ANNUAL REPORT 2014-2015

BAOSTEEL-AUSTRALIA
JOINT RESEARCH AND DEVELOPMENT CENTRE

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

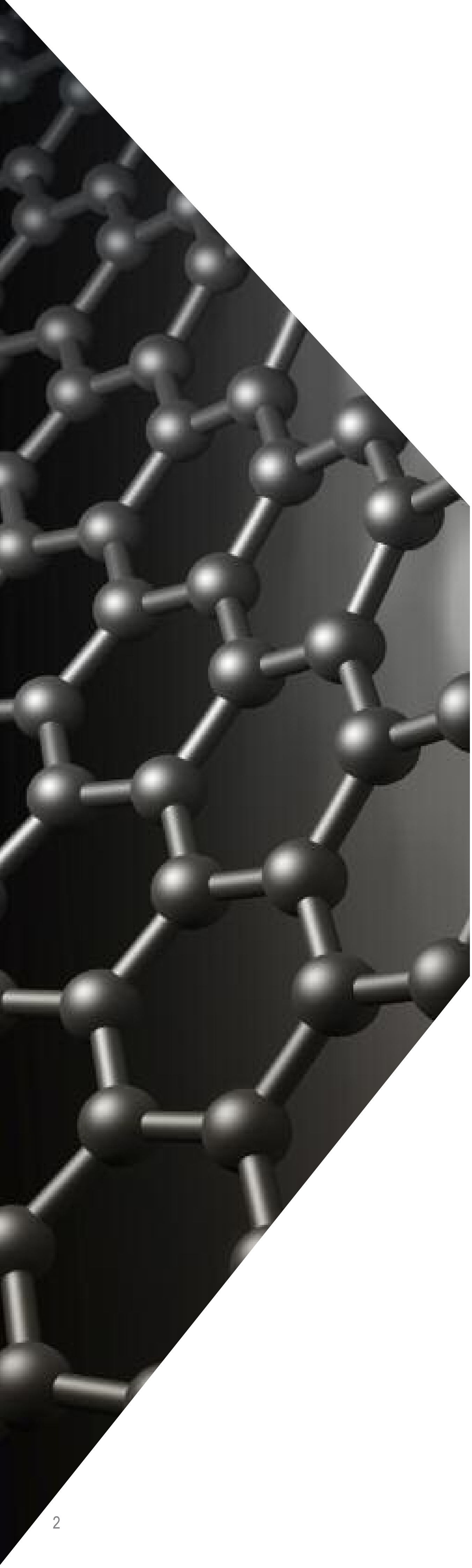
KEY CAPABILITIES

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

- **Engaged over 100 eminent researchers based in Australia and China**
- **Supported 36 innovative research projects**
- **Disbursed a total of A$13.1 million in project funding**
- **Attracted A$21.7 million in-kind partnership contributions**
- **Leveraged A$6.2 million in ARC Linkage and CRC grants**
- **Published and presented more than 150 academic papers**
- **Filed 7 patents**
- **Hosted 3 annual conferences**

Through its partners the Centre has access to 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 & VISION

Established in 2011, the Baosteel-Australia Joint Research and Development Centre (BAJC) is a world-first joint venture between Baosteel - one of the world's largest steel companies, based in China - and four research-intensive Australian universities: The University of Queensland, The University of New South Wales, Monash University and the University of Wollongong.

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

While functionally located within The University of Queensland's School of Chemical Engineering, the BAJC fosters collaboration between all participating research teams.

Harnessing and developing both the existing and the emerging talent within its participating institutes, the BAJC:

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

BOARD CHAIR'S MESSAGE

It gives me great pleasure to introduce this year's Baosteel-Australia Joint Research and Development Centre annual report.

When the Centre was established in 2011, we broke new ground: with one of the world's largest steel companies, we brought together Australia's leading research teams dedicated to developing innovative metal-based materials and the means to manufacture them in economically and environmentally sustainable ways.

Now in its fifth year, this enduring collaboration continues to explore and develop new knowledge and technologies of particular significance for Baosteel's longer term, strategic development and business activities.

Working directly with Baosteel has enabled our highly skilled research teams to focus on company-specific challenges and envisage how their efforts might transform the entire industry.

In turn, our researchers impart their discoveries and practical experience to their students, giving the future engineers and metallurgists graduating from our partner Australian universities a distinct advantage. The number of postgraduate students involved with the Centre's projects also bears testament to its contribution to learning as well as discovery.

The calibre and outcomes of the Centre's research have attracted wide international interest and highlighted the individual as well as the combined strengths of our university partners.

The leverage potential is substantial, as represented by the ARC Linkage grants awarded this year to Professor Han Huang at The University of Queensland for his novel nano-additive water-based lubrication technology; and to Monash University's Dr Yansong Shen, who is investigating the potential for low-cost ironmaking with brown coal. We congratulate both research leaders and their teams on this achievement.

The Centre's efforts to date prove that while individual research and industry institutions can make a difference, together that change can be stronger, come sooner, and reach much more widely across the globe.

Thank you for your interest in the Centre. I hope that from reading our 2015 annual report you will be impressed, as I am, with the solid ground that has been both covered and broken to advance materials science.

PROFESSOR G.Q. MAX LU
Board Chair

DIRECTOR'S REPORT

The Baosteel-Australia Joint Research and Development Centre has continued to produce exciting outcomes in terms of discoveries, publications, patents, and plans for commercialising intellectual assets. I am proud to present a summary of these outcomes in the 2015 report on the Centre's operations.

The Centre's cash commitments for research since projects started in 2012 totals $19 million, plus we have received an additional $21 million of value as in-kind support. The majority of this report describes how these disbursements have translated into strategic research supporting Baosteel's business interests.

Projects are grouped by theme this year, to highlight areas of interest, particularly for readers less familiar with the Centre's research priorities and strengths: metallurgical processing, metal manufacturing, light metals and energy materials.

Our portfolio has grown by 38 percent and now includes 36 projects, and more pages have been dedicated to our ever-expanding publications output, making this the most substantial report we have produced to date.

Some of the new projects funded this year are led by researchers whose first projects commenced when the Centre was established in 2011 and have now been completed. We are pleased to have retained them for new work, some of which relates to their previous BAJC projects and builds continuity for our sponsor, Baosteel. This 'repeat business' also underlines how the Centre's framework is conducive to the researchers' interests and aspirations.

If you would like to know more about any of the projects summarised in this report, please contact the Centre or the chief investigators directly.

Our purpose is to create an internationally recognised Centre of excellence by harnessing and developing existing and emerging talent within our participating universities. Excellence can only be achieved when everyone shows deep commitment to common goals.

I would like to acknowledge the researchers' achievements and thank them for their hard work and collaborative spirit.

I also thank our small but effective management team for ensuring the Centre operates efficiently, and for soundly underpinning the joint venture's success.

PROFESSOR VICTOR RUDOLPH
Centre Director

PROJECT INDEX BY UNIVERSITY

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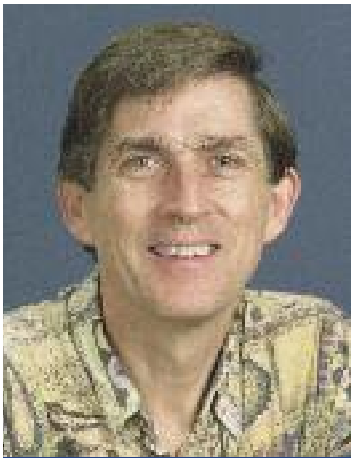
Total Projects	36				

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.

IRONMAKING ENERGY EFFICIENCIES

Improving energy efficiencies and reducing CO_2 emissions with innovative chemistries for ironmaking



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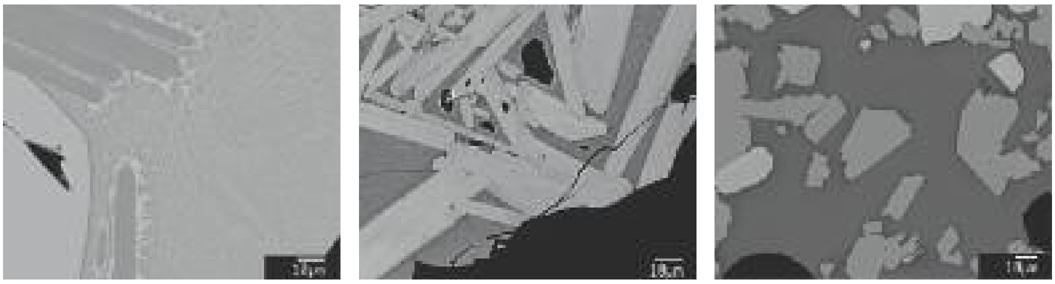
BA11012



Variations in sinter microstructures.

OBJECTIVES

The blast furnace is the principal technology used in ironmaking. Improving the quality of the iron ore sinter feed could lead to thermal and chemical efficiencies of the process. Microstructure is critical to sinter quality and highly sensitive to the chemical composition of the matrix material. With new fundamental information on the high temperature chemistry of iron ore sinters, novel ways could be developed to reduce CO_2 emissions and total energy consumption during the ironmaking process. The research team has developed new experimental techniques that provide this key data on the chemical phase equilibria in conditions encountered in sinter production, allowing sinter microstructures to be better understood.

POTENTIAL IMPACT

Sinter plant and blast furnace performance should be optimised when phase equilibrium information is applied to predict the crystal phases that form during the sintering process and the proportions of these phases. Identifying the ideal conditions for high quality iron oxide sinter will also reduce CO_2 emissions and maximise the energy/tonne of hot metal in the blast furnace ironmaking process.

Unlike the empirical approaches currently used to assess the relationships between material and process parameters, which are ore and process specific, this research is establishing the fundamental chemical processes that occur during the sintering process. This will reveal essential information to plug important gaps in the scientific knowledge base on these topics. The outcomes could also apply to a wide range of ore sources and process chemistries and temperatures.

HIGHLIGHTS AND ACHIEVEMENTS

- Continued experimental studies on characterising the phase equilibria and liquidus for the Fe_2O_3-SiO_2-CaO-Al_2O_3 system in air in the primary phase fields of the oxide solid solution SFCA, Fe_2O_3, $CaO.Fe_2O_3$, $CaO.2Fe_2O_3$.
- Determined the SFCA liquidus under CO_2 1atm pressure - the new data show clearly that the stability of SFCA phase increases with an increase of bulk Al_2O_3 content and decreases with a decrease of effective oxygen partial pressure.
- Showed that the phase assemblages and the microstructures observed in the Baosteel plant sinter can be reproduced in the laboratory under controlled temperature and gas conditions, clearly demonstrating the role of both phase equilibria and reaction kinetics in developing sinter structures; and building confidence in the method's ability to test and verify proposed reaction mechanisms.
- Developed a methodology to investigate the elementary reactions occurring between components of sinter (limestone, iron ore); the techniques allow the accurate control of the heating and cooling of the materials, thus reproducing conditions within the sinter during production.
- Identified the phases formed at specific reaction times and temperatures with the ability to rapidly cool the samples; the initial results indicate a very different reaction sequence to that reported in the literature and these reactions will be studied and analysed more closely in the remaining time available on this project.
- Visited the Baosteel Ironmaking Institute in Shanghai in 2014 to present the latest findings and discuss research plans and priorities for the coming year.

IRONMAKING PROCESS MODELLING AND ANALYSIS

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

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

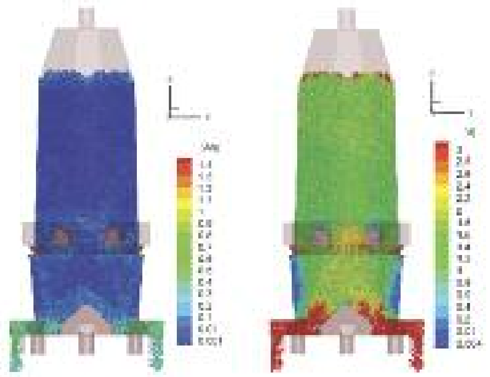
With validated computer models answering fundamental questions about blast furnace and COREX operations and quantifying the effects of a range of variables, Baosteel's ironmaking will experience extended life campaigns; better operational control; decreased fuel consumption; improved productivity; and reduced CO_2 emissions. Because of iron making'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

Blast furnace (BF) work:

- 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 optimise BF operations.



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

- Studied the effects of operational parameters on BF performance indicators, e.g. coke rate and coal combustion efficiency.
- Examined possibilities for 10 kg/tHM coke reduction based on current operational and material conditions.
- 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.
- Based on the experimental BF, studied the effects of shaft injection with respect to gas component, temperature, and injection position.

COREX research:

- Developed a DEM-based model to simulate solid flow in a screw feeding system.
- Conducted a parametric study to understand the effect of cohesive force and rotational speed of the screw feeder.
- Developed a combined CFD-DEM model to investigate the effect of gas flow in a reduction shaft.
- Studied the solid flow in the full-scaled reduction shaft to understand the effects of cohesive force and the rotational speed of screws in three geometry settings (simplified, with and without AGD).
- Formulated measures to reduce the effect of cohesive force on solid flow in the reduction shaft.
- Developed a combined CFD-DEM model for a melter gasifier to investigate gas-solid flow behaviour.
- Conducted a preliminary test of a thermo-chemical model.
- Generated preliminary results from incorporating a heat transfer model in the combined CFD-DEM model for Baosteel's reduction shaft and melter gasifier.

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

BA11009-ARC
PL120200469

OPTIMUM CONTROL OF RACEWAY OPERATIONS

Investigating multiphase flow and thermochemical behaviours in the lower part of blast furnace ironmaking to improve stability, decrease emissions, and reduce costs

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

BA114026-ARC PL150100112

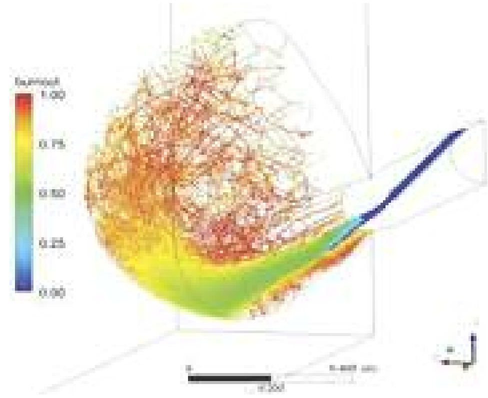
OBJECTIVES

Understanding the fundamentals governing multiphase flow and thermochemical behaviours in the lower part of blast furnace ironmaking, and identifying optimal control strategies for raceway operations, will lead to improved process stability, lower costs and fewer polluting emissions. This Monash University-based 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 blast furnace performance. The project is exploring practical scenarios to formulate and test optimum design and control strategies for Baosteel's blast furnace operations.

POTENTIAL IMPACT

To maintain a competitive blast furnace ironmaking cost position, Baosteel needs to reduce energy consumption and CO_2 emissions. 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 can reveal information that other types of modelling cannot adequately provide, such as in-situ measurements, experimental studies and even mathematical approaches supported by lab or plant experiments.

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 measureable economic benefits.



Refined PCI model describes mutliphase flow and thermochemical behaviours.

HIGHLIGHTS AND ACHIEVEMENTS

- Conducted a systematic literature review of PCI modelling and raceway modelling to formulate research components.
- Refined the existing PCI model with new features, to reliably describe the multiphase flow and thermochemical behaviours associated with PCI operations.
- Collected and analysed data from Baosteel's ironmaking plant to determine and test simulation conditions.
- Conducted parametric studies based on operational conditions of Baosteel blast furnaces, e.g., comparing coals under typical PCI conditions.

COST EFFICIENT SLAG SYSTEMS

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

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.

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.

Dr Xiaodong Ma (Postdoc Fellow) polishing samples for microscopy analyses.

HIGHLIGHTS AND ACHIEVEMENTS

- Determined the phase equilibria in the system MgO-Al_2O_3-(CaO+SiO_2) with CaO/SiO_2 = 1.3 (directly related to the bosh and final slags of BF) with over 100 experiments.
- Determined the phase equilibria in the system MgO-Al_2O_3-(CaO+SiO_2) with CaO/SiO_2 = 1.5 for bosh slags related to the Baosteel BF operations, finding that at high CaO/SiO_2 ratio, dicalcium silicate is much more stable and the liquidus temperatures are significantly higher.
- Commenced systematic studies of the phase equilibria in the system "FeO"-MgO-Al_2O_3-(CaO+SiO_2) with CaO/SiO_2 = 1.3 to characterise the primary and intermediate BF slags (over 400 experiments in equilibrium with metallic iron).
- Investigated the formation of primary slag in the cohesive zone of the BF using industrial iron sinter, pallet and lump.
- Conducted systematic studies, including phase equilibria, viscosity and sulphur partitioning, to assist in Baosteel plant trials to reduce MgO in BF slag.
- Analysed slags associated with tuyere coke.
- Experimentally determined equilibrium sulphide capacities for synthetic slags and compared the results with the kinetic sulphur partitioning results and industrial measurements.
- One paper has been accepted for publication in *ISIJ International*, with remarkable comments from reviewers.
- Two papers were accepted for the 6th Baosteel biennial academic conference.

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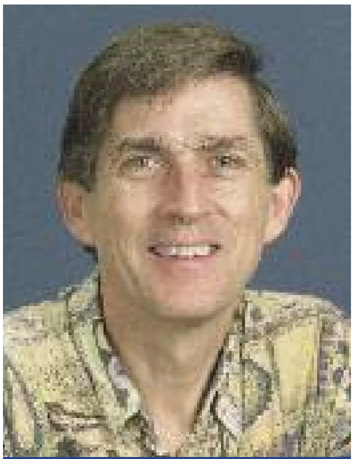
BA12002

IRON SINTER OPTIMISATION

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



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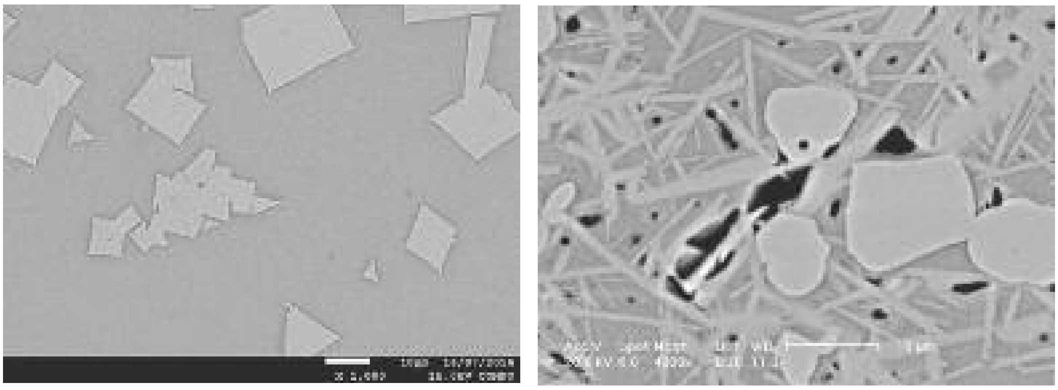


Examples of different sinter microstructures produced in the laboratory using standard chemical reagents controlling sinter chemistry, peak bed temperature, atmosphere and cooling conditions.

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

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.

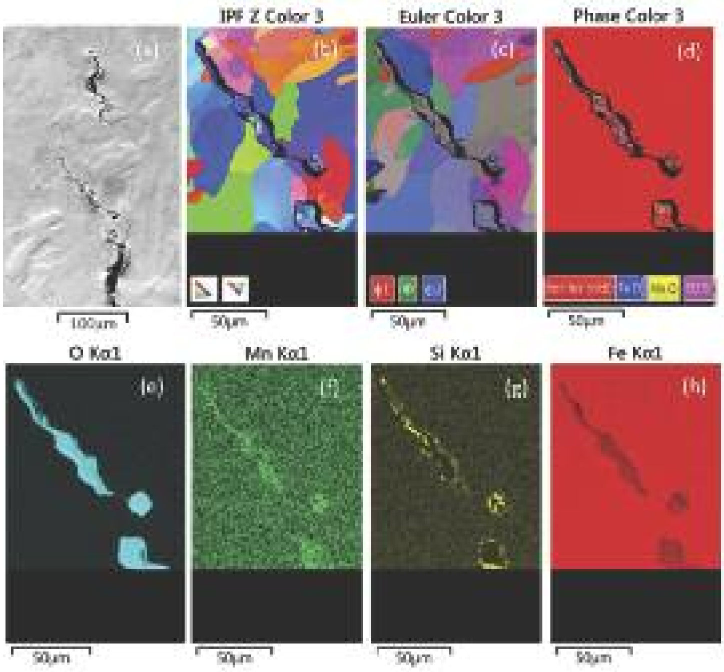
This improved understanding of the process will lead to enhanced iron blast furnace performance and economy. The advanced thermodynamic models for identifying the conditions necessary to achieve optimum sinter properties will enable Baosteel to make informed decisions about purchasing ore, using complex ore mixes, optimising process parameters, and designing sinter blends.

HIGHLIGHTS AND ACHIEVEMENTS

- Reviewed Fe-Al-Ca-Mg-Si-O thermodynamic databases for conditions relevant to iron ore sinter.
- Established a database of relevant original research papers on phase equilibria in this system; these papers contain experimental data necessary for database development for the proposed study.
- Demonstrated that critical gaps exist in the information available in the literature - not only pertaining to the key data on the liquidus in the Fe-Al-Ca-Si-O system in the iron-rich oxides but also on the extent of solid solutions, in oxygen partial pressures between the operating limits of air and iron saturation; nor was data found on the influence of MgO on the liquidus or SFCA stability in iron ores.
- Identified target issues to be resolved/experiments to be undertaken.
- UQ team visited Baosteel Ironmaking Institute in Shanghai to present findings and discuss the plan for further research on this topic.

DEFECT-FREE STRIP-CAST STEEL PRODUCTS

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



The characterisation of the (a) dendritic structure formed in the bottom of straight crack by (b-d) EBSD and (e-h) EDS showing its orientation and composition.

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BA14013

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 technology 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. 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 – 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 will 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

- Determined the steel compositions (e.g. Si+Mn+Nb microalloyed low carbon steel) and type of casting defects (e.g. longitudinal surface cracks parallel to the strip casting direction) to be investigated.
- Applied optical microscopy, SEM and EBSD techniques to study how the microstructure and crystallography of surface cracks change significantly during sectioning.
- Commenced formulating the mechanisms of critical defect formation.
- Continued investigating the dip-cast structure and mechanical properties of low carbon TRIP steels: for possible use as automotive structural components; and to identify the most desirable steel compositional range and casting parameters for generating optimal cast structures and properties in the TRC plant.
- Progressed initial investigations of the structure and hardness of as-cast strips.

FLUORIDE-FREE MOULD FLUX FOR CONTINUOUS CASTING

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.

BA12011-ARC PL130100773

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 properties and appropriate heat transfer. However, fluorine's high volatility leads to pollution, corrosion, and health and safety hazards. This project examines the melting properties, viscosity, crystallisation and thermal conductivity of fluorine-free mould fluxes, the interaction of molten flux with steels and non-metallic inclusions, and flux stability. With a deeper understanding of fluorine-free fluxes, Baosteel can develop more environmentally friendly steel casting technology.

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.

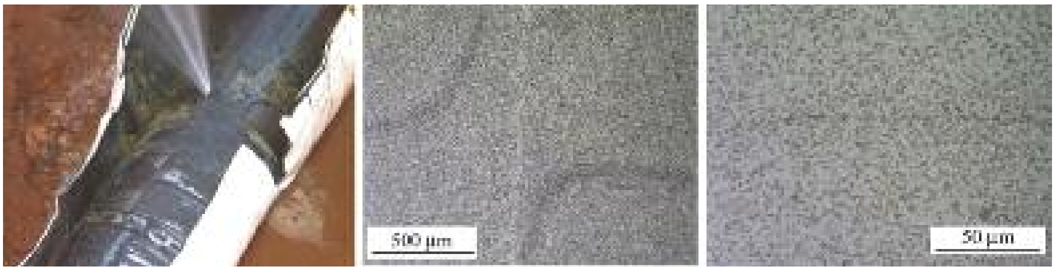
This research, the first systematic study of boracic flux volatility, is establishing new experimental data to reveal the mechanisms of flux crystallisation and the extent of boron volatility in different fluxes. The data will pave ground for flux design to achieve high quality steel continuous casting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

HIGHLIGHTS AND ACHIEVEMENTS

- Examined crystallisation behaviour of CaO-SiO_2-Na_2O-B_2O_3-TiO_2-Al_2O_3-MgO-Li_2O mould fluxes with CaO/SiO_2 mass ratios from 0.9 to 1.2 using single and double hot thermocouple techniques (SHTT and DHTT).
- Constructed continuous cooling transformation (CCT) and time-temperature transformation (TTT) diagrams which showed that the crystallisation tendency increased significantly with the increase in the CaO/SiO_2 mass ratio.
- Determined the crystal phases in the fluxes quenching at different temperatures using XRD analysis and comparing them with the calculated phase diagrams.
- Studied the crystallinity evolution using DHTT in the simulated temperature gradient between copper mould and strand in steel continuous casting, discovering the flux film quenched after the experiment was analysed using SEM and EDS.
- Studied the effects of the CaO/SiO_2 ratio (0.83-1.5) on the melting properties and viscosity of the CaO-SiO_2-Al_2O_3-B_2O_3-MxOy (MxOy: Na_2O, TiO_2, MgO) fluxes.
- Found that: adding Na_2O (7-11 wt%) increased break temperature, but decreased viscosity and hemispherical temperature; increasing the MgO (3-5 wt%) concentration reduced viscosity, break temperature, and hemispherical temperature slightly; increasing TiO_2 (2-6 wt%) content reduced both viscosity and break temperature; the effects of the CaO/SiO_2 ratio on the flux melting temperature and viscosity varied with different oxide additions.

EVALUATING CENTRELINE SEGREGATION

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



Leaking in field hydrostatic test caused by centreline segregation in steel pipe.

OBJECTIVES

Steel solidification proceeds by the nucleation and growth of dendrites with a composition different to the liquid from which it forms. As a result, modern continuously cast steel contains a non-uniform distribution of elements, or segregation, particularly along the mid thickness region of the slab which is the last region to solidify. Centreline segregation can be harmful to the weldability and integrity of any fabricated steel product, especially line pipe. At present, there is no international consensus on evaluation methods of centreline segregation.

Targeting new metallurgical processes, in particular advanced technologies for steelmaking, this project is developing a simple computer vision-based prototype segregation evaluation method (with acceptance criteria validated against the Mannesmann Scale) to assess centreline segregation objectively. Recommendations for minimising segregation will be presented through controlling critical parameters such as steel composition, electromagnetic stirring, secondary cooling conditions, machine stiffness and alignment.

POTENTIAL IMPACT

This research has enormous potential to improve Baosteel's market share, product quality, and reputation for setting new standards in steelmaking technology. Best-practice control of roll gap settings, superheat control, casting speed, etc., will enable Baosteel to produce high quality slabs with minimal segregation and compete successfully in the global line pipe market.

Currently, no international consensus exists for an evaluation method that can objectively and reproducibly assess the level of macrosegregation in continuously cast steel. With higher accuracy and sensitivity than current methods, the draft protocol being developed for Baosteel as an internal Standard Operating Procedure will advance knowledge about centreline segregation and may become an ISO standard.

HIGHLIGHTS AND ACHIEVEMENTS

- Completed a literature review on the strategies for mitigating and minimising segregation.
- Adjusted the MATLAB program for evaluating centreline segregation severity, ready for tests with real slabs.
- Developed a new rule based on existing experts' rules from other steel making plants and the Mannesmann standard.
- Investigated samples of cast slabs and rolled strips with segregation levels of Mannesmann level 1.4 and 2.0 in detail.
- Investigated the influence of segregation severity on the properties of strips rolled from the corresponding slabs.
- Observed discontinuous segregated lines of pearlite structure for hot strips rolled from slabs.
- Conducted transverse and z-direction Charpy impact tests on the strips and found that centreline segregation does influence the Charpy impact properties of line pipe steel.

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BA12035

STRONGER, TOUGHER, DUCTILE STEEL

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

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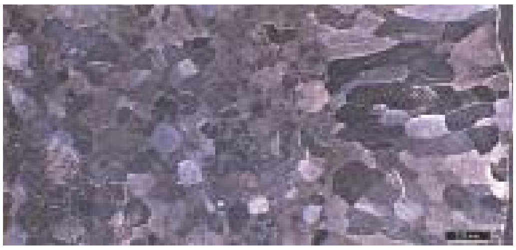
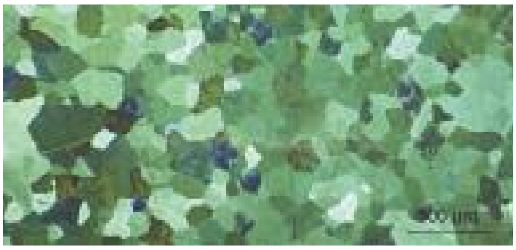


Grain refinement in Fe-4Si through LaB_6:
(a) base alloy without additions

(b) Fe-4Si with 0.5% LaB_6

(c) Fe-16Mn-0.6C TWIP steel



(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 edge-to-edge matching model (E2EM), 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 steel-making 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

- Experimentally verified in laboratory scale (computational results from crystallographic calculation using the E2EM model) that: LaB_6 is an effective grain refiner for ö-ferrite; adding less than 0.5wt%LaB_6 into the Fe-4Si alloy reduces the as cast grain size from 770 tm down to 150 tm; and adding 0.1wt%TiN can effectively eliminate the columnar structure.
- Theoretically identified and experimentally verified that the addition of Cu can significantly refine as-cast grains and increase the fraction of equaxed grains in Baosteel H1 steel.
- Found that solidification cooling rate significantly affects the microstructure of high Mn steel ingots (reducing the cooling rate leads to more equaxed and finer grains); which is a different result from most previously reported results, i.e., that slow cooling tends to produce coarse grains.

MAXIMISING PIPELINE SAFETY AND DURABILITY

Understanding strain ageing in fusion-bonded epoxy-coated pipeline steel to improve its strength and safety

Project technical meeting 28 July 2015.

OBJECTIVES

The world's voracious oil and gas industries have increased demand for steel pipelines to carry richer mixtures and be operated at higher pressures. A fusion-bonded epoxy coating is widely used in pipeline construction to protect the steel from corroding under these new conditions. This thermal coating process changes the mechanical properties of line pipe steels: it increases yield strength as well as 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.

Strain ageing is a big concern in pipeline design as natural gas, with its lower CO_2 emissions, becomes more popular as an energy source. Some 30,000 km of pressurised gas transmission pipelines, for example, currently deliver about 20 percent of Australia's total energy consumption. This ratio is expected to exceed 37 percent in the next two decades, requiring thousands of kilometres of more pipelines to be built. However, when gas pipelines fail, the subsequent damage to life, property, reputation and revenue can be catastrophic.

This project seeks to learn more about strain aging so that Boasteel pipelines are strong and tough enough to compete in this market and mitigate the risks of gas pipeline failure. The researchers are investigating strain ageing in low carbon and low nitrogen pipeline steels with strong carbon and carbonitride alloys; characterising mechanical property changes; investigating the effect of coating process parameters on mechanical property; studying the influence of strain ageing on pipeline fracture control; and determining a limit of the Y/T ratio for coated pipes to control pipeline fracture.

POTENTIAL IMPACT

The study of strain ageing mechanics will be a substantive contribution to metallurgical science. Until now, a quantitative analysis of carbon and/or nitrogen interstitial atom concentrations in line pipe steels has not been reported. Importantly, understanding and optimising strain ageing effects and their structural consequences will help to advance Baosteel's longer term, strategic development and business activities in Australia. The research will also look for an optimum coating process that results in a satisfactory bonding quality that does not significantly increase the Y/T ratio. This will help Baosteel improve line pipe quality without investing in new equipment.

HIGHLIGHTS AND ACHIEVEMENTS

- Held two technical meetings with Australian and Baosteel pipeline experts to scope the research and collaboration.
- Recruited a Research Fellow and a PhD student.
- Conducted heat treatments and mechanical tests on Baosteel line pipe steels.

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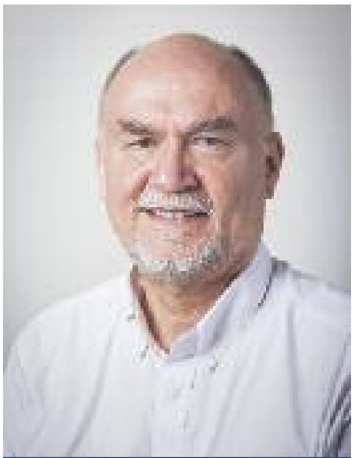
BA14002

AUTO STEELS WITH HIGHER HE RESISTANCE

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



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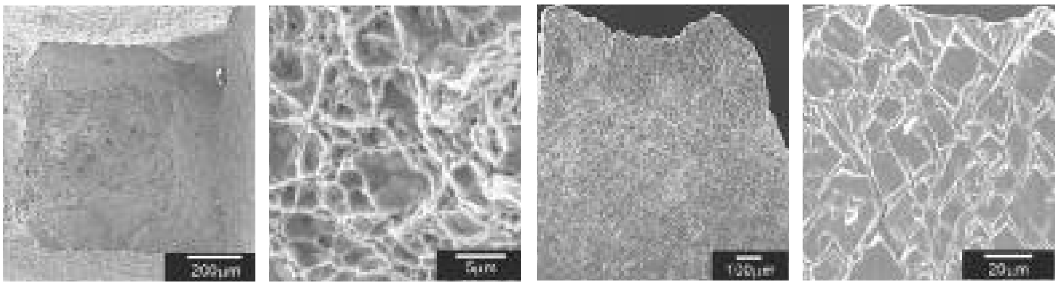


Ductile fracture appearance of MS980 after LIST at 0.064 MPa s^{-1} and charging at -1.800 $V_{Ag/AgCl}$ as viewed from the top at (a) low and (b) high magnification; and from the short transverse side at (c) low and (d) high magnification.

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 of this project are pursuing a deeper understanding of how hydrogen interacts with steel, to reduce and eliminate HE. Access to a new state-of-the-art Thermal Desorption Spectroscopy (TDS) apparatus, built for this purpose with an Australian Research Council Linkage grant, will allow them 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

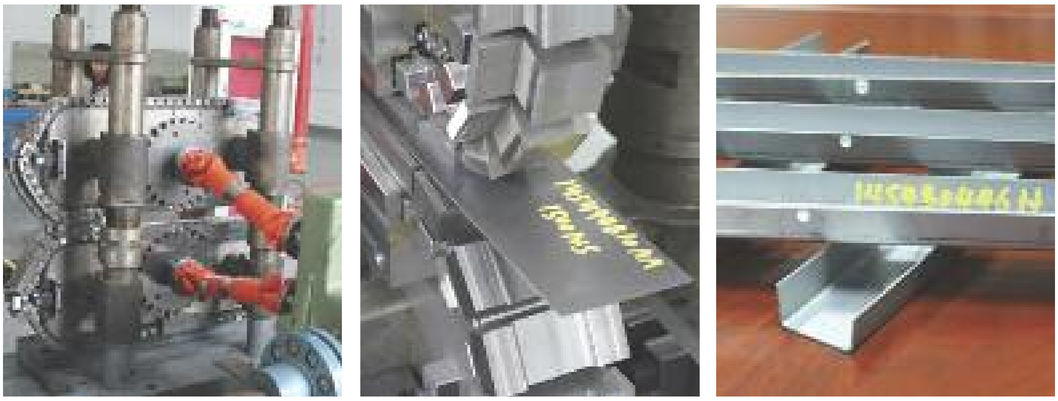
- Studied the influence of hydrogen on the mechanical and fracture properties of four martensitic advanced high strength steels using the linearly increasing stress test and electrochemical hydrogen charging.
- Found that the hydrogen influence increased with steel strength, decreasing charging potential, and decreasing applied stress rate. Increased hydrogen influence for slow applied stress rates was manifest in (i) the decreased yield stress attributed to solid solution softening by hydrogen and (ii) the reduced macroscopic ductility, and by the change from ductile cup-and-cone fracture to macroscopically brittle shear fracture, attributed to a dynamic interaction of hydrogen with the dislocation substructure somewhat similar to the HELP mechanism. Such an influence of hydrogen may have little relevance to the use of these steels in service in cars.
- Investigated the hydrogen permeation behaviour of DP and Q&P grades of advanced high strength steels using the permeability experiments (i) under cathodic charging at different potentials in 0.1 M NaOH solution, (ii) in 3% NaCl solution at the free potential simulating the corrosion behaviour of non-galvanized steel in service, and (iii) at zinc potential for the corrosion condition of the galvanized steel during actual service. Hydrogen fugacity during service for DP & Q&P steels appears to be much lower than during cathodic hydrogen charging.

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.

ADVANCED HIGH STRENGTH STEELS FOR AUTO FUEL EFFICIENCY

Studying the processing quality and precision of chain-die fabricated non-uniform AHSS products to produce stronger, light-weight automotive steels



A pilot chain-die former and a formed sample.

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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 non-uniform 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.

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

- Established the FEA modelling to simulate the chain-die forming process on both regular (2D and 3D) and irregular profiled products.
- Generated new knowledge about plastic deformation on flanges of non-uniform profiles.
- Progressed experimental work on regular profiles, including 1.6 mm and 1.0 mm AHSS.
- Observed that nearly no product defects occur in the highest strength material, and that the formed samples show very encouraging compatibility with the new technology.
- Revealed evidence to prove the new method is superior to roll forming for this purpose.

OPTIMISING STRIP CASTING PERFORMANCE

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

OBJECTIVES

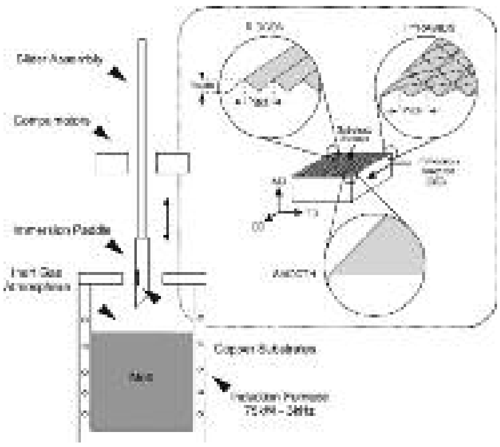
The massive scale of conventional metallic strip processing (e.g., billet, slab or ingot casting and their secondary processing stages) is energy-intensive and detrimental to the environment. Casting defects can prevent as-cast strips being manufactured to a consistent high standard in the processing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



Schematic diagram of the substrate immersion technology with the inset illustrating some of the possible substrate surfaces

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

HIGHLIGHTS AND ACHIEVEMENTS

- Completed the experimental program on defect formation processes and mechanisms in strip-cast low carbon steel, culminating in several recommendations to Baosteel for eliminating large-scale cracking on as-cast LC strip in the TRC plant in Ningbo, China.
- Submitted a comprehensive report to the BAJC on all the research completed up to June 2015.

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BA11001-ARC LP120200499

REDUCING DEFECT RATES IN HOT ROLLED STAINLESS STEELS

Developing control strategies to improve the surface quality of hot rolled austenitic, ferritic and martensitic stainless steels

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OBJECTIVES

Different types of surface defects can occur when stainless steels are rolled using current hot rolling method's - damaging work rolls, reducing production rates, and increasing the costs and consumption of materials and energy. Thick oxide scale, deep internal oxidation and lamination cracks are common problems. A small surface defect in a continuously casted slab, for example, can elongate during rolling and become an extensive product defect, requiring expensive additional conditioning and making quality assurance difficult. Controlling the surface quality of ferritic stainless steels with medium chromium is especially challenging, as high oxidisation resistance and adhesiveness make strips prone to sticking, marking, folding, scratching and peeling.

This fundamental and applied research project, which commenced in 2011 and was completed at the end of 2014, investigated the mechanisms of the surface deterioration, reheating temperature effect and the potential for lubrication oil to play a more beneficial role in the rolling process.

POTENTIAL IMPACT

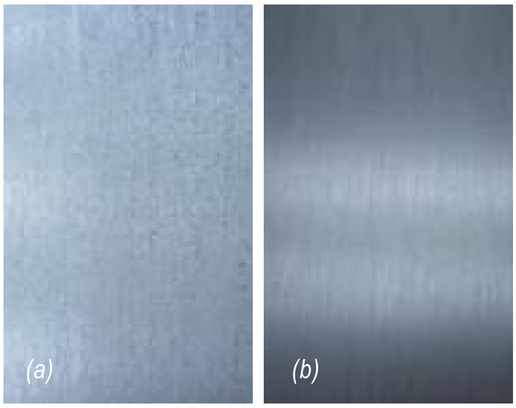
Introducing evidence-based techniques for generating uniform, well-structured and deformable oxide scale will help to improve the surface quality of key Baosteel stainless steels. Optimum surface conditioning strategies can also be designed with a better understanding of how surface defects in continuous casting slab evolve during hot rolling, how different grinding methods affect rolling processes, and how reheating temperatures and Extreme Pressure (ZP) in lubricants affect the surface sticking of stainless steels in hot rolling.

Developing effective control strategies for hot rolling, and thus improving surface quality and cost efficiency, will boost Baosteel's competitiveness in domestic and international stainless steel markets.

HIGHLIGHTS AND ACHIEVEMENTS

- Carried out thermogravimetric analysis (TGA) under various atmospheres to confirm the optimum reheating temperature to significantly improve the surface sticking of ferritic stainless steels in hot rolling.
- Understood the mechanism of oxidation behaviour of ferritic stainless steels in hot rolling with various atmospheres.

Investigating oxidation kinetics in the School of Mechanical, Materials & Mechatronic Engineering at the University of Wollongong



Strip surface quality (a) with sticking and (b) without sticking

- Conducted hot rolling trials on a 2-high Hille 100 experimental rolling mill, adding zinc dialkyl dithio phosphate (ZDDP) around 20% in lubricant and confirmed that sticking defects are expected to be eliminated in hot rolling of stainless steels.
- Analysed the mechanism of extreme pressure (EP) agents in hot rolling.
- Used thermogravimetric analysis (TGA) under isothermal conditions to investigate the oxidation behaviour of high-speed steel, which is used to manufacture work rolls in hot rolling mills, then investigated oxidation kinetics based on the TGA results.
- Investigated the oxidation of indefinite chill (IC) roll samples, also using TGA under isothermal conditions, revealing that graphite degradation can be avoided if the IC roll temperatures are controlled to remain under 650 °C.
- Generated new IP for a mini hot rolling mill to equip the Gleeble 3500 thermal-mechanical simulator.

ENVIRONMENTALLY FRIENDLY MILL LUBRICANTS

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

OBJECTIVES

Lubrication in hot rolling steel reduces friction, roll load and wear and power consumption. It also helps control surface finish and sometimes acts as a coolant. Thousands of tons of mineral oils and rolling oil emulsions are used in rolling mill lubrication for steel strip manufacturing every year. However, these oils significantly affect the quality of rolled strips, roll wear, and energy consumption. 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.

This research is developing novel nano-additive water based lubricants which will improve rolled steel product quality and reduce resources utilisation. Nano-mechanical 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.

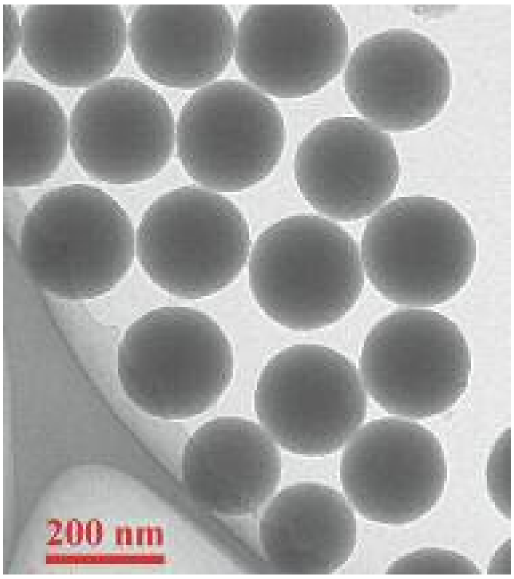
POTENTIAL IMPACT

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

- Prepared TiO_2 suspensions with two different particle sizes (7-9 and 20-30 nm) and selected effective surfactants for them to improve the stability of the resultant suspension



TiO_2 nanoparticles used for water based lubricants.

- Identified several parameters as key factors in determining the suspension stability, such as the mass ratio of nano-additive, surfactant selection, and pH value.
- Synthesised (by hydrothermal method) cubic Fe_2O_3 nanoparticles with three different sizes (40, 120, and 180 nm).
- Conducted pin-on-disk testing for all the nano-additive lubricants, with SiO_2 and TiO_2 suspensions giving a comparable COF-to-oil lubricant benchmark.
- Modified the pin-on-disk tester to reduce data scattering.
- Improved the synthesising route to reduce contaminants.
- Added glycerol to modify suspension viscosity and improve affinity to steel surface.
- Conducted hot rolling tests at temperatures of 850 and 1050°C under various lubrication conditions.
- Conducted a pickling test by immersing the rolled steels to 10% HCL solution, revealing that oxide scale produced using 4% TiO_2 water-based lubricant could be removed more easily.
- Conducted a tribology test under load of 50N with 30mins at room temperature, showing that COF under TiO_2 water-based lubricants was much lower than that with water and dry conditions.
- Conducted wettability tests, showing that PEI improved the wettability of TiO_2 water-based lubricants significantly.
- Presented new findings to Baosteel in December 2014.
- Hosted a visit from Baosteel in May 2015 to present the new research results in rolling mill tests.

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

BA13012-ARC
LP150100591

CHARACTERISING COLD STRIP ROLLING

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

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BA12003

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 the causes of rolling deformation in mixed lubrication, and lead to new technology for superior precision manufacturing and metal surface integrity.

POTENTIAL IMPACT

The project's novel characterisation method will enrich the 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.

Baosteel visiting fellow Peilei Qu (front), working with UNSW PhD student Chuhan Wu (back) on an interface friction experiment at UNSW.

HIGHLIGHTS AND ACHIEVEMENTS

- Successfully established the multi-scale analysis method characterising the interface friction in cold rolling.
- Introduced to the mechanics modelling an equivalent interface layer between the roll and strip interfaces to capture the microscopic asperity deformation and asperity/lubricant interaction.
- Conducted an FEA to catch the macroscopic bulk deformation of the strip.
- Developed a statistical analysis of elasto-plastic contact of rough surfaces.
- Conducted experimental investigations on interface friction.
- Performed preliminary lubricant oil tests.

SAFER, RIDGE-FREE FERRITIC STAINLESS STEEL PRODUCTION

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

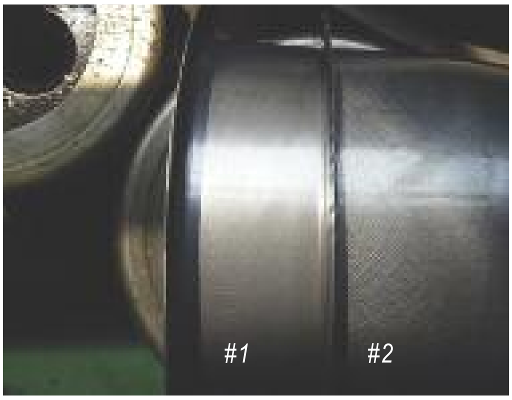
OBJECTIVES

With the high and often fluctuating cost of nickel, ferritic metals are now more prevalent in new stainless steels, particularly those originating from China. 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. 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.

This fundamental research, with numerical and practical simulations, focuses on ridging and aims to understand the mechanism that causes ridging in selected Baosteel ferritic stainless steels (FSS). The potential for cold rolled processes to achieve equal or better quality results is also being explored.

POTENTIAL IMPACT

Knowing how to increase the fraction of transformed ferrite, based on the nucleation of austenite-phase islands with even more advanced alloy design and processing optimisation, will be a breakthrough for developing ridging resistance properties in Baosteel products. Decreasing the ridging height for FSS products would reduce the subsequent machining costs and extend the market volume growth of Baosteel FSS products. Reducing the dust generated during polishing and finishing processes would mitigate the negative impacts of the process on the environment and health of workers. By proposing practical solutions and developing novel technologies for reducing ridging height, a new benchmark will be set for ridging control worldwide.



Improved ridging outcomes for Baosteel FSS 430, with #1 showing the effect after optimising alloy design, rolling and annealing processes and #2 showing the product before optimisation

HIGHLIGHTS AND ACHIEVEMENTS

- Conducted field investigations at Baosteel.
- Recruited two PhD students to join the project.
- Welcomed Dr Wei Du to UOW as a Senior Visiting Fellow to lead hot deformation tests and ridging defect characterisation.
- Organised a seminar within the research team to enhance the experimental work and to focus on the practical solution to ridging defects.
- Surveyed the literature, focusing on the evolution of texture during hot and cold rolling of FSSs and the relationship between the texture and the ridging defect.
- Prepared a detailed research plan and the primary experimental scheme, determining FSSs 430 and 430LR as the main steel grades for investigation.
- Received the first batch of samples from Baosteel for experiments.
- Conducted high temperature isothermal compression and hydra-wedge tests to simulate the hot rolling process.
- Employed a finite element method (FEM) simulation to model the ridging evolution of FSS during stamping.

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BA14014

MAXIMISING HOT STEEL ROLL LIFE

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

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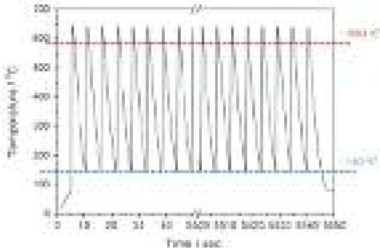
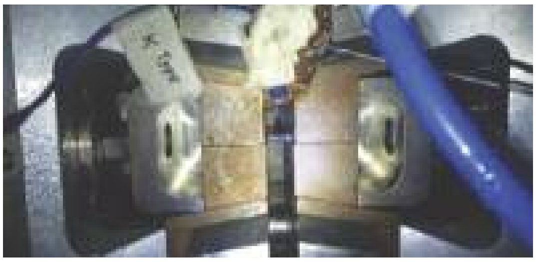




Cyclic heating of HSS on the Gleeble thermo-mechanical simulator and oxide surface after 10000 cycles.

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.

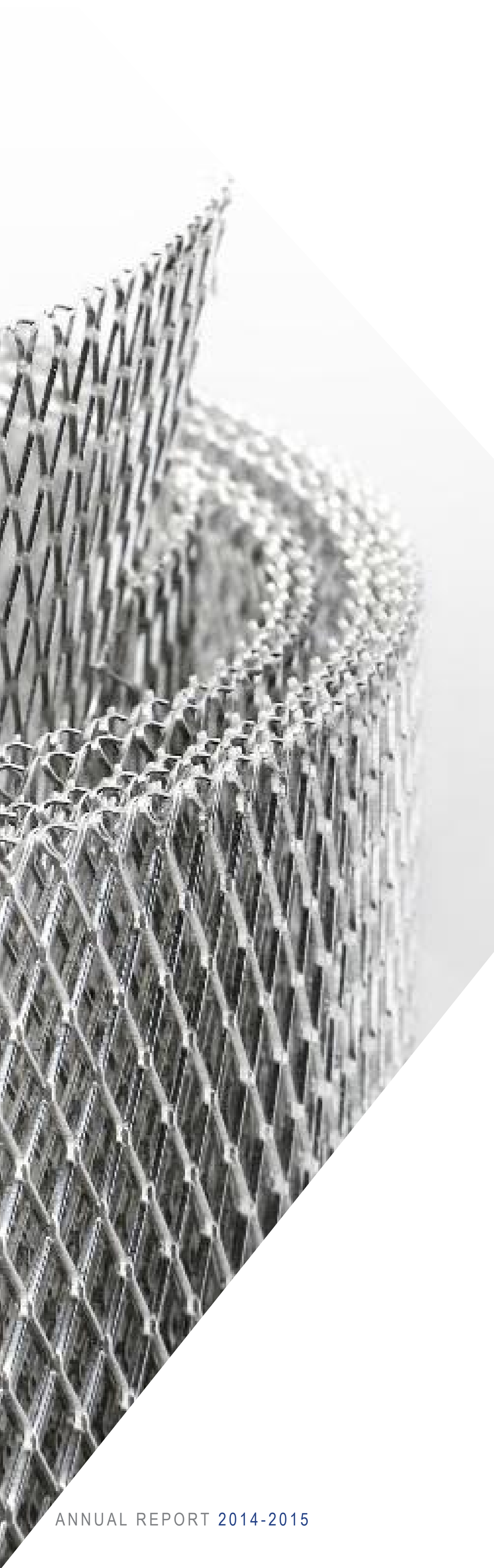
POTENTIAL IMPACT

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

- Conducted microscopy on HSS roll materials currently used by Baosteel in its hot strip plant, revealing specific differences between Japanese and US work rolls.
- Found in preliminary tests that the uniform distribution of carbides can effectively increase the surface hardness, and spherical carbides can effectively stop the propagation of cracks and improve wear resistance.
- Conducted high temperature oxidation/wear tests of HSS work roll material on a (world-first) high temperature roller-on-disc test rig up to 900°C.
- Confirmed that rolling pressure plays a significant role in compact oxide scale forming on HSS roll surfaces and that the rolling schedule can be adjusted to promote an effective scale formation at higher pressure.
- Applied x-ray powder diffraction techniques (in the laboratory as well as at the Australian Synchrotron) to investigate in-situ the HSS work roll sample from room to high temperature, revealing that minimal phase transformation occurs when the temperature is lower than 600°C, but the residual stress in both the oxide scale layer and the steel substrate increases with temperature rises.



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.

NEXT GENERATION 6XXX SERIES ALUMINIUM ALLOYS

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

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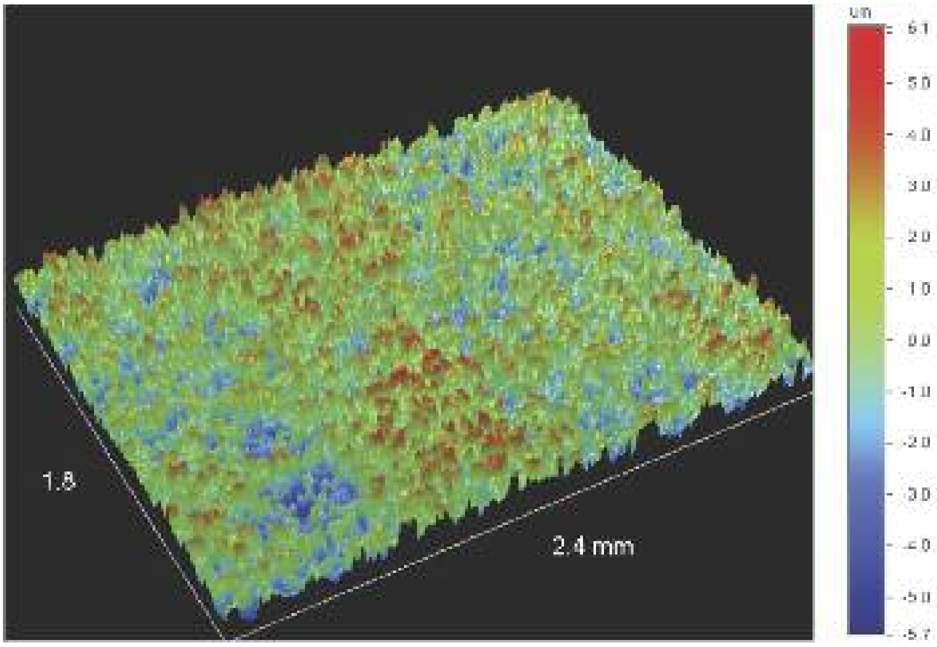


Optical profilometry image of surface roughness of prestrained alloy.

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. However, until the manufacturing problems of high cost and poorer formability are resolved, 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.

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. The development of 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

- Provided details of the production process to Baosteel in early May.
- Casted and tested 12 more alloy compositions for mechanical and hemming.
- Duplicated four previously identified compositions for further testing.
- Developed and trained a neural network model.
- Both PhD candidates working on this project successfully completed their mid-candidature reviews.

STRONG, FORMABLE LIGHT METAL LAMINATES

Creating hybrid composite metal laminates for the auto industry with impact cores designed for high manufacturability

OBJECTIVES

High-speed transport systems rely on stiff, light-weight metal panels with low density cores to provide robust impact resistance and sound absorption, in flooring, cabin structures, and external frames for example. Despite their exceptional properties in flat panel form, traditional foam core systems have low formability, with bending and shaping panels causing major core damage and strength reduction. The development of hybrid composite metallic laminates has stimulated lucrative opportunities in these transport markets for metal-based laminates with low density core foams with excellent strength-to-weight ratios and high levels of manufacturability.

This project is designing novel, cost-effective light-weight metal laminate materials that offer both strength and formability. The researchers are testing lattice cores which enable the material to be shaped into panels with high strength-to-weight ratios. Using computational simulation techniques and analytical modelling, they are investigating 2D and 3D truss core architectures followed by prototyping to ascertain core-sheet bonding, confirm optimised truss elements and post-deformation behaviour, and create the optimum formable laminate designs.

POTENTIAL IMPACT

The auto industry is potentially the greatest user of these new materials. For example, high strength-to-weight and stiffness-to-weight characteristics within chassis structures will elicit considerable fuel efficiency, from lower weight structures and the need for lower capacity engines and braking systems. Most significantly, these weight-saving advantages will be possible without reducing, and likely enhancing, the vehicle's energy absorption capacity, therefore retaining desirable levels of passenger and pedestrian safety.

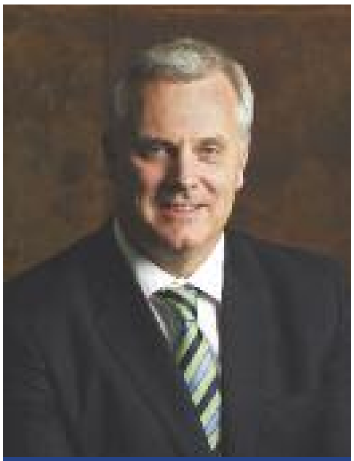
The research will also provide the light metal manufacturing industry with new analytical formulae and models for predicting and mitigating the failure rates of laminates.

(a) Testing 2D panels for buckling failure.

(b) Buckled 3D panel under bi-axial bending.

HIGHLIGHTS AND ACHIEVEMENTS

- Constructed 2D and 3D specimens of single and double–clad AA3003 Al sheets, of different core thickness and pitch, and subsequently tested them to bending with a curved punch, confirming formability.
- Validated failure modes by the previously developed analytical model for 2D panels.
- Developed analytical models for 2D and 3D panel failure, taking into account the bi-axial nature of bending.
- Using the analytical model, constructed a failure map based on simultaneous occurrence of failure modes for the panel architecture and the 'hard' material in the original FEA simulations.
- Initiated an experimental program on bi-axial bending of 3D panels, cutting the core material with a guillotine and preparing a specimen by tacking the struts to the facesheets at the edges of the panel.



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BA11018

HIGH PERFORMANCE HOMOGENEOUS TITANIUM

Study on homogenisation and recrystallisation effects in forged Ti64-ingot and research in powder HiPping of Ti64 powder

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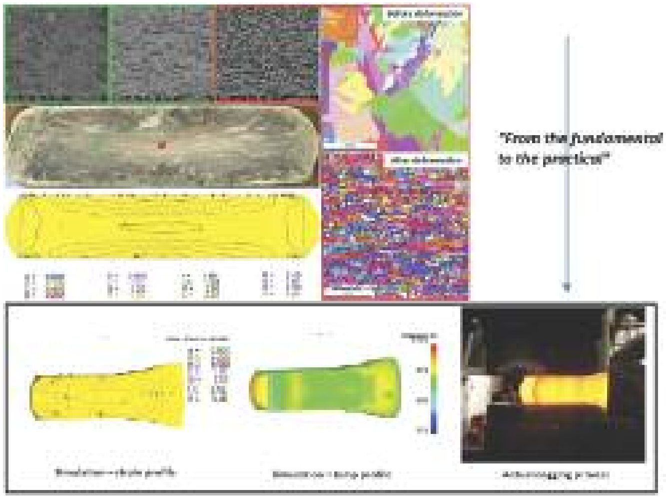


Representative results of the fundamental study of process parameter effect on microstructure evolution of Ti-6Al-4V and the linking of the fundamental understanding to the application of forging Ti alloy billets in Baosteel via process simulation.

OBJECTIVES

From engine to airframe, the world's leading aircraft manufacturers are introducing more titanium alloys into aircraft structures, with Ti-64 being the most widely used titanium alloy over all applications. The energy-efficient process of net-shape HIPping is commonly employed to make complex components with Ti-64. Aerospace companies consider net-shape HIPping to be a critical manufacturing process because it can reduce wastage to just five percent, cut the lead-time between component design and final component from the current 24-36 months to three to four months, and embody large components with static mechanical properties equivalent to, or superior to, forged material.

But like other alloys, Ti-64 has limitations. The fatigue performance of powder HIPped Ti-64 depends on powder size distribution and inclusions, and the characteristics of commercial powders from different batches and different suppliers can vary. Without a solution to the problem of non-uniform mechanical behaviour in larger parts, all design has had to be based on the lowest properties that may be routinely achieved. This project is studying the relationship between microstructure, strain distribution and forging conditions to improve Ti-64 forged ingot homogeneity and also the industrial scale HIPping of Ti-64 powder. The aim is to remove or reduce variability to obtain a uniform microstructure, leading to increased reliability, reduced localised strain accumulation, and more realistic as well as cost-effective processing design criteria.

POTENTIAL IMPACT

The knowledge gained from this project will be useful for addressing general problems associated with titanium ingot production and forging technology. The modelling tool introduced and design table developed can help in Baosteel's Ti alloy production efficiency by designing a cogging sequence with less processing steps yet maintaining billet quality. It can also aid in processing consistency.

With the fundamental understanding and modelling capability, Baosteel can produce customer-specified quality billet and become a main player in the domestic and international aerospace material market. From this project, Baosteel has already begun supplying billets for Ti-6Al-4V powder production and the powder has met international aerospace standards. Moving forward, Baosteel can become the world's first large quantity supplier of Ti-64 powder or powder HIPped components and thus revolutionise aerospace component manufacturing.

HIGHLIGHTS AND ACHIEVEMENTS

- Provided Baosteel with full knowledge of the quality of its cast product in terms of microstructure, macrostructure, chemical variation and β- transus temperature.
- Generated knowledge of the processing window for the (α+β) forging of the Ti-6Al4V billet.
- Improved understanding of the possible source for quality inconsistency in billet production.
- Devised how to improve uniformity quality in the forged billet.
- Clarified the issues related to microstructure evolution and strain distribution.
- Developed a cogging process design table to help understand and control the cogging process.
- Completed the project and presented the final report to Baosteel.

ADVANCED TITANIUM MANUFACTURING

Enabling low cost fabrication of high performance titanium alloys from powder to create a viable titanium business

OBJECTIVES

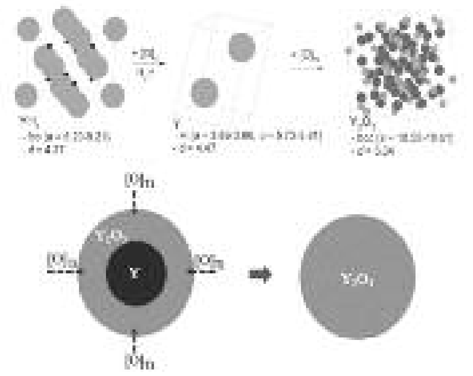
Baosteel has unrivalled access to inexpensive titanium powder in China, the world's largest titanium sponge producer (50 percent world production capacity).The mechanical properties of titanium products fabricated from powder, especially their ductility, show substantial variations, depending on the 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, mining and industries; as well as draw other hi-tech titanium business 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.



Scavenging of oxygen by yttrium hydride from powder metallurgy titanium and titanium alloys [Yan, M., Liu, Y., Schaffer, G. B., Qian, M., 2013, Scripta Materialia, 68(1), 63-66].

HIGHLIGHTS AND ACHIEVEMENTS

- Recruited a research fellow, technician, and PhD student.
- Purchased, fully characterised, and tested all necessary raw materials, including the titanium powder and alloying additives.
- Selected titanium alloys (invented at UQ) and conducted preliminary manufacturing trials.
- Reached a general agreement with Adelaide-based Advanced Metallurgical Solutions (AMS) to use its commercial MIM facilities for preliminary manufacturing trials.

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BA11014RPP

ECONOMIC TITANIUM FABRICATION

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.

BA110014-ARC LP 130100913

OBJECTIVES

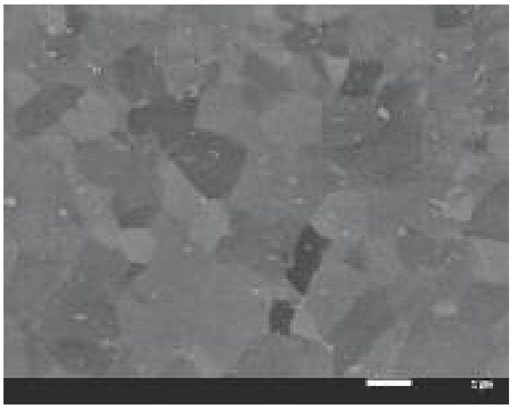
While titanium and its alloys possess an array of outstanding properties, their low affordability has restricted their applications to a few industries on a small scale. The high cost of a titanium product arises from the titanium metal as well as the manufacturing process. This project aims to develop a fast, eco-friendly method that can enable the fabrication of low-cost, high-performance titanium components using less expensive titanium hydride (TiH_2) powder. Effort is also being made to design and develop low-cost high-performance powder metallurgy (PM) titanium alloys and composites.

POTENTIAL IMPACT

With the potential new developments to be made in this project, Baosteel can broaden its titanium portfolio for wider applications, primarily in the automotive and aerospace industries. The new fabrication techniques are expected to be more environmentally friendly, due to less stock waste and less energy consumption than conventional powder metallurgy routes.

HIGHLIGHTS AND ACHIEVEMENTS

- Produced ultrafine grained titanium samples (30 mm diameter) with grain sizes in the range of 1-3 µm, reinforced with nanometric ceramic additives.
- Commenced characterisation, including mechanical property testing.
- Fabricated new alloys and processed them under different conditions, including a Ti-Al-Si and a Ti-0.33H (wt.%).
- Presented a paper at the conference of Powder Metallurgy Titanium 2015 in Germany.
- Completed a review paper on TiH_2 powder metallurgy.
- Ran the project completion workshop at Baosteel Research Institute in June 2015.
- As a continuation of BA110014, revised and completed the patent application for filing.



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

NEW Ti ALLOYS FOR THE AEROSPACE INDUSTRY

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

OBJECTIVES

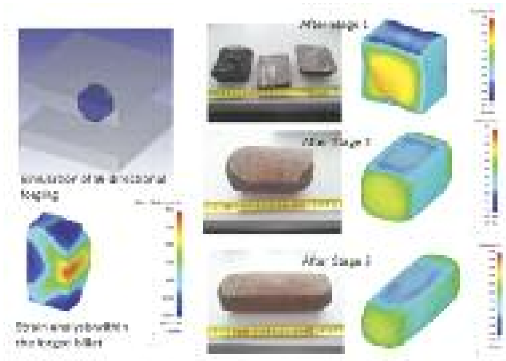
Enhanced processes and a guaranteed consistent product quality will boost Baosteel's profile as a major supplier to the aerospace market. A reliable quality titanium alloy billet has a homogeneous globularised microstructure throughout, leading to uniform mechanical properties being achieved repeatedly. 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 of this project are working with Baosteel to establish the relationship between accumulated strain profiles and microstructure at the industrial scale. They are implementing a new model to simulate 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.

POTENTIAL IMPACT

An established modelling tool and microstructure data base will allow Baosteel to combine current experience with new information and thus design for improved material processing. The resulting high-quality Ti-64 alloys will meet the standards of international aerospace clients and be cheaper to produce as well. If found feasible, the new pass schedule for TRL5 industrial ingots of about 20 tons (760mm diameter) can be integrated immediately into Baosteel's production system.

Baosteel will also be able to use the simulation model to improve the efficiency and processing of other titanium alloy ingot sizes, for example by reducing processing steps and minimising inconsistency in material quality.



FEM simulation of the bi-directional non-isothermal forging of Ti-6Al-4V billet and the comparison of the shape of the physical forged sample with that predicted by FEM, showing the strain of the interior of the forged billet can be analysed from the FEM.

HIGHLIGHTS AND ACHIEVEMENTS

- Sourced and obtained material.
- Identified and tested the forging system.
- Installed the data acquisition system on the forging system.
- Tested and evaluated the forging system at Shanghai Jiaotong University (SHJT).
- Completed the forging sequence simulation for the 80mm billet at SHJT.
- Conducted two sets of experiments on the forging of 80mm billet at SHJT.
- Established that strain path affects the globularisation and lamellae break-up of the titanium billet.
- Identified from simulation that the rotation sequence in billet forging can have an improved effect on strain homogeneity with increased strain at the near surface regions.
- Began using multi-directional forging test samples to evaluate strain path effect on microstructure and texture evolution.

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BA14011

HIGHLY FORMABLE MAGNESIUM SHEET

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

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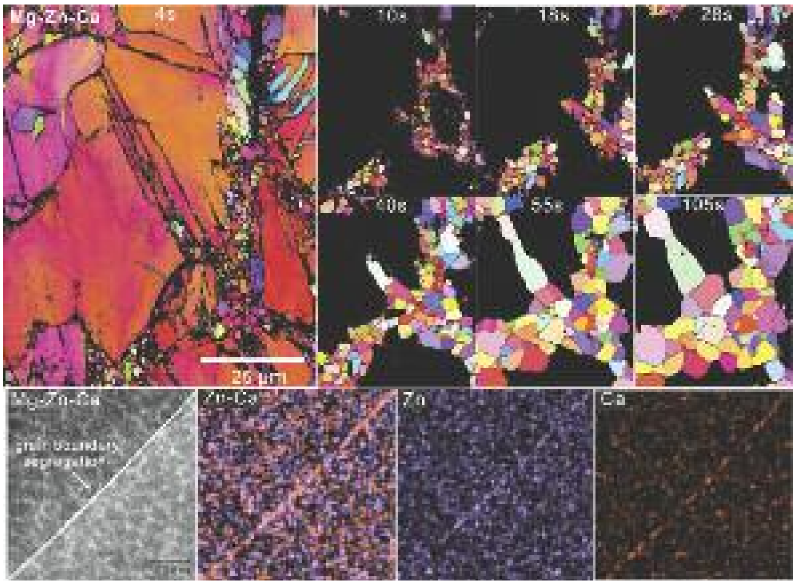


Understanding how grain growth behaviours and solute segregation (like the ones here) influence texture weakening is helping to design highly formable Mg sheet alloys via texture engineering.

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 of this project 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.

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.

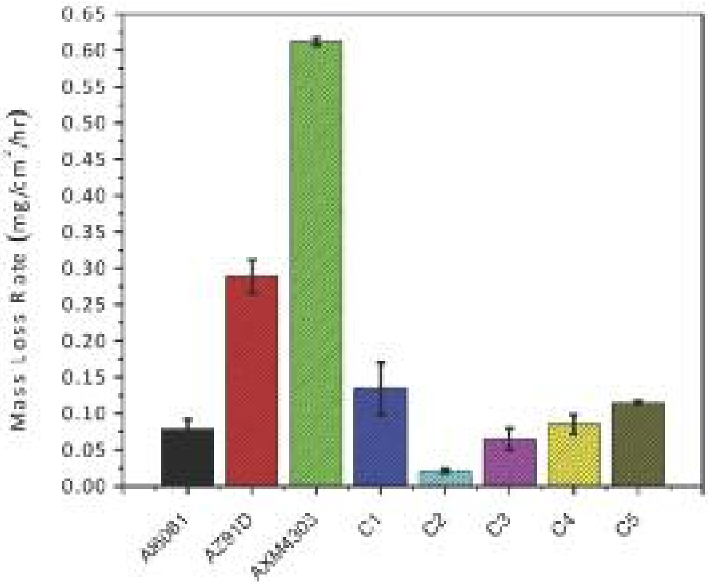
Meanwhile, the development of highly formable, lightweight magnesium sheet is strategically and commercially important to Baosteel's expansion in current automotive, rail transport, cycling, and computer-related markets. Establishing a business to commercialise value-added magnesium products for these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

HIGHLIGHTS AND ACHIEVEMENTS

- Developed a highly formable magnesium alloy that is far better than commercial magnesium sheet alloy and comparable with commercial aluminium sheet alloy.
- Found that the rollability of magnesium alloy sheet is remarkably improved by high speed rolling and therefore that large reduction per pass is achievable.
- 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.
- Discovered that this processing technique could significantly increase the productivity of Mg alloy sheet and that sheets prepared by this method showed extraordinarily well-balanced mechanical properties in terms of strength and ductility.
- Using a quasi-in-situ characterisation method, revealed the significant influence of grain growth behaviours on texture weakening.
- Applied for two patents; with a third, mature patent under preparation.

NEXT GENERATION COATINGS FOR MAGNESIUM ALLOY

Transforming the magnesium alloy market with next generation protective conversion coatings



Mass loss rate of our patented coatings in comparison with bare Al6061, Mg AZ91D and Baosteel AXM4303 Mg alloy after immersion in 0.1 M NaCl over 120 hours.

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BA12031

OBJECTIVES

Magnesium alloys, despite being the lightest structural metal and popular in automotive and aerospace industries, have not been more widely applied due to their susceptibility to atmospheric and galvanic corrosion. Magnesium can corrode rapidly, resulting in decreased mechanical stability and undesirable appearance. To realise mass-market applications of magnesium 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 resultant conversion coatings should be adhesive, compact, stable and defect-free.

This project is developing a world-first technology for protective conversion coatings which will be simple to operate, non-hazardous, cost efficient, environmentally friendly and multi-functional. 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 magnesium alloys have the functionality to meet the needs of different end users; and testing the corrosion resistance under service conditions.

POTENTIAL IMPACT

Advancing the knowledge base with pioneering methods and insights about corrosion will be valuable to both the fundamental science and the practical applications relating to magnesium alloys. The scientific developments from this project will guide Baosteel's magnesium products portfolio and position the company strongly as a global supplier of wrought and cast products to magnesium 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

- Optimised the newly developed pre-treatment approach for Mg-Ca-Al, Mg-Ca-Zn and Mg-Al-Zn to create a surface with homogenous composition and facilitate subsequent conversion coating formation.
- Established a Baosteel-accepted corrosion testing protocol to provide direct evidence and evaluations on corrosion performance of newly developed Mg alloys and coating technology.
- Established three ways to achieve targets, including tailoring coating structure and properties; improving coating function; and utilising graphene (rGO), ZnO and SiO_2 nano materials to dope existing conversion coatings for desirable corrosion resistant performance.
- Lodged two patent applications: for a new conversion coating technique along with coating solution compositions; and a new but simple hydrothermal coating technique.

HIGH PERFORMANCE MAGNESIUM EXTRUSION ALLOYS

Realising new property space to produce next generation magnesium alloy extrusions

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OBJECTIVES

The demand for lightweight structural metals has accelerated rapidly over the past five years, 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 lightweight 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.

POTENTIAL IMPACT

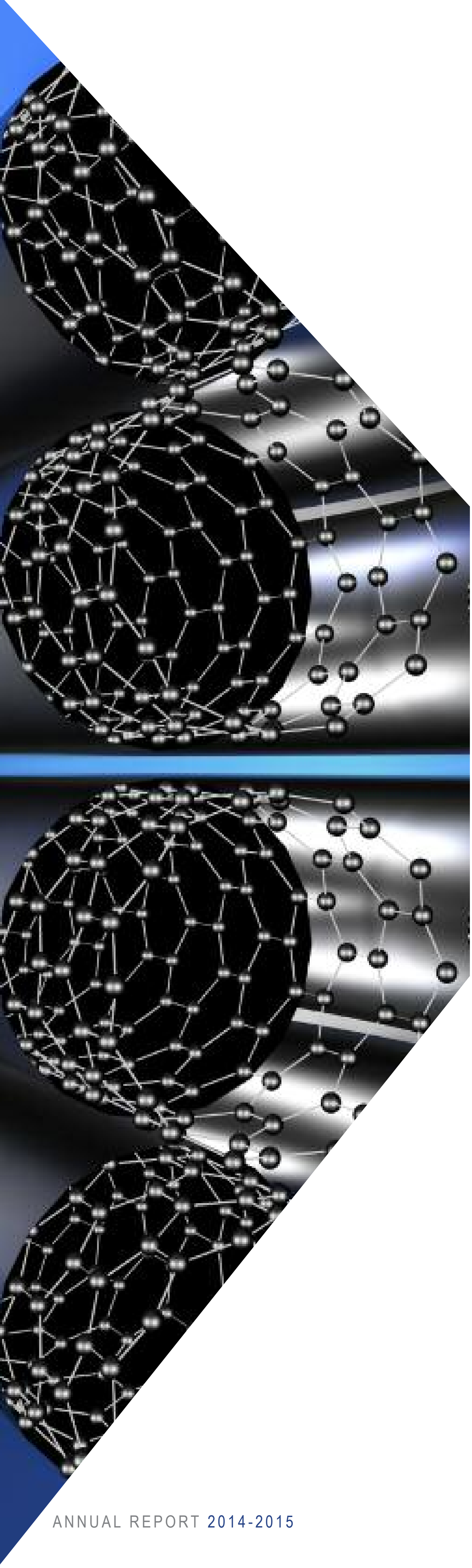
A clear understanding of the microstructure from the atomic level and up is a prerequisite for characterising novel alloys, and this project will significantly advance the fundamental science underpinning microstructural genesis in magnesium alloys based on Mg-Al-Ca-Mn, Mg-Zn-Ca-Mn and Mg-Zn-Al-Mn. This 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.

Monash University's alloy extrusion rig

HIGHLIGHTS AND ACHIEVEMENTS

- Configured an extrusion press for Mg-alloy extrusion at high speed.
- Configured and produced dies suitable for (comparatively rapid) Mg-alloy extrusion.
- Recruited and trained a technician to execute the extrusion and necessary operation work.
- Recruited a scientific research fellow.



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.

NOVEL NANOCRYSTALLINE ALLOYS FOR ELECTRIC MOTORS

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

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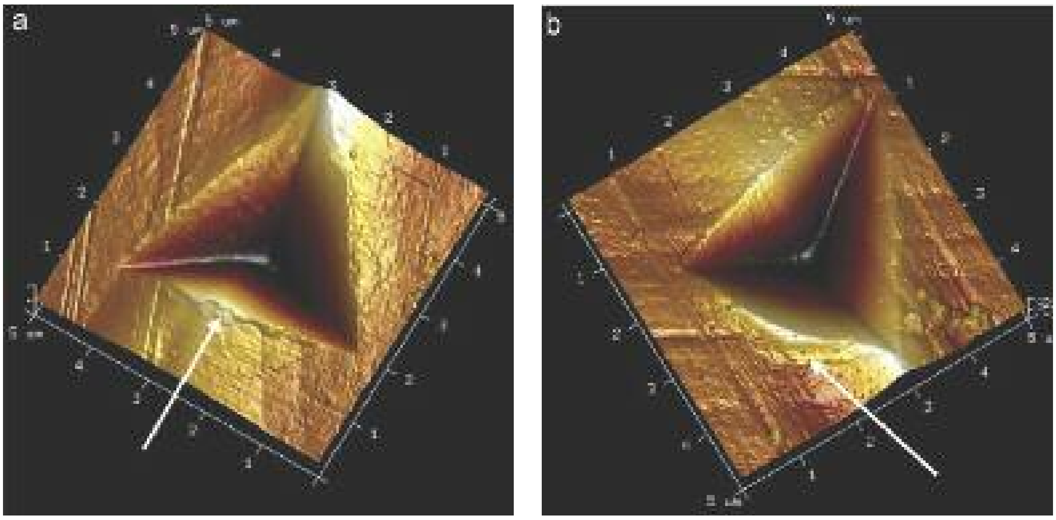


Three-dimensional images of an indented surface (70 mN load) corresponding to the (a) sample 1 annealed at 500 °C for 5 minutes, and (b) sample 3 annealed at 460 °C for 5 minutes.

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.

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, for example, 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

- Designed and carried out Mössbauer Spectroscopy experiments to explore composition change and phase transformation at different temperature in three different samples.
- Used nano-indentation to estimate the mechanical properties of small scale samples where other destructive methods such as tension, compression, etc. are not doable.
- Confirmed that the saturation magnetisation of the produced ribbons is comparable to the available commercial one.

HARVESTING WASTE ENERGY WITH THERMOELECTRIC POWER

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

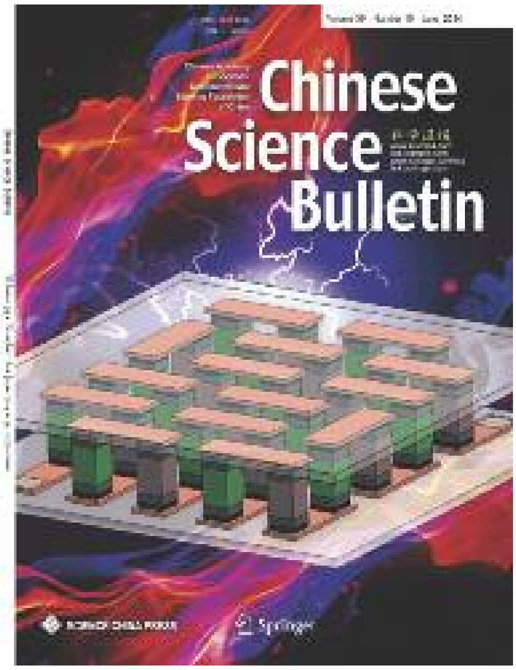
OBJECTIVES

More than 60 percent of 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.

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.



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

HIGHLIGHTS AND ACHIEVEMENTS

- Developed a robust low-cost and high-efficiency ambient aqueous approach for scalable synthesis of different surfactant-free thermoelectric metal chalcogenide nanostructures.
- Submitted details of the technology for patenting.
- Demonstrated the potential of CuAgSe to simultaneously serve (at different temperatures) as both an n-type and a p-type thermoelectric candidate.
- Prepared n-type and p-type PbTe powders for fabrication of thermoelectric modules.

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

BA11011-ARC LP120200289

SMART POLYMER HYDROGELS FOR ENERGY EFFICIENCY

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

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BA130015-ARC LP140100051

Forward osmosis testing system.

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 freshwater consumption, and effective utilisation of waste heat generated in the steel manufacturing process. Opportunities may also be exploited for Baosteel to expand the reach of this technology 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

- Investigated a polymer hydrogel-driven FO system using simulated steel mill wastewater as feed.
- Received approval for a PCT patent application relating to designs for novel bifunctional polymer hydrogels.

LOW COST SOLAR ON STEEL FOR ENERGY EFFICIENT BUILDINGS

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

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 analternative 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 cells on top of both rigid and flexible Baosteel stainless steel will accelerate high performance BIPV technology for steel construction materials towards commercialisation. As a major supplier of steel roofing materials, combining its steel technology with the most promising 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.

Dr Fangyang Liu performing buffer layer growth using a Chemical Bath Deposition method.

HIGHLIGHTS AND ACHIEVEMENTS

- Welcomed Dr Suzhen Luo, who has brought to the project her expertise in the surface treatment of stainless steel (replacing Dr Wenbo Dong).
- Explored the option of growing of CZTS on enamelled steel substrates.
- Commenced preliminary experimental work for CZTS-coated enamelled steel proof-of-concept studies.
- Fabricated CZTS absorber layers on enamelled steel substrates successfully.
- Found that the designed average precursor composition affects phase homogeneity significantly and that a low Zn/Sn atomic ratio could improve the compactness, homogeneity and phase purity.
- Investigated further optimisation on high quality CZTS grown on enamelled steel.
- Enhanced the device performance by sodium incorporation.
- Investigated a CZTS absorber with slightly higher Cu ratio.
- Investigated further optimisation on high quality CZTS grown on stainless steel.
- Developed beyond 4% efficient CZTS solar cells on stainless steel.

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BA13051-ARC LP150100911

ETHANOL ENERGY FROM STEELMAKING'S RESIDUAL H_2 AND CO

Converting syngas to ethanol with nano and micro-scale engineered MoS_2-based catalysts

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

BA1LP1100-ARC
LP0991958

OBJECTIVES

With a global imperative to develop alternatives to oil-based fuels, ethanol has emerged as a viable and direct substitute for transport petrol in low blends (e.g. 10 percent ethanol, E10). Domestic production of ethanol is possible from the waste gas that Australia currently vents or flares into the atmosphere via heavy manufacturing. Steelmaking, for example, produces large quantities of residual H_2 and CO_2, which could be converted into value-added commercial ethanol if problems relating to suitably high yields, selectivity, and process intensification were overcome.

This project addresses these issues by working on: high selectivity through new catalyst development; very close control of the reaction temperature using high thermal conductivity, geometrically structured catalyst support; and microchannel reactor architecture for high throughput. A special feature is the novel heat management approach for the reaction system to assure high selectivity-to-ethanol and good conversion. The development of a small scale, modularised gas-to-ethanol plant is expected to show how greenhouse gas emissions can be reduced substantially.

POTENTIAL IMPACT

A local E10 industry powered by steelmaking waste energy could help to reduce Australia's oil trade deficit by $1 billion per year and save $500 million per year in lower carbon imposts to industry and government. Urban air would cleaner and healthier with some fewer 25 million tonnes of CO_2 per year released into the atmosphere from cars. With the technology to convert syngas into commercially viable ethanol for use as a petrol substitute, Baosteel could pursue new opportunities in the global transport fuel market.

Miss Swathi Mukundan, a PhD student, running the laboratory-scale reaction system.

HIGHLIGHTS AND ACHIEVEMENTS

- Prepared a new series of catalysts by a micro-emulsion technique that resulted in a new composition: (0.5Ni+0.5Co)-MoS_2 and Co-MoS_2.
- Compared (0.5Ni+0.5Co)-MoS_2 and Co-MoS_2 on catalytic activities and selectivities to the Ni-MoS_2 original synthesised catalyst.
- Demonstrated the flexibility of the system to produce either oxygenated carbon compounds such as ethanol or straight hydrocarbon (diesel type), depending of the market needs.
- Successfully conducted pilot plant tests using a Ni-MoS_2 catalyst loaded on an innovative micro-channel reactor.
- Ran the pilot plant micro-channel reactor for longer periods up to 3 months to access catalyst and reaction stability.

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

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

OBJECTIVES

The intermittent use of electricity generated from renewable sources requires efficient energy storage. The development of new energy storage systems is critical if large-scale solar or wind-based electrical generation is to be practical and able to meet continuous energy demands. 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.

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 lifetime, 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

- Developed a new way to produce electrochemically prepared graphene oxide.
- Found that electrochemically prepared graphite oxide (EPGO) has very good reproducibility and the structure of EPGO is different from chemically prepared graphite oxide.
- Published a review paper in *Materials Today* (IF = 10.850).
- Filed a full patent on novel method and materials in progress.
- Prepared a manuscript based on the investigation of the structure and properties of EPGO.

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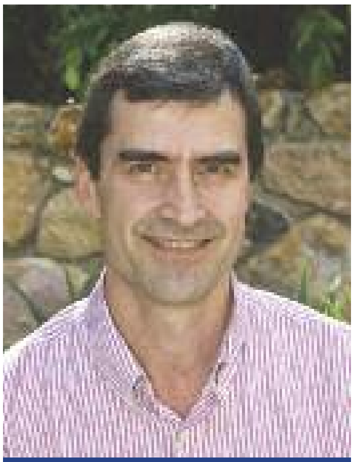
BA11006

STABLE, HIGH ENERGY CARBON-SUPPORTED SULFUR CATHODES

Designing advanced materials for a new generation of clean energy storage and supply technologies



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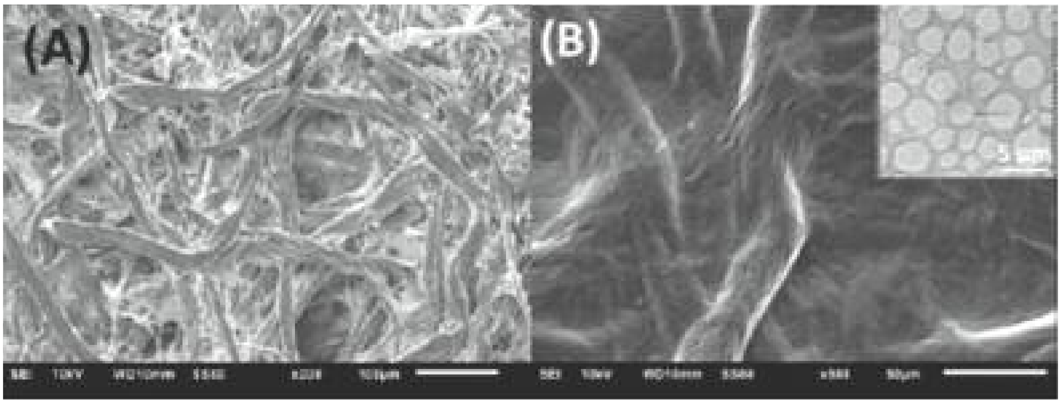
BA11016



SEM images of cellulose separator (A) and graphene oxide-coated cellulose separator (B)

OBJECTIVES

Clean energy supply, storage and utilisation are fundamental to the sustainable growth of the economy. Rechargeable high-energy batteries are attracting increasing attention for this purpose. Sulfur is a low-cost material that has potential as the basis of a high-capacity cathode for rechargeable batteries. However, sulfur cannot sustain a long battery life. Recent research has identified a new lithium-sulfur battery (Li-S) using a sulfur cathode and a lithium anode as a viable rechargeable battery option, if the limitations of instability and low electrical conductivity can be overcome.

This project is working on carbon-supported sulfur cathodes with excellent stability and high specific capacity, with a plan to incorporate them into practical high-energy Li-S batteries. The researchers are creating a novel class of core-shell structured sulfur-carbon particles with a conjugated shell using innovative Li-S technology developed at UQ, to enhance the energy and stability of the sulfur cathode.

POTENTIAL IMPACT

When the problem of sulfur cathode instability is solved, the commercialisation of Li-S batteries will accelerate. This is a much-anticipated outcome for the clean energy storage and supply market, particularly for electrical vehicles. Batteries with stable, high energy carbon-supported sulfur cathodes will greatly extend the driving distance of emission-free electrical vehicles, which will boost their convenience, efficiency and popularity.

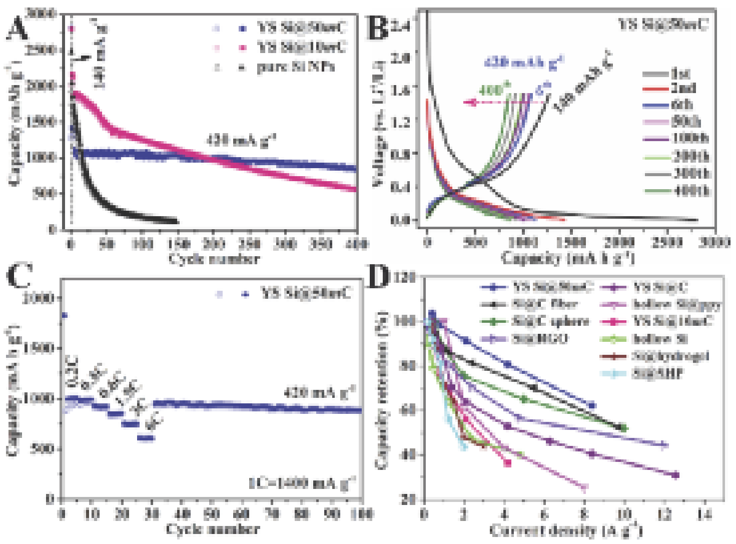
The potent attributes of these new Li-S batteries will bolster the renewable energy industry, providing efficient bridge power for wind and solar power plants, and transform power supplies in remote and disaster areas. Delivering this technological breakthrough will see Baosteel contributing significantly to the reduction of global greenhouse emissions, fossil fuel consumption, and crude oil dependence.

HIGHLIGHTS AND ACHIEVEMENTS

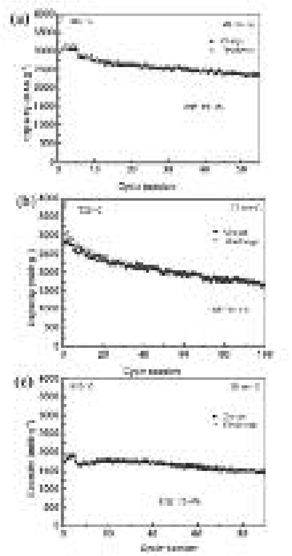
- Added graphene/MWNTs in the electrolyte to buffer the polysulfide dissolution phenomenon, leading to further improved industrial benefits.
- Conducted further continuous experiments using the synthesis of polymer encapsulated Li_xS ($0<x\leq2$) nanoparticles, the selection of new binders and functional grafting of cellulose separator with graphene oxide to boost the cathode performance, achieving very promising results.
- Submitted a BAJC Invention Disclosure for the new cathode material.

OPTIMISED ANODE MATERIALS FOR LARGE Li BATTERIES

Developing alternative high energy anode materials for safe, powerful energy storage



(A) Charge-discharge cycling performance of two represented samples YS Si@50mC, YS Si@10mC, and commercial Si NPs electrodes. (B) Charge-discharge potential profiles of the samples YS Si@50mC at different cycles at a current density of 420 mA g-1. (C) Rate performance of YS Si@50mC. (D) Rate capacity retention of YS Si@50mC, YS Si@10mC, Si@C fiber, Si@C sphere, Si@RGO, YS Si@C, hollow Si@ppy, hollow Si, Si@hydrogel, and Si@SHP electrodes cycled at various current densities.



Cycling performance of core-shell Si/C at different carbonization temperatures (a) 600 oC, (b) 700 oC, and (c) 900 oC,

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BA14006

OBJECTIVES

Electric vehicles (EVs) are expected to occupy 60 percent of the worldwide vehicle market by 2030, contributing to the global market for energy storage, which is on its way to reaching US$114 billion by 2017. Lithium ion batteries (LIBs) are widely regarded as the best choice for powering EVs, but their limitations are impeding a greater uptake of EVs at present. These include high cost; insufficient energy density for an extended driving range; low power density for easy recharge; and flammable electrolytes which affect reliability and safety.

This project is applying novel methods to study high energy anode materials and developing alternative ones with high energy capacity, high rate capability, reduced cost, and long cycle life for LIBs. The research involves characterising the electrochemical performance of Si-based anode materials at coin-cell scale; synthesising and scaling up anode materials; and testing pouch-type fuel-cells to adjust the parameters in the laboratory. The optimised Si anode materials and developed scalable technology will be transferred to Baosteel for commercial exploitation.

Cost savings are also being investigated with the use of cheaper raw materials such as Si sourced naturally from rice husks, low cost SiO_2, carbon from carbohydrates and waste materials (e.g., coal pitch tar), and binder materials like seaweed alginate.

POTENTIAL IMPACT

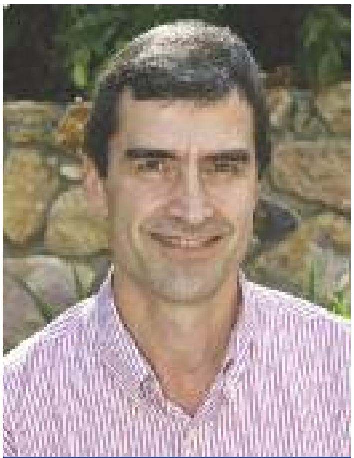
This collaborative research project will produce anode materials with optimised composition and architecture. It will also determine the means to scale the technology for fabricating these safer, high performance anode materials. The research to date has involved synthesis methods for both anode materials that are straightforward and easy to scale up. The raw materials are low cost, and no expensive synthesis facilities are required. The optimised Si anode materials and developed scalable technology can be transferred to Baosteel for commercial exploitation. The development of this innovation will create new business opportunities for Baosteel and position Baosteel and Australia at the forefront of an emerging energy storage market.

HIGHLIGHTS AND ACHIEVEMENTS

- Successfully fabricated the designed yolk-shell Si@mesoporous carbon composite (YS Si@50mC and YS Si@10mC), the core-shell silicon-carbon (Si/C) nanospheres, and Si/Fe_2O_3@carbon nanosheets.
- Achieved excellent electrochemical performances of Si @50mC.

SAFER, STABLE, POWERFUL Li-S BATTERIES

Overcoming technical obstacles to produce better anode materials for rechargeable batteries



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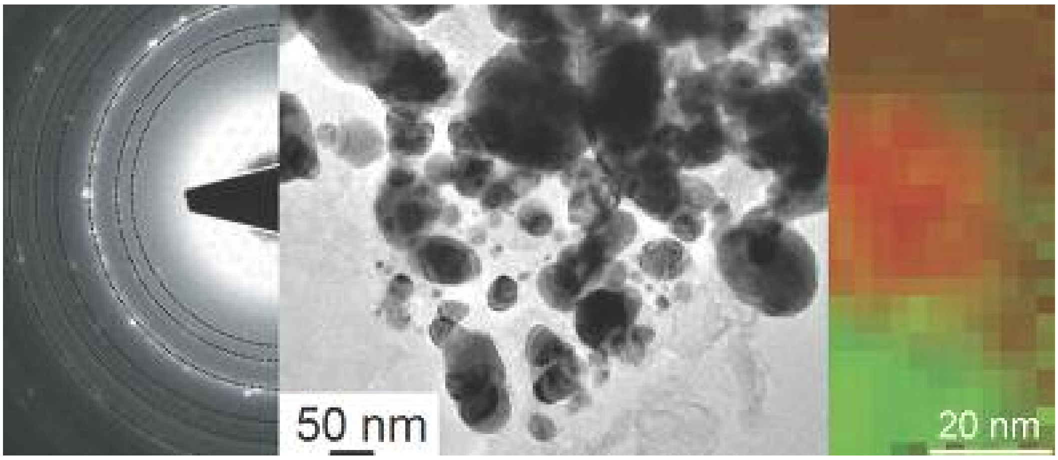
Dr Guodong Du (Baosteel)

BA14017



LiH nanoparticles prepared by the catalytic hydrogenation of lithium naphtalenide and stabilised with a conducting shell.

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 about 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.

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 unprotected metals.

HIGHLIGHTS AND ACHIEVEMENTS

- Developed a new approach to making the nanoporous carbon matrix to accommodate lithium electrodes.
- Tested a proof-of-concept method in other systems of metals, by which the metals can be sealed inside the reduced carbon materials; the technique is applicable to lithium metal particles with different dimensions.
- Confirmed that both new approaches can be performed at room temperature with no requirement for high temperature processing.

PUBLICATIONS

Since 2011, the Centre's research teams have published and presented 84 journal papers, three book chapters, 96 conference papers, and filed seven patents.

The following pages list the publications for 2014-2015.

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Wu, C. H., et al. (2014). Effect of asperity plastic deformation on the interface friction in metal forming. *12th Asia-Pacific Conference on Engineering Plasticity and Its Applications*. Kaohsiung, Taiwan.

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Wu, C. H., et al. (2015). A unified approach for characterizing multiple lubrication regimes involving multiscale plastic deformation. *Proceedings of the 42nd Leeds-Lyon Symposium on Tribology*. Lyon, France.

Xu, W. (2013). EBSD and its applications. *Short Course to Baosteel Talent Development Institute*. Shanghai, China.

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Yang, J., et al. (2015). A study of the effect of CaO/SiO2 Ratio on the crystallisation behaviour of fluoride-free mould fluxes using single and double hot thermocouple techniques. *The 6th International Congress on the Science and Technology of Steelmaking (ICS2015)*. Beijing, China.

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Yu, A. B., et al. (2014). Process modelling and analysis of iron-making processes for improving energy efficiency in Baosteel. *The 2nd Baosteel-Australia Joint Research and Development Centre Conference*. Melbourne, Australia.

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PATENTS

Jiang, Z. Y., et al. (2015). Mini Hot Rolling Mill for Equipping on a Thermal-Mechanical Simulator.

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Nie, J. F., et al. (2015). Strain-Induced Strengthening in Dilute Magnesium Alloy Sheets.

Nie, J. F., et al. (2015). Formable Magnesium Based Wrought Alloys.

FINANCIAL & GOVERNANCE

FINANCIAL SUMMARY

Financial Statement for the period from 01 July 2014 to 30 June 2015

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)
Queensland Smart Futures Fund

Cash Balance as at 01-07-2014 $3,246,026.72

INCOME (CASH)

Grant and Collaborative Research

	Baosteel R & D Fund (Round 4 - Year 1)	$900,000.00
	Baosteel R & D Fund (Round 3 - Year 2)	$750,000.00
	Baosteel R & D Fund (Round 2 - Year 3)	$940,000.00
	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	**$3,090,000.00**
	Total Leveraged ARC-Linkage Grant	$661,250.00
	Total Leveraged CRC Grant	$205,000.00
	Total Leveraged Queensland RPP Grant	$157,093.00
TOTAL INCOME (EXCLUDING IN-KIND)		**$4,113,343.00**

EXPENDITURES

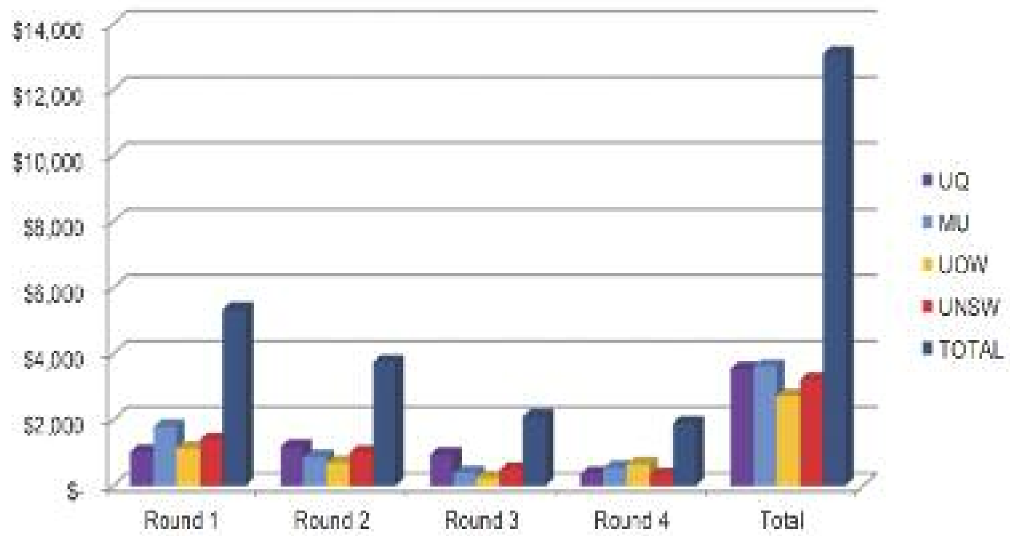
	Grant and Collaborative Research	
	Payment in cash to collaborative approved projects	$3,036,250.00
	Allocated ARC Linkage Grant	$661,250.00
	Allocated CRC Grant	$205,000.00
	Allocated Queensland RPP Grant	$157,093.00
	Total Grant and Collaborative Research Expenditures	**$4,059,593.00**
Baosteel Centre - Management		
	Personnel - salaries	$306,012.49
	Staff development costs	$25.80
	General operating (consumables, stationery, telecommunications)	$5,949.57
	Services (professional consultancy)	$17,912.72
	Equipment for office	$4,808.19
	Travel and hospitality[1]	$53,530.43
	Financial costs & taxes	$1,965.59
	Total Centre Management Expenditures	**$390,204.79**
TOTAL EXPENDITURES (INCLUDING GRANT & RESEARCH FUND ALLOCATION)		**$4,449,797.79**
Operating Result[2] Cash Balance as at 30 June 2015		**$2,909,571.93**

*Note:
1) Travel and hospitality include partial costs associated with TAC and Board meetings.
2) Cash balance includes cash funds to be paid to the approved projects in second half of calendar year 2015.

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

	Y2011-12	Y2012-13	Y2013-14	Y2014-15	Total
Baosteel	$75,000	$1,020,267	$1,132,171	$1,593,105	$3,820,543
Monash University	$965,112	$972,293	$1,398,361	$1,369,024	$4,704,790
The University of New South Wales	$1,053,928	$767,828	$1,392,810	$1,060,057	$4,274,623
The University of Queensland	$1,192,320	$1,368,430	$1,708,070	$1,803,071	$6,071,891
University of Wollongong	$381,288	$620,592	$1,053,235	$860,065	$2,915,180
Total in-kind contribution	$3,667,648	$4,749,410	$6,684,646	$6,685,322	$21,787,026

Funding Distribution ($K) by University



Leveraged Grants ($K) by University

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 8 representatives, comprising a Board Chair appointed by Baosteel, and The University of Queensland, 4 members from Baosteel (including the Board Chair), 2 members from The University of Queensland (including the Chair and the Centre Director), and 1 member each from the other participating universities. The Centre Deputy Director, who serves as the Board Secretary, and the Chair of the Technical Advisory Committee (TAC), each have observer status.

Professor G.Q. Max Lu
Board Chair
Provost and Senior Vice-President
The University of Queensland

Professor Judy Raper
Deputy Vice-Chancellor (Research)
University of Wollongong
Executive Director, Australian
Institute of Innovative Materials

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

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

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

Dr Pijun Zhang
Assistant President
Baosteel Group Corporation

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

Professor Freider Seible
Dean, Faculty of Engineering
Monash University

Dr Warwick Dawson
Director of Research
The University of New South Wales

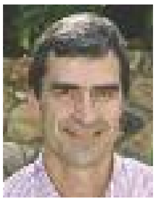
Professor Aibing Yu (observer)
Chair of the Technical Advisory
Committee (TAC)
Pro Vice-Chancellor and President
(Suzhou)
Monash University

TECHNICAL ADVISORY COMMITTEE

The Technical Advisory Committee (TAC) conducts technical assessments of research proposals and recommends funding disbursements for the Board to approve

The TAC consists of a Committee Chair, 4 internationally recognised Australia-based academics and experts recommended by the participating universities and approved by the Board, and 4 technical liaison advisors appointed by Baosteel. The TAC Chair is jointly nominated by Baosteel and The University of Queensland and approved by the Board.

Professor Aibing Yu
Technical Advisory Committee Chair
Pro Vice-Chancellor and President (Suzhou)
Monash University



Professor Ian Gentle
School of Chemistry and
Molecular Biosciences
The University of Queensland

Professor Xinhua Wu
Department of Materials
Engineering
Faculty of Engineering
Monash University

Professor Yuri Estrin
Department of Materials
Engineering
Faculty of Engineering
Monash University

Professor Shi Xue Dou
Faculty of Engineering
Director, Institute for
Superconducting and Electronic
Materials
University of Wollongong

Dr Pijun Zhang
Assistant President
Baosteel Group Corporation

Emeritus Professor David Young
School of Materials Science and
Engineering
The University of New South Wales

Dr Laizhu Jiang
Senior Engineer
Vice 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

MANAGEMENT TEAM AND PARTNER UNIVERSITIES

MANAGEMENT TEAM

The Management Team comprises the Director (50% full time equivalent), a Deputy Director and a Centre Operations and Finance Officer. 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 also responsible for organising Technical Advisory Committee meetings and the Centre's annual conference, hosting visits from Baosteel personnel, and managing the website. A Baosteel coordinator also participates in the Centre's management.

Centre Director
Professor Victor Rudolph, The University of Queensland

Centre Deputy Director
Professor Geoff Wang, The University of Queensland

Centre Operations and Finance Officer
Ms Wendy Zhang, The University of Queensland

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

AUSTRALIAN PARTNER UNIVERSITIES

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

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

UNSW AUSTRALIA

The University of New South Wales
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Telephone: +61 2 9385 1000

MONASH University

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

UNIVERSITY OF WOLLONGONG

University of Wollongong
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Wollongong, New South Wales
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CONTACT DETAILS

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Deputy Director: Professor Geoff Wang

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