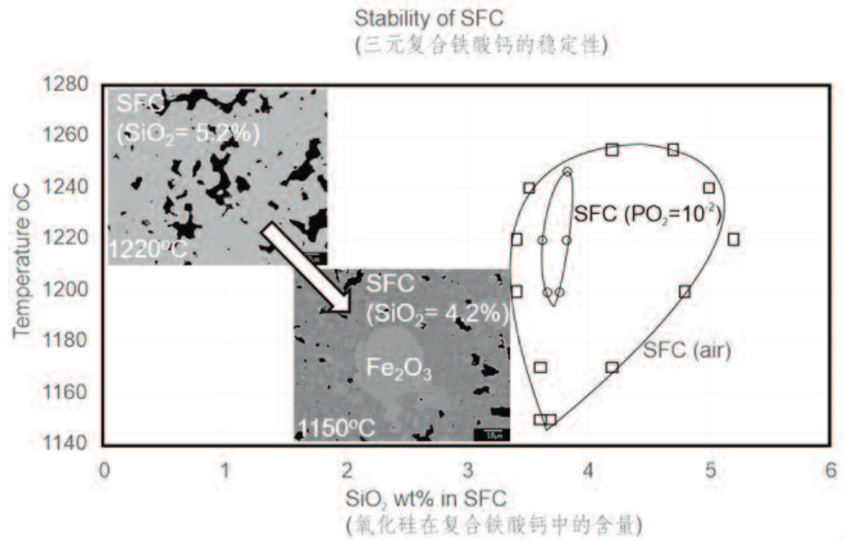

Example of decomposition of SFC at low temperature

OBJECTIVES

In recent research for the BAJC, the PYROSEARCH team established the key conditions for the SFCA phase to form in iron ore sinters. Building on these findings, the team is now working on new, state-of-the-art, predictive, fundamentally-based thermodynamic tools. The project's experimental measurements are extracting critical data that describe the complex chemistry, enabling advanced thermodynamic databases and accurate predictive models to be developed.

POTENTIAL IMPACT

The data obtained in this study has significant implications for future thermodynamic modelling for iron ore sinter making. Iron ore sinter blends, consisting of low cost materials from a variety of sources, are typically used to produce synthetic iron-containing feedstock for iron blast furnaces. Maintaining or improving the energy efficiency of the process while using low cost, low grade ores is an ongoing challenge for iron makers. Ironmaking consumes approximately two thirds of the total energy required to make steel, so the downstream effects of sinter production are significant. Currently, the selection of ore compositions, blends and sinter process conditions is based on extensive and expensive pilot test programs using largely empirical correlations.

Controlling the phase assemblages and microstructures present in the sinter is the key to detecting optimum sinter properties. The research to date has shown that reaction conditions can be controlled to produce different sinter microstructures. This improved understanding of the process will lead to enhanced iron blast furnace performance and economy. The advanced thermodynamic models for identifying the conditions necessary to achieve optimum sinter properties will enable Baosteel to make informed decisions about purchasing ore, using complex ore mixes, optimising process parameters, and designing sinter blends.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Characterised the phase equilibria of $FeO-Fe_2O_3-CaO-Al_2O_3$ system in air in compositional ranges, finding that the solubility of Fe_2O3 in the $CaO(Al_2O_3,Fe_2O_3)_3$ solid solution (TYPE1 SFCA) is higher than previously reported in the temperature range of interest.**

2. **Demonstrated via systematic experimental studies on the reducibilities of various SFC solid solutions that the reduction mechanism and kinetics of the SFC phase are very different compared to the hematite phase.**

3. **Discovered that the SFCA-I and SFCA, which were described in the previous research literature as two distinct phases, are within one continuous solid solution: the liquidus in the hematite and $C(A,F)_3$ primary phase fields were also determined at 1200-1300°C in air.**

AUTO STEELS WITH HIGHER HE RESISTANCE BA13037

Investigating the influence of hydrogen on automotive steels to reduce and eliminate dangerous hydrogen embrittlement (HE)

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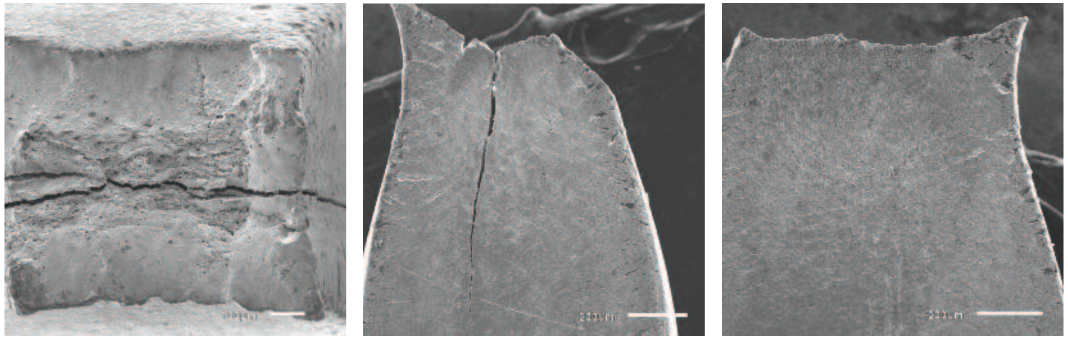

SEM images of the fracture surface and side surfaces of MS1500 at 0.0080 MPa s^{-1} at EZn (-752 ^{mV}SHE) in 3.5% NaCl with Pt counter eectrode. The fracture was ductile microvoid coalescence despite the amount of hydrogen adsorbed under these simulated service conditions.

OBJECTIVES

Hydrogen embrittlement (HE) in 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 (typically with yield strength above 1000 MPa) are particularly prone to HE, such as the steels developed for car manufacturers wanting to offer motorists the benefits of lighter weight vehicles. Failure-causing hydrogen leading to embrittlement can emerge in the steel making and auto construction stages (including painting), or enter the steel as a result of corrosion during service, e.g. from de-icing salts. Because HE can cause structural collapse on impact loading (particularly devastating in a crash situation) the HE risk of a car body needs to be considered over its lifetime, and this influences car manufacturers' steel supply choices.

The researchers are pursuing a deeper understanding of how hydrogen interacts with steel, to reduce and eliminate HE. Access to a state-of-the-art Thermal Desorption Spectroscopy (TDS) apparatus, built for this purpose with an Australian Research Council Linkage grant, is helping to assess the influence of hydrogen on key auto steels; evaluate if Baosteel products have the necessary resistance to the hydrogen fugacity associated with auto construction and service; identify relevant metallurgical features; and recommend countermeasures for improved HE resistance.

POTENTIAL IMPACT

This project will help Baosteel develop technical capabilities in the newest HE assessment methodology, evaluate the components of new and existing steels as fit-for-purpose, and produce automotive steels with higher resistance to HE compared to major competitors' products.

For the steel and energy sectors generally, the outcomes of the research will illuminate potential new knowledge pathways. For example, HE is also an issue for commercial medium strength steels used in hydrogen pipelines, pressure vessels and turbogenerator components. While high-strength steels with good HE resistance currently exist, steels with similar metallurgies can have significantly different resistance to HE and therefore the metallurgical reasons for the HE resistance are not clear, and it is not possible at present to determine HE resistance from steel composition or processing.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Conducted permeability experiments to study hydrogen diffusion and trapping in dual phase (DP) and quenched and portioned (Q&P) advanced high strength steels, and also in simulated service conditions.**
2. **Confirmed that the hydrogen influence of materensitic advanced high strength steels (AHSS) increases with steel strength, decreasing charging potential, and decreasing applied stress rate.**
3. **Conducted tensile tests at substantial stress rates, including simulating possible crash situations, revealing that little influence of hydrogen existed for the four MS-AHSS due to corrosion in simulated due to corrosion in 3.5 wt% NaCl, or for hydrogen-precharged MS1300 and MS1500.**

FLUORIDE-FREE MOULD FLUX FOR CONTINUOUS CASTING BA12011 LP130100773

Developing a fluorine-free mould flux for continuous casting to decrease the environmental impact of steelmaking

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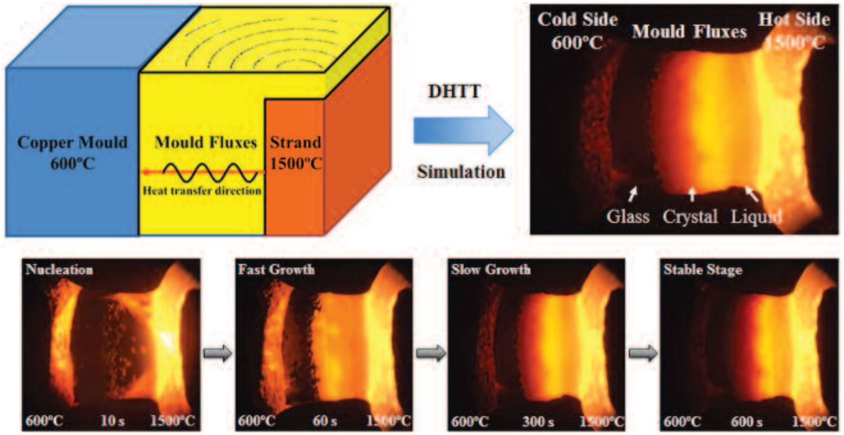
This project also receives leverage funding from an ARC Linkage Grant.

OBJECTIVES

Mould flux plays an important role in continuous steel casting, providing a high quality steel surface and trouble-free caster operation. Mould flux contains fluoride for good lubrication and appropriate heat transfer. However, high volatility of fluorine leads to environment pollution, equipment corrosion, and health and safety hazards. The ultimate aim of this project is to establish scientific ground for developing a fluoride-free mould flux and the feasibility of using this flux in industrial steel casting. This project investigates the melting properties, viscosity, crystallisation of fluorine-free mould fluxes, the interaction of molten fluxes with steels, and flux stability. A deeper understanding of fluorine-free fluxes will lead to the development of more sustainable steel casting technology for Baosteel.



Double Hot Thermocouple Technique for investigating fluorine-free mould fluxes

POTENTIAL IMPACT

Although the harmful environmental and technology impact of fluorine in mould flux is well recognised, a lack of understanding of flux properties and behaviour in steel continuous casting means no appropriate alternative has yet been developed. Replacing fluoride with environmentally friendly constituents while achieving the same functions as fluoride-containing mould flux would represent a major technological advancement for the continuous casting process. The economic and technology benefits include reduced time and expense for equipment maintenance and the post-treatment of slag.

This research is establishing new experimental data to reveal the mechanisms of flux crystallisation and the extent of boron and sodium volatility in different fluxes. The data will pave ground for flux design to achieve high quality steel continuous casting without harmful environmental impact. The theory of metallurgical processes will also be expanded, with particular values for flux chemistry and pyro-metallurgy, phase transformation in the process of flux crystallisation, and the thermodynamic and kinetic properties of molten flux.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Identified the main phases in the CaO-SiO_2-Al_2O_3-B_2O_3-Na_2O-TiO_2-MgO system and determined the effects of CaO/SiO_2 and Na_2O on these phase formations.**
2. **Developed the BP neural network viscosity model and used it successfully to predict the effects of temperature and flux composition on viscosity.**
3. **Constructed continuous cooling transformation (CCT) and time-temperature transformation (TTT) diagrams with data on flux crystallisation that showed increasing CaO/SiO_2 ratio and Na_2O content raised the critical cooling rate and shortened the incubation time of mould fluxes, and therefore enhanced the crystallisation tendency of mould fluxes.**

EVALUATING CENTRELINE SEGREGATION BA12035

Establishing a simple prototype computer vision-based aggregation evaluation method with acceptance

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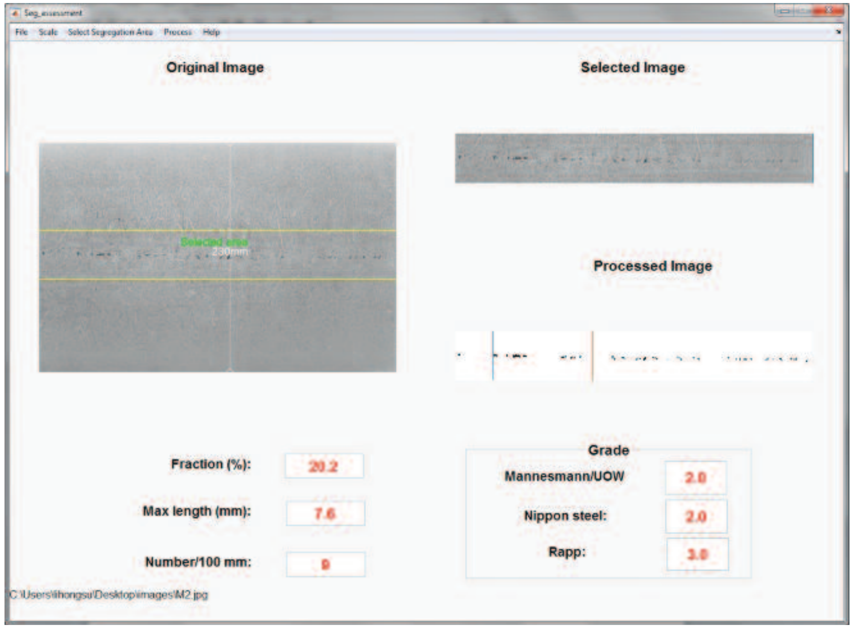
OBJECTIVES

Steel solidification proceeds by the nucleation and growth of dendrites with a composition different to the liquid from which it forms. Centreline segregation occurs as a positive concentration of alloying elements like C, Mn and P in the mid thickness region of continuously cast slabs. Depending upon its severity, it may harm the weldability and integrity of line pipes.

Well-known methods for controlling centreline segregation include caster design and maintenance, super heat, and casting speed. However, different methods are used by different suppliers and no international consensus exists on evaluation methods for assessment.

A repeatable and objective method for evaluating centreline segregation is highly desirable for steelmaking process improvement and for predicting final product performance. This project is working on a simple prototype computerised centreline segregation evaluation method based on and validated against the Mannesmann Scale.



Example of automatic centerline segregation evaluation using the developed software.

POTENTIAL IMPACT

With the prototype's potential for higher accuracy and sensitivity than current methods, the outcomes of this project have already drawn attention from world leading pipeline experts. The research has informed discussions with some of Baosteel's key customers on segregation assessment and related matters. Ideally, the steel mill and the line pipe users will collaborate to employ the automatic assessment method and rationalise the acceptance criteria.

HIGHLIGHTS AND ACHIEVEMENTS

1. After a comprehensive literature review, selected macro etching followed by computer assisted image processing as the best evaluation method for more objective assessment outcomes.
2. Developed a MATLAB program for centreline segregation assessment and validated it against Mannesmann standard charts and real production macro etched slab images. The program is more objective and reproducible than current methods.
3. Drafted a procedure to standardise each step of segregation assessment to ensure results are consistent.

STRONGER, TOUGHER, DUCTILE STEEL BA12029

Refining grains in continuous and ingot casting to produce smooth, strong, malleable steel

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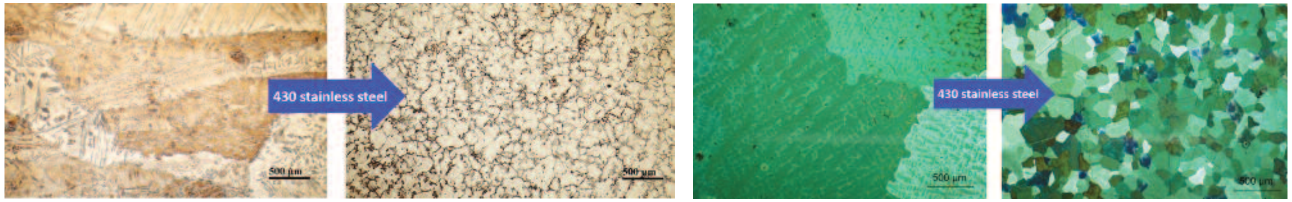

Examples of grain coarsening with varied alloying elements.(d) Fe-16Mn-0.6C TWIP steel with 1.5wt%Cu

OBJECTIVES

Rolling or forging steel ingots and continuous cast products with a fine grained microstructure not only leads to better properties in the final product, but also increases the uniformity of plastic deformation because small grains improve hot workability. Refining the grain size, decreasing porosity, and eliminating macro-segregation will improve the mechanical properties and overall quality of steel products. However, effective grain refiners for steel do not yet exist. This project is using well-established grain refinement theories (crystallographic and interdependence) for non-ferrous alloys to develop new and effective grain refiners for continuous and ingot steel casting.

The researchers are identifying potent grain refiners using the E2EM model, the associated database, and effective solute elements for sufficient constitutional supercooling. This includes validating predicted grain refiners and solute elements in steel casting; developing effective grain refining master alloys to be added during casting; and optimising the casting conditions, such as the addition level, holding time and cooling rate, to achieve the best grain refining efficiency.

POTENTIAL IMPACT

The proposed method of grain refinement extends the successful approaches used in Al and Mg alloys, and represents an innovative concept for steelmaking processes. Efficient grain refinement will simultaneously improve steel strength, toughness and ductility.

Minimising macro-segregation, columnar grains and cracking will produce higher quality billets, blooms and slabs. Improving the performance of rolled steels will result in better mechanical properties, a smoother surface finish, and fewer defects.

Manufacturing steel products will become more economical and environmentally friendly. Broadly, the outcomes of this research will generate new scientific knowledge about the physical metallurgy of steels and revolutionise grain refinement in steelmaking worldwide.

For Baosteel specifically, the novel technology can be patented, with the manufacture and marketing of the master alloys creating a new and profitable business opportunity.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Identified new grain refiners as effective nucleants for both ferritic and austenitic steels; the addition of less than 0.5wt% of such grain refiners led to 80% grain reduction.**

2. **Discovered that although adding alloying elements to wither ferritic steels or austenitic steels can lead to grain refinement with different grain refining efficiency, there is a critical addition level for all alloying elements over which grain coarsening would occur. This level, like an overdose poisoning effect, varies with alloying elements.**

3. **Continued developing grain refinement techniques, towards a promising industrial scale trial, that will enable steel makers to improve the quality of the both cast and wrought products.**

COST EFFICIENT SLAG SYSTEMS BA12002

Investigating the performance of low grade iron ores and fuels in slag systems to reduce ironmaking costs

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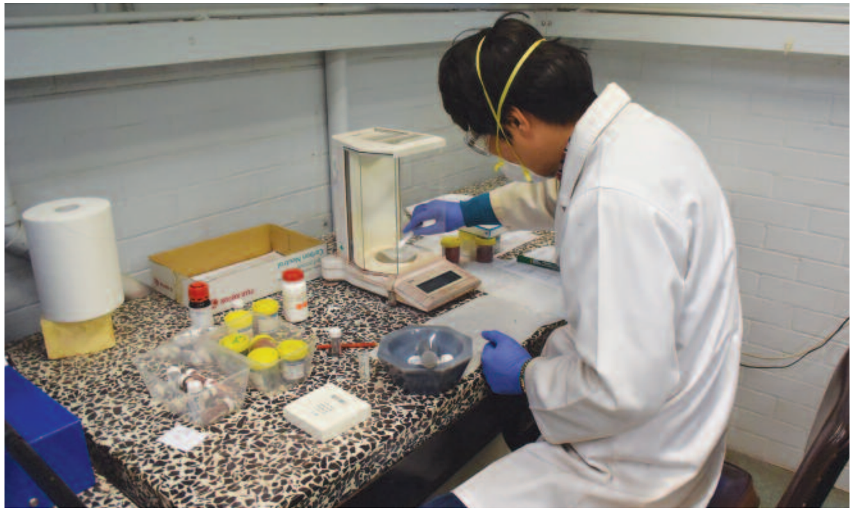
OBJECTIVES

Iron ores and fuel (coke and coal) represent a major cost in the ironmaking process. To help Baosteel reduce the cost and achieve its sustainability objectives, this project is investigating the impact of using low-MgO and/or high Al_2O_3 slags on blast furnace performance. The research aims to identify optimum slag compositions for (a) low-MgO and/or high Al_2O_3 operations and (b) for controlling sulphur concentrations in hot metal when poor-quality coals are used. The research will also develop systematic phase diagrams of the full composition range of blast furnace slag to help metallurgists manage the compositions of bosh and final slags properly.



Dr Kyoung-Oh Jang preparing samples for phase equilibria experiments.

POTENTIAL IMPACT

The continuous drop in steel prices globally is driving the industry to find cost-efficient ways of making high-quality hot metal with less expensive low-grade iron ores and coals. Considering the scale of the ironmaking industry, the potential cost savings will be huge.

Scientifically, this research will provide new and systematic fundamental benchmarks for the physico-chemical properties and behaviours of slag systems CaO-MgO-Al_2O_3-SiO_2-"FeO" directly related to ironmaking processes, including blast furnace and COREX. This is especially important for the latter process, in which coal is used to replace coke.

Determining optimal operations of the COREX process will help to overcome the high cost and environmental problems currently associated with coke-making. Employing cutting edge research techniques and state-of-the-art analytical equipment, the project will also provide new systemic data for the first time on the phase equilibrium of "FeO"- Al_2O_3-CaO-MgO-SiO_2 system.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Conducted systematic studies, including phase equilibria, viscosity and sulphur partitioning, to assist in Baosteel plant trials to reduce MgO in BF slag.**

2. **Determined the phase equilibria in the system "FeO"-MgO-Al_2O_3-(CaO+SiO_2): with CaO/SiO_2 = 1.3 to characterise the intermediate BF slags (over 400 experiments in equilibrium with metallic iron); and with various CaO/SiO_2 ratios to characterise the primary BF slags (over 200 experiments in equilibrium with metallic iron).**

3. **Compared the results of experimentally determined equilibrium sulphide capacities for synthetic slags with the kinetic sulphur partitioning results and industrial measurements.**

IRONMAKING PROCESS MODELLING AND ANALYSIS BA11009 ARC LP120200469

Understanding and modelling the fundamentals governing multiphase flow and thermochemical behaviour to achieve energy efficiencies

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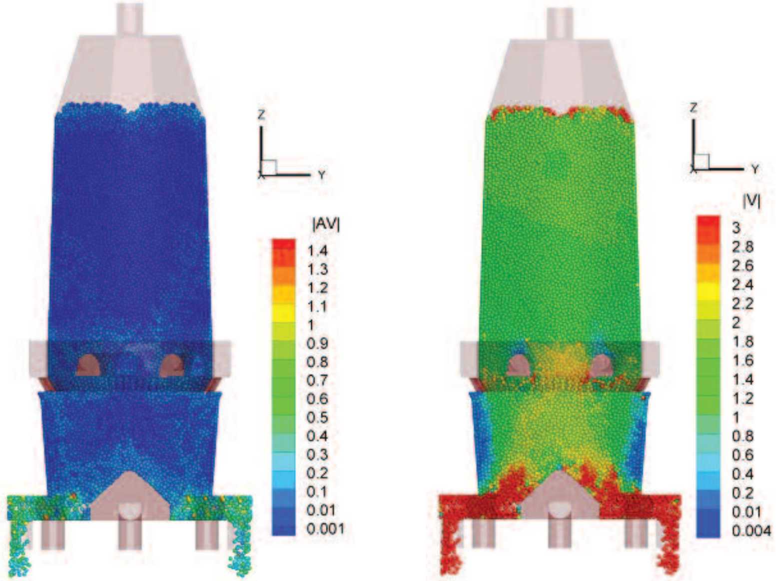
This project also receives leverage funding from an ARC Linkage Grant.



Computer modelling of reduction shaft processes has revealed new data about COREX thermal behaviour.

OBJECTIVES

Process engineering plays a critical role in mineral processing and extractive metallurgy, including blast furnace and alternative melter gasifier technologies, e.g. COREX. Computer simulation and modelling has emerged as a powerful tool for research and development of these processes, helping Baosteel design, optimise and control more competitive and sustainable operations. The aim of this project is to understand and model the fundamentals governing the multiphase flow and thermochemical behaviour in ironmaking processes, including blast furnace and COREX. The research team is developing and validating computer models that can reliably describe the multiphase flow and thermochemical behaviour in blast furnace and COREX ironmaking processes; using these developed models to investigate the effects of key variables related to raw materials, operational conditions and geometrical conditions on blast furnace or COREX flow and performance; and formulating and testing strategies for the design, control and/or optimisation of blast furnace or COREX ironmaking processes under different conditions.

POTENTIAL IMPACT

With validated computer models answering fundamental questions about blast furnace and COREX operations and quantifying the effects of a range of variables, Baosteel's ironmaking will experience extended life campaigns; better operational control; decreased fuel consumption; improved productivity; and reduced CO2 emissions. Because of ironmaking's extremely large scale, operational improvements like these can generate multimillion dollar economic benefits.

The project will also build knowledge about COREX, a relatively new ironmaking technology and one of the few industrially and commercially proven direct smelting reduction processes. Understanding the problems currently experienced with COREX will help Baosteel develop its potential advantages, such as flexible raw material utilisation and production, reduced raw material costs, and reduced environmental pollution.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Refined and modified existing BF models (BF process and tuyere) for their applications to specific Baosteel BFs, improving their numerical stability and accuracy and verifying that the models can be used to examine and**

2. **Integrated a sub-model with the present BF process model to investigate shaft injection and test the integrated model using data measured in a lab-scale BF.**

3. **Developed DEM-based and CFD-DEM-based models to simulate solid flow in a screw feeding system; investigate the effect of gas flow in a reduction shaft; and investigate gas-solid flow behaviour in a melter gasifier.**

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.

ASSESSING THERMODYNAMICS IN LUBRICANT PERFORMANCE BA15001

Analysing lubricant performance on high speed tinplate and stainless steel cold rolling

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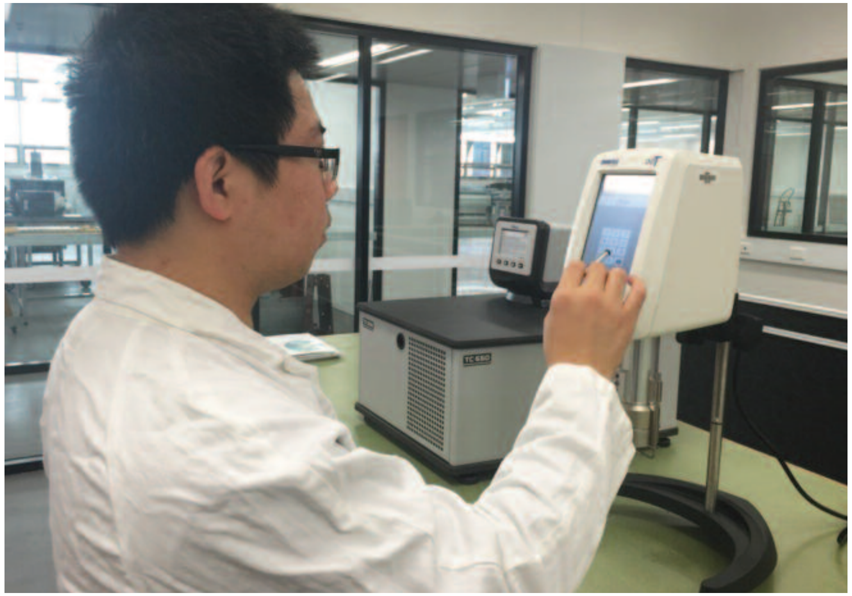
OBJECTIVES

Lubricant plays an important role in minimising defects during the cold rolling of metals such as tinplate and stainless steel, which are used to manufacture everything from bridges to beer cans. Too little generates friction and reduces protection; too much can cool the metal too soon, before pits and other abrasions can be smoothed. While thermal effects are less significant in cold rolling than in hot metal rolling, deformation work and friction do generate heat. Temperature rises can affect viscosity and the performance of the lubricant. Understanding how rolling temperature, property changes and asperity-lubricant interaction affects lubricant performance is critical for achieving the consist high quality output needed for different products.

To maintain a strong market position in metal manufacturing, Baosteel has set unprecedented high speeds targets for cold rolling tinplate and stainless steel. While some problems with high speed stainless steel manufacturing are known, such as 'heat scratch' occurring at around 300m/min, no knowledge is available about the lubricant performance.

This project is investigating lubricant performance under high rolling speeds and an effective method for assessing optimum outcomes. The research includes developing an approach to characterise the effects of temperature, material property change and abrasion-lubricant interaction on lubricant performance when speeds are increased.



Characterising the tribological properties of rolling coolant at UNSW's Research Laboratory for Precision and Nano Processing Technologies.

POTENTIAL IMPACT

Cold rolled steel, with its more precise dimensions and versatility compared to hot rolled steel, attracts a higher market price. Thus, the economic incentives for improving cold rolling processes and productivity are strong. This research will lead the development of cold rolling worldwide. Its potential contribution to both the mechanical manufacturing discipline and Baosteel innovation will be significant.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Assessed lubricant performance under high temperature using a specially modified tribometer, discovering that the interface friction stress can significantly increase due to the drop in lubricant viscosity when the lubricant temperature rises; and that the existence of lubricant additives can alter lubricant performance considerably.**

2. **Commenced development of a multiscale statistical characterisation model involving thermal dynamic analysis.**

3. **Conducted a preliminary tribology test to explore the mechanism of heat scratch in rolling stainless steel.**

SAFER, RIDGE-FREE FERRITIC STAINLESS STEEL PRODUCTION BA14014

Finding practical solutions to reduce ridging defects in the production of ferritic stainless steels

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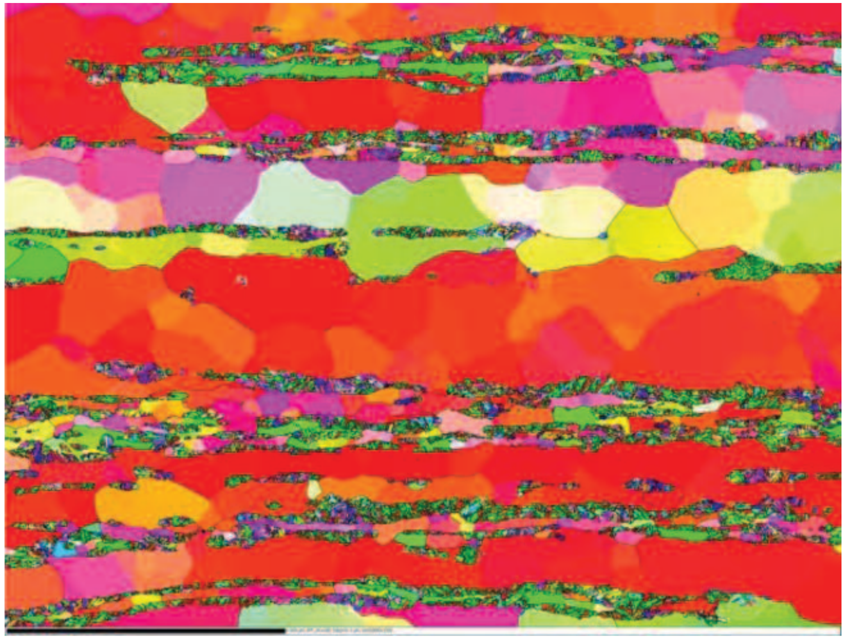
OBJECTIVES

Two major economic, environmental and employee safety problems for the worldwide stainless steel industry are ridging defects that occur during rolling and forming processes, and the sticking of ferritic metal during the hot rolling process. In most stamping works, the ridging defect unavoidably leads to manual polishing and finishing after the forming process, which significantly increases cost and has proved detrimental to the environment and personal health.

While Baosteel's efforts to optimise alloy design, rolling and annealing processes have helped to alleviate these defects, no stainless steel manufacturer to date has solved the ridging problem to avoid the defect completely.



Dynamic recrystallisation behaviour of ferritic stainless steel 430 during hot deformation.

The project aims to understand the mechanism that causes the ridging defect of selected typical Baosteel ferritic stainless steel grades. This will lead to proposing practical solutions for reducing ridging height to achieve the advanced level in the field of ridging worldwide. Increasing the competitiveness of Baosteel ferritic stainless steel products in both domestic and international markets is also anticipated.

POTENTIAL IMPACT

The outcomes of the project will have a significant impact on reducing ridging defects and improving the quality of rolled ferritic stainless steel products. This, in turn, will decrease the subsequent machining costs; extend the market volume growth of Baosteel ferritic stainless steel products; reduce the prevalence of dust generated during polishing and finishing processes; and therefore mitigate negative effects on the environment and the health of workers.

HIGHLIGHTS AND ACHIEVEMENTS

1. Analysed the mechanism of microstructural evolution of ferritic stainless steels under different temperatures and strain rates, based on the stress-strain curves, microstructural observation and EBSD analysis.
2. Conducted practical rolling tests and annealing treatment to reduce ridging generation - the ridging height of samples with 70% reduction was found to be 20-30% lower than that of samples with 50% and 90% reductions, mainly induced by different anisotropic properties of crystals.
3. Compared numerical and experimental results to validate a ridging model that considered EBSD texture information and crystal plasticity to analyse the generation of ridging of FSS species during tensile deformation, discovering that the results matched well with each other.

ADVANCED HIGH STRENGTH STEELS FOR AUTO FUEL EFFICIENCY BA13014

Studying chain-die fabricated non-uniform AHSS products to produce stronger, light-weight automotive steels

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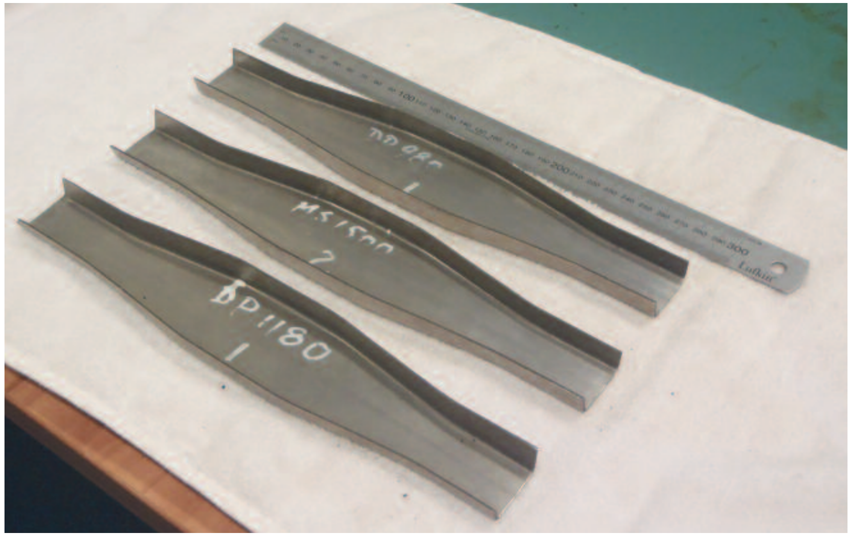
OBJECTIVES

Global demand is increasing for motor vehicles that are more economical to run and that generate less pollution. Reducing just 10 percent of a vehicle's body weight can reduce fuel consumption, and therefore emissions, by a commensurate percentage. Manufacturing car parts from lighter weight, high strength steels and non-ferrous materials requires different forming methods, with chain-die forming emerging as an alternative to roll-forming and stamping. Chain-die forming was proposed and developed at The University of Queensland and University of Wollongong.

This project is exploring ways to overcome problems with manufacturing Advanced High Strength Steels (AHSS) for the motor vehicle industry, which occur as bottle necks in the process of turning flat sheet AHSS into irregular products; and how chain-die forming may prove to be a better means of manufacturing components, e.g., the structural parts of cars. The researchers have modified an existing pilot chain-die former for experimental studies. This allows them to work on a theoretical model of chain-die forming to classify the typical structural parts based on the strains developed during the forming process, as well as understand the limits of different AHSS when applied to chain-die forming. Their theoretical and experimental analyses will inform studies on force and energy consumption in relation to manufacturing new auto steels.



Formed samples of high strength materials with no defects.

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 higher quality formed products. Another advantage is that this technology requires less space to operate. With an efficient and economical method of chain-die forming, Baosteel will be well-placed to become a world-leading manufacturer of AHSS and meet the needs of car and other automotive industries. Importantly, the successful integration of strong yet light-weight chain-die formed steels in motor vehicle production will have a significant impact on urban pollution.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Established the FEA modelling to simulate the chain-die forming process on both regular (2D and 3D) and irregular profiled products, generating new knowledge about plastic deformation on flanges of irregular profiles.**

2. **Observed that almost no product defects occur in the highest strength material, and that the formed samples show very encouraging compatibility with the new technology.**

3. **Demonstrated that the new method is superior to roll forming for this purpose.**

CHARACTERISING COLD STRIP ROLLING BA12003

Analysing the performance of lubricant and characterising rolling pressure for lower cost cold rolling techniques

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OBJECTIVES

Cold strip rolling plays a vital role in the process of metal forming. While different additives to lubricants are known to alter lubricant performance and therefore change the product quality, a deeper understanding of the complex asperity-asperity contact between the roll and strip surfaces and the coupled solid-fluid interactions of cold strip rolling interface contact have eluded researchers to date.

Successful control and optimisation of cold rolling would be achieved with more comprehensive knowledge about the mechanisms of surface roughness degradation and the role of lubricant emulsion.

This project is developing an effective method for exploring such mechanisms and establishing a feasible solution for high performance cold strip metal rolling. It involves a novel multi-scale analysis which considers instant lubricant viscosity, asperity flattening and asperity/lubricant interaction simultaneously. Accurately characterising roll-strip interactions, including the effect of lubricant and lubricant additives on rolling pressure and performance, will reveal what causes rolling deformation in mixed lubrication, and lead to new technology for superior precision manufacturing and metal surface integrity.

Project closure presentation at Baosteel.

POTENTIAL IMPACT

The project's novel characterisation method will enrich understanding of a major obstacle to high quality output from low cost cold rolling. With a comprehensive model to predict friction and pressure at the rolling gap under mixed lubrication conditions, engineers can observe production processes in their multi-scale intricacy and customise innovative high performance rolling lubricant and processes. Importantly, the capability to predict interface friction behaviours with greater accuracy will boost Baosteel's competitiveness.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Established a new statistical approach to calculate asperity contact pressure and contact ratio in the rolling bite, and a novel method to predict the surface roughness evolution of strips during rolling.**

2. **Enabled, for the first time in a single step, unified simulation of all lubrication regimes (i.e., hydrostatic, mixed and boundary lubrication regimes) involving asperity–lubricant interaction at the roll bite.**

3. **Developed two computer codes, which Baosteel has verified in-situ production measurements and are ready to be commercialised.**

ENVIRONMENTALLY FRIENDLY MILL LUBRICANTS BA13012 ARC LP150100591

Developing novel nano-additive water-based lubrication technology to improve steel hot rolling outcomes

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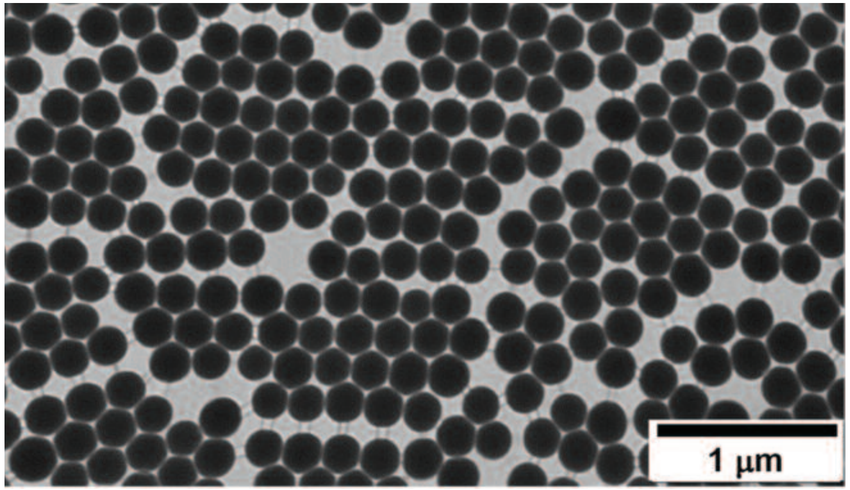
This project also receives leverage funding from an ARC Linkage Grant.

OBJECTIVES

Lubrication in hot rolling steel reduces friction, roll load and wear, and power consumption. Presently, oil-based lubricants are used in finishing rolling mills, but the lubrication effect is alleviated because oil lubricants can be swept away by cooling or descaling water. This makes the control of strip surface defects difficult and hence influences final product quality. Also, burning of oil in the process and disposal of waste lubricants are of environmental concern. The development of an alternative lubrication technology is thus timely and essential.

Contamination from oil in the machinery, metal particles from the rolling process, and bacteria growth all contribute to roll degradation. Burning oil at high temperatures and dealing with the subsequent waste create complicated environmental issues. Cost and product quality-wise, the positive lubrication effects are often reduced when cooling water to control surface temperature sweeps the oil away.



Synthesised SiO_2 nanoparticles of 220 nm in diameter for rolling lubrication.

This research is developing novel nano-additive water based lubricants which will improve rolled steel product quality and reduce resources utilisation. Nanomechanical and nano-tribological tests are being used to understand oxide scale evolution and its effect on lubrication behaviour. Developing recycling technology for the new lubricants is also proposed.

POTENTIAL IMPACT

The development of novel nano-additive water-based lubrication for hot rolling is generating new science. Until now, severe conditions in the deformation zone have prevented researchers from understanding the lubrication mechanism at the interface between rolls and workpiece in hot rolling. This research is adopting advanced testing methods to investigate the mechanism associated with nano-additive water-based lubricants, which has never been done before.

Ultimately, the high wettability, affinity to steel surfaces, and stability at high temperature of this environmentally friendly technology will improve lubrication effects in Baosteel's hot rolling mills. The innovation could also be marketed to other mills in China and around the world, opening up a lucrative new business opportunity for the company.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Demonstrated that water based lubricants with 2D Graphene oxides improve lubrication effect and rolling performance.**
2. **Tested TiO_2 suspensions in the large laboratory rolling mill in Baosteel, which showed promising lubrication performance.**
3. **Successfully filed a patent in China for "Water-based nanolubricants for hot steel rolling".**

MAXIMISING HOT STEEL ROLL LIFE BA12045

Applying new modelling techniques to predict wear and improve the quality of high-speed hot roll steel products

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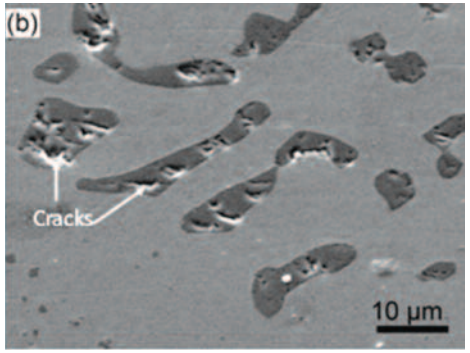

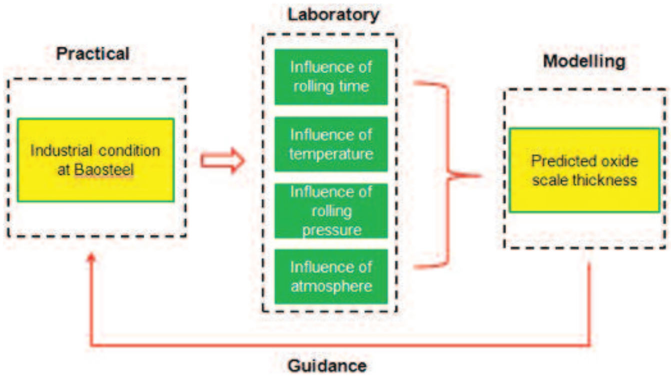

Cracks of carbides at 5000 thermal cycles.

OBJECTIVES

High-speed steel (HSS) rolling has improved strip surface quality grade by up to 20 percent and can extend the life of a rolling campaign. However, thermal cycles cause superficial oxide scale to form, which affects contact friction and wear. High loading and shear force also result in fatigue and wear.

Extremely arduous working conditions at high temperatures cause work rolls to deteriorate, shorten working life and ultimately affect the strip quality (e.g., shape, thickness, roughness). The cost of roll wear can be as high as 10 percent of the total cost of steel production.

To extend roll life, increase productivity and reduce production costs, this project is investigating the wear and failure mechanism of oxidised HSS rolls in a hot strip rolling campaign with innovative experimental work and modelling.

It is considering various complex and interacting factors that affect the contact, such as the characterisation of oxide scale (morphology, thickness, mechanical properties at elevated temperatures) formed during high frequency heating/cooling; the behaviour of oxide scale and wear debris in the contact; and wear mechanisms for multi-phase material.

POTENTIAL IMPACT

The research will break through, theoretically and experimentally, the obstacles currently preventing steel makers from advancing the characterisation of oxide/carbides and forming a comprehensive picture of both the HSS oxidation process and the tribology of abrasive wear.

The novel methodology could also, potentially, be applied to the abrasive wear of multiphase composite materials and HSS tools in other metal forming.

With a quantitative understanding of tribological contact and wear mechanics, Baosteel can maximise the performance and cost efficiency of its HSS hot rolls and, with a higher quality product, offer greater value to customers down the supply chain in the automotive, white goods and packaging industries.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Developed a world-first a high temperature wear/oxidation roller-on-disc testing rig to simulate realistically the rigorous service working conditions of HSS work rolls in hot rolling process.**

2. **Conducted a series of cyclic oxidation tests of HSS on the Gleeble 3500 thermal mechanical simulator at high frequency thermal conditions, with up to 10,000 thermal cycles (this thermal cycling can accurately account for the effects of surface morphology of the roll in service).**

3. **Experimentally investigated and proposed a novel concept of off-line pre-oxidation of HSS to reduce the number of warm-up coils in the beginning of a hot rolling process, potentially generating a significant cost saving.**

OPTIMISING STRIP CASTING PERFORMANCE BA11001 ARC LP120200499

Investigating how thin-gauge metallic strips form to enable more efficient manufacture of high-quality sheet metals and alloys

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This project also receives leverage funding from an ARC Linkage Grant.

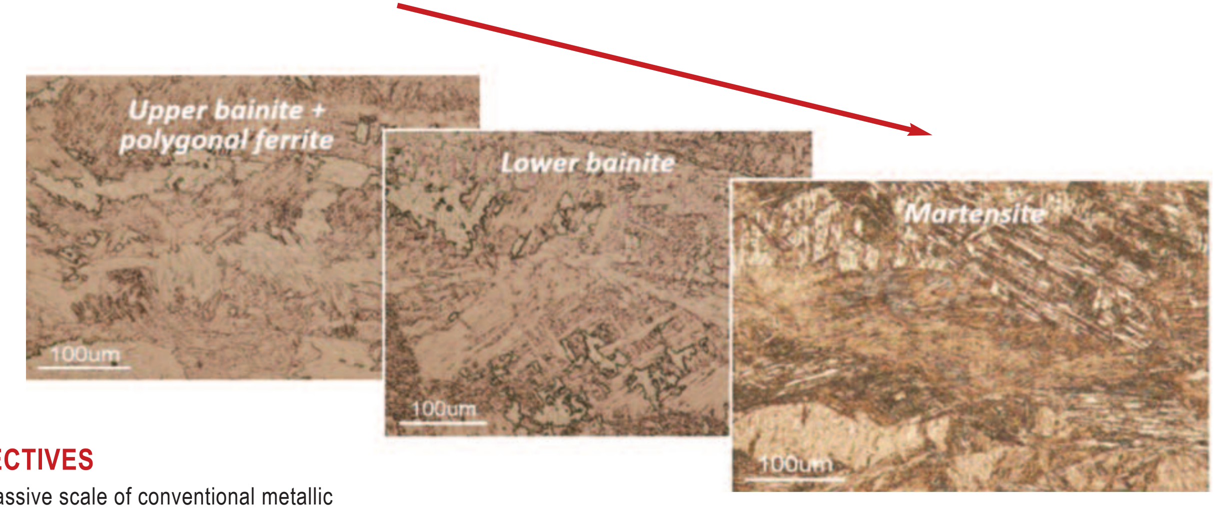

Fig. 1. Strip-cast C-Nb-Mn-Si steels showing the pronounced influence of Mn + Si concentration on as-cast structure, which can generate steel strip with structures ranging from soft upper bainite + polygonal ferrite to hard martensite.

OBJECTIVES

The massive scale of conventional metallic strip processing (e.g., billet, slab or ingot casting and their secondary processing stages) is energy-intensive and detrimental to the environment. Casting defects can prevent as-cast strips being manufactured to a consistent high standard in the processing plant, therefore reducing the strength, quality and value of the final products.

To reduce the economic and environmental impact associated with traditional metal strip processing, the researchers are using a novel, powerful substrate immersion technique, coupled with twin roll casting (TRC) trials, to investigate the effect of key processing parameters on the early stages of solidification in the as-cast structure of various steels. Identifying, characterising and classifying certain casting defects will also improve understanding about plant variables, and how they could be altered and controlled during the metal's molten state to reduce defects. Efficiencies in the process are also expected to result in significant cost and energy savings.

POTENTIAL IMPACT

Baosteel operates in a US$1 trillion metallic sheet production market serving the construction, automotive, packaging, aircraft and aerospace industries. This research will help Baosteel sharpen its competitive edge with innovative strip processing technologies that reduce capital and running costs, improve performance, and generate new strip products with novel microstructures and properties.

The environmental outcomes expected from optimised strip casting performance include minimal feed material wastage (e.g. with the ability to readily accommodate recycled/scrap feedstock), a decrease in greenhouse emissions by up to 80 percent over conventional strip processing routes, and a much smaller landscape footprint compared to existing plants.

The project will also contribute to new fundamental knowledge about metallurgical and processing, leading to a direct and profound impact on strip casting methods globally.

HIGHLIGHTS AND ACHIEVEMENTS

1. Completed the experimental program on defect formation processes and mechanisms in strip-cast low carbon steel.
2. Recommended to Baosteel that it eliminate large scale cracking on as-cast LC strip in the TRC plant in Ningbo, China.
3. Submitted a comprehensive report to the BAJC.

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.

STRONG STRUCTURAL AUTOMOTIVE ALUMINIUM ALLOYS BA15008

Developing high strength 6xxx series aluminium alloy sheet for automotive structural applications

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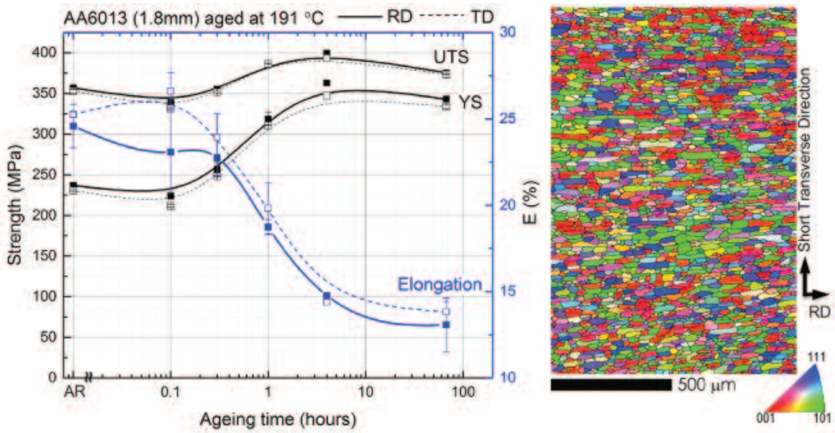
OBJECTIVES

The automotive vehicle sector dominates global demand for aluminium (Al) components, with the market for high strength aluminium automotive sheet continuing to grow. Al suppliers are now offering new products such as A and B pillars, chassis, frames and crash systems; however, these applications require higher specific strengths than body sheet. More highly alloyed 6xxx series Al-Mg-Si(-Cu) materials have been identified, which offer an attractive combination of properties to address this need.

Building on this knowledge, the researchers are conducting experimental, modelling and benchmarking activities to determine an alloy composition and processing route that will produce a competitive 6xxx series Al alloy with very high strength and adequate formability. The project is pursuing an alloy in the compositional space close to those of AA6013, AA6111 and AA6181A. This includes developing innovative alloy processing technologies (especially heat treatments).



Tensile properties measured in the rolling direction (RD) and long transverse direction (TD) for a benchmarking 6xxx alloy sheet in both the as-received (AR) condition and as a function of ageing time (left). Electron back-scattered diffraction (EBSD) results reveal that this high strength 6xxx series benchmarking material has a fine recrystallised grain structure across the thickness of the sheet (right).

POTENTIAL IMPACT

This research will improve understanding of the mechanisms governing the relationships between composition, processing, microstructure and properties of concentrated 6xxx alloys. The outcomes are expected to generate new intellectual assets for Baosteel that may include sufficient novelty for patenting, a new Aluminium Association AA alloy designation, and/or know-how related to alloy design, production, processing and evaluation. With particular emphasis on advancing the technology readiness level and ensuring that the solution is implementable in production, the project will position Baosteel favourably to offer competitive high strength 6xxx alloy sheet solutions.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Conducted a thorough literature review, which was presented to Baosteel.**
2. **Characterised high strength 6xxx series aluminium alloy benchmarking sheet materials (obtained in two different sheet thicknesses and with two different compositions) in both the as-received condition and after ageing.**
3. **Performed CALPHAD simulations and designed a series of eight experimental alloys, which were then cast, homogenised and rolled into sheets ready for evaluation.**

NEXT GENERATION 6xxx SERIES ALUMINIUM ALLOYS BA12014

Designing new aluminium automotive body panel materials with improved strength and formability

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OBJECTIVES

The global emissions-driven push for lighter weight vehicles has opened up opportunities for Baosteel to secure a strong position in the market for lightweight aluminium alloy automotive body panels. Currently, 5xxx series alloys are popular for internal panels due to their superior formability. Meanwhile, 6xxx alloys have emerged as the main contenders for external panels due to their bake hardening characteristics and improved surface quality.

Until the manufacturing problems of high cost and poorer formability are resolved, however, such new materials struggle to compete with the established advantages of steel.

A focus on alloy and process design, emphasising specialised cold rolling, heat treatment and alloy composition, is helping the researchers address the formability shortcomings of 6xxx series aluminium alloys. They are establishing new ways of engineering the microstructure to reduce strain localisation and increase the work hardening capacity. They are also evaluating the effects of changing the cold rolling reduction and comparing the results obtained from normal symmetric rolling with those from different types of asymmetric rolling. Novel alloy process combinations are being developed that achieve better formability than existing benchmark alloys and steels, without degrading valuable mechanical properties.

Experimental casting of a candidate alloy.

POTENTIAL IMPACT

The critical metallurgical knowledge, processing know-how and advanced technical solutions this research is generating means Baosteel can respond confidently to customer demands for lighter weight alloys. Developing a cost-effective and patentable new aluminium alloy for both exterior and interior automotive body panel applications will enable Baosteel to market a more comprehensive portfolio of materials and increase its market share of an industry keen to move from steel to aluminium as the material of choice.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Casted and tested more than 12 alloy compositions for mechanical and hemming examination.**
2. **Conducted intergranular corrosion and microstructure studies, including grain boundary analysis using high resolution electron microscopy.**
3. **Developed and trained an effective neural network model for predicting target properties.**

FAST EXTRUSION OF MG ALLOYS BA15007

A thermomechanical technology for processing wrought alloy components at significantly higher production rates

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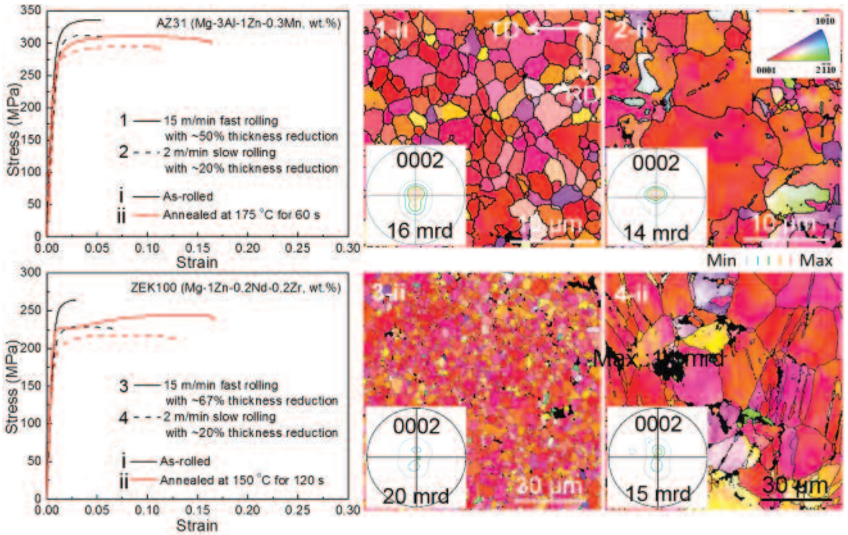
OBJECTIVES

Wrought alloys are usually stronger than cast alloys; however, low production rate and high processing cost have inhibited the current use of magnesium (Mg) wrought alloys. One way to solve this problem is to develop an alloy and a thermomechanical processing technology that can deliver wrought products at significantly higher production rates.

The researchers are developing a high speed extrusion/rolling technology for wrought Mg alloys which will increase production efficiency and therefore significantly reduce the processing cost. The resulting wrought Mg alloys will have improved extrudability, rollability, formability and mechanical properties.



Improved tensile properties of Mg sheet produced by fast rolling and annealing.

POTENTIAL IMPACT

As more Mg alloy processing and manufacturing technologies become available, large-scale use of magnesium products will generate higher demand for exported Australian magnesite.

Aligning with Baosteel's core business and expertise relating to metallic sheet and wrought Mg products, this project is strategically and commercially important to Baosteel's expansion in the market.

The research outcomes will enable Baosteel to extend its knowledge base and develop economical technologies for producing wrought Mg products for automotive applications. Establishing a new business to market low-cost Mg products would generate million-dollar annual profits.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Found that the rollability of magnesium alloy sheet is remarkably improved by high speed rolling, allowing a large reduction per pass.**

2. **Designed a low-cost thermomechanical process which combines high reduction rolling and low-temperature short-time annealing treatment, from which a high performance magnesium alloy sheet was fabricated.**

3. **Discovered that this processing technique could significantly increase the productivity of Mg alloy sheet, and that this sheet showed extraordinarily well-balanced mechanical properties (strength and ductility).**

HIGH PERFORMANCE MAGNESIUM EXTRUSION ALLOYS BA14027

Realising new property space to produce next generation magnesium alloy extrusions

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OBJECTIVES

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. Cost and property comparisons with steel and aluminium have delayed the market penetration of magnesium alloys to date. Modern applications have also highlighted deficiencies in the 'property space' of magnesium alloys, restricting their use and exploitation. However, it is possible to modify and expand the property space of magnesium alloys without decreasing valuable properties, allowing the lower density of magnesium to be exploited for lighter and 'greener' applications.

Extruded products represent an important portion of the magnesium market. This project addresses the problem by producing magnesium extrusions targeting two specific property space gaps: (i) alloys with moderate strength and high ductility; and (ii) alloys with appreciable strength and practical ductility. Such properties, when balanced with fatigue and heat resistance, corrosion performance and cost, represent the greatest potential for meeting the needs of the hungry light-weight structural metals market. Fundamental physical metallurgy dictating the microstructure-property relationship will be pursued for specific alloys that offer high strength, moderate ductility, and a medium to high speed extrusion rate for a low cost.

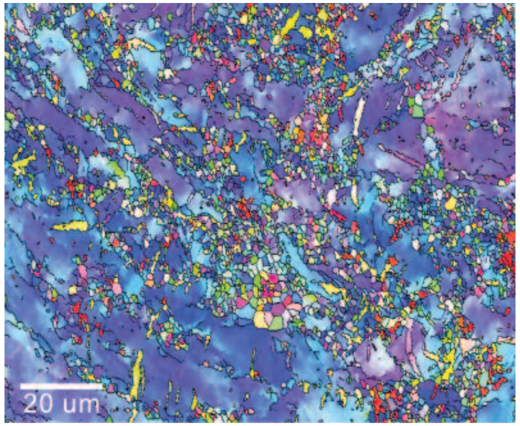


Fig. 1. Electron backscattered diffraction map showing microstructure of high-strength alloy X subjected to warm extrusion.

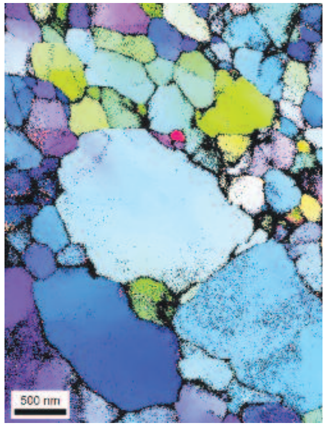


Fig. 2 Transmission Kikuchi diffraction map showing nano-grains in high-strength low-anisotropy alloy Y.

POTENTIAL IMPACT

A clear understanding of the microstructure from the atomic level and up is a prerequisite for characterising novel alloys, and this project will significantly advance the fundamental science underpinning microstructural genesis in magnesium alloys based on Mg-Al-Ca-Mn, Mg-Zn-Ca-Mn and Mg-Zn-Al-Mn. This capability will enhance Baosteel's magnesium expertise and the knowledge gained in the above systems will enable Baosteel to optimise their properties.

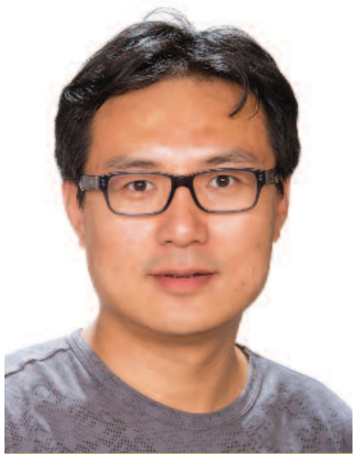
Commercially, the systematic design-processing work will lead to new patentable alloys and these unique commodity extrusions with new property space will help Baosteel safeguard its market share as lighter metals become the material of choice for many consumer goods. A business devoted to commercialising these value-added magnesium products would potentially attract billion dollar profits for Baosteel each year.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Produced an ultra-high-strength and rare-earth-free alloy X with yield strength more than 410 MPa and usable ductility.**
2. **Generated a high performance rare-earth-free alloy X with balanced yield strength (320 MPa) and ductility (17.5%), resulting in yield strength × elongation > 5500 MPa·%.**
3. **Developed an ultra-high-strength and cost-effective alloy Y without any yield anisotropy.**

NEXT GENERATION COATINGS FOR MAGNESIUM ALLOY BA12031

Transforming the magnesium alloy market with next generation protective conversion coatings



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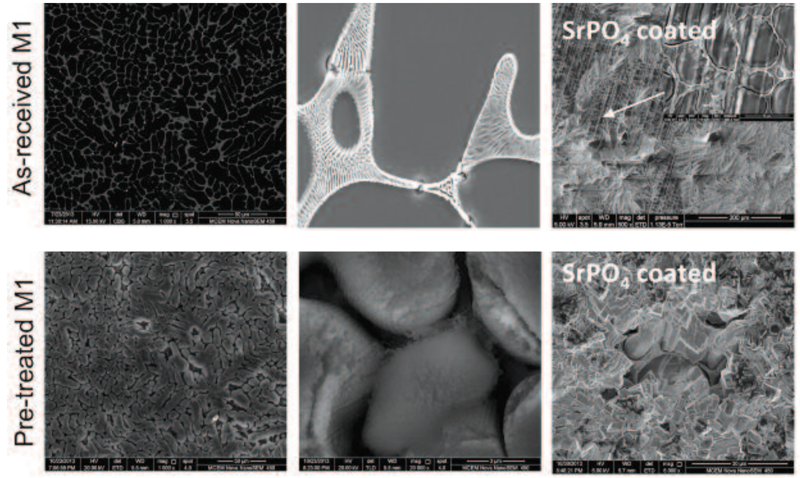
OBJECTIVES

Magnesium (Mg) alloys, despite being the lightest structural metals and popular in automotive and aerospace industries, have not been widely applied due to their susceptibility to atmospheric and galvanic corrosion. Mg can corrode rapidly in contact with air or water, resulting in decreased mechanical stability and undesirable appearance.

To realise mass-market applications of Mg alloys (and to reap the associated energy and environmental benefits), an alternative method must be developed for producing practical chromium-free conversion coatings that actively protect the alloys from corrosion; and the resulting conversion coatings should be adhesive, compact, stable and defect-free.

This project aims to develop a world-first technology for producing protective conversion coatings, which should be simple to operate, non-hazardous, cost efficient, environmentally friendly and multi-functional.



SEM images indicating the growth of SrP coating on AXM4303 (Bao-M1 alloy) with (bottom row) and without (top row) pretreatment.

The researchers are systemically studying how to transit conversion coating techniques from lab scale to industrial production. They are also developing pre-treatment processes to achieve a favourable intermetallic-free surface; building appropriate condition windows using computed forms of equilibrium thermodynamic calculations; applying a protective metal phosphate conversion coating so that Mg alloys have the functionality to meet the needs of a broad range of end users; and testing the corrosion resistance under various service conditions.

POTENTIAL IMPACT

Advancing the knowledge base with pioneering insights about corrosion will be valuable to both the fundamental science and the practical applications relating to Mg alloys. The scientific developments from this project will guide Baosteel's Mg products portfolio and position the company strongly as a global supplier of wrought and cast products to Mg component manufacturers. Enabling industry users to produce lightweight metal parts for energy-efficient transportation vehicles at a scale yet to be seen means this project has powerful potential to significantly transform the market.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Developed a new and efficient pre-treatment approach to gain homogenous surface chemistry of Mg alloys for subsequent coating growth.**

2. **Further optimised the pre-treatment approach for the Mg alloys invented by Baosteel, such as Mg-Ca-Al, Mg-Ca-Zn and Mg-Al-Zn, to meet the requirements for scale-up implementation.**

3. **Designed a new and simple steam coating technique which can significantly reduce the corrosion rate of Mg alloys, including RE-containing.**

HIGHLY FORMABLE MAGNESIUM SHEET BA11003 ARC LP120200741

Designing a strong, lightweight magnesium sheet with traditional stiffness, corrosion-resistance and environmental efficiency attributes

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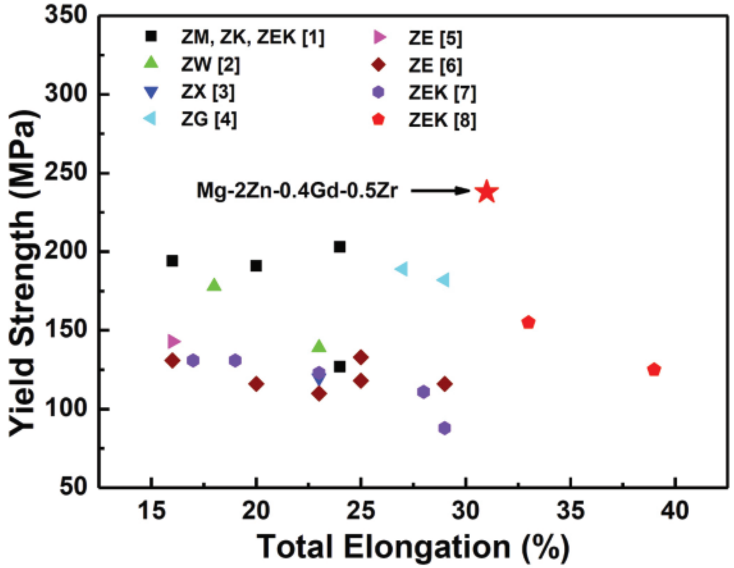
This project also receives leverage funding from an ARC Linkage Grant.

OBJECTIVES

Lightweight magnesium sheet has attracted considerable interest from industries that manufacture automotive vehicles, light-rail and high-speed trains, and the ‘3C’ (computer, communication and consumer electronics). One reason for their popularity is that magnesium alloys have various environmentally friendly attributes: for example, they can be readily machined with approximately half the power required to machine aluminium and its alloys; and lightweight parts in automotive vehicles can improve fuel efficiency and reduce greenhouse gas emissions.

Another reason is that they have the highest specific stiffness and strength of all structural alloys. However, one of the technical problems restricting wider applications for magnesium sheet is its low formability because of the strong texture of magnesium grains in the sheet. The researchers are working on a cost-effective magnesium alloy with superior formability and thermo-mechanical processing parameters, to fabricate stronger, highly formable and corrosion-resistant sheet at near room temperatures with satisfactory environmental performance and coatability.



Tensile properties of highly formable Mg alloy sheet.

POTENTIAL IMPACT

The global market for magnesium products will expand significantly when more magnesium alloy, processing and manufacturing technologies become available. Increasingly large-scale use of magnesium products will trigger international demand for the magnesium metal, which in turn will lead to a substantial boost to the export of Australian magnesite.

Meanwhile, the development of highly formable, lightweight magnesium sheet is strategically and commercially important to Baosteel’s expansion in current automotive, rail transport, cycling, and computer-related markets. Establishing a business to commercialise value-added magnesium products for these applications would generate considerable revenue for Baosteel each year.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Developed a highly formable magnesium alloy that is far better than commercial magnesium sheet alloy and comparable with commercial aluminium sheet alloy.**
2. **Found that the rollability of magnesium alloy sheet is remarkably improved by high speed rolling and therefore that large reduction per pass is achievable.**
3. **Designed a low-cost thermomechanical process for fabricating a high performance magnesium alloy sheet with extraordinarily well-balanced mechanical properties in terms of strength and ductility.**

ECONOMIC TITANIUM FABRICATION BA11014 ARC LP130100913

A fast, eco-friendly approach to fabricating low-cost, high-performance titanium components

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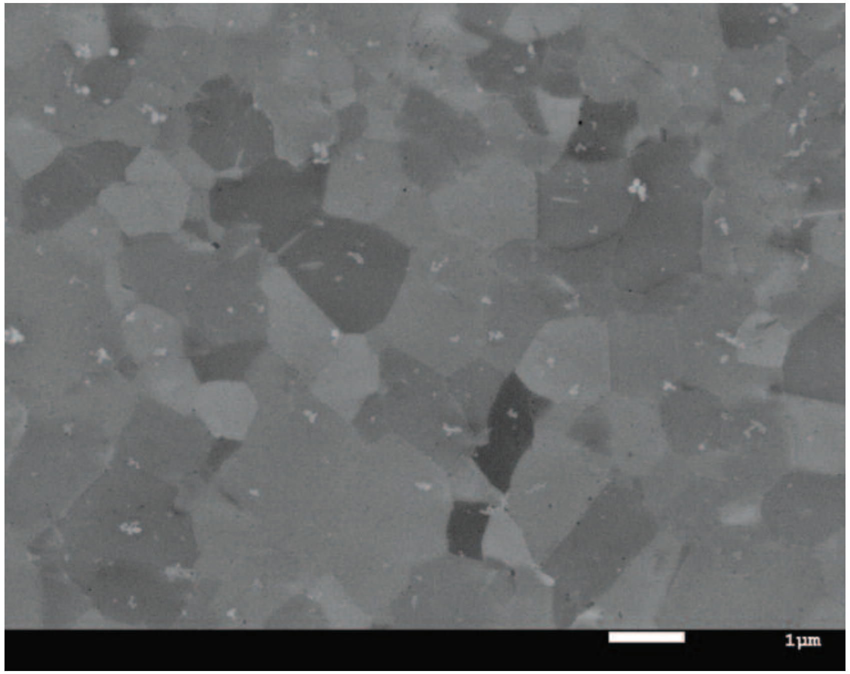
This project also receives leverage funding from an ARC Linkage Grant.

OBJECTIVES

While titanium and its alloys possess an outstanding array of properties that are not readily achievable with other materials, low manufacturing affordability and high wastage means their applications have been limited to a few industries on a small scale. The high cost of a titanium product arises from the metal as well as the manufacturing process. Historically, titanium components are machined from wrought stock, with as much as 90 percent of the stock material being scrapped. Titanium is difficult to machine and not easy to recycle by remelting because, when molten, it reacts with most materials which might serve as melting crucibles and also with most gas atmospheres.

This project is working towards a fast, eco-friendly method for fabricating low-cost, high-performance titanium components on a bigger scale using inexpensive titanium hydride (TiH_2) ceramic powder rather than titanium metal powder. One advantage of TiH_2 ceramic powder advantage over titanium metal powder is its potent responsive nature to pure microwave radiation for rapid and consistent heating to ≥1300°C for pressure-less sintering. It is also cheaper and delivers much denser microstructures with lower oxygen contents.



As-sintered ultrafine grained Ti-6Al-4V with nanometric ceramic additives.

POTENTIAL IMPACT

With this economical approach to fabricating high performance titanium alloys and their components directly from less expensive TiH_2 powder, Baosteel can broaden its titanium portfolio and attract interest from many more applications, primarily in automotive and aerospace industries. The new fabrication techniques will also be more environmentally friendly due to less stock waste and hazardous gas reactions.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Developed novel strong and ductile powder metallurgy titanium metal matrix composites with more than double the tensile strength and tensile elongation still greater than 15%.**
2. **Submitted a patent application for review.**
3. **Continued close collaboration with the Baosteel team to deliver research outcomes.**

ADVANCED TITANIUM MANUFACTURING BA11014-RPP

Enabling low cost fabrication of high performance titanium alloys from powder

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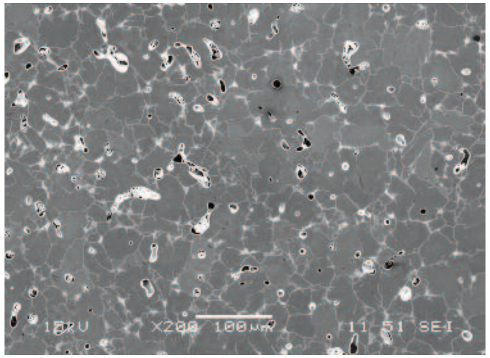

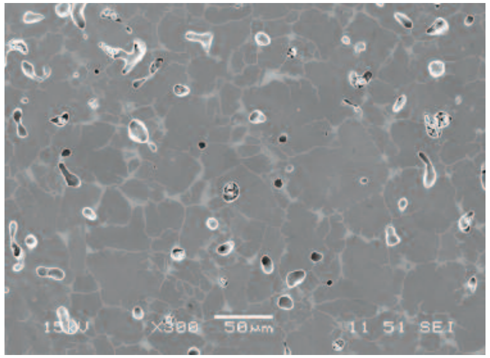

SEM Microstructure of Ti-6Al-4V alloy manufactured by Metal Injection Moulding with a high density of >96%.

OBJECTIVES

Baosteel has unrivalled access to inexpensive titanium powder in China, the world's largest titanium sponge producer (50 percent world production capacity). The mechanical properties of titanium products fabricated from powder, especially their ductility, show substantial variations, depending on the oxygen content of the powder used. When the oxygen content is low, fine titanium powder can produce excellent properties. However, the inability to mitigate the effect of oxygen has been a major obstacle to advancing titanium powder metallurgy (PM).

With an atomic scale understanding of titanium characteristics, this project is using inexpensive titanium powders to develop low-cost, medium-to-high strength PM titanium alloys and their fabrication processes. These key technologies will enable the manufacture of affordable, high performance titanium alloy products with metal injection moulding - an advanced manufacturing process that combines the geometrical complexity of plastic parts with the outstanding properties of titanium alloys.

POTENTIAL IMPACT

Commercially, this research will provide the basis for a new smart titanium manufacturing business for Queensland and project participants Baosteel and Partec. With patentable technologies to manufacture low-cost, high performance powder metallurgy titanium products, this venture will attract customers in aerospace, marine, defence, chemical processing and mining industries; as well as attract other hi-tech titanium businesses to operate and develop from Queensland.

Scientifically, a new fundamental, atomic scale basis will be formed for understanding and controlling the effect of oxygen on the mechanical properties of PM titanium products. The practical solutions developed to mitigate the detrimental effect of oxygen will resolve a critical issue and significantly advance the technical capabilities of PM titanium.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Identified all necessary parameters required for successful Metal Injection Moulding (MIM) of titanium and titanium alloys using inexpensive hydride-dehydride powders.**

2. **Shared the necessary materials and experimental setup with the project industrial collaborator (AMS Australia), which will be used to manufacture the first industrial part.**

3. **Identified two components for MIM trials, based on discussions with Baosteel.**

NEW Ti ALLOYS FOR THE AEROSPACE INDUSTRY BA14011

Implementing a numerical modelling capability for achieving aerospace quality in Ti alloy forging

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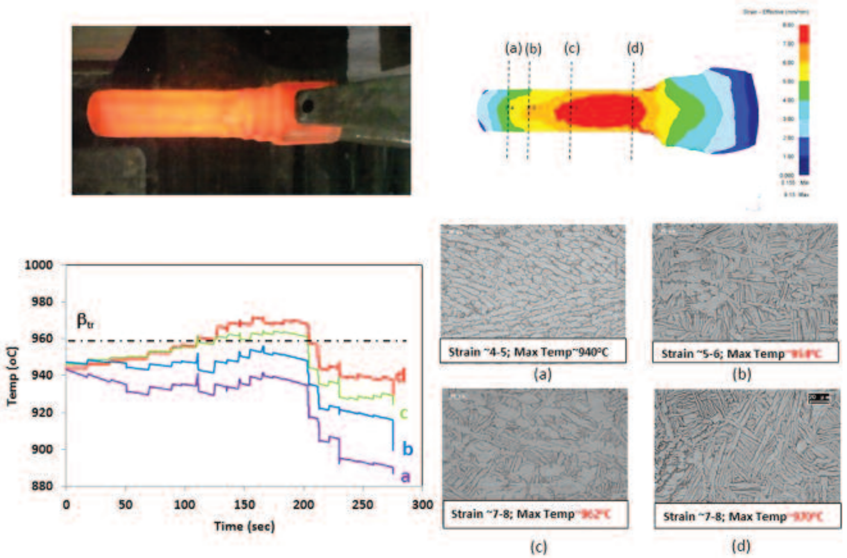
OBJECTIVES

A titanium alloy billet of quality has a homogeneous globularised microstructure throughout, leading to uniform mechanical properties being achieved repeatedly. If the commercial benefits of the novel billets are to be realised, the shop-floor production has to adapt with new knowledge about optimised titanium forging and upscaling.

The researchers are working with Baosteel to establish the relationship between accumulated strain profiles and microstructure at the industrial scale. They are simulating forging titanium alloys in an industrial operation environment similar to actual production conditions. This includes investigating the rotation sequence effect on strain and temperature homogeneity, especially in the radial direction of the billet, and designing a new pass schedule.



FEM simulation of forging Ti-6Al-4V billet on the shop-floor and the strain as well as temperature analysis obtained. Microstructures were analysed and correlated to the strain and temperature results.

POTENTIAL IMPACT

Using the established modelling tool and microstructure data base will allow Baosteel to combine current experience with new information in designing improved material processing. The resulting high-quality Ti-64 alloys will meet the standards of international aerospace clients and be cheaper to produce. The new pass schedule can be integrated immediately into Baosteel's production system, with the reduced processing steps potentially saving RMB$150,000 per year (based on 100T of Ti64 forging for every reduction of one forging reheat sequence). With this new capability, Baosteel can produce aerospace quality billet to customers' specifications, which will enhance its key position in the domestic and international aerospace materials market.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Installed and tested a data acquisition system on the forging testing platform system set-up at Shanghai Jiaotong University (SHJT) to provide easy future access for Baosteel engineers.**
2. **Established that strain path affects the globularisation and lamellae break-up of the billet and identified the critical strain for globularization to occur.**
3. **Designed and validated on the Baosteel shop-floor a new processing schedule that reduced the reheat sequence while obtaining a high quality billet having globularized microstructure.**

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.

OPTIMISED ANODE MATERIALS FOR LARGE Li BATTERIES BA14006

Designing and constructing unique nano-architectures for Si-based anodes for superior electrochemical performance

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OBJECTIVES

Innovative and sustainable solutions for large-scale storage of renewable power sources, electric vehicles, and hybrid electric vehicles are increasingly in demand, with high-capacity silicon anode (4200 mAh g^{-1} based on $Si_{4.4}Li$) triggering the most extensive research. Si, however, suffers from great challenges, such as unstable solid electrolyte interphase film and significant volume variation, which lead to rapid capacity fading and electrode failure during repeated lithiation and delithiation processes.

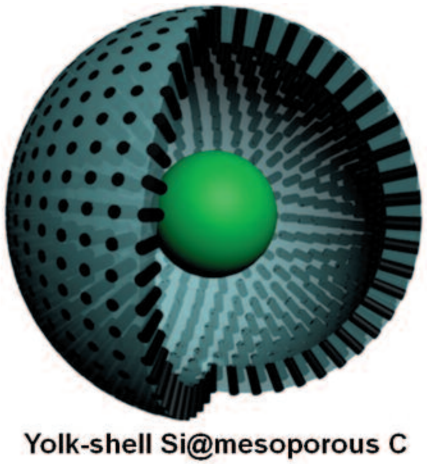

Fig. 1: The void space between yolk and shell provides enough room for Si expansion.

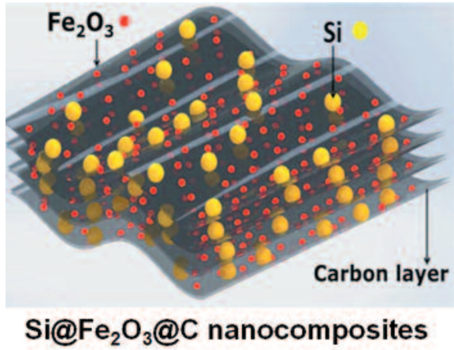

Fig. 2: Sandwiched Si nanoparticles between Fe_2O_3-embedded porous carbon sheets enhance overall electronic conductivity.

Configuring various nanostructures to overcome these limitations is critical for improving the electrochemical performance of Si-based anodes.

Developing alternative Si-based anode materials with high-energy capacity, high-rate capability, reduced cost, and long-cycle life for lithium-ion batteries (LIBs) is the focus of this research project.

POTENTIAL IMPACT

The scientific, technological, economic, and social benefits to Baosteel and Australia are considerable. Producing anode materials with optimised composition and architecture, and designing the technology for fabricating safer, high performance anode materials on a large scale, will create new business opportunities and position Baosteel and Australia at the forefront of an emerging energy storage market.

HIGHLIGHTS AND ACHIEVEMENTS

1. Engineered unique void-containing mesoporous carbon-encapsulated commercial silicon nanoparticles (NPs) in yolk-shell structures, with the void providing sufficient room for Si expansion and the porosity of the carbon shell enabling fast transport of Li^+ ions between electrolyte and silicon.

2. Revealed for the first time, via ex-situ characterisation, that a favourable homogeneous and compact solid electrolyte interphase (SEI) film formed along the mesoporous carbon shells exhibits long cycling stability and superior rate-capability.

3. Developed a facile one-step method for constructing $Si@Fe_2O_3@C$ nanocomposites with unique characteristics that facilitate the collection and transport of electrons, resulting in high capacity and good cycling stability.

SAFER, STABLE, POWERFUL Li-S BATTERIES BA14017

Overcoming technical obstacles to produce better anode materials for rechargeable batteries

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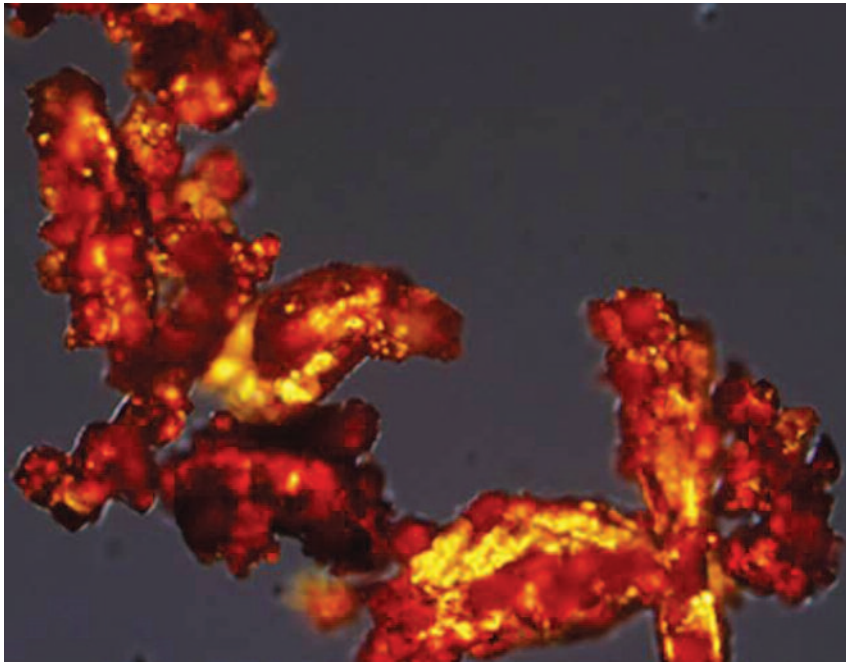
OBJECTIVES

Lithium sulphur (Li-S) batteries are widely believed to offer the most potential as a source of rechargeable power for electric vehicles EVs, but a number of technological obstacles need to be resolved before Li-S batteries can safely and reliably power them. The insulating nature of sulphur means a conducting support is required for it to be used as an electrode. The solubility of polysulfide intermediates formed during the charge/discharge process in the electrolyte causes instability (the so-called "polysulfide shuttle"). Lithium is highly moisture-sensitive, so a metallic lithium anode may not be safe. The formation of dendrites that can occur with a lithium metal anode could lead to short circuits and cell failure.

This project is designing a novel lithium anode material. Replacing the Li metal anode with a composite anode composed of Li nanoparticles encapsulated in carbon materials should overcome the problems of stability, safety, and dendrite formation. The research will go beyond the materials science to fabricate materials for the anode, and demonstrate a prototype battery that will have far greater capacity than the best lithium ion technology available today.



Sulphur crystal in a Li-S cathode.

POTENTIAL IMPACT

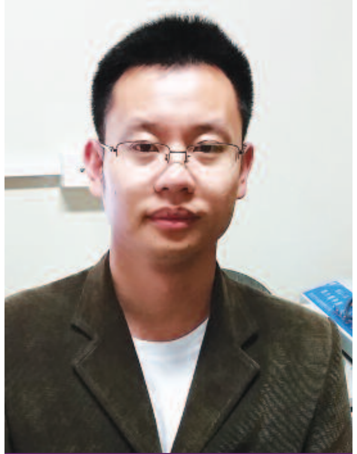
The patentable carbon-coated lithium anode fabrication technique will give Baosteel a competitive edge in the new energy materials market. The stability problems and dendrite formation will be largely alleviated. New room temperature techniques will cut the manufacturing cost. The air-tolerant Li-rich anode materials will allow pouch cell production to be directly performed in a dry room, rather than an Ar-filled glove box, significantly increasing productivity and reducing costs. The full potential of Li-S batteries to power EVs can be exploited as the new Li-metal based anode materials will reduce the likelihood of serious hazards associated with un-protected metals.

HIGHLIGHTS AND ACHIEVEMENTS

1. Achieved a key goal: higher sulphur utilisation using a polymerisation facilitator.
2. Developed a new recipe to modify polyacrylonitrile, to maximise the sulphur content of the cathode.
3. Confirmed that the cathode capacity is now close to 500 mAh/g, measured according to the whole weight of the cathode material.

NOVEL NANOCRYSTALLINE ALLOYS FOR ELECTRIC MOTORS BA12053

Engineering Fe-based nanocrystalline alloys with low coercive force and high saturation magnetic flux density



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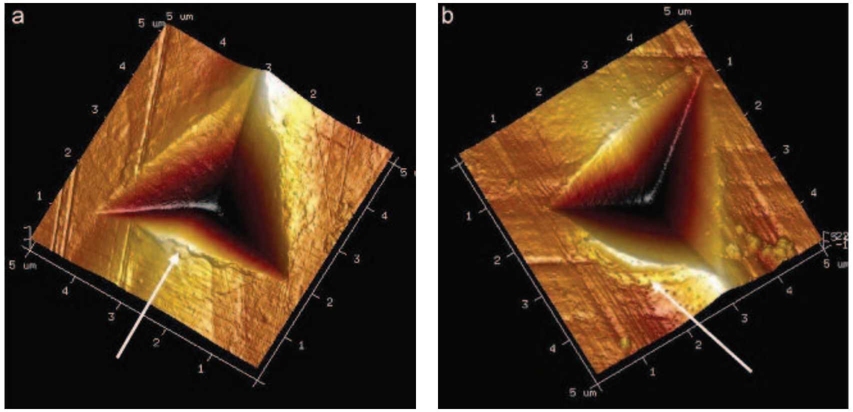
OBJECTIVES

Electric motors are widely used every day, everywhere, to convert electricity to mechanical power for manufacturing, transportation, tools, home appliances, etc. Their energy conversion efficiency is determined by their intrinsic material properties: saturation magnetic flux density (Bs), coercive force (Hc) and electrical conductivity (σ). Silicon steels (Fe-Si) are widely used as magnetic cores in various electrical devices because of their high saturation magnetic flux density. However, magnetised rotation leads to high core loss, a major cause of energy waste in rewound motors accounting for more than 25 percent of motor inefficiency. Significant energy savings could be achieved if existing Fe-Si-based magnetic cores were replaced with novel soft magnetic materials such as iron-based nanocrystalline/amorphous heterostructural alloys. This energy efficiency would translate into fewer greenhouse emissions.



Three-dimensional images of an indented surface (70 mN load) corresponding to the (a) sample 1 annealed at 500 °C for 5 minutes, and (b) sample 3 annealed at 460 °C for 5 minutes.

This project focuses on the experimental and theoretical development of advanced iron-based nanocrystalline alloys with optimised soft magnetic properties, which can be used to manufacture high-performance, energy-efficient, next-generation electrical motors, generators and transformers.
The researchers are employing a novel concept of specific element-doped nanocrystalline /amorphous heterostructures to produce Fe-based nanocrystalline alloys with saturation magnetic flux density.

POTENTIAL IMPACT

Advanced Fe-based nanocrystalline alloys with low energy loss and high permeability have enormous potential to replace the Fe-Si now used in electric motors. Baosteel is the world's largest Si-steel manufacturer, so the push for more energy efficient motors will have a significant impact on this aspect of the company's portfolio. Over 720 million electric vehicles are expected to be running worldwide by 2030, so the innovative control and reliability attributes this research is developing will help Baosteel safeguard and expand its share of the global electric motor market with new products.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Carried out two types of heat treatment on amorphous ribbons under Argon protective atmosphere: (i) annealing at peak temperature of the first crystallisation, and (ii) stress-relaxation treatment at glass transition temperature (T_g).**

2. **Revealed that heat treatment temperature varies with chemical composition.**

3. **Showed that B_s value increases upon crystallisation but this drastically deteriorates the ductility of the ribbon; however, stress-relaxation treatment at T_g can improve the soft magnetic behaviour without affecting the ductility considerably.**

HARVESTING WASTE ENERGY WITH THERMOELECTRIC POWER BA11011 ARC LP120200289

Improving waste heat recovery in steelworks using advanced thermoelectric materials and generator technology

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This project also receives leverage funding from an ARC Linkage Grant.

OBJECTIVES

More than 60 percent energy produced is wasted in the form of heat. In the process of ironmaking and steelmaking, the amount of heat exhausted is substantial. Direct conversion of such huge amounts of waste heat into electricity would significantly decrease energy consumption. Thermoelectric materials enable heat to be transformed into electrical energy. Thermoelectric generators (TEG) have been used in space-based and other niche applications, but their potential value in steelmaking has not been explored until now.

This project is using advanced thermoelectrical (TE) technology to develop superior prototype TEGs. The researchers are investigating, developing and optimising bulk TE modules made from naturally abundant elements which are stable at high temperatures and have high comparative conversion efficiency. The experimental and theoretical data produced will help to design and manufacture an industrial scale TE device.

Chinese Science Bulletin cover showing the thermoelectric module for waste heat recovery (Volume 59 12th edition 2014).

POTENTIAL IMPACT

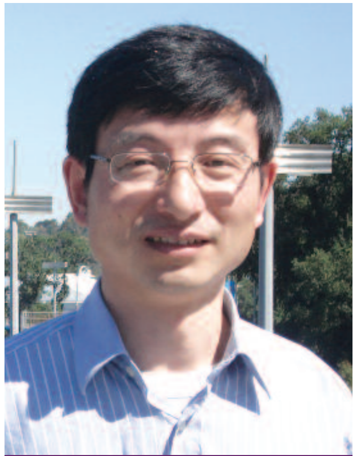
The recovery of even a small fraction of waste heat would significantly impact global energy consumption. This large research effort will broaden the fundamental knowledge of TE power and lead to innovative and environmentally sustainable steelmaking. Novel thermoelectric materials will be developed and manufactured. New architectures will be designed for thermoelectric modules with higher thermoelectric conversion efficiencies. Importantly, using TE power modules and generators to harvest waste energy will reduce Baosteel's carbon footprint and energy costs. Plus, Baosteel's uptake of this technology will set an exemplary model for all industries in energy efficiency and environment protection.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Developed high performance Cu_2Te nanostructures for application in solar cells, with the counter electrodes from Cu_2Te nanosheets showing the maximum power conversion efficiency of 5.35%.**
2. **Summarised several new strategies with the hope they can inspire further enhancement of performance both in metal chalcogenides and in other materials.**
3. **Prepared n-type and p-type PbTe powders for fabrication of thermoelectric modules.**

SMART POLYMER HYDROGELS FOR ENERGY EFFICIENCY BA13005 ARC LP140100051

Developing a hydrogel-driven forward osmosis process for simultaneous waste heat utilisation and waste water treatment



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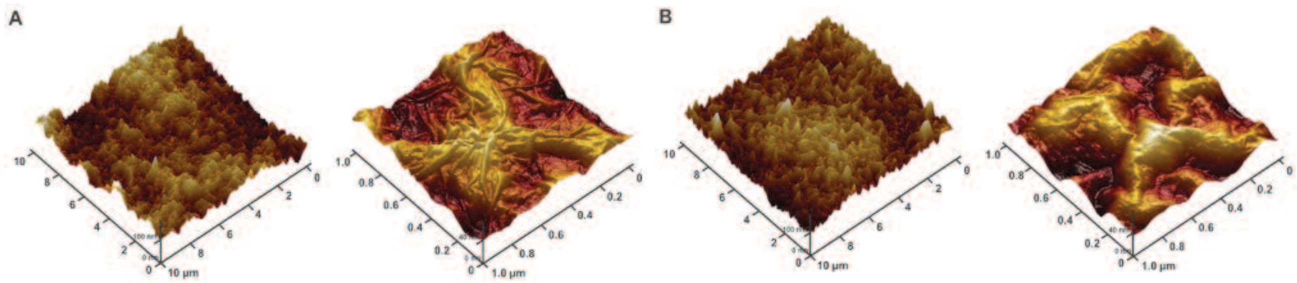
This project also receives leverage funding from an ARC Linkage Grant.



3D AFM images of (A) GO-polymer composite forward osmosis membrane and (B) layered GO membrane prepared by spin-coating.

OBJECTIVES

Energy consumption in the iron and steel industry accounts for 15-20 percent of total industrial energy use in China. Although the energy efficiency of steel manufacturing has been improved, a further 20 percent of energy in waste heat needs to be utilised to further reduce the carbon footprint. Steelmaking also uses around 3-4.2 cubic metres of freshwater per ton of steel, generating enormous amounts of wastewater that must be treated before it is recycled or discharged.

Membrane technologies have become popular in water purification and recycling, but the operating costs and other issues of existing reverse osmosis process combined with microfiltration or ultrafiltration, for example, have hindered their widespread commercial use in the steel industry. Modelling has shown that forward osmosis (FO) technology could offer comparative energy savings ranging from 72 – 85 percent, and also cause much less membrane fouling in the water treatment processes; however, a high-performance draw agent (solute) needs to be developed to make it a reality.

In this project, dual-functionality, temperature-responsive polymer hydrogels are being developed as draw agents for a continuous FO wastewater treatment process, using low and medium temperature waste heat as a green energy input. For the first time, strategically-designed, fast swelling/fast de-swelling bi-functional polymer hydrogels are being tested to separate pure water from wastewater through a selective membrane. After contaminants are rejected, the pure water is recovered from the swollen hydrogel using waste heat as a temperature stimulus.

POTENTIAL IMPACT

The outcomes of this research will deliver significant economic and environmental benefits for Baosteel and the steel industry: reduced wastewater treatment costs, decreased fresh water consumption, and effective utilisation of waste heat generated in the steel manufacturing process. Opportunities may also be exploited for Baosteel to expand into the rapidly emerging and energy-efficient FO technology market, which is responding to the demand from other high industrial users of both wastewater and desalination treatments.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Investigated the fouling behaviour of commercial forward osmosis membrane in the treatment of simulated steel mill wastewater.**

2. **Developed a patentable forward osmosis membrane by forming a highly crosslinked polymer-graphene oxide thin composite layer on a porous polymer support, showing 3.7x higher water flux and 5.3x lower reverse salt flux than the commercial membrane.**

3. **Modified the swelling property of hydrogel with hydro-phobic, elastic polyester microfibers and compression force in an ionic hydrogel, producing 2x water flux compared to the pure hydrogel.**

LOW COST SOLAR ON STEEL FOR ENERGY EFFICIENT BUILDINGS BA13051 ARC LP150100911

Exploiting the eco-friendly properties of CZTS thin film solar cells to make cost-effective stainless steel for BIPV applications

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Dr Hongyun Bi (Baosteel)

This project also receives leverage funding from an ARC Linkage Grant.

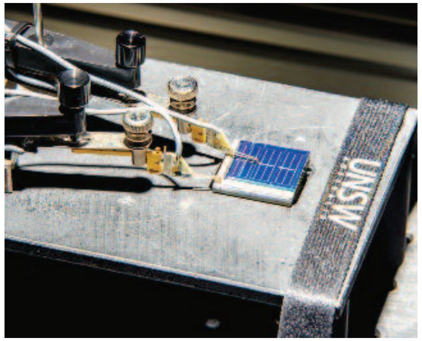

Fig. 1: The CZTS solar cell device performance (energy conversion efficiency) measurement.

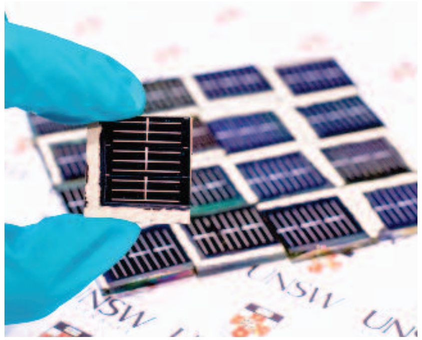

Fig. 2: The completed CZTS solar cell device fabricated at UNSW.

OBJECTIVES

The market for Building Integrated Photovoltaics (BIPV) is growing fast and exponentially with the demand for more energy-efficient construction components, such as rooves and facades that integrate photovoltaic power generation into sunlight-exposed stainless steels. Current solar cells for this purpose, such as $Cu(In,Ga)Se_2$ (CIGS), are highly efficient but use toxic and rare raw materials, which limit their sustainability prospects. Presently, the cost of Indium accounts for around five percent of the total cost of CIGS solar cell modules. Indium costs would be pushing very high with the significantly increasing demand alongside its increased consumption in LED lighting and LCD flat panels market. The high cost per kilowatt-hour of CIGS would limit its wide deployment in the photovoltaics market. The earth-abundant and eco-friendly Cu_2ZnSnS_4 (CZTS) solar cell, however, provides an alternative to CIGS and shows promise as the ideal candidate for BIPV applications, especially with its lower cost (minimum material and energy input per watt output) and large-scale integrated manufacturability.

The researchers are working with Baosteel to exploit the technologies of CZTS solar cells on Baosteel rigid/flexible stainless steel for BIPV applications. They are developing technologies compatible with existing commercial equipment options for high-volume production as well as strategies for integrating the systems into buildings. The measurable target is to increase the CZTS cell efficiency to beyond 10 percent and ultimately approach 20 percent at lower cost. Efforts to achieve these targets include an integrated and synergistic combination of materials growth and advanced characterisation, growth kinetics modelling, and device fabrication and characterisation.

POTENTIAL IMPACT

Developing high performance CZTS semiconductor solar cells on top of both rigid and flexible Baosteel stainless steel will accelerate high performance BIPV technology for steel construction materials towards commercialization. As a major supplier of steel roofing materials, combining its steel technology with the most promising non-toxic and earth-abundant thin film solar cell technologies will place Baosteel in a strong position to access a significant share of the BIPV market and make Baosteel stainless steel specialty products more competitive.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Developed a reproducible baseline device configuration of "stainless steel/Ti & Mo combined back contact/CZTS/buffer layer/window layer (ZnO & ITO)/Al front contact".**

2. **Devised effective sodium doping strategies for CZTS solar cells on stainless steel, including sodium source, the effect of NaF position, effect of K and role difference of Li and Na and K.**

3. **Tested low carbon steel sheets as the substrate for CZTS solar cells, identifying surface roughness of enamelled steel as the major factor limiting device performance.**

GRAPHENE WITH HIGH CAPACITY AND STABILITY FOR ULTRA-FAST ENERGY STORAGE BA11006

Scalable production of graphene-based bulk nanomaterials for advanced energy storage

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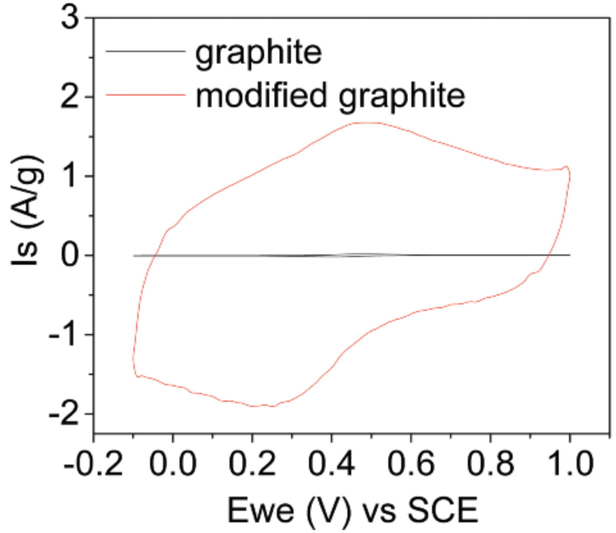
OBJECTIVES

The intermittent 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 meeting continuous energy demands. Chemical energy storage devices (batteries) and supercapacitors are increasingly preferred for this purpose. Graphene, with its extraordinary electrical, thermal and mechanical properties as well as high specific surface area and remarkable chemical stability, has been targeted to supersede traditional electrodes in energy storage/conversion systems and high performance nanocomposites.

This project is addressing the industrial challenges inherent in the cost effective and scalable production of graphene, and its bulk assembly for use in high performance energy storage devices. Key technical objectives include exfoliating graphite into corrugated graphene sheets; processing exfoliated graphene into thin films; and assembling graphene thin films into new-generation energy storage devices.



Cyclic voltammetry plots of graphite and modified graphite measured in 1.0 M H_2SO_4.

POTENTIAL IMPACT

Like plastics and steel, graphene is emerging as a new category of commodity-type material for both structural and functional applications. With advanced, patentable technologies for cost-effectively transforming an ordinary mineral into a new class of functional materials, Baosteel can open up a new portfolio of high value-added products in the rapidly growing market for energy-related materials.

Exploiting the use of these materials will produce a new generation of supercapacitors that combine a long life-time, high energy and power density; and 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.

A deep understanding will also be gained about the behaviour of graphene platelets which, when able to be controlled, hold promise for more applications in the future.

HIGHLIGHTS AND ACHIEVEMENTS

1. **Confirmed that electrochemically prepared graphite oxide can be reduced electrochemically.**
2. **Demonstrated that the ion-accessible surface area of electrochemically prepared graphene can be significantly improved though a novel electrochemical treatment.**
3. **Determined that electrochemically modified graphite (graphene) is conductive and structurally stable, and hence shows promise for supercapacitor applications.**

PUBLICATIONS AND PATENTS

Since 2011, the Centre's research teams have published and presented 129 journal papers, three book chapters, 117 conference papers, and filed 15 patents. The following pages list this year's publications and a full list of patents.

JOURNAL PAPERS

Bian, M. Z., et al.(2016). "Improved Formability of Mg-Ca-Zr Sheet by Microalloying of Zn." *Advanced Engineering Materials*: in press.

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Cui, Y., et al.(2015). "Phase Equilibria of Fluoride-Free Boracic Mould Flux for Steel Continuous Casting." *Steel Research International*, **86** (6): 662-669.

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Hao, L., et al.(2015). "Effect of extreme pressure additives on the deformation behavior of oxide scale during the hot rolling of ferritic stainless steel strips." *Tribology Transactions*, **58** (5): 947-954.

Hao, L., et al.(2016). "Experimental and Numerical Study on the Effect of ZDDP Films on Sticking During Hot Rolling of Ferritic Stainless Steel Strip." *Metallurgical and Materials Transactions A*, **47** (10): 5195-5202.

Hao, L., et al.(2015). "Effect of extreme pressure agents on the anti-scratch behaviour of high-speed steel material." *Tribology International*, **81**: 19-28.

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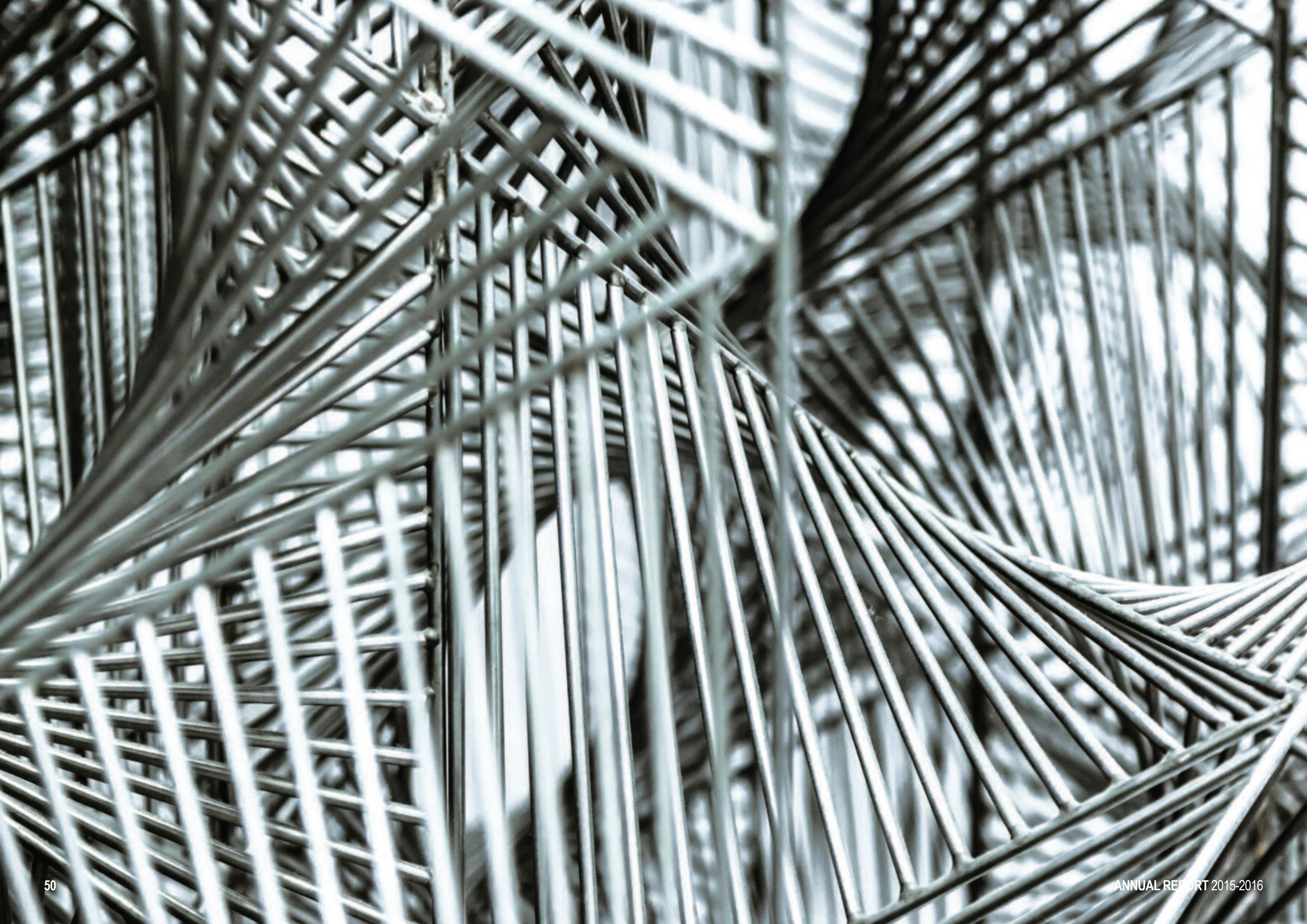


FINANCIAL AND GOVERNANCE

FINANCIAL SUMMARY

Financial Statement for the period from 01 July 2015 to 30 June 2016

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 01-07-2015
$2,959,571.93

INCOME (CASH)

Grant and Collaborative Research	
Baosteel R & D Fund (Round 5 - Year 1)	$950,000.00
Baosteel R & D Fund (Round 4 - Year 2)	$700,000.00
Baosteel R & D Fund (Round 3 - Year 3)	$650,000.00
Baosteel - management support	$250,000.00
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	**$2,800,000.00**
Total Leveraged ARC-Linkage Grant	$719,417.00
Total Leveraged CRC Grant	$80,000.00
Total Leveraged Queensland RPP Grant	$161,605.00
TOTAL INCOME (EXCLUDING IN-KIND)	**$3,761,022.00**

EXPENDITURES

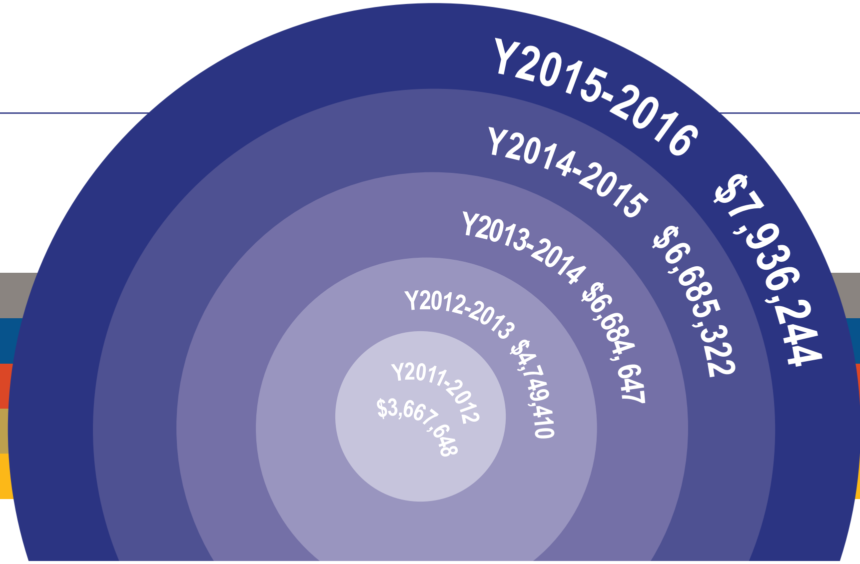
Grant and Collaborative Research	
Payment in cash to collaborative approved projects	$2,657,672.00
Allocated ARC Linkage Grant	$719,417.00
Allocated CRC Grant	$80,000.00
Allocated Queensland RPP Grant	$161,605.00
Total Grant and Collaborative Research Expenditures	**$3,618,694.00**
Baosteel Centre – Management	
Personnel - Salaries	$344,690.45
Staff Develop & Health Cost	$236.64
General Operating (consumables, stationery, telecommunications)	$11,334.69
Services (professional consultancy)	$119,054.04
Office Equipment	$6,834.36
Travel and Hospitality [1]	$36,051.95
Hospitality	$22,694.02
Other Expenses	$10,691.83
Total Centre Management Expenditures	**$551,587.98**
TOTAL EXPENDITURES (INCLUDING GRANT & RESEARCH FUND ALLOCATION)	**$4,170,281.98**
Operating Result Cash Balance as at 30 June 2015	**$2,550,311.95**

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

BAOSTEEL-AUSTRALIA
JOINT RESEARCH AND DEVELOPMENT CENTRE

Partnership In-Kind for Research Projects (based on Project Scopes)

	Y2011-2012	Y2012-2013	Y2013-2014	Y2014-2015	Y2015-2016	Fund Distribution
Baosteel	$75,000	$1,020,267	$1,132,171	$1,593,105	$2,048,861	$5,869,404
MU	$965,112	$972,293	$1,398,361	$1,369,024	$1,378,601	$6,083,391
UNSW	$1,053,928	$767,828	$1,392,810	$1,060,057	$1,348,479	$5,623,102
UQ	$1,192,320	$1,368,430	$1,708,070	$1,803,071	$2,334,528	$8,406,419
UOW	$381,288	$620,592	$1,053,235	$860,065	$825,777	$3,740,957
Total	$3,667,648	$4,749,410	$6,684,647	$6,685,322	$7,936,244	$29,723,271



TOTAL	$3,722	$3,244	$3,633	$2,731
ROUND 5	$100	$30	$100	–
ROUND 4	$550	$325	$375	$650
ROUND 3	$400	$500	$950	$250
ROUND 2	$870	$1,000	$1,180	$700
ROUND 1	$1,802	$1,389	$1,028	$1,131

Year-to-Date Baosteel Funding Distribution ($K) by Round

	ARC-Linkage					CRC	QLD Smart Grant
	Round 1	Round 2	Round 3	Round 4	Total		
MU	$450		$450		$900	$750	
UNSW	$570	$250	$290	$550	$1,660		
UQ	$870		$377		$1,247		$500
UOW	$400				$400	$500	
TOTAL	$2,290	$250	$1,117	$550	$4,207	$1,250	$500

Leveraged Grants ($K) by University

BAOSTEEL | MONASH University | UNSW AUSTRALIA | THE UNIVERSITY OF QUEENSLAND AUSTRALIA | UNIVERSITY OF WOLLONGONG

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 Jian Yang
Senior Engineer, Baosteel Research Institute (R&D Center)
Baoshan Iron and Steel Co. Ltd

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

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

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

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

Professor Freider Seible
Dean, Faculty of Engineering
Monash University

TECHNICAL ADVISORY COMMITTEE

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

Professor Nick Birbilis
Monash University

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 and Finance Officer
Ms Cathy Yuan, The University of Queensland

Baosteel Coordinator Research Engineer
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
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BAOSTEEL-AUSTRALIA
JOINT RESEARCH AND DEVELOPMENT CENTRE

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