A CLOSER LOOK AT INCREASING HPGR EFFICIENCY VIA REDUCTIONS IN EDGE EFFECT

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Abstract

Edge effect is the widely observed condition of impaired comminution performance at the edges of High Pressure Grinding Roll (HPGR) tires. This effect is caused by a reduction in the local crushing pressure at the edges of the tires resulting from the interaction between the static cheek plates and HPGR feed material. In open circuit operations, this effect results in coarser particles reporting to downstream equipment. In closed circuit applications, edge effect results in an increased circulating load and diminished HPGR circuit capacity.

Results will be presented to demonstrate how edge effect was significantly reduced through innovations in the Metso HRC™ HPGR design, which incorporates an Arch-frame and a flanged tire design. Through a series of pilot plant tests comparing a 750 mm x 400 mm HPGR with flanges versus the same HPGR with traditional cheek plates, the enhanced performance when operating with a flanged tire design are demonstrated. A detailed description of the pilot testing protocols, results and analysis are presented. In addition, insights into the implications for circuit design, energy efficiency and overall plant performance are also presented.

Introduction

The mining industry is faced with a growing challenge of lower ore grades and rising operating costs. In this business environment, the selection of an efficient comminution circuit is critical to the long term profitability of an operation. These realities are continually driving the market towards more energy efficient solutions.

Comminution circuits incorporating High Pressure Grinding Rolls (HPGRs) have been shown to be an energy efficient alternative to conventional circuit designs. The basic operating principle of HPGRs, in which a fairly uniform pressure is applied to a bed of material in the compression zone, results in this improved efficiency (Morley, 2006). Even after accounting for auxiliary power needs, studies indicate an energy savings in the range of 10-15% is possible when comparing an HPGR circuit to a more traditional SABC circuit (Rosario & Hall, 2008).

While it is accepted that HPGRs are more efficient than tumbling mills in most applications, the technology has substantial room for improvement. One aspect of the traditional HPGR design that leads to inefficiencies is edge effect. Edge effect describes a condition of impaired comminution performance at the edges of the tires due to a reduction in crushing pressure (Morley, 2010; van der Meer, 2010). This effect is caused by the interaction between the ore and tire surfaces (in motion) and the cheek plates (relatively static). Figure 1 compares a traditional HPGR tire and cheek plate arrangement to an HRC™ HPGR's tire arrangement with flanges.

On the HRC™ HPGR, flanges bolt onto the edges of one tire and rotate with the bed of material as it passes through the crushing zone. In this design, performance is enhanced because the flanges move with the ore drawing material into the crushing zone while closing off the edge of the tire.

Prior work in the area of edge effect has focused on accurate modeling (Morrell et al., 1997) and scale-up (van der Meer, 2010) with minimal focus on enhancing the comminution performance at the edges of the HPGR tires. This paper tests the hypothesis that an HRC™ HPGR with a flanged tire can measurably reduce the negative impacts of edge effect.

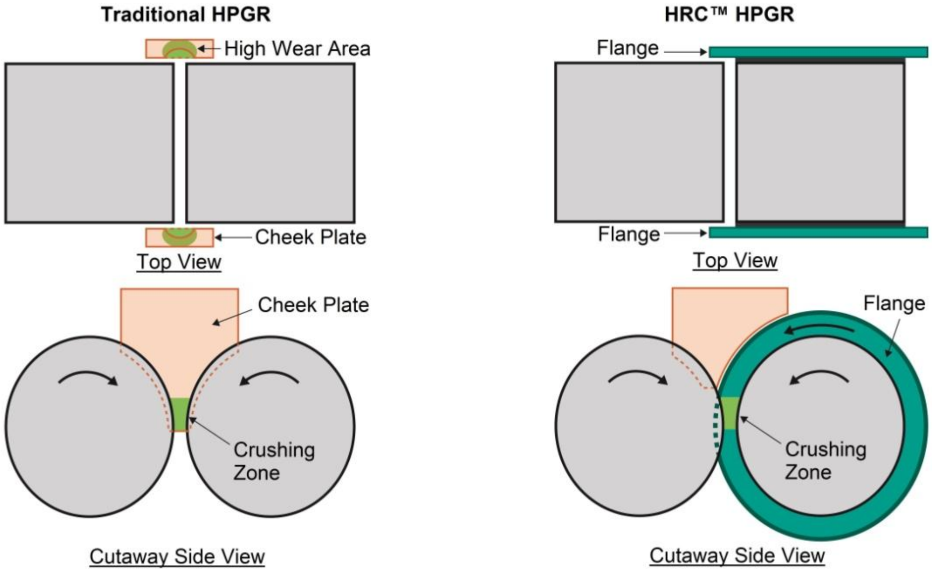

Figure 1. Traditional HPGR arrangement (left), HRC™ HPGR arrangement with flanges (right)

Edge Effect Consequences

Edge effect negatively impacts the process and operation of HPGRs in a number of ways. Traditionally, the industry faces three main problems associated with edge effect: (i) coarser particle sizes discharging at the edges of the tire, (ii) an uneven wear pattern on the tire due to the differential in pressure between the center and edges of the tires; and (iii) decreased energy efficiency due to the higher than optimal pressure being applied to material at the center of the tire. The cumulative effect of these problems on operating efficiency, availability and operability, make any measureable reductions in edge effect attractive to the plant operator.

In HPGR operations, the specific force can be adjusted to optimize particle breakage for a given application. Even when operated at the optimum specific force, an HPGR with the traditional cheek plate design will have a lower pressure at the edges of the tires, resulting in a coarser product size distribution. In closed circuit applications, edge effect will result in an increased circulating load and diminished HPGR circuit capacity. In open circuit operations, edge effect results in coarser particles reporting to downstream equipment, increasing the demand on these machines. In an attempt to compensate for the edge effect, some open circuit applications even use a dividing chute below the HPGR to separate the center product from the coarser edge product, recirculating the edge product back to the HPGR feed (Gerrard, Costello & Morley, 2004).

The uneven pressure across the width of the tires also results in an uneven wear pattern with higher wear rates in the center of the tire, described as a “bath tub” (Morley, 2006). The higher pressure in the center of the tire can also increase the risk of stud breakage, influencing the stud hardness that can be selected for a given application. In some applications with very hard ore, such as at Newmont’s Boddington operation, the stud hardness needed to be reduced to minimize the chipping of studs (Hart et al., 2011). If the variation in pressure across the width of the tire is reduced, harder studs could potentially be utilized, resulting in an increase in tire life and higher machine availability.

Variations in pressure across the width of the tire can also decrease the HPGR energy efficiency. With a traditional cheek plate design, the uneven pressure across the width of the tire results in local inefficiencies, with the edges operating below the optimum pressure and the center operating significantly above the optimum pressure.

Testing Methodology

Flanged Tire Concept

Metso’s HRC™ HPGR design utilizes flanges to minimize the amount of material bypassing the crushing zone. A bolt-on flange design can be used because of the Metso’s patented anti-skewing Arch-frame. With this design, the frame mechanically connects both bearings of the tire assembly to a base plate, absorbing any uneven forces. While traditional HPGR frames lack this rigid structure, Metso’s Arch-frame is able to maintain a parallel relationship between the tires.

Figure 2 shows the actual pressure applied to a bed of material in a lab HPGR apparatus. This pressure is measured via sensors that are embedded in the tire of the apparatus, monitoring the crushing pressure throughout the tire rotation. As expected, the highest pressure in the crushing zone occurred at the center of tire during the cheek plate test. When flanges were installed on the same unit, the variation in pressure across the tire was greatly reduced.

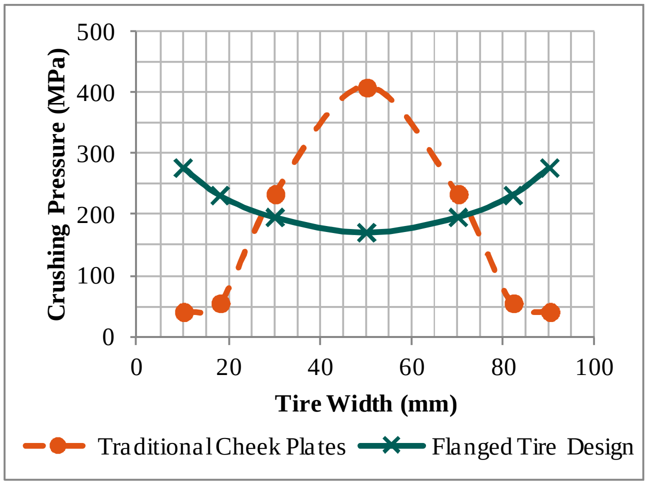

Figure 2. Pressure distribution across width of HPGR tire (cheek plates versus flanges)

Pilot Plant Testing

The pilot plant, located at the Freeport-McMoRan Inc. (FCX) Morenci Concentrator, is a collaborative research and development project between FCX and Metso to test the Metso HRC™ HPGR. The pilot plant layout and equipment design allows for modification of the comminution circuit arrangement to test the process performance in a range of operating conditions. During testing, the pilot plant operated for over 11,950 hours and processed over 667,000 metric tons of ore. Some 114 separate process surveys were conducted according to an experimental design jointly developed by FCX and Metso. Forty (40) of these experimental runs were focused on quantifying the HRC™ HPGR circuit performance. Since completion of the testing program in December 2013, the pilot plant has continued to operate for production purposes.

The pilot plant's HPGR crushing circuit includes an HRC™ HPGR with 750 mm x 400 mm tires, a primary (wet) screen, and a secondary (wet) screen. The primary screen removes the fines from the feed prior to entering the HPGR. The HPGR is fed by the primary and secondary screen oversize. The HPGR discharge is then conveyed to the secondary screen. The primary and secondary screen undersize drops through chute work and discharges into the product tank. From this tank, the crushed product is pumped to the downstream grinding process.

Throughout the circuit, automated samplers and additional monitoring instrumentation have been incorporated in the design to ensure the best possible survey. The HPGR includes a specially designed discharge chute. This chute allows for the collection of multiple samples across the width of the HPGR discharge to assess the crushing performance at the edges of the tires.

A series of tests was completed at the pilot plant to determine the process effects, if any, of the flanges as compared to a traditional cheek plate design. This test series consisted of 12 process surveys, testing the following variables: presence of flanges, relative wear of flanges or cheek plates, and the HPGR specific force. For the non-flanged portion of this test series, the flanges were replaced with fixed cheek plates set at the same offset of 3 mm from the edge of the tires and the circuit was tested using the same procedures as the flanged condition. For each test, the primary screen and secondary screen were fitted with 3 mm and 5 mm aperture panels, respectively.

The pilot plant was operated to achieve stable operating conditions prior to each survey. Composite samples were collected throughout the HPGR circuit over a period of two hours on 15-minute intervals. These samples were analyzed on site for particle size distribution and percent solids. Laboratory testing on representative samples was also completed to provide an understanding of the ore characteristics (Packed Bed Compression Testing, Drop Weight Testing, Bond Ball Mill Work Index, mineralogy, etc.). For each survey, data from the available instrumentation was retrieved from the historian on ten second intervals. The sample analysis results and instrument data were then analyzed to provide a mass balance and circuit performance analysis for each test run.

Results and Discussion

Pilot plant testing has demonstrated that the use of flanges on the HRC™ HPGR results in significant process improvements by minimizing the edge effect. This reduction in edge effect in turn results in a reduction in the circulating load and circuit specific energy. The unique design of the flanged tire was also shown to draw more material into the crushing zone, resulting in a higher specific throughput and an increase in net power draw.

The enhanced comminution performance at the edges can be illustrated by comparing the HPGR discharge particle size distributions from tests Z2B and Z8A in Figure 3. These two tests represent a direct comparison between new cheek plates (Z2B) and new flanges (Z8A), both operating at a specific force of 4.5 N/mm^2.

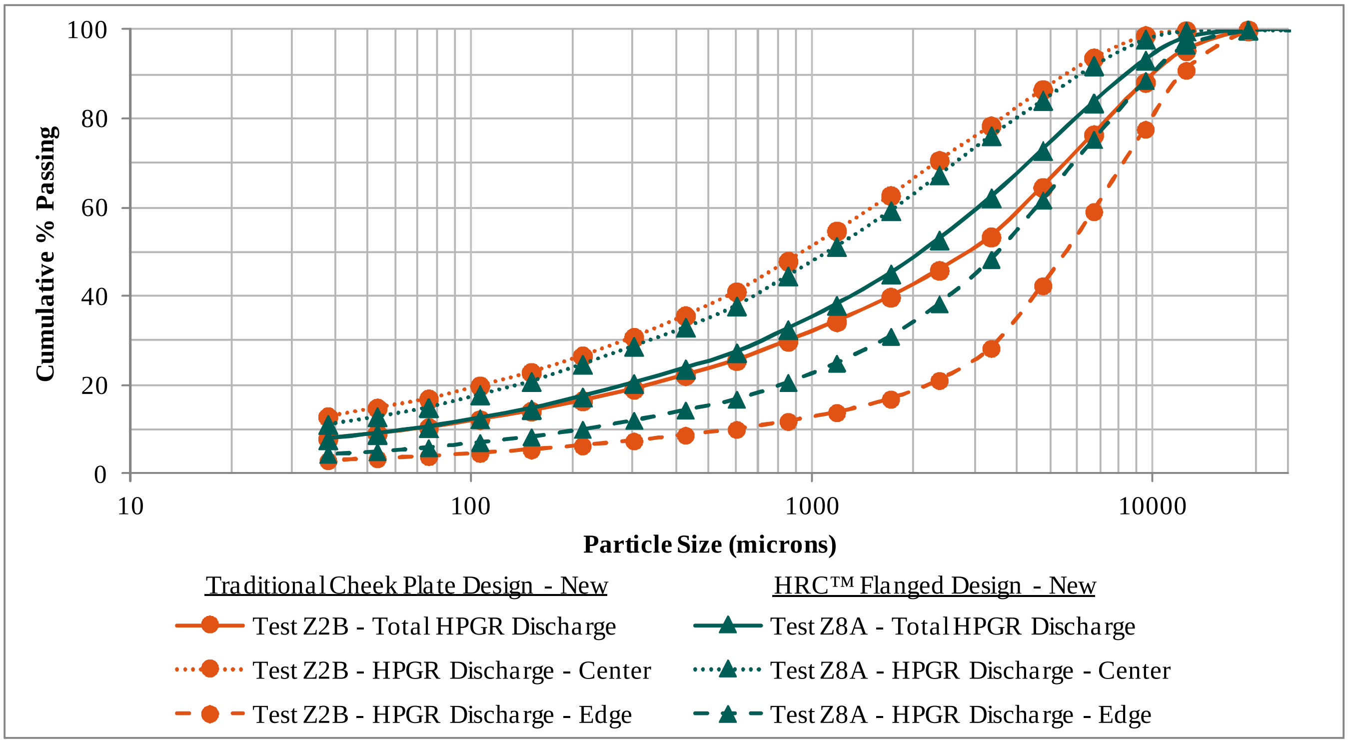

Figure 3. Comparison of HPGR discharge samples (total, center, & edge) from tests Z2B and Z8A

As shown in Figure 3, the HPGR discharge sample was collected in several different streams during each test run. The entire sample was collected via an automated belt cut sampler on the product conveyor. Separately, individual edge samples were collected via gates located directly below the tires. These gates collected a sample from a width of ~ 100 mm at each edge. Simultaneously, a product sample was collected from the middle 200 mm of the tire by the automated belt sampler.

The resulting particle size distributions demonstrate the effects of the flanges on the HRC™ HPGR at the pilot plant scale. While the edge effect was not completely eliminated, it is clear from these results that the use of flanges significantly increased the particle breakage on the edges of the tires. This results in a finer particle size distribution in the total discharge sample with a reduction in the product P80 from 7,491 microns in Test Z2B (cheek plates) to 6,004 microns in Test Z8A (flanges). Table 1 provides a summary of the process conditions during these two tests.

This additional breakage at the edges has significant implications on the overall circuit performance. As a result, the circulating load and specific energy were both reduced in Test Z8A. As shown in Table 1, a notable increase in plant capacity was achieved despite operating at a slightly lower tire speed. Finally, the operating gap and specific throughput show a significant increase in Test Z8A.

Across all twelve tests in this matrix, with varying wear conditions and specific forces, the flanged tire design showed a clear benefit. As shown in Table 2, the presence of flanges resulted in a consistent reduction in circuit specific energy and circulating load. In addition, the specific throughput and power draw of the HPGR both showed a notable increase when operating with the flanged tire design.

In order to assess the change in net power draw across the range of test conditions, the force acting angle from each test was compared. Force acting angle (β) relates to HPGR power draw by the following (Klymowsky, 2006):

$$P = 2 \times \sin\beta \times u \times F$$

Where, P is the total net power (kW)
u is the circumferential speed of the tires (m/s)
F is the applied press force (kN)

This allows for a comparison of the HPGR's ability to pull power across a range of operating speeds and crushing forces. The force acting angle for each test is presented in Table 2. The increase in force acting angle when operating with flanged tire design demonstrates an increase in power for a given crushing force and tire speed.

Table 1. Balanced plant survey results with new cheek plates (Test Z2B) versus new flanges (Test Z8A)

Test number	**Test Z2B**	**Test Z8A**	**% change**
Test description	Cheek plates - new	Flanges - new	
Plant feed tonnage (dry MTPH)	35.3	42.8	+21%
HPGR discharge percent solids (%)	95.9	96.2	+0.3%
HPGR specific force (N/mm^2)	4.49	4.51	+0.3%
HPGR tire speed (RPM)	23.2	22.3	-3.7%
HPGR throughput (dry MTPH)	57.7	61.7	+6.9%
HPGR operating gap (mm)	15.6	17.2	+10%
HPGR specific throughput (t·s/m^3·hr)	215.6	240.0	+11%
HPGR net power (kW)	107.4	116.4	+8.4%
HPGR net circuit specific energy (kW·hr/tonne)	3.04	2.72	-11%
Circulating load (%)	111%	87%	-22%
Circuit feed F80 (microns)	11,825	12,133	+2.6%
HPGR feed F80 (microns)	11,577	11,502	-0.7%
HPGR product P80 (microns)	7,491	6,004	-20%
HPGR circuit product P80 (microns)	1,700	1,697	-0.1%

Table 2. Balanced test results summary for all twelve tests of the "edge effect" matrix

Test #	**Cheek plate / flange - wear**	**Specific force (N/mm^2)**	**Specific throughput (t·s/m^3-hr)**	**Net circuit specific energy (kW·hr/tonne)**	**Circulating load (%)**	**Force acting angle (deg)**
Z1B	Cheek plates - new	3.49	178.5	2.82	107%	2.7
Z2B	Cheek plates - new	4.49	215.6	3.04	111%	2.6
Z3A	Cheek plates - half worn	4.51	213.5	3.34	124%	2.6
Z4A	Cheek plates - half worn	3.49	203.9	2.82	135%	2.7
Z5A	Cheek plates - fully worn	3.50	210.7	2.81	122%	2.7
Z6A	Cheek plates - fully worn	4.49	223.4	3.05	114%	2.6
	Average cheek plate results		**207.6**	**2.98**	**119%**	**2.7**
Z7A	Flanges - new	3.50	231.6	2.67	93%	3.1
Z8A	Flanges - new	4.51	240.0	2.72	87%	2.9
Z9A	Flanges - half worn	3.49	279.8	2.35	102%	3.1
Z10A	Flanges - half worn	4.51	239.7	2.65	80%	2.9
Z11A	Flanges - fully worn	4.49	236.6	2.71	78%	2.9
Z12A	Flanges - fully worn	3.50	256.5	2.35	102%	3.1
	Average flanged tire results		**247.4**	**2.57**	**90%**	**3.0**

Implications for Large Scale Operations

These results at the pilot scale have major implications for the design and operation of HPGR circuits. A detailed scale up analysis was completed, including simulation and modeling in order to provide predicted results for a full scale HRC™ HPGR operation. Based on this analysis, significant improvements in the areas of comminution efficiency, tire wear, and circuit design were predicted for full scale HPGRs with flanged tires. The first opportunity for demonstrating these benefits has been in the tertiary HPGR crushing circuit at FCX's Metcalf Concentrator at the Morenci operation.

Installed in this tertiary crushing duty, the HRC™3000 is the world's largest HPGR and the first large scale unit operating with a flanged tire design. This unit has been in operation since May 2014 and as of the date of this publication has run for over 4,200 hours, processing over 16 million metric tons of porphyry copper ore. The HRC™3000 includes 3.0 m diameter by 2.0 m wide tires driven by a total installed power of 11.4 MW. The plant is nominally designed for 65,000 metric tons per day.

Preliminary observations indicate the predictions from the flanged tire pilot plant scale up well to the full size operation. This is best illustrated by the observed circulating load, operating gap and specific throughput with the HRC™3000, all of which meet or exceed the predicted performance from the pilot plant analysis as shown in Table 3. Future work will provide more details on the performance of the HRC™3000 in this application.

Table 3. Observations of HRC™3000 at Morenci operation

	Prediction based on flanged-tire pilot plant	HRC™3000 observations
Specific throughput (t·s/m3-hr)	276	275-325
Operating gap (mm)	99	93-112
Circulating load (%)	58-85	45-55

The observed improvements in particle breakage and increased unit capacity resulting from the flanged tire design can have an impact on the equipment selection during plant design. The finer product size improves the open circuit performance of the HRC™ HPGR, potentially allowing for open circuit arrangements to be applied in a broader range of applications. In closed circuit applications, it may be possible to reduce the size of the HPGR, as well as the screening and conveying equipment, for a given plant capacity due to the lower predicted circulating load. This translates to savings in both capital and operating expenses. Of course plants also have the option of maintaining the same equipment size and realizing the benefits of flanges through a higher plant capacity.

The ability of a flanged tire design to provide an even pressure distribution across the width of the tire also has implications on tire design and wear life. A more even wear rate across the tire would avoid the negative effects of a "bath tub" wear pattern. In addition, the lower peak pressure at the center of the tire allows for harder, more wear resistant carbide studs to be embedded on the tire surface without risk of fracture. Less tire change outs will result in a lower cost of wear parts and increased machine availability.

Overall, the cumulative benefits in operating efficiency, increased tire wear and circuit design support the use of a flanged tire HPGR design at a larger scale.

Future Work

The findings discussed in this paper are based on a 750mm diameter pilot testing unit. Future work includes continuing to refine our understanding of how flanges affect the crushing efficiency on larger size units. In addition, the knowledge gained in this study will be used to incorporate the effects of flanges into simulation and modeling tools.

Future work will highlight other aspects of the HRC™ HPGR development program. This will include: presenting the full scope of the pilot plant HPGR study and providing a detailed review of the installation, commissioning and operation of the HRC™3000.

Conclusion

Through a combination of laboratory testing and pilot plant surveys, the ability to reduce edge effect via the utilization of a flanged tire design has been investigated. The presence of flanges has been shown to provide a more consistent pressure across the width of the tire, yielding better particle breakage at the edges. Testing using a 750 mm x 400 mm Metso HRC™ HPGR with and without flanges demonstrates the increase in particle breakage at the edges and the process benefits associated with this reduction in edge effect. At this scale, the flanged tire design has been shown to reduce circuit specific energy by an average of 13.5% and lower circulating load by approximately 24%, while increasing the specific throughput by 19%.

Preliminary observations with the HRC™3000 at Freeport-McMoRan's Metcalf Concentrator suggest that these benefits have scaled as predicted to the full scale 3-meter diameter unit. These findings have significant implications on the unit capacity, energy efficiency and tire wear life of the HRC™3000 relative to HPGRs with a traditional cheek plate design.

Acknowledgements

The authors would like to thank Freeport-McMoRan Inc. and Metso Minerals Industries for their hard work, support and dedication to this project.

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