Session 4: Early Career Professionals Session

Dr Pedro Yunes
“Overview of the waste recycling process in the Zinc smelter at Nyrstar Port Pirie”

Presented by
Dr. Pedro Yunes
Nyrstar Port Pirie
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• Nyrstar – Company Overview
• Nyrstar – Port Pirie
• Process Flow
• Slag Fuming and Kiln Process Operations
• Recycling in the Slag Fuming Process
• The Transformation – Securing our Future
Company Overview

Nyrstar at a glance

Nyrstar is an integrated mining and metals business with market leading positions in zinc and lead, and growing positions in other base and precious metals; essential resources that are fuelling the rapid urbanisation and industrialisation of our changing world. Nyrstar has mining, smelting, and other operations located in Europe, the Americas, China and Australia. Nyrstar is incorporated in Belgium and has its corporate office in Switzerland.

Fast facts...

- Nine mining operations
- Six smelters
- Approximately 7,000 employees across five continents
- Listed on NYSE Brussels: NYR

By region

Australia (1,233)
Europe (1,453)
Americas (4,284)

By segment

Mining (3,991)
Smelting (2,788)
Corporate (191)
The world of Nyrstar
Nyrstar Port Pirie

Fast facts...

Location
- Port Pirie, South Australia

Technology
- lead smelter – sinter plant, blast furnace and refinery
- zinc – slag fuming leach electrowin
copper – solvent extraction/electrowin (SXEW)

Products
- Commodity grade lead, zinc, silver, copper cathode, gold and sulphuric acid

Employees
- 734

Production 2012
- 158,000 tonnes lead metal
- 31,000 tonnes zinc metal
- 3,000 tonnes copper cathode
- 13,806,000 troy ounces silver
- 56,000 troy ounces gold
Slag Fuming and Kilns - Process Operations

- Blast Furnace Slag
- Rich Slag Mix
- Spent Slag
- Secondary Air (cold)
- Natural Gas

Slag Fuming Furnaces

PCI

Secondary Air (hot)

Recuperators

Bag House

Weak Wash Water

Rotary Kilns

Ball Mills

Leach Plant
Slag Fuming and Kilns Process Operations

WESTERN SIDE OF THE SLAG FUMING PLANT

ROTARY KILN #2
Slag Fumer – Internals

% Boiler Ash in Rich Slag Mix (35% Zn)

% Skull fines in Rich Slag Mix (15% Zn)

% Zn Dross Fines in Rich Slag Mix (61% Zn)

% KDR U/F in Rich Slag Mix (35% Zn)
Slag Fumers – External

% EAF Dust in Rich Slag Mix (30% Zn)
The Transformation – Today

From being primarily a lead smelter…. 

Schematic of the sinter plant that will be phased out
The Transformation – Tomorrow

...to become an state-of-the-art poly-metallic processing and recovery facility
The Transformation - Benefits

- Step change reduction in emissions from the site
- Greater flexibility for processing wider range of raw materials
- Key e-waste materials can be recovered (Au, Ag, Ge, In, Te, etc)
- Energy content in plastics will be recovered to reduce coal consumption
The Transformation – Securing Our Future

The Present

Australia has no facility to process and recover the valuable metals in this growing waste stream.

The Future

The transformed Port Pirie facility will have the process capability to meet this need.
Questions ??

Thanks for your attention
Session 4: Early Career Professionals Session

Lisa Green
Working with Industry to Achieve Compliance

Lisa Green
Intelligence Unit
Department of Environment and Heritage Protection
Background to EHP

Mission:

Strong environmental regulator which supports sustainable long-term economic development in Queensland

Enabled by:

– Building relationships with government, business, industry and the community
– Innovative, evidence-based environmental policies, programs and services
Regulatory Strategy

- Greentape – streamlining application processes to reduce regulatory burden, increasing compliance effort
- Department to work with industry
- Compliance priorities are targeted, transparent, risk based
- Good performers monitored less, poor performers monitored more
Regulatory Strategy

- Greentape - streamlining application processes to reduce regulatory burden, increasing compliance effort
- Department to work with industry
- Compliance priorities are targeted, transparent, risk based
- Good performers monitored less, poor performers monitored more

Greentape Reduction
Smarter greener partnerships
Waste Industry

- Much of Queensland’s waste is sent straight to landfill – valuable resources are being lost
- Waste levy was repealed following 2012 Queensland State Elections
- Challenge – encourage innovation and investment in the state’s recycled waste industry without a levy
- Queensland is currently reviewing its waste strategy through an ‘industry-led’ process
Compliance

• Department has increased compliance effort
• Compliance focus is risk-based, targeted and transparent
• Compliance is not intended to inhibit industry’s drive for innovation
• It is to: understand where key risks exist, why they exist and develop effective and appropriate strategies to target these risks
• The department will take prompt, strong enforcement action to those who intentionally choose not to comply
Intelligence-Led Compliance

• **Purpose:**

  *Collate and analyse information to understand risk to inform policy development and compliance planning*

• **This function:**
  – monitors and identifies risk
  – establishes causes of non-compliance
  – identifies instances of unlicensed activity
  – monitors and informs management and officers of new technologies and processes
Composting

- Composting is a growth industry which promotes reuse and recycling of waste.
- Odour and waste acceptance are risk areas to the department.
- Developed a capacity building project to work with industry.
- Incorporates industry-led waste strategy review.
Unlined Landfills

• Leachate is a key risk of unlined landfills
• Intelligence Unit is analysing data from a variety of sources to identify high risk unlined landfill sites
• The department will work with site operators and incorporate new technologies to improve monitoring
Summary

Sustainable development is a collaboration between regulators, industry and the community.

The department will increase its monitoring to ensure compliance.

Business and industry are best-placed to work out how to stay compliant.

EHP will work collaboratively with industry and the community to develop standards, policies to manage and protect environment and heritage yet assist investment in the state’s recycled waste industry.
Session 4: Early Career Professionals Session

Dr Nawshad Haque
Life cycle based greenhouse gas footprints of metal production with recycling scenarios

Dr Nawshad Haque, Team Leader
4 October 2013
Outline

• Introduction to LCA
• LCA of mining and metals
• Material recovery facility
• Boundary and assessment
• Key results for steel and aluminium
• Concluding remarks
Life cycle

Resource

Extraction

Processing & Manufacturing

Transport

Landfill

Use phase

Use and Maintenance

Packaging and Distribution

Disposal

Recycling of Materials and Components

Reuse

Extraction of Raw Materials

Recovery

Design and Production

SMaRT@UNSW 2013 International Sustainability Symposium
Stages of LCA

- Goal and scope definition
- Inventory analysis
- Impact Assessment
- Why and for whom?
- Boundary demarcation, data collection
- Impact category selection, characterisation
- Assessment, interpretation, sensitivity analysis
- Update & improvement with new data
Assessment - LCA Impact/Indicators

Environmental interventions
- Raw material extraction
- Emissions (in air, water and soil)
- Physical modification of natural area (e.g., land conversion)
- Noise

Impact categories
- Climate change
- Resource depletion
- Land use
- Water use
- Human toxic effects
- Ozone depletion
- Photochemical ozone creation
- Ecotoxic effects
- Eutrophication
- Acidification
- Biodiversity

Damage categories
- = Midpoints
- = Endpoints

Areas of Protection
- Human health
- Resource depletion
- Ecosystem quality
Example flowsheet
Metals – “Cradle-to-Gate” – GWP

LCA works of CSIRO in Mining & Metals

Nawshad Haque
Scientist, CSIRO
Life cycle assessment - mineral processing - drying
Verified email at csiro.au
Homepage

Citation indices

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Citations to my articles

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<td>Energy and greenhouse gas impacts of mining and mineral processing operations</td>
<td>56</td>
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<td>Journal of Cleaner Production 18 (3), 266-274</td>
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Material Recovery Facility (MRF)

- Courtesy (Visy, 2013)
Material Recovery Facility (MRF)

Household → Kerbside → Truck → Manual sorting line → General waste

Steel

Steel magnet → Steel, aluminium, plastic → Star screen sorting → Paper waste

Aluminium

Eddy current separator → Plastic → Glass sorting line → Glass breaker → Glass

Paper mill
MRF Product Composition

Source: Sustainability Vic (2011)
MRF Product Revenue (crude estimate)
MRF GHG footprint distribution

- Trommel screen
- Front-end loader
- Conveyor
- Glass breaker
- Magnetic separator
- Eddie current separator
GHG footprint of recycled steel if sent overseas for reprocessing

Gross total recycling footprint = 703 kg CO₂-e/t steel

cf Gross total for blast furnace route footprint = 2,030 kg CO₂-e/t primary steel
GHG footprint of recycled aluminium if sent overseas for reprocessing

Gross total recycling footprint = 1,607 kg CO₂-e/t recycled aluminium

cf Gross total footprint = 24,000 kg CO₂-e/t primary aluminium (coal based electricity)
Key messages

• Process evaluation assists with decision making
• Life Cycle Assessment (LCA) is a recognised objective tool
• Metals have different specific carbon footprint
• Specific carbon footprint is not the only story but consider the overall total production of particular metal
• Carbon footprint can be reduced with various measures such as recycling
• Collection GHG can be 10 times higher than MRF GHG
• Most benefit of GHG reduction if it is processed locally
• There are other environmental and social impacts need consideration
International activities and engagements

• Australia-India Workshop on LCA for mining, mineral processing metal making industries
• Dates: 20 & 21 January 2014
• Will be supported by Indian School of Mines University and Australia India Council division of DFAT

• Working under CSIRO-KIGAM Korea collaboration on rare earth and recycling

• Bangladesh CSIR and CSIRO Collaboration on metals and mineral sands processing
• Hosted Ministerial delegation visit, developed list of action items about process evaluation and other studies
• Mineral samples analysed, recommendations made
• Secondment of a BCSIR staff and a joint workshop planned in January 2014
Acknowledgements

• For assistance & supports:
  • CSIRO Colleagues (T. Norgate, Dr. S. Jahanshahi, Dr. J. Rankin, A Monch, S Northey, A Littleboy, M Cooksey)

• An unnamed City Council

• For more information:
  • Explore website csiro.au
Thank you

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Session 4: Early Career Professionals Session

Manudha Herath
Structural Optimisation Using Bend-Twist Coupling For Wind Turbine Blades

Prepared By: Mr Aaron Lee

Supervisor: A/Prof. B. Gangadhara Prusty

Co-Supervisor and Presenter: Mr Manudha (Thinu) Herath
Presentation overview

- Background
- Introduction of shape-adaptive blades
- Past research findings
- Our approach - Preliminary design framework
  - Differential Stiffness Bend-Twist (DSBT) Coupling
  - Composite material layup optimisation
- Summary and future work
Why should we study wind turbines?

According to the U.S. National Renewable Energy Laboratory (NREL)....

- Class 5 & 6 wind farm sites
  - Higher wind speeds
  - 7.5 – 8.8 m/s
  - 500 miles away from load centres (class 6)
- Sites are limited
- Most desirable sites have been developed

- Class 4 wind farm sites
  - Lower wind speeds
  - Avg. 7.25 m/s
  - 100 miles away from load centres
- Contains 20 times the wind potential
- Lower transmission cost
Why should we study wind turbines?

In Australia…

- High wind energy potential along the southern coast
- Class 4-6 onshore wind farm sites found
- Renewable Energy Target: 20% of electricity from renewable sources in 2020
- Plenty of wind farms currently being developed

Ref: Geoscience Australia and ABARE, 2010
What are shape-adaptive wind turbine blades?

- Geometry changes based on:
  - Turbine rotation speed
  - Incoming wind speed
- Loads experienced varies
- Pitch angle changes according to the bending loads applied
- Achieved by bend-twist coupling

Ref: Capellaro, 2012

Structural Optimisation Using Bend-Twist Coupling
For Wind Turbine Blades
What is bend-twist coupling?

- One of the passive pitch control methods
- Bending introduces torsional deformation
- Usually achieved by using the anisotropic properties of composites

Ref: Jones, 1999
Why do we need shape-adaptive blades?

- For bend-twist coupled blades that twist towards feather:
  - Bending load increases as wind speed increases
  - Induced twist lowers the pitch angle
- Lower aerodynamic loads experienced
  - Reduced fatigue damage
    - Lower maintenance cost
    - Extended service life
  - Weaker, lighter structures can be use
    - Larger blades can then be designed
    - More energy can be captured
- Design improvements promote the development of low-wind speed sites
Past research findings

- Instability observed for coupled blades twisting towards stall
- Lower fatigue loads for coupled blades twisting towards feather

Ref: Adapted from Lobitz and Laino, 1998
Past research findings

- Damage normalised to the uncoupled blade
- 3 types of materials
  - Welded Steel (3)
  - Aluminium (6)
  - Composite (9)
- 3 wind speed settings
  - 8, 14 & 20 m/s
- Fatigue damage reduced for all coupled blades twisting towards feather

Ref: Adapted from Lobitz and Laino, 1998
Past research findings

- Not pre-twisted
  - no power regulation
  - Increased average power
- Pre-twisted
  - Max. power regulated
  - Resemble typical operation
  - Average power is similar to that of uncoupled blades
- Primary benefit of coupled blades is load reduction

Ref: Adapted from Lobitz and Laino, 1998
Past research findings

- Conventional design approach
  - Fibres placed at an angle to the flexural axis to create biased laminates
  - Biased laminates applied either at the skin panels or the spar caps
- Strain incompatibilities found
  - Upper and lower skin joint
  - Spar cap/web connection

Ref: de Goeij et al., 1999
Our approach - DSBT coupling

- Definition of Differential Stiffness Bend-Twist (DSBT) coupling:

  “to control the bend-twist coupling of the global structure by incorporating structural sub-components with distinctly different stiffness values that would experience bending as their main deformation”

- Avoids the design of bend-twist coupled sub-components
  - Minimise/eliminate strain incompatibilities at joints
Our approach - Preliminary design for DSBT blades

- Blade profile, Pressure loads
  - Model idealisation
    - Stiffener geometry
    - Number of stiffeners
    - Stiffener positions (spacing)
    - Skin thickness
  - Boom areas
  - Boom locations
  - Loads in components

- Structural idealisation
  - Numerical analysis
    - Young’s modulus distribution
  - Maximum deflection < Acceptable limit?
    - Yes
    - Achieved desired change in pitch angle?
      - Yes
      - Young’s modulus values
      - No
      - Achieved desired change in pitch angle?
        - Yes
        - Young’s modulus values
        - No
          - Preliminary material design
            - Composite layup sequence
            - Ply layup sequences

- Finite Element analysis
  - Composite layup optimisation

Preliminary design of DSBT blade

Structural Optimisation Using Bend-Twist Coupling
For Wind Turbine Blades

SMaRT@UNSW
Our approach - DSBT coupling

- Stiffeners are the structural sub-components
- They are used to introduce bend-twist coupling
- Differential bending
  - Stiffeners with higher stiffness displace less
  - Vice versa
- Introduces twist in overall structure
Our approach – DSBT feasibility study

- Structural idealisation
  - Existing technique
  - Used in aircraft structural design
  - Stiffeners replaced by booms
  - Booms carry all bending loads
  - Skin panels only carry shear load

Ref: Megson, 2007
Our approach – DSBT feasibility study

- Finite Element analysis
  - Idealised thin-walled box beam studied
  - Cantilevered boundary conditions
  - Dimensions and material properties parameterised
  - Booms modelled with beam elements
  - Skin modelled with shell elements
Our approach – DSBT feasibility study

- Uncoupled model
- Uniform Young’s modulus distribution
- Uniform bending observed
- No twist
Our approach – DSBT feasibility study

- DSBT model
- Higher Young’s modulus value applied to the left booms
- Differential bending observed
- Twist of 3.28 degrees at tip
- Main deformation in booms remained as pure bending
Our approach - Composite layup optimisation

- Limited Young’s modulus values from typical isotropic materials
  - Steel alloys (ASTM A36)
    - $E = 200 \text{ GPa}$
  - Aluminium alloys (Al2024-T3)
    - $E = 74 \text{ GPa}$

- Composites can provide a range of effective Young’s modulus by varying the layup
  - Carbon fibre composite (AS4/3501-6)
    - $E_1 = 126 \text{ GPa}$
    - $E_2 = 11 \text{ GPa}$

- Genetic Algorithm is used to search for optimum layup
Our approach - Composite layup optimisation

- Material design – formulate requirements
  - Sub-components remain in pure bending
  - Composite bending stiffness matrix:

\[
\begin{bmatrix}
M_{xx} \\
M_{yy} \\
M_{xy}
\end{bmatrix} =
\begin{bmatrix}
D_{xx} & D_{xy} & D_{xs} \\
D_{yx} & D_{yy} & D_{ys} \\
D_{sx} & D_{sy} & D_{ss}
\end{bmatrix}
\begin{bmatrix}
\kappa_{xx} \\
\kappa_{yy} \\
\kappa_{xy}
\end{bmatrix}
\]

- Composite bending Matrix:

\[
\begin{bmatrix}
M_{xx} \\
M_{yy} \\
M_{xy}
\end{bmatrix} =
\begin{bmatrix}
D_{xx} & D_{xy} & D_{xs} \\
D_{yx} & D_{yy} & D_{ys} \\
D_{sx} & D_{sy} & D_{ss}
\end{bmatrix}
\begin{bmatrix}
\kappa_{xx} \\
\kappa_{yy} \\
\kappa_{xy}
\end{bmatrix}
\]

- In-plane loads and out-of-plane deformations are decoupled
  \[D_{xx} = \frac{EI_{xx}}{b}, \quad D_{xs} = D_{sx} = D_{ys} = D_{sy} = 0\]

  Other \(D\) matrix elements are not of interest at this stage

- Cross-ply balanced symmetric layup sequence required
Our approach – Genetic Algorithm program

- In-house Genetic Algorithm (GA) program used for optimisation
  - Input variables: Fibre orientation angle of each ply
  - Target: Required $D$ matrix values
  - $f(\theta)_{\min} = |D_{xx req} - D_{xx GA}|$

- GA optimisation procedure
  - 1st generation randomly formulated
  - Evaluate error
  - Formulate next generation through natural selection, cross-over of parent generation and mutation
  - Iterate until satisfactory results are obtained
Our approach - Genetic Algorithm program

- Required:

\[
D_{32\text{GPa}} = \begin{bmatrix} 124416 & D_{xy} & 0 \\ D_{yx} & D_{yy} & 0 \\ 0 & 0 & D_{ss} \end{bmatrix}
\]

- Achieved by GA program:

\[
D_{32\text{GPa}} = \begin{bmatrix} 124416.78 & 8850.99 & 0 \\ 8850.99 & 62846.83 & 0 \\ 0 & 0 & 18651.03 \end{bmatrix}
\]

- Required:

\[
D_{25\text{GPa}} = \begin{bmatrix} 97200 & D_{xy} & 0 \\ D_{yx} & D_{yy} & 0 \\ 0 & 0 & D_{ss} \end{bmatrix}
\]

- Achieved by GA program:

\[
D_{25\text{GPa}} = \begin{bmatrix} 97199.01 & 8850.99 & 0 \\ 8850.99 & 90064.59 & 0 \\ 0 & 0 & 18651.03 \end{bmatrix}
\]
Summary

- Preliminary design procedure
  - Structural idealisation
  - Finite element analysis to predict twist
  - Genetic algorithm for layup optimisation
- DSBT is a feasible concept
  - Achieved by applying non-uniform Young’s modulus distribution in sub-components
- Composite layup can be optimised
  - Provides the required Young’s modulus value
Future work – where to now?

- Experimental verification of the DSBT concept
- Improve the design procedure by:
  - Adapt the procedure for complex non-symmetrical structures
  - Integrate the FE analysis and the GA program
  - Consider different load cases
  - Incorporate failure theories
Structural Optimisation Using Bend-Twist Coupling For Wind Turbine Blades

References


Thank you

Questions??
Session 4: Early Career Professionals Session

Hewitt Park
The influence of CaO-Fe$_x$O$_y$-Al$_2$O$_3$-SiO$_2$ oxide system on the reduction of carbon composite pellet

04/10/2013

Hewitt Park* and Veena Sahajwalla

Centre for Sustainable Materials Research & Technology (SMaRT@UNSW)
SMaRT Centre

SMaRT@UNSW
Centre for Sustainable Materials Research and Technology
Director
Professor Veena Sahajwalla

Thermo gravimetric analyzer (TGA)
Horizontal Furnace & gas analyzer
Fixed bed reactor
BET machine
Drop Tube Furnace (DTF)
Why Carbon Composite Pellets?

- Depletion of high quality coal and iron ore
- CO$_2$ Emission Kyoto protocol 20% ↓ by ‘2020
- Diversifying carbon sources (Non-coking coal, hydro carbons)
- Utilization of secondary materials (mill scale, dust and slags)
- Consumption of low grade ores (goethite, limonite etc.)
- Sustainable development of steelworks
- Depletion of high quality coal and iron ore
- CO$_2$ Emission Kyoto protocol 20% ↓ by ‘2020
- Diversifying carbon sources (Non-coking coal, hydro carbons)
- Utilization of secondary materials (mill scale, dust and slags)
- Consumption of low grade ores (goethite, limonite etc.)
- Sustainable development of steelworks
Direct reduced iron (DRI) making process

- Mill scale
- Iron ore
- Coal

Raw material storage pile

Rotary Heart Furnace (RHF)

Room temp. → 1723K (1450°C)
Coal composite iron ore pellet

ITmk3 process®

Floor of rotary hearth furnace

8 ~ 12 minutes

DRI

FASMET®, INMETCO®

Electric Arc Furnace (EAF)

Iron nugget

Hot Metal

Iron nugget

Slag??
Thermodynamics of slags

CaO – SiO$_2$ – Al$_2$O$_3$ – MgO – Fe$_x$O –..

Mass %  35 - 45  30 - 40  12 - 18  3 - 8

Table 1. Index of slag basicity (Ban-ya, 1988)

<table>
<thead>
<tr>
<th>Classification of oxide</th>
<th>Oxide</th>
<th>Electro-negativity of cation</th>
<th>Cationic radius (Å)</th>
<th>Ion-oxygen attraction</th>
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<td>↑</td>
<td>CaO</td>
<td>1.0</td>
<td>0.99</td>
<td>0.70</td>
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<tr>
<td>Basic</td>
<td>FeO</td>
<td>1.7</td>
<td>0.75</td>
<td>0.87</td>
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<td>↑</td>
<td>MgO</td>
<td>1.2</td>
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<td>Intermediate</td>
<td>Fe$_2$O$_3$</td>
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<td>0.60</td>
<td>1.50</td>
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<td>Al$_2$O$_3$</td>
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<tr>
<td>Acidic</td>
<td>SiO$_2$</td>
<td>1.8</td>
<td>0.41</td>
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Research interests

1. CaO-SiO$_2$-Al$_2$O$_3$ ternary oxide system
2. Influence of dolomite (MgO)
3. Raw materials from steelworks
Research objective

- Understand the influence of CaO-Fe$_{x}$O$_{y}$-Al$_2$O$_3$-SiO$_2$ oxide system on the reduction behavior of carbon composite pellet
- Investigate the individual effect of alumina and silica on the reduction
- Obtain enough reduction degree of pellets at low temperature below 1473K (1200°C)
- Discover the optimum reaction condition (temperature, compositions) for carbon composite pellet
Effect of CaO-SiO$_2$-Al$_2$O$_3$ ternary system

Chemical composition

- Silica-rich oxide
- Blast furnace slag
- Alumina-rich oxide

T = 1500°C (1773K)

A schematic apparatus

Sample specification

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<th>Diameter &amp; Weight</th>
<th>10mm &amp; 1.0 - 1.2g</th>
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<tr>
<td>Oxides amounts</td>
<td>10wt% of pellet weight</td>
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- **In-situ & Microscopic study**

- **In-situ visual image**
  - A. Silica-rich oxide system
  - B. Blast furnace slag system
  - C. Alumina-rich oxide system

- **Optical microscopic image**
  - 30 sec. 2 mm
  - 120 sec. 2 mm
  - 300 sec. 2 mm
**X-Ray Diffraction analysis**

![X-Ray Diffraction Analysis](image1)

A. Silica-rich oxide system

B. Blast furnace slag system

C. Alumina-rich oxide system

**Reaction rates (Infrared gas analysis)**

![Reaction Rates](image2)

Fig.3 Reacted fraction of carbon composite pellet at 1773K(1500°C)
Mechanical property & Optimum carbon contents

- Shapes of pellets

Fig.4  Compressive strength of pellet after reduction
### Table 2. Chemical composition of pellets

<table>
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<th>Sample</th>
<th>Composition of oxides</th>
<th>Total Weight (g)</th>
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<tr>
<td>CF2</td>
<td>15</td>
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### Table 3. Chemical details (Supplied by Sigma-Aldrich Australia)

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<thead>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>≥ 99.0%</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>~99%, 0.5-10µm</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>99.7%, 10µm</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>≥ 99%, &lt;5µm</td>
</tr>
<tr>
<td>Graphite</td>
<td>Flakes</td>
</tr>
</tbody>
</table>
**Experimental equipment**

Balancing equipment

Cooling water

Expansible bellow

Suspension wire

Alumina tube

Heating element

Isothermal zone

Thermocouple

Purging gas

**Weight change**

**Reaction conditions**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>1000-1200°C</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>30 min.</td>
</tr>
<tr>
<td>Gas atmosphere</td>
<td>Argon gas flow (1L / min.)</td>
</tr>
<tr>
<td>Crucible</td>
<td>Alumina</td>
</tr>
</tbody>
</table>

Fig. 6 Thermo Gravimetric Analyser (TGA)
Thermodynamic & kinetic study

Temperature dependence

Weight loss

Fig. 7 - Temperature dependences of reduction degree for CF2 sample compared to previous research

Fig. 8 - Effect of Al₂O₃ and SiO₂ on the weight loss of carbon composite pellets during reduction at 1200°C
Thermodynamic & kinetic study

- **Reduction degree**

[Graph showing reduction degree of pellets at 1200°C]

- **Uniform international reduction**

[Graph showing ln(1-X) plot with time at 1200°C]

1. **Rate equation**: \( \ln(1 - X) = -k \cdot t \)


2. \( \ln(1 - X) = -k \cdot \left( P_{CO_2} - P_{CO_2}^{eq} \right) t \)

Jeremy and Veena; ISIJ International, 2003

3. Reaction rate \( \propto \) Surface area

4. New kinetic model of reaction:

\[
\ln(1 - X) = -k \cdot S \cdot (P_{CO_2} - P_{CO_2}^{eq}) \cdot t
\]
X-ray Diffraction (XRD) results

- Fe$_2$O$_3$
- Fe
- CaO
- CaAl$_2$O$_4$
- Fe$_2$SiO$_4$
- Fe

SEM / EDX results

- Fe
- CaO
- Fe$_2$O$_3$
- CaAl$_2$O$_4$
- Fe$_2$SiO$_4$

20.0kV 10.6mm x 500 BSECOMP

20.0kV 10.4mm x 1.00k BSECOMP
Conclusions

✓ A study on the effect of CaO-Al\textsubscript{2}O\textsubscript{3}-SiO\textsubscript{2} ternary oxide system at 1500\degree C
  • Silica-rich pellet was disintegrated due to the violent reaction, while alumina-rich pellets maintained denser internal structure through overall reduction process.
  • Silica-rich systems formulated fayalite phase which have delayed solid-gas reaction, while alumina rich system did not show any critical change in morphology due to its low solubility to iron oxide.

✓ An investigation on the individual effect of alumina and silica at 1200\degree C
  • While silica slows down the overall reaction, alumina increases reaction rate
  • Alumina content supports the pellet to maintain large surface area due to its high melting temp.
  • Development of new kinetic model for carbon composite pellets

\[
\ln(1 - X) = -k \cdot S \cdot (P_{CO_2} - P_{CO_2}^{eq}) \cdot t
\]
Thank you for attention