HRC™: Taking HPGR efficiency to the next level by reducing edge effect

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High Pressure Grinding Roll (HPGR) technology has been accepted as an energy efficient alternative to conventional comminution circuits in the mining industry. There are, however, aspects of this technology that can be improved to enhance efficiency. Edge effect is a common problem associated with HPGRs. Edge effect is a general industry term that describes a condition of impaired comminution performance at the edges of the tyres due to a reduction in crushing pressure. In open circuit operations, this effect results in coarser particles reporting to downstream equipment, increasing the demand on these machines. In a closed circuit application, edge effect will result in an increased circulating load and diminished HPGR circuit capacity.

This paper will discuss how edge effect was significantly reduced through innovations in the HRC™ HPGR design, which incorporates an Arch-frame and a flanged tyre solution. Lab scale testing showed flanges provided a more consistent pressure distribution across the width of the tyre, allowing for better particle breakage at the edges of the tyre. Through a series of pilot plant tests comparing a 750×400 mm HPGR with flanges versus the same HPGR with traditional cheek plates, the introduction of flanges reduced the overall specific energy by an average of 13.5% and lowered the circulating load by an average of 24%, while increasing the specific throughput by 19%.

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 tyres due to a reduction in crushing pressure (Morley, 2010; van der Meer, 2010). This effect is caused by the interaction between the ore and tyre surfaces (in motion) and the cheek plates (relatively static). Figure 1 compares a traditional HPGR tyre and cheek plate arrangement to an HRC™ HPGR's tyre arrangement with flanges.

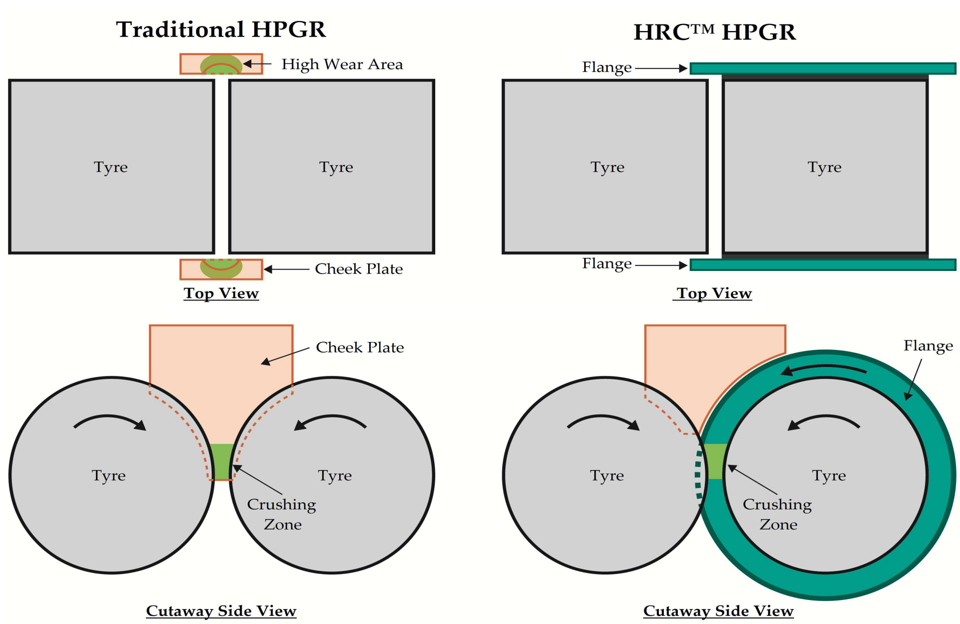

Figure 1 Traditional HPGR arrangement (left), HRC™ HPGR arrangement with flanges (right)

On the HRC™ HPGR, flanges bolt onto the edges of one tyre and rotate with the bed of material as it passes through the crushing zone. The design is proposed to enhance local edge performance because the flanges will move with the ore and more effectively draw material into the crushing zone while closing off the edge of the tyre.

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 tyres. This paper tests the hypothesis that an HRC™ HPGR with a flanged-tyre can measurably reduce the negative impacts of edge effect.

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 tyre, (ii) an uneven wear pattern on the tyre due to the differential in pressure between the center and edges of the tyres; and (iii) decreased energy efficiency due to the higher than optimal pressure being applied to material at the center of the tyre. 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 tyres, 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 tyres also results in an uneven wear pattern with higher wear rates in the center of the tyre, described as a "bath tub"(Morley, 2006). The higher pressure in the center of the tyre 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 tyre is reduced, harder studs could potentially be utilized, resulting in an increase in tyre life and higher machine availability.

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

METHODOLOGY

Flange 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 ability of Metso's patented Arch-frame to avoid skewing. With this design, the frame mechanically connects both bearings of the tyre 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 tyres.

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 tyre of the apparatus, monitoring the crushing pressure throughout the tyre rotation. As expected, the highest pressure in the crushing zone occurred at the center of tyre during the cheek plate test (dashed orange line). When flanges were installed on the same unit (solid green line), the variation in pressure across the tyre was greatly reduced.

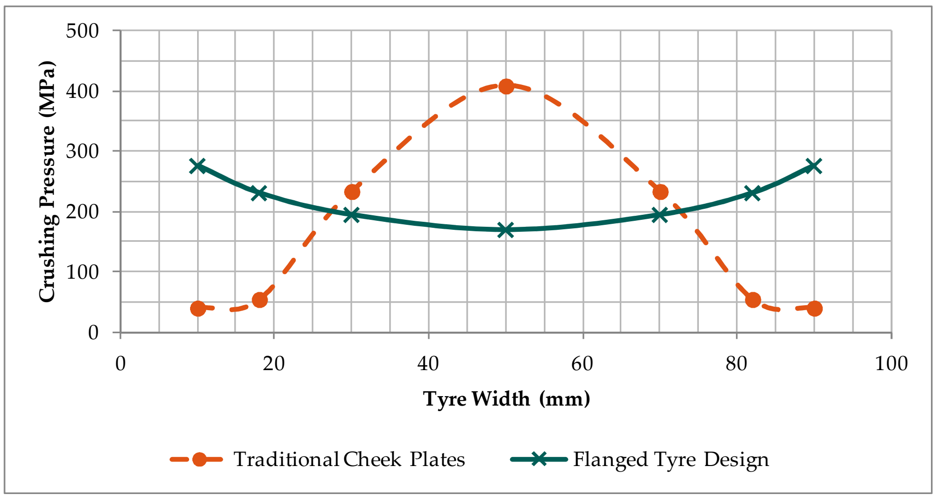

Figure 2 Pressure distribution across width of HPGR tyre (cheek plates versus flanges)

Pilot plant testing

The pilot plant, located at the Freeport-McMoRan Copper & Gold (FCX) Morenci Concentrator, is an ongoing 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. Through June 2013, the pilot plant has operated for over 8,800 hours and processed over 420,000 tons of ore. Some 114 separate process surveys have been conducted according to a factorial experimental design jointly developed by FCX and Metso. Forty (40) of these experimental runs were focused on quantifying the HRC™ HPGR circuit performance.

The pilot plant's HPGR crushing circuit includes an HRC™ HPGR with 750 mm × 400 mm tyres, 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 tyres.

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 tyres 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. These samples and data were then analyzed to provide a mass balance and circuit performance analysis for each test run. 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.

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 enhanced comminution performance at the edges can be illustrated by comparing 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/mm².

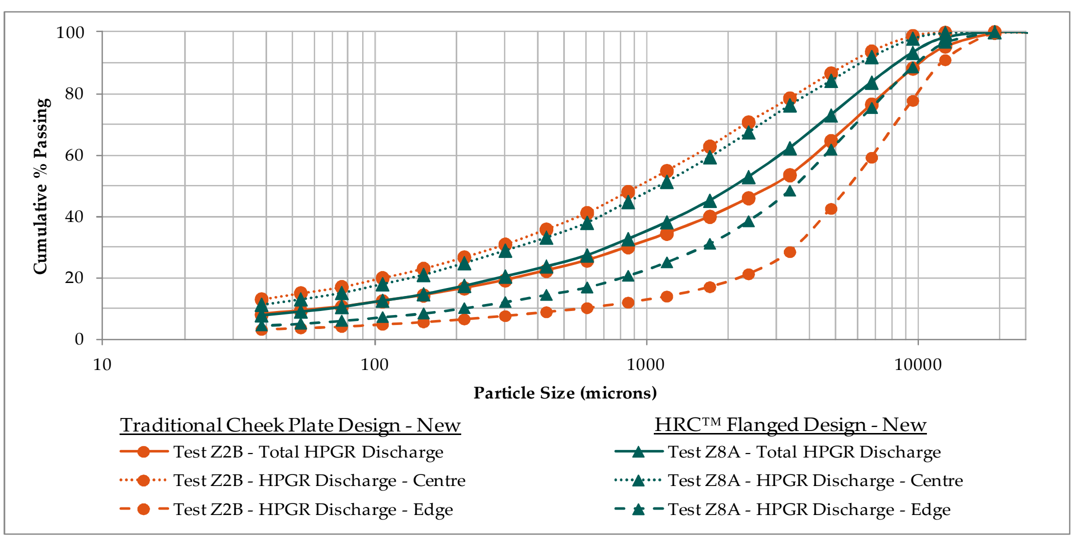

Figure 3 Comparison of HPGR discharge samples (total, center, & edge) from tests Z2B and Z8A

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 tyres. These gates collected a sample from a width of ~ 100 mm at each edge. Simultaneously, a product sample was collected from the middle 200mm of the tyre 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 tyres. 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 tyre speed. Finally, the operating gap and specific throughput show a significant increase in Test Z8A.

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 tyre 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 ($t{\cdot}s/m^3{\cdot}hr$)	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%

Across all twelve tests in this matrix, with varying wear conditions and specific forces, the flanged-tyre 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 of the HPGR showed a notable increase when operating with flanges.

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 (ts/m3-hr)	Net circuit specific energy (kW·hr/tonne)	Circulating load (%)
Z1B	Cheek plates - new	3.49	178.5	2.82	107%
Z2B	Cheek plates - new	4.49	215.6	3.04	111%
Z3A	Cheek plates - half worn	4.51	213.5	3.34	124%
Z4A	Cheek plates - half worn	3.49	203.9	2.82	135%
Z5A	Cheek plates - fully worn	3.50	210.7	2.81	122%
Z6A	Cheek plates - fully worn	4.49	223.4	3.05	114%
	Average cheek plate results	**4.00**	**207.6**	**2.98**	**119%**
Z7A	Flanges - new	3.50	231.6	2.67	93%
Z8A	Flanges - new	4.51	240.0	2.72	87%
Z9A	Flanges - half worn	3.49	279.8	2.35	102%
Z10A	Flanges - half worn	4.51	239.7	2.65	80%
Z11A	Flanges - fully worn	4.49	236.6	2.71	78%
Z12A	Flanges - fully worn	3.50	256.5	2.35	102%
	Average flanged tyre results	**4.00**	**247.4**	**2.57**	**90%**

Laboratory ore characterization testing, including: packed bed compression testing, drop weight testing, Bond work index testing, and mineralogical assays were completed on the circuit feed to assess ore variability during this testing program. Preliminary review indicates that the ore remained relatively consistent throughout this testing program. Further work is required to normalize the test results based on ore crushability in order to understand the full magnitude of the reduction in edge effect when using flanges.

FUTURE WORK

The findings discussed in this paper are preliminary results from the pilot plant testing program. 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 computer models.

The detailed analysis of the pilot plant data is ongoing and future work will highlight the results from the various other aspects of the testing program. This will include: demonstrating the HRC™ HPGR performance across the full range of test conditions, presenting the performance of the various wear components on the HRC™ HPGR, and reviewing the performance of downstream grinding circuits in combination with the HRC™ HPGR.

CONCLUSION

Through a combination of laboratory testing and pilot plant surveys, the ability to reduce edge effect via the utilization of a flanged-tyre design has been investigated. The presence of flanges has been shown to provide a more consistent pressure across the width of the tyre, yielding better particle breakage at the edges. Testing using a 750 mm × 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-tyre 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%.

These results have major implications for the design and operation of HPGR circuits. Significant improvements in the areas of comminution efficiency, tyre wear, and circuit design are possible if the presence of flanges can provide a more even pressure distribution across the width of a production scale tyre. As shown at the pilot scale, the additional particle breakage at the edges of the tyres would substantially affect the HPGR circuit performance. This advantage could potentially be leveraged during the design stage to reduce the equipment size as well as the screening and conveyance requirements; or the process benefits of the flanges could be realized through increased plant capacity. The potential to provide an even pressure distribution across the width of the tyre also has implications on the tyre design and wear life. A more even wear rate across the tyre would avoid the negative effects of a "bath tub" wear pattern. In addition, the lower peak pressure at the center of the tyre may allow for harder, more wear resistant carbide studs to be embedded on the tyre surface without risk of fracture. Overall, the cumulative benefits in operating efficiency, availability and operability support the use of a flanged-tyre HPGR design.

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