The Selection Design and Application of Mill Liners for Large Wet Grinding Mills

Presented by Damian Connelly
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Key Attributes

Pragmatic, efficient, complete engineering through quality, personalised & exceptional service delivery

> Working globally since 1988
> Dynamic and innovative niche consultancy
> Dedicated team providing customised service
> Specialist in Mineral Processing & Engineering Projects
> Unique solution finder
Introduction

- History is that mill liners have evolved over time

- Liner design has a significant effect on mill performance and liner life

- Engineering approaches have highlighted mill performance with mill modelling and the use of improved materials

- Liner design, with the advent of large diameter SAG mills, the issues of design, selection, monitoring and evaluation of mill performance is critical

- Mill trajectory modelling can be used to great effect in improving liner design
Liners and Lifters

- Protect the outer shell of the mill from wear and damage
- Enhance the efficiency of the grinding process
- Need to be replaced regularly

- Steel liners advantages
  - Cope with variety ores
  - Superior large AG/SAG, ball mills
  - Robust application

- Rubber liners advantages
  - Softer ores
  - Less noise
  - Ease of replacement

Source: Metso website (2013)
High Aspect SAG Mill

- Crushed Feed and Cyclone Underflow
- Trunnion Bearings
- Shell
- Liners and Lifters
- Grate
- Girth Gear
- Trommel
- Discharge
- Scats
Grate Inside A SAG Mill

Source: Growth Steel Group Library (2013)
Factors Influencing the Grinding Rate

- The mill density
- Characteristics of the grinding media
- Viscosity
- The chemical environment
- Lifter and liner arrangement
- Grate discharge
- The mill load
- Temperature
- pH
- Feed size and type
- Mill speed % critical

![Mill Power Vs Mill Speed](chart.png)
Types of Liners

- Solid wave
- Grid liners
- High low double wave
- High low lifters
- Wedged liners
> For large mills these are mandatory

> Requires flat floor mill surrounds as a part of the design

> Access and space to store liners. Retractable feed chute
Integral units with integral lifters

Traditional cast liners - designs vary

High scrap weight

Few pieces and easy to install

Mill performance deteriorates over the liner life (this can be said for all liner types after reaching optimal performance)

Source: Growth Steel Group Library (2013)
Grid Liners

- Developed in South Africa
- Suited to high critical speed applications
- Economic for highly abrasive ores
- Low scrap weight
- Removal can be difficult—manganese flows
- Safety inside mill—balls drop

Source: Growth Steel Group Library (2013)
High Low Double Wave

- Commonly used and convenient (picture is a “hump” design commonly used in ball mills)
- Correct wave angle needs to be specified
- Require ongoing development to get right

Source: Growth Steel Group Library (2013)
High Low Lifters

- Economical and convenient
- Alternating change outs
- Used in primary SAG mills
- Applicable where ore packing is not an issue

Source: Growth Steel Group Library (2013)
## Characteristics of Cast Irons

Comparative qualities of cast irons \[4\]

<table>
<thead>
<tr>
<th>Name</th>
<th>Nominal composition [% by weight]</th>
<th>Form and condition</th>
<th>Yield strength [ksi (0.2% offset)]</th>
<th>Tensile strength [ksi]</th>
<th>Elongation [% (in 2 inches)]</th>
<th>Hardness [Brinell scale]</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey cast iron (ASTM A48)</td>
<td>C 3.4, Si 1.8, Mn 0.5</td>
<td>Cast</td>
<td>-</td>
<td>50</td>
<td>0.5</td>
<td>260</td>
<td>Engine cylinder blocks, flywheels, gearbox cases, machine-tool bases</td>
</tr>
<tr>
<td>White cast iron</td>
<td>C 3.4, Si 0.7, Mn 0.6</td>
<td>Cast (as cast)</td>
<td>-</td>
<td>25</td>
<td>0</td>
<td>450</td>
<td>Bearing surfaces</td>
</tr>
<tr>
<td>Malleable iron (ASTM A47)</td>
<td>C 2.5, Si 1.0, Mn 0.55</td>
<td>Cast (annealed)</td>
<td>33</td>
<td>52</td>
<td>12</td>
<td>130</td>
<td>Axle bearings, track wheels, automotive crankshafts</td>
</tr>
<tr>
<td>Ductile or nodular iron</td>
<td>C 3.4, P 0.1, Mn 0.4, Ni 1.0, Mg 0.06</td>
<td>Cast</td>
<td>53</td>
<td>70</td>
<td>18</td>
<td>170</td>
<td>Gears, camshafts, crankshafts</td>
</tr>
<tr>
<td>Ductile or nodular iron</td>
<td>-</td>
<td>Cast (quench tempered)</td>
<td>108</td>
<td>135</td>
<td>5</td>
<td>310</td>
<td></td>
</tr>
<tr>
<td>Ni-hard type 2</td>
<td>C 2.7, Si 0.6, Mn 0.5, Ni 4.5, Cr 2.0</td>
<td>Sand-cast</td>
<td>-</td>
<td>55</td>
<td>-</td>
<td>550</td>
<td>High strength applications</td>
</tr>
<tr>
<td>Ni-resist type 2</td>
<td>C 3.0, Si 2.0, Mn 1.0, Ni 20.0, Cr 2.5</td>
<td>Cast</td>
<td>-</td>
<td>27</td>
<td>2</td>
<td>140</td>
<td>Resistance to heat and corrosion</td>
</tr>
</tbody>
</table>
Mill Liner Materials

- Austenitic Manganese Steel (AMS)
- Low carbon chrome moly steel
- High carbon chrome moly steel
- Nihard liners
- High chrome iron liners
- Chrome moly white iron liners
- Rubber liners
- Magnetic liners
Austentitic Manganese Steel (AMS)

- Hadfields steel - 1.2% C and 12% mn
- Used for grid liners - work hardens under stress
- Spreads with impact without fracture
- Liners can be difficult to remove
- Heat treatment strengthens manganese steel - solution annealing and quenching
Low Carbon Chrome Moly Steel

- Used for AG/SAG and ball mills
- Excellent wear characteristics and some impact resistance
- Good for discharge grates
High Carbon Chrome Moly Steel

- 325 to 380 BHN

- Chromium and molybdenum both individually increase the hardenability of low alloy steel. Important synergistic effects, not yet fully defined, can also occur when Cr and Mo are used in place of single elements.

- Chromium brings resistance to corrosion and oxidation, high temperature strength and abrasion resistance. Molybdenum helps maintain a specified hardenability and increases high temperature tensile and creep strengths. These grades are generally heat-treated to specified properties.

- Used for SAG mill liners.
Nihard Liners

Produced for more than 50 years, effective materials for crushing and grinding in industry.

Consists of martensite matrix, with nickel alloyed at 3-5% in order to suppress transformation of austenite to pearlite.

Chromium usually included between 1.4-4% to ensure carbon phase solidifies to carbide, not graphite. (Counteracts the graphitizing effect of Ni).

Abrasion resistance (usually desired property of this material) increases with carbon content, but toughness decreases.

Various grades class I type A abrasion resistant; class I type B toughness.

Applications: Because of low cost, used primarily in mining applications as ball mill liners and grinding balls.

Source: Perez and Stameroff (2003)
High Chrome/Moly Iron Liners

- 600 – 700 BHN Cr iron-rod mills and ball mills

- Excellent abrasion resistance. Provide the best combination of toughness and abrasion resistance among white cast irons. The tradeoff is between wear resistance and toughness

- Two types:
  - the hard, discontinuous, X7C3 eutectic carbides present in the microstructure
  - the softer, more continuous, X3C present in irons containing less chromium.

- Usually produced by hypoeutectic compositions

- For abrasion resistance: 11-23%Cr, 3.5%Mo. Usually supplied as cast with an austenitic or austenitic-martensitic matrix, or heat treated with a martensitic matrix. Considered the hardest of all grades of white cast iron

Schematic showing the heterogeneous micro-structure of high-chromium white irons.
Source: Perez and Stameroff (2003)
Chrome Moly White Iron Liners

- 600 to 700 BHN white iron
- Used for abrasion resistance
- Common in cement mills
- Large ball mills

Malleable Iron: cast as white iron, then malleabilised, or heat treated, to impart ductility. Consists of tempered graphite in an α-ferrite or pearlite matrix.
Rubber Liners

- Commonly used for ball mills because of long life
- Change out is easy
- Polymet-steel rubber composite
- Reduced grinding capacity can be an issue
- Not for primary AG/SAG mills

Source: Growth Steel Group Library (2013)
Magnetic Liners

- Magnets embedded in rubber blocks
- Useful in secondary and regrind mills
- Can provide many years of trouble free operation
- Applicable where wear is a major consideration

Source: Growth Steel Group Library (2013)
Current Liner Designs

- Influence of lifter height
- Finite stress analysis
- Testing wear rates
- Mill drilling patterns - rubber or steel
- Modelling

Source: Growth Steel Group Library (2013)
Bad Liner Designs

- Noisy mills
- Loose or broken bolts
- Excessive wear
- High scrap weight
- Throughput & liner life
- Not recognising differences

Source: Growth Steel Group Library (2013)
Mill Liner Wear

> Monitor wear rates at frequent intervals - mechanical gauge
> Electronic measuring devices are also available - METSO Scanalyse
> Liners could last 18 months so this is a slow optimisation process
> Monitor cracks, damage bolts, pegging, broken balls, steel scats

Source: Growth Steel Group Library (2013)
Liner Profiles and Trajectories

- A very useful tool for predicting mill trajectory
- Optimise speeds, liner height, bar spacing, etc.
- For large SAG mills the new liners can be 73% critical whilst worn liners require 80% critical
Commissioning

> Learning curve - start with very low ball charge and build up over time. Do not let the mill charge run down

> Soft oxide ore low charge - high risk of liner damage- can be catastrophic

> First set of liners should take ore into account- conservative design

> Low feed rates only with low ball charges- use mill trajectory modelling
Conclusions

> Mill throughput and efficiency gains are iterative over time

> Mill trajectory modelling based on bar heights, angles, spacing and speed is very predictive

> Field trials are the acid test - operator, designer and vendor

> Optimisation strategy:
  - Maximise impact grinding AG/SAG mills
  - Avoid impact on the shell rather the toe of the charge
  - Maximise liner life by protecting with mill lifters
  - Prevent ball breakage- impact on toe of charge
  - Check profiles regularly to accurately predict change out
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References

> Mineral Engineering Technical Services Pty Ltd Image Library 2013
> Growth Steel Ltd Image library 2013
> E.Perez,A.Stameroff, 2003 ‘Metallurgical Properties of Cast Irons’. Engineering 45 SRJC, Santa Rosa, CA
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