Improving Comminution Circuit Performance in an Iron Processing Plant: No-Capital-Investment Approach

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Abstract. To conserve energy, efforts are made to increase the efficiency of conventional comminution circuits. As a case study, this research conducted a process audit of the comminution circuit in an iron processing plant to identify low-cost solutions (i.e., with no capital investment) for improving product quality and reducing maintenance and operating costs. The main challenges were the crusher operation in a partially full condition, high-pressure grinding roll operation in a non-standard condition, and poor screen efficiency. Additionally, the makeup ball size regime and ball filling were significant issues for the ball mill. Following the initial study, a series of modifications were made to the operation of the crushing and grinding circuit. This consequently resulted in 9.3% increase in the crushing plant throughput after operating the crushers in choked condition. By increasing the HPGR operational pressure and the hopper level, the BBWI of the HPGR product was reduced by approximately 5%. By modifying the screen process, the circulating load decreased by about 20%, and the screen efficiency increased from 63.5% to 89.5%. Furthermore, a new combination of makeup ball size regime decreased the P80 of the grinding circuit from 133 to 96 microns, along with a 9.5% increase in production rate.

1 Introduction

Comminution is essential for liberating valuable minerals, improving material handling, and producing controlled particle sizes [1]. High-pressure grinding rolls (HPGRs) have recently emerged as an intermediate device between fine crushing and coarse grinding [2]. Since comminution accounts for the largest share of energy consumption in mineral processing, significant efforts have focused on improving equipment efficiency [3]. Cone crusher performance strongly influences downstream processes, making optimization critical [4-5]. The shift from conventional three-stage crushing to HPGR-based circuits has increased complexity, but HPGR offers advantages such as lower operating costs and higher energy efficiency [6]. Key HPGR parameters include hydraulic pressure, roll speed, and hopper level [7-9]. In grinding circuits, simulations combined with ball wear laws have shown that optimal ball size distribution is essential for efficient breakage and minimizing ultrafine particles. A mixed ball regime (80% 80 mm and 20% 60 mm) improved fines production by 4% compared to mono-sized balls [10].

This research investigates various faults and challenges in operating conditions that significantly impact process performance. The process audit in the case study plant was used to identify operating faults and propose appropriate solutions to enhance comminution circuit performance. All the required modifications that had a significant impact on the process were implemented at minimal costs with no capital investment required.

1.1 Iron Ore Processing of Steel Iron Ore Complex

Figure 1 shows a process flowsheet of the Steel Iron Ore Complex processing plant. The comminution circuit has been provided to prepare the desired feed for two plants. The concentrator plants are designed to produce an iron ore concentrate with a Fe grade of 68%.
Three stages of crushing were considered to provide the proper feed for the concentration plant. Jaw crusher, standard head cone crushers, and short head cone crushers were used as the primary, secondary, and tertiary crusher units, respectively. In the concentration plant, an HPGR in closed circuit with a wet vibrating screen was used as the pre-grinding circuit. The final product of the HPGR circuit (screen underflow) is fed to a ball mill-hydrocyclones circuit.

2. Materials and Methods

Plant audit was selected as a monitoring method in order to standardize the whole crushing, pre-grinding and grinding process plant. The main troubles were as follows: all the crushers operated in a partially full condition, the HPGR operated in a non-standard condition, resulting in a high amount of reject materials

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in the HPGR circuit, and the screen operated in a low-efficiency mode. Also, the ball mill operated with low ball filling (%) - defective balls and hydrocyclones worked in high solid content.

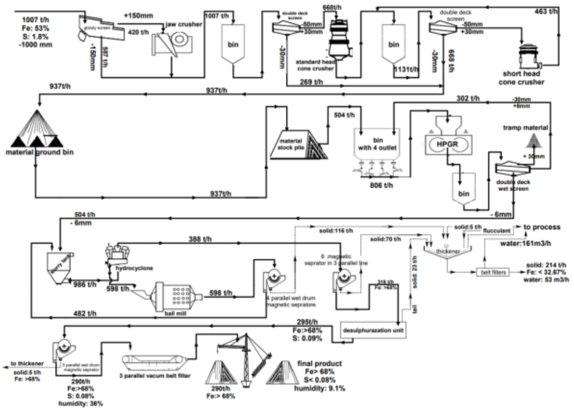
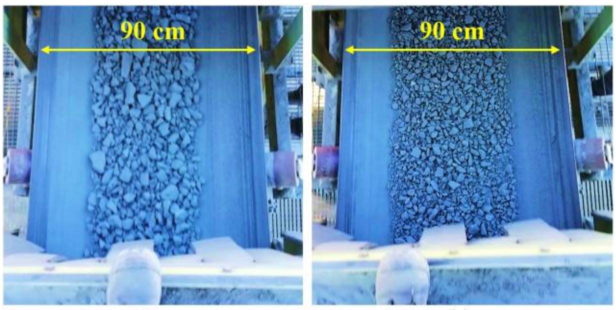


Fig. 1. Process flowsheet of the Iron Ore Complex.

3 Results and Discussion

3.1. Crusher circuit

Three crushing stages were considered in the crushing circuit. Based on the design data, the feed rates of the primary, secondary and tertiary crushers were 433, 689, and 477 t/h, respectively, and the power draws of the crushers were 160, 315 and 315 kW, respectively. Process audit of primary (Closed Side Setting; CSS = 185 mm), secondary (CSS = 58 mm), and tertiary (CSS = 28 mm) crushers in 4 months showed that the average feed rates were 368, 510, and 405 t/h, respectively, and their average power draw were 115, 102, and 127 kW, respectively. The investigation results revealed that the crushers operated in a partially full condition. The reasonable solutions were to adjust the crushers' closed side setting (CSS), modify the feeders, and increase the feed rate to achieve a choke-fed operating condition.
Two trials were conducted at the partially full and super-choked conditions (Figure 2). The results obtained indicated that the operating crushers in the super-choked condition reduced the P80 of the final (ground bin feed), secondary, and tertiary products by 15.2%, 17.5%, and 16.5%, respectively, compared to those in the partially full mode.



(a) (b)

Fig.2. Product view of tertiary crusher in (a) partially full and (b) choke-fed operating conditions.

When operating the crushers in super-choked mode, as opposed to partially full, there was a 9.3% increase in plant throughput, and the size-specific energy at -32 mm decreased by 15.6%.

3.2. HPGR circuit

To increase the HPGR comminution efficiency, the operational pressure and hopper level were modified. The pressure and the hopper level were increased from 120 bar and 25% to 160 bar and 55%, respectively. Changing the operational pressure and hopper level caused an increase in the reduction ratio from 1.8 to 2.4. A snapshot view of the HPGR belt product in the operational pressures of 120 bar and 160 bar is shown in Figure 3. The ideal mode of the HPGR product is a compacted cake or flake. The product BBWI of the choked condition was obtained to be 15.2 ± 0.25 kWh/t as opposed to the BBWI of 16.1 ± 0.10 kWh/t for the partially full condition.

Fig.3. HPGR belt product in the operational pressures of 120 bar and 160 bar.

Wet screen audits showed that the upper deck's small apertures (14 mm) reduced open area, limiting fine particle passage and preventing effective stratification on the lower deck. This caused finer particles to recirculate to the HPGR, increasing the circulating load and reducing the screen product rate. Increasing two lower deck rows from 6 mm to 8 mm by operators reduced circulating load but introduced coarse particles to the underflow, raising wear by 7% and coarsening the hydrocyclone overflow. To improve efficiency and reduce rejects, increasing the upper deck aperture size to 30 mm is recommended (Figure 4).

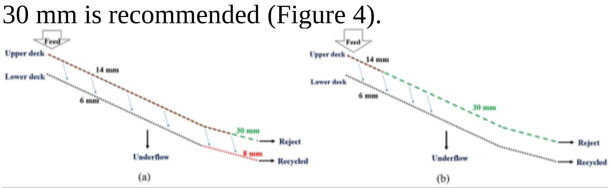


Fig.4. Wet double screen before (a) and after (b) modifications.

As the results indicated, the screen feed and underflow rate increased from 699 and 387 t/h to 738 and 463 t/h, respectively. The amount of the desired product (-6 mm material) and the material thickness on the second deck decreased from 46% and 47 mm to 20% and 33 mm, respectively. Therefore, by modification, the circulating load decreased from 79% to 59% and the screen efficiency increased from 63.5% to 89.5%. In addition, the down-stream results indicated a reduction of the ball consumption from 565 g/ton to 535 g/ton. A snapshot of the recycled material before and after the modifications is shown in Figure 5.

(a) (b)

Fig.5. Recycled material of screen (a) before and (b) after modifications.

3.2. Grinding circuit

The operating parameters, such as overflow and underflow solid content, as well as operating pressure, were controlled and monitored. If the ball mill feed becomes too dilute, the wear rate of grinding media inside the ball mill increases. When it becomes too dense, it causes a reduction in the media kinetic energy and breakage efficiency. Increasing overflow solid content causes an increase in overflow d80 at the same operating pressure [10]. Table 1 shows the average operating data of hydrocyclones before and after modification.

Table 1- The average operating data of hydrocyclones before and after modification

	Design	Before modification	After modification
Underflow percent solid	75	77	76
Overflow percent solid	30	34	30
Pressure (kPa)	120	85	115

The filling charge of balls inside the mill was around 27%; it was increased to 30%. However, owing to some restrictions, it wasn't possible to reach the design by about 35%.

A random sample of balls from the mill showed that the percentage of defective balls was 29%. The defective balls were categorized into conical, holed, and layered types. These balls (broken) could cut the rubber lining of the mill due to their sharp edges and increase grinding media consumption.

Furthermore, none of the balls had a diameter of 25.4 mm (1 inch), which was supposed to be 15% of the total based on Rowland and Kjos formulas [40]. The quality of the balls is poor, as they lose their spherical shape at this size. In fact, the balls below 30 mm were deformed. The absence of small balls affects the grinding efficiency.

The optimum ball size distribution was determined to improve the operating efficiency of the ball mill through two techniques: theoretical modelling and a practical approach. Thereupon, a new combination make-up ball size regime was proposed rather than using two-sized balls (60 and 40 mm). To decrease particles coarser than 0.5 mm (reject) 5% by weight was added to the 60 mm ball. Also, to obtain small spherical shaped balls, 15% of the 25mm ball was considered (Figure 6).

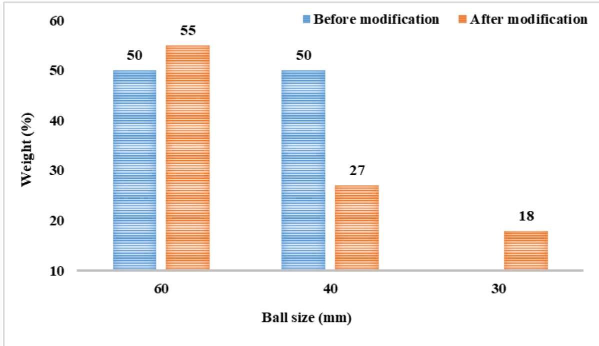
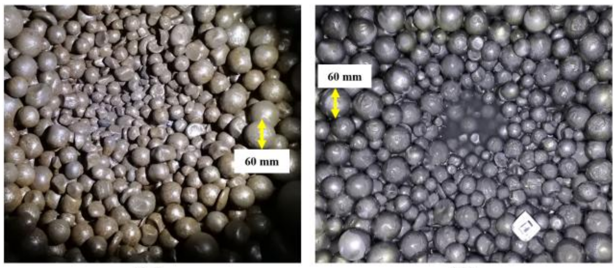


Fig.6. The old and new combination make-up ball size regime

Periodic observations from inside ball mills showed that the number of perfect balls smaller than 30 mm is observed in mills (Figure 7).



(a) **(b)**

Fig.7. Balls inside mill (a) before and (b) after new combination make-up ball size regime

P80 of the final product during the optimization process decreased from 133 to 96 microns. Furthermore, the Blaine number of the final product not only increased from 980 to 1170 (g/cm2), but also the final production rate increased by around 9.5%.

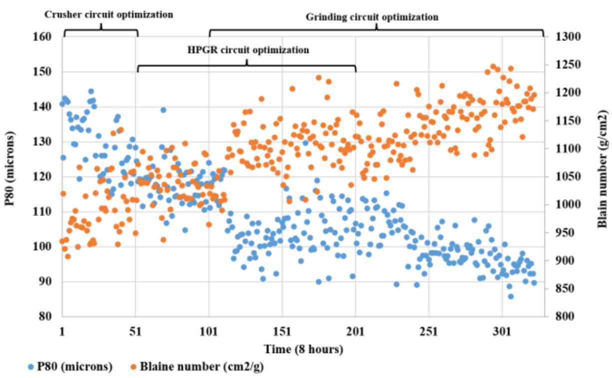


Fig.8. P80 and Blaine number of final product during optimization process

4. Conclusions

In this research work, to increase the comminution circuit efficiency, a process audit and several low-cost modification routes were presented and implemented at the iron ore crushing, pre-grinding, and grinding plant of the Steel Iron Ore Complex.

It was shown that the super-choked condition of the crushers reduced the P80 of the final product and the size-specific energy at -32 mm by 15.2% and 15.6%, respectively, compared to the partially full mode. Additionally, the crushing plant's throughput increased by 9.3%.

By increasing the HPGR operational pressure (from 120 bar to 160 bar) and the hopper level (from 25% to 55%), the particle grindability, measured as BBWI, decreased by 5.6%. In addition, the reduction ratio increased from 1.8 to 2.4.

By increasing the aperture size of the upper deck from 14 mm to 30 mm (useful area), the circulating load decreased from 79% to 59%, and the screen efficiency increased from 63.5% to 89.5%. Also, the amount of the rejected materials decreased from 1.6% to 0.5%.

By applying all previous modifications and combining the makeup ball size regimes, the P80 of the final product decreased significantly. Blaine number product during the optimization process increased from 980 to 1170 (g/cm2). Moreover, the final production rate increased by around 9.5%.

5 Acknowledgement

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