Total primary milling cost reduction by improved liner design

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Synopsis

Total milling cost is composed of energy, liner and grinding media costs.

In primary high ball load milling, the grinding media play the biggest role in total milling cost. This cost can be drastically reduced by improving the impact condition inside the mill. The impact condition inside the mill is influenced by shell liner design (as well as feed end and discharge design) and the type of discharge. The improvement of the impact condition will result in a significant decrease in grinding media consumption. The softened impact condition allows for better alloy optimization, resulting in a further reduction in grinding media consumption.

Optimized liner design can also improve energy consumption as less energy is wasted in the projection of the grinding media. Magotteaux utilizes tools to simulate and show the grinding media trajectories for shell and end liners.

This paper will present some practical examples where the media and energy consumption can be or has been reduced by optimizing liner design.

Keywords

Comminution, grinding, liner design, grinding media wear.

Introduction

Mill liners have a dual purpose: firstly, to protect the shell of the mill from wear, and secondly to transmit energy to the charge (ore + grinding media). The design of the liner must take these two aspects into consideration. The optimal design is a compromise between lifetime and efficiency.

Liner design

The liner design has a huge impact on the mill performance and the total milling cost. The incorrect liner design for a certain application can have very important repercussions on mill efficiency and/or total milling cost.

Primary/run of mine ball mill

In a primary mill application, liner design is very important if the total milling cost needs to be kept within a reasonable limit. In the case of incorrect liner design, the grinding media will be projected on the liner and not on the toe of the charge.

Figure 1 shows the difference between optimized liner design and non-optimized liner design and their influence on the total milling cost. Figure 1 (non-optimized case) shows a total milling coat of 100. The liner cost is only 10% of the total cost. Although, the maximum liner lifetime is achieved, the grinding media cost is significantly higher that what it should be because these liners are not optimized for the grinding media. As a consequence of this incompatible design, grinding media are thrown on the liner, causing breakages wasting energy and reducing grinding efficiency.

Figure 1 (optimized case) shows the total milling cost with an optimized liner design. The cost of liners is higher than in the non-optimized case but the total milling cost is 25% lower. This decrease is mainly due to the substantial drop off in grinding media consumption. This liner design does not produce inefficient grinding media trajectories and does not induce impact of the media on the liner. Energy is more efficiently utilized.

The Table I shows that by increasing the liner cost (optimized liner) by 34.7%, the total milling cost decreases by 25.5%. The optimized liner design compensates for the increase of liner cost by drastically decreasing the media cost.

Tools

Shell

Magotteaux has developed a tool to simulate and view grinding media trajectories by modifying a laboratory batch mill. One end has

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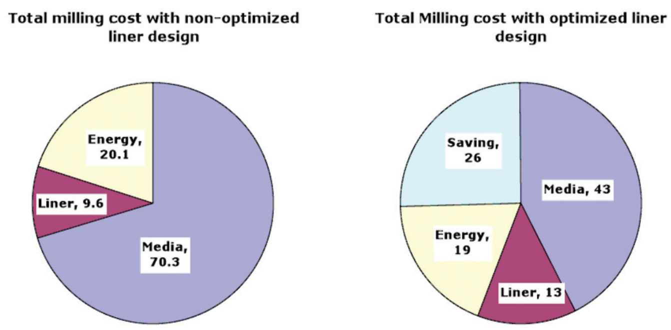

Figure 1—Total milling cost difference with optimized and non-optimized liner design (hypothetical case)

Table I

Total primary milling cost optimized vs. non-optimized liner

	Non-optimized liner	Optimized liner	Difference in cost
Media	70	43	-39%
Liner	10	13	+35%
Energy	20	19	-6%
Total	100	75	-26%

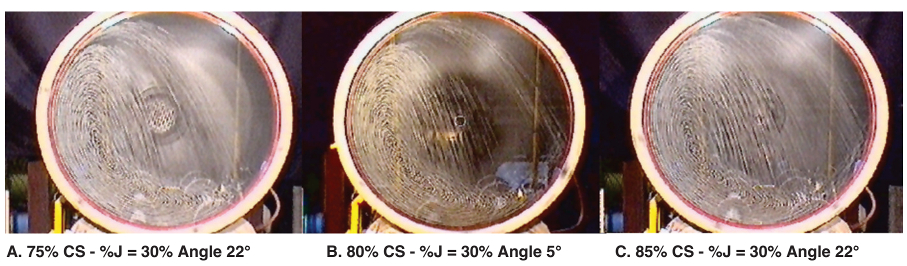

Figure 2—Video footage

been fitted with Plexiglas, which allows a video camera to record the trajectories. This tool was used to test different liner designs by changing the following parameters:

- % Critical speed
- % Ball filling degree
- Lifter angle
- Lifter height.

Video footage of each test has been analysed in Figure 2 to determine the trajectories.

This video footage has been used to validate internally the MillTraj® software developed by Prof. M. Powell. This software is now used by the Magotteaux's technical department to make recommendations on liner design.

The main influencing factors for optimal liner design are the following:

- Lifter angle
- Mill speed
- Total filling degree.

Figure 3 and Figure 4 show the influence of the lifter angle and critical speed on the ball trajectories. The ideal trajectory for a ball allows the ball to fall inside the charge. The position of the toe of the charge depends on the total filling degree (grinding media + ore) inside the mill. The positions of the toe for different total filling degrees are also shown in Figure 3 and Figure 4. The 3 main influencing factors above must be taken into account when designing a liner.

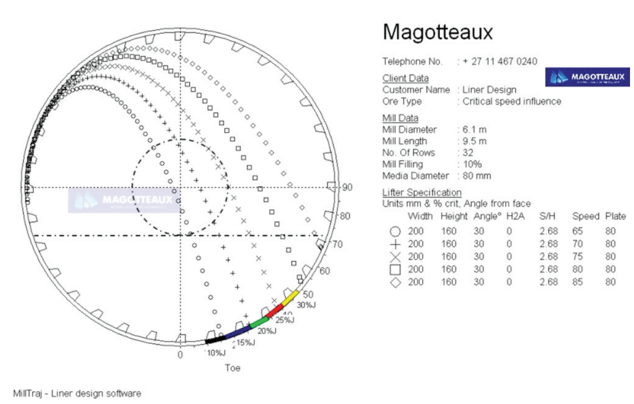

Figure 3—Lifter angle influence on trajectories

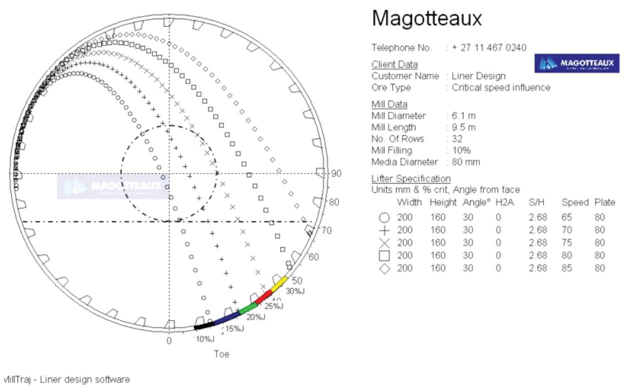

Figure 4—Critical speed influence on trajectories

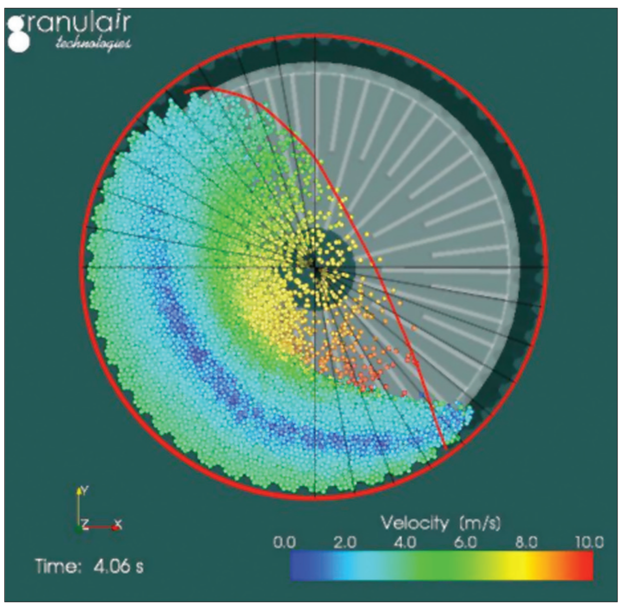

Figure 5—Optimized end liners (view from the feed end)

Example

A ball mill is designed to run at 25% total filling degree with a fixed speed of 75% CS (critical speed). A lifter angle of 30 degrees will produce trajectories where the grinding media fall on the toe of the charge thereby limiting the risk of breakage.

Due to the lack of available ore, the plant decides to drop the filling degree to 15%. The 30 degrees lifter angle will still induce the same trajectory but the balls will now fall on the shell, shown by the reducing toe position in Figure 3, thereby increasing the risk of breakage.

Feed and discharge ends

The influence of the feed and discharge ends on the grinding media wear/breakage was not well known. Magotteaux has recently decided to study what influence the lifter angle and lifter height of the ends has on the ball trajectories. Some discrete element modelling (DEM) has been performed on optimized and non-optimized liner design.

Figure 5 and Figure 6 show the DEM for an optimized end liner, while Figure 7 and Figure 8 show it for aggressive end liners. The two simulations have been made with the same optimized shell liner but with different end liners. In Figure 5, all balls fall on the charge whereas in Figure 7 some balls fall on the liner, thereby causing breakage. Comparing Figure 8 to Figure 6, the aggressive end liners lift the balls higher, resulting in the balls being projected onto the liner.

Remark on design

Dog bone

As explained previously, it is very important to determine the right lifter angle for the application (depending on operating

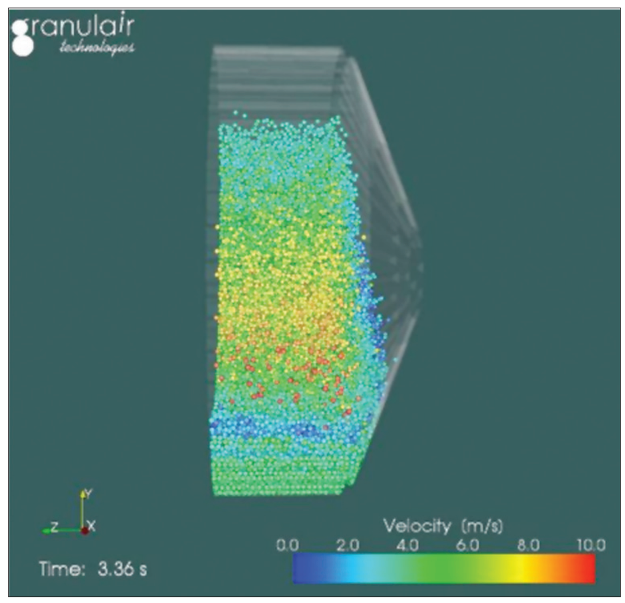

Figure 6—Optimized end liners (view from the side)

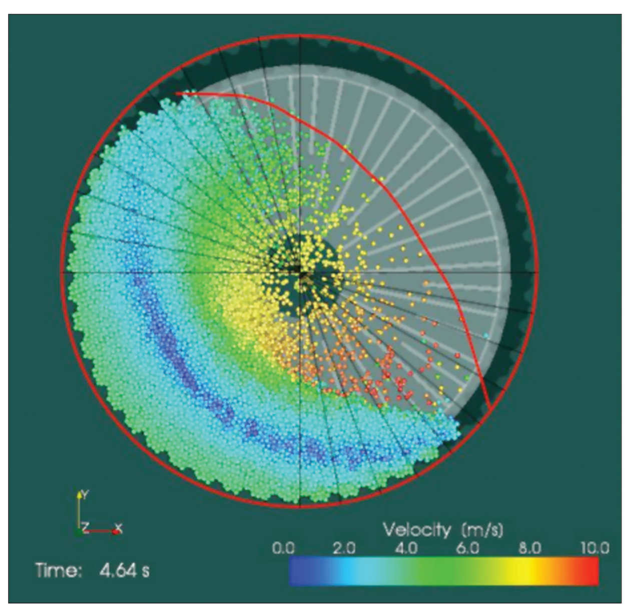

Figure 7—Aggressive end liners (view from the feed end)

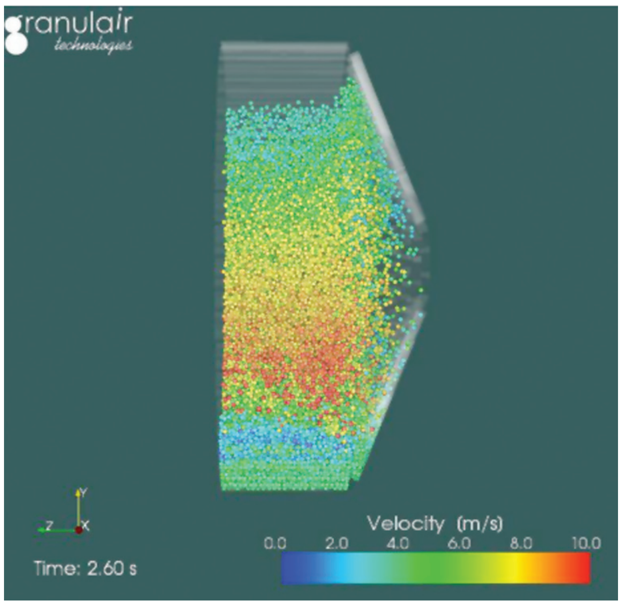

Figure 8—Aggressive end liners (view from the side)

parameters). It is also important that this angle be kept constant along the full length of the lifter. For practical reasons, some manufacturers use reinforcement around liner bolt hole, resulting in a modified angle at this specific point. This angle modification can induce an incorrect trajectory which can result in media breakage.

Height to angle (H2A)

The height to angle is the vertical part of the liner before the angle (see Figure 9).

If this H2A is bigger than half of the ball diameter, the ball will see an angle of 0° and then be projected on the shell. In this case the lifter angle has little effect and the risk of ball breakage is increased.

Overflow vs. grate discharge

The type of discharge is an important factor when it comes to wear of the grinding media. Tests have shown 30% less grinding media wear in overflow configuration vs. grate discharge for the same alloy. This percentage could be much higher if breakage occurs inside the mill. In overflow configuration, the grinding media which misses the charge will fall into the pool, resulting in less impact on the liner. The impact between media and liner is softened due to the cushioning effect of the pulp. As a result, the wear by breakage is much lower in overflow than in grate discharge. In addition, the softened impact condition allows for better alloy selection, bringing about a further reduction in grinding media consumption

Industrial examples

Incorrect grate design

Plant A decided to convert from overflow to grate discharge with an aggressive grate design (lifter height = 200 mm, lifter angle = 5°). Breakage and spalling occurred for both balls and liners (see Figure 10 and Figure 11) The grinding media wear rate increased from less than 400 g/t to 1200 g/t (3 x more). Grinding media with special high impact heat treatment was supplied and the wear went down. Two months later, Plant A converted back to overflow discharge and the grinding media wear rate returned to the normal level.

AG liner used in SAG (UG2)

Plant B was designed to run with the primary mill as an autogenous mill (AG) but it was decided to use balls in the primary mill. The liner design was retained, resulting in very

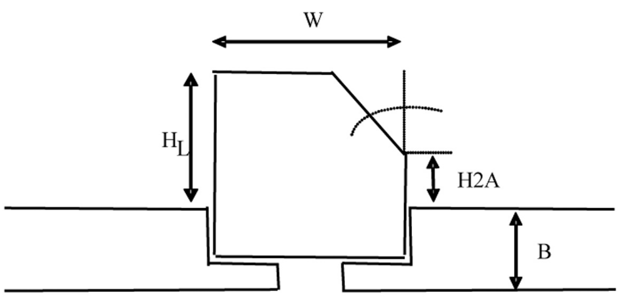

Figure 9—Height to angle (H2A)

Figure 10—Effect of the discharge modification on the balls

Figure 11—Effect of the discharge modification on the liners

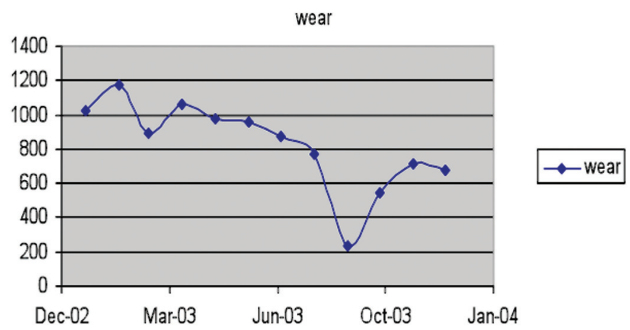

Figure 12—Wear reduction due to correct liner design

Table II

Comparison overflow and grate discharge

	GD	OF
Wear rate (g/ton)	1194	683
Absorbed power (kW)	3761	3247
Throughput (t/h)	243	243
kWh/ton	15.48	13.36
Grind (%<75 microns)	46.60	42.20
Grind (%>150 microns)	26.30	30.80
kWh/ton <75 microns	39.06	37.94
kWh/ton <150 microns	26.75	25.04

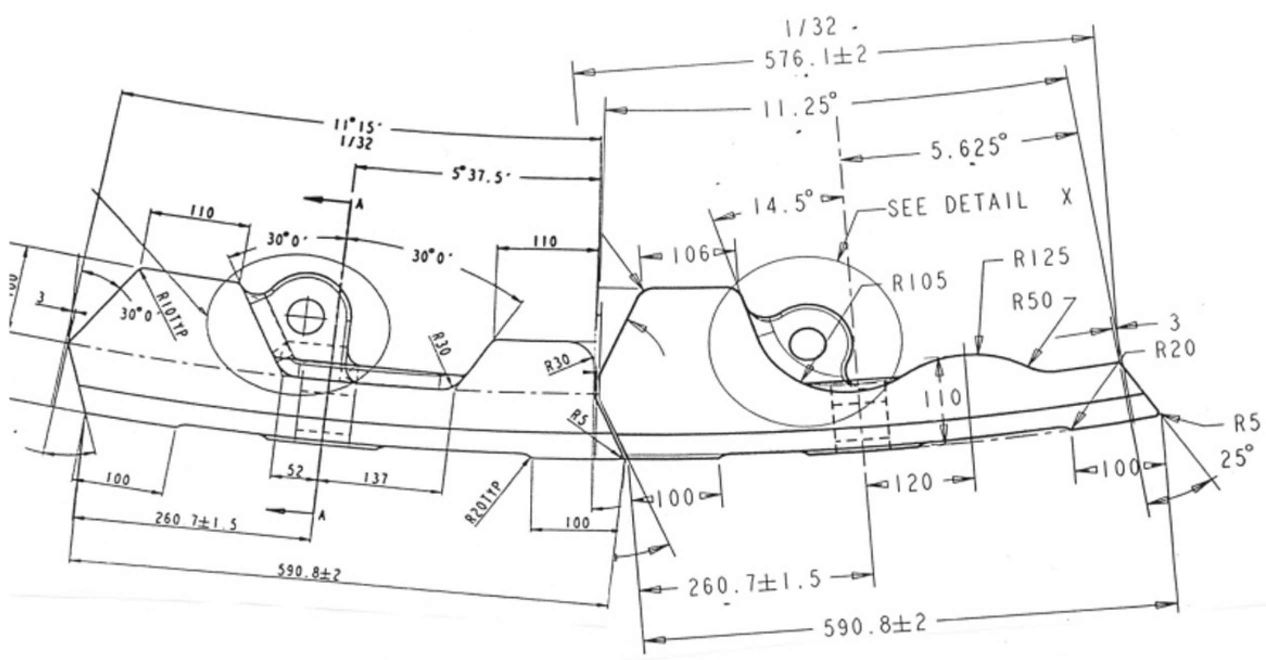

Figure 13—New liner design (left) with AG liner (right)

high grinding media wear rate (1 200 g/t). A new liner design was proposed to the plant in order to reduce media wear. This new design (see Figure 13).

- ➤ Use of remaining stock of incorrect AG mill liners
- ➤ Correct ball trajectories and hence improved grinding efficiency and lower ball wear (less impact and harder alloy)
- ➤ Cost saving on ball consumption: 30%.

Grate discharge to overflow conversion in UG2

In order to reduce the ball wear rate, Plant C converted their primary ball mill from grate to overflow discharge while monitoring different parameters before and after the conversion.

The feed to the mill had 6.98% and 15.83% passing 75 and 150 microns respectively. F80 = 12 mm

The overflow configuration seems to be more efficient with the operating work index being lower than in grate configuration. The mill absorbs less power and the percentage passing 75 µm has reduced, The increase in grind size can be reduced by increasing the ball filling degree (absorbed power) The wear rate decreased from 1194 g/t to 683 g/t, partially due to a reduction of the impact condition and partially due to the fact that a more abrasion resistant alloy could now be utilized (Table II).

Conclusions

The total milling cost is composed of grinding media cost, energy cost and liner cost. Whereas liners are an important part of the total milling cost, the influence of liner design on this total milling cost is even more significant. Incorrect liner design can increase the total milling cost by causing ball breakage and spalling, resulting in less efficient utilization of energy. When designing mill liners, the importance of the impact condition on mill performance and on grinding media wear must always be kept in mind. If this critical factor is neglected, the effect on the total milling cost will be dramatic. ◆