Successful debottlenecking of front end section of a PGM concentrator – selous metallurgical complex sag mill feed preparation

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Zimplats is equipped with a primary crushing circuit followed by a SABC circuit at its Selous Metallurgical Complex (SMC) concentrator. As part of their continuous improvement, Zimplats SMC, based on the ore hardness and the main equipment dimensions and installed power, identified the front end circuit before the SAG mill as the plant bottleneck to increase the plant capacity above 290 t/h while maintaining a grind of 80% passing 75 microns. DRA Global investigated the option of implementing a secondary crushing stage before the SAG mill to debottleneck the circuit. From different options of secondary crushing before a SAG mill which could be implemented, it was established that the option of crushing an intermediate or critical size fraction was the best option due to the ball milling circuit capacity limitations at Zimplats SMC. Based on data available and simulations conducted, it was established that the intermediate size range to be crushed was the -135 + 50 mm size fraction. A layout was proposed with two screening stages before crushing to ensure maximum screening and crushing efficiency and a high availability of the secondary crushing circuit. The secondary crushing circuit was designed to receive a feed of at 675 t/h and Sandvik CH 660 was selected for this duty. The selection of the Sandvik CH 660 offered not only an advantage due to commonality of equipment on site but also the flexibility to increase the range of intermediate size crushed from +50 – 135 mm to +30 – 180 mm. The milling circuit simulations results indicate that the throughput will increase from 273 t/h (base case SABC circuit) to 310 t/h (14% increase) when the secondary crushing circuit is implemented to the current circuit with a HPGR (High Pressure Grinding Roll) operating on the pebble crusher product. The target grind of 80% passing 75 microns will also be achieved. Plant records from the time the pre-crushing circuit was commissioned indicate that the SAG mill has achieved a milling rate of 305$\pm$5 t/h at a grind of 78$\pm$2% passing 75 microns The project met the company's hurdle rates of return on investment and performance since a throughput of more than 300 t/h was achieved.

Keywords: Pre-crushing, secondary crushing, SAG mill optimization

INTRODUCTION

Zimplats Selous Metallurgical Complex (SMC) comminution circuit involves a primary crushing circuit followed by a SABC circuit. The primary crushing stage is conducted at the mine using a jaw crusher while the milling stage is conducted at SMC concentrator located a few km from the mine. SMC grinding circuit is a typical SABC circuit equipped with 26 ft x 11.6 ft (D x L) SAG mill with a 4.475 MW installed power, a 18 ft x 28.6 ft (D X L) Ball mill with 4.475 MW installed power and a pebble crusher. The SABC grinding circuit was modified in December 2019 to include a HPGR on the pebble crusher product. The simplified SMC comminution circuit after the implementation of an HPGR is reported in Figure 1.

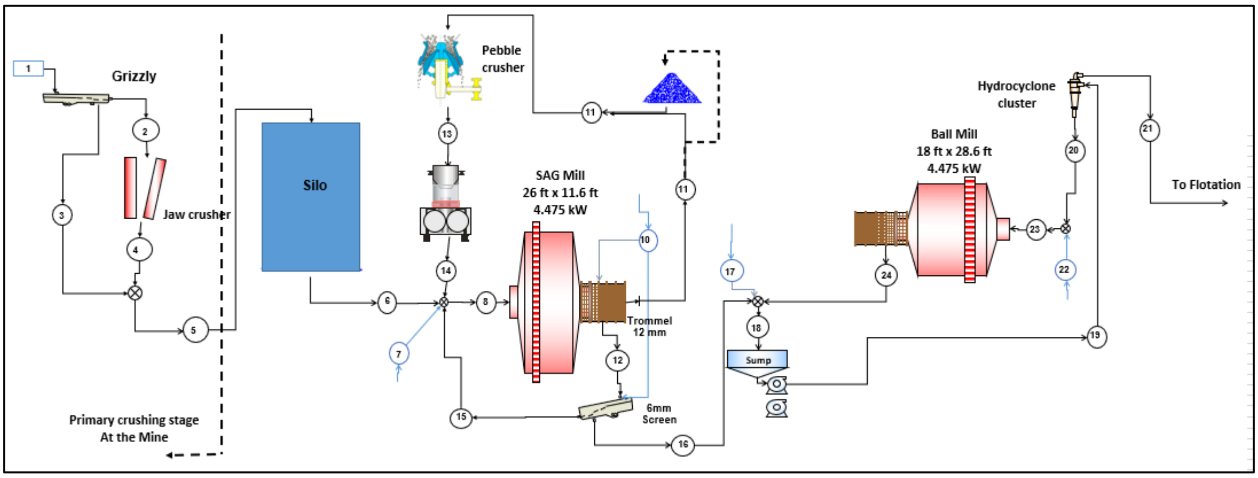


Figure 1. Simplified Zimplats SMC comminution flowsheet

As part of their continuous improvement program, SMC explored different options for improving their plant performances, and specifically the throughput. Based on the ore hardness and the main equipment dimensions and power installed, the front end of the milling circuit was identified as a bottleneck of the circuit. Studies were initiated to debottleneck the circuit by adding a secondary crusher before the SAG mill. To study the best option to implement a secondary crushing stage, Zimplats SMC approached DRA Global to conduct this study. Zimplats SMC provided current and historical plant operating data to ensure that the predictions of throughput, grind and mass balance for different streams were accurate.

Ore Characteristics

Table I represents the Zimplats SMC ore hardness testwork results used in the simulations.

Table I. SMC ore hardness

Bond ball mill work index (BBWI)	kWh/t	22.3
Crusher work index (CWI)	kWh/t	18.5
A		80
B		0.51
A x b		40.8
Ta		0.41

The SMC ore is classified as hard at coarser size (Axb = 40.8; CWI=18.5 kWh/t) and very hard at finer size (BBWI = 22.3 kWh/t). Zimplats SMC provided monthly average SAG mill feed particle size distribution (PSD) data covering the period from July 2018 to June 2019. Data provided are reported in Table II. These data revealed that the primary crusher product which constitutes the feed to the SAG mill at SMC is typically coarser in comparison to a target and standard primary crusher product of F80=150 mm.

Table II. SAG mill feed particle size distribution at SMC

Screen size [mm]	Jul 18 MTD	Aug 18 MTD	Sep 18 MTD	Oct 18 MTD	Nov 18 MTD	Dec 18 MTD	Jan 19 MTD	Feb 19 MTD	Mar 19 MTD	Apr 19 MTD	May 19 MTD	Jun 19 MTD
300	100	100	100	100	94	100	100	95	100	97	100	100
212	100	100	93	86	86	100	87	83	87	90	96	100
150	90	83	79	69	74	89	74	71	64	69	74	77
95	73	62	65	55	58	71	62	56	52	51	63	62
75	64	53	56	45	50	64	46	44	41	41	53	50
53	47	41	44	32	39	54	37	32	31	32	39	40
38	37	34	34	24	29	45	28	25	27	26	32	33
27	31	29	28	20	24	40	23	22	24	22	28	28
19	25	26	24	17	19	34	19	19	21	18	25	25
13	21	22	20	14	16	30	16	16	18	15	22	22
F80 (mm)	111.13	140.82	153.57	184.38	176.45	117.66	173.34	192.36	187.24	176.43	160.29	151.75
F50 (mm)	57.03	68.44	62.52	85.47	74.20	45.22	80.12	84.36	91.78	92.39	69.92	73.94
F25 (mm)	18.37	17.95	21.05	39.30	28.88	0.00	31.77	37.87	31.08	35.07	18.27	19.41

The data provided were used to derive a finer, average and coarser size distribution as represented in Figure 2. The derived size distributions were used in the simulations.

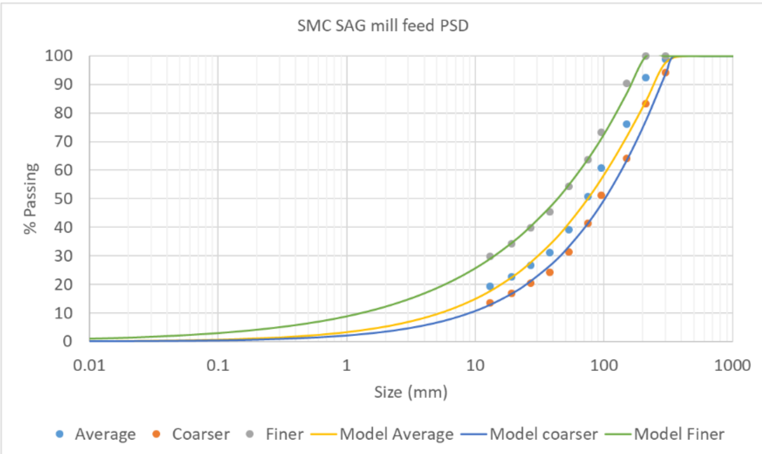


Figure 2. SMC SAG mill PSD

Secondary crusher before the SAG Mill

The topic of implementing a secondary crushing stage of ore before SAG milling has been explored extensively in recent years to increase the throughput of many operations or maintain the throughput when the ore is harder. A review of different operations which have installed a secondary crusher before their SAG mill was published by Siddal B. and Purtland B., 2007 and updated by Kalala *et al.,* (2018). There are mainly three types of secondary crushing of ore before a SAG mill: i) Total option which consists of totally crushing a coarser size fraction (for instance + 50 mm) before a SAG mill, ii) a partial option which consists of crushing a portion of a coarser size fraction, iii) intermediate or critical size crushing option which consists of crushing a SAG mill critical size fraction (for instance + 30 to - 120 mm) before the SAG mill. Each case should be taken into consideration at design stage to implement the optimal solution for a plant.

The secondary crushing of an intermediate size fraction before SAG milling is the most 'elegant' way of increasing the SAG mill throughput in comparison to a full crushing because it addresses directly the issue of slowing down in breakage rate of a critical size inside the mill while maintaining the need for coarser fraction inside the SAG mill to operate as grinding media. It is however the most difficult option to implement in terms of i) plant layout, ii) predicting the circuit performance and iii) sensitivity to change in feed size distribution and hardness. When designed properly, the secondary crushing of an intermediate size fraction should result in a lower OPEX in comparison to a secondary full crushing option which is basically similar to a three-stage crushing with the SAG mill pushed to operate as a ball mill.

A review of operations which have implemented an intermediate size crushing before their SAG mill is represented in Table III.

Table III. Review of projects which have implemented an intermediate size secondary crushing stage before their SAG mill

	Plant capacity	Circuit	*Location*	Feed splitting	Challenges just after the installation of a secondary crusher	Summary of modifications on the SAG/Ball mill after introduction of secondary crushing
Asarco	4 MTPA	SABC	Before stockpile	Scalp 120 x 30 mm	- Secondary crusher screen blinding and plugging -Increase in ball mill circulating load	- Decreasing grate open area from 11.7 to 9.6% - Operating the mill at higher mill charge volume
Geita	6 MTPA	SABC	Before stockpile	Scalp 120 x 30 mm	-Blinding of grizzly screen at the secondary crushing circuit -Difficulty to screen wet oxide ore and dust generation -990 t.h achieved instead of 1200 t/h design	-Upgrading of 22 ft diameter ball mill by reducing the trunnion opening to 1.6 m for the mill to retain 35% balls
Freda Rebecca	0.8 MTPA	SSSAG Mill	Before Stockpile	Scalp 100 x 40 mm	-Increase in % circulating load	_

The secondary crushing of an intermediate size fraction target, mainly the size fraction showing a slowing down in breakage rate as indicated in Figure 3.

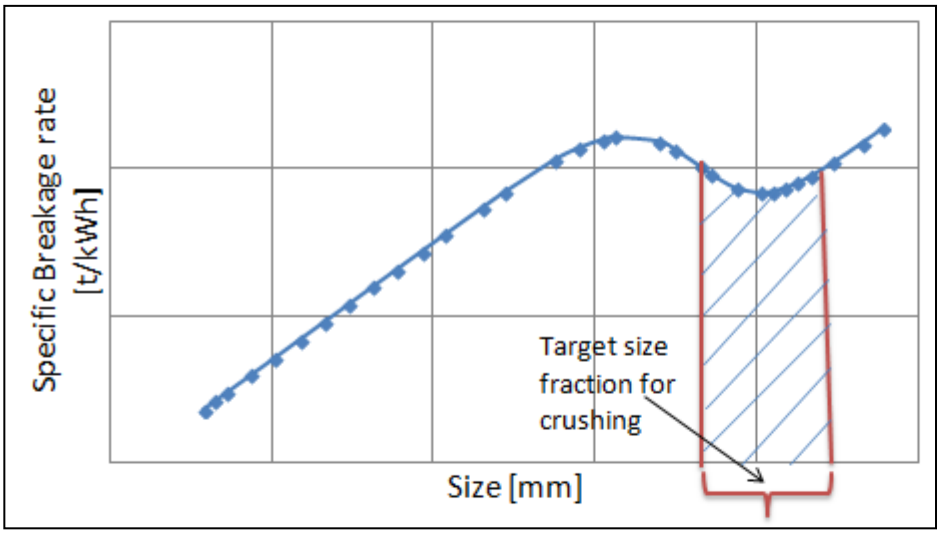
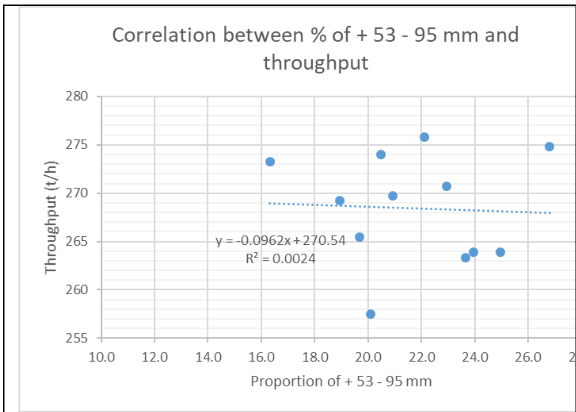
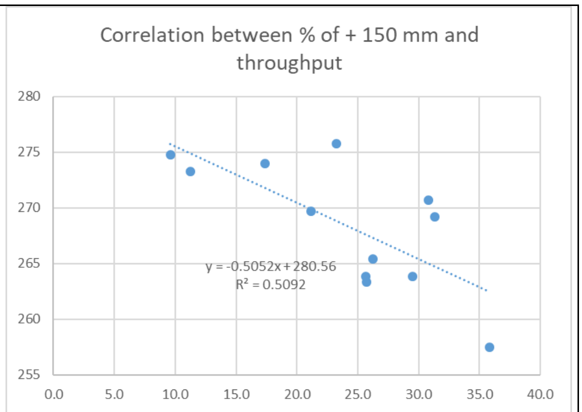
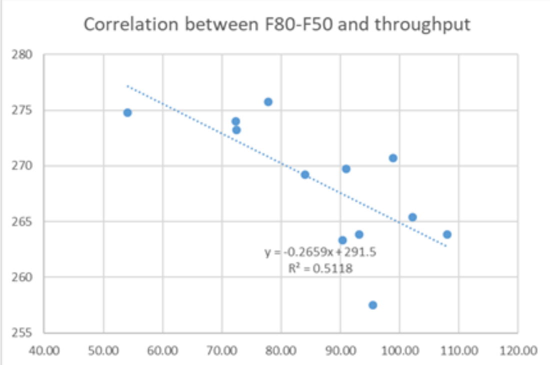


Figure 3. Typical specific breakage rate as a function of ore particle size in a SAG mill

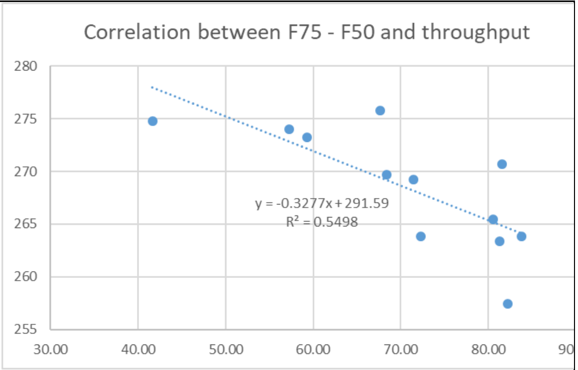
The secondary crushing of an intermediate size does not usually result in an increase of the transfer size to the ball milling circuit. This is very important in the case of SMC since there is no extra capacity in the ball milling circuit to deal with an increase in transfer size. For this reason, this option was selected for SMC to ensure that the target grind is consistently achieved. DRA Global analysed production data and size distribution to assess the correlation between different size fractions and the SAG mill throughput. The results are represented in Table IV.

Table IV. Correlation between the SAG mill throughput and different size fractions.

	
Correlation between SAG mill throughput and proportion of + 53 – 95 mm	Correlation between SAG mill throughput and proportion of + 150 mm



Correlation between SAG mill throughput and proportion of F80 – F50



Correlation between SAG mill throughput and proportion of F75 – F50

Table IV indicates that there is no strong correlation between the proportion of +53 -95 mm and the throughput. However, there is a reasonable correlation between:

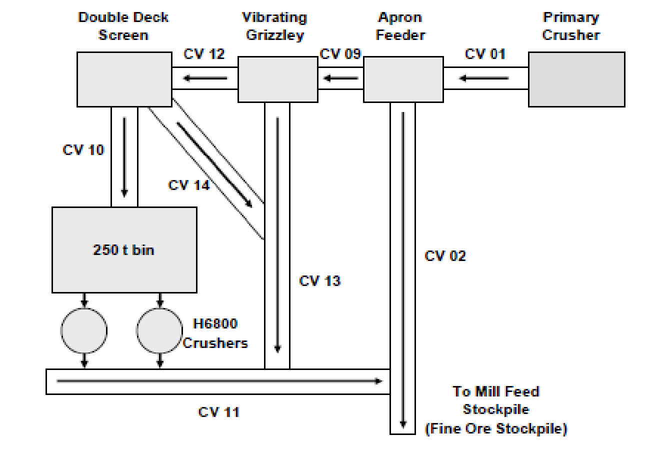
- The proportion of + 150 mm size fraction and the throughput
- The proportion of F80 to F50 and the throughput
- The proportion of F75 to F50 and the throughput.

DRA Global conducted simulations based on the population balance model to determine the intermediate size fraction to be crushed. The results indicate that a size fraction between 135 mm and 50 mm should be targeted to achieve the target throughput while maintaining the grind.

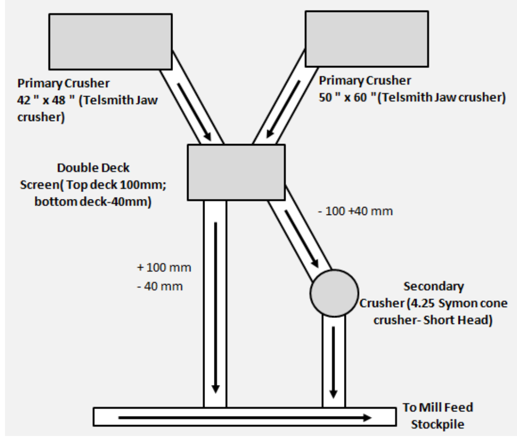
Layout and Sizing of the secondary crusher circuit

A review of the secondary crusher circuits layout implemented with the crushing of the critical size fraction indicate that careful considerations should be taken in terms of:

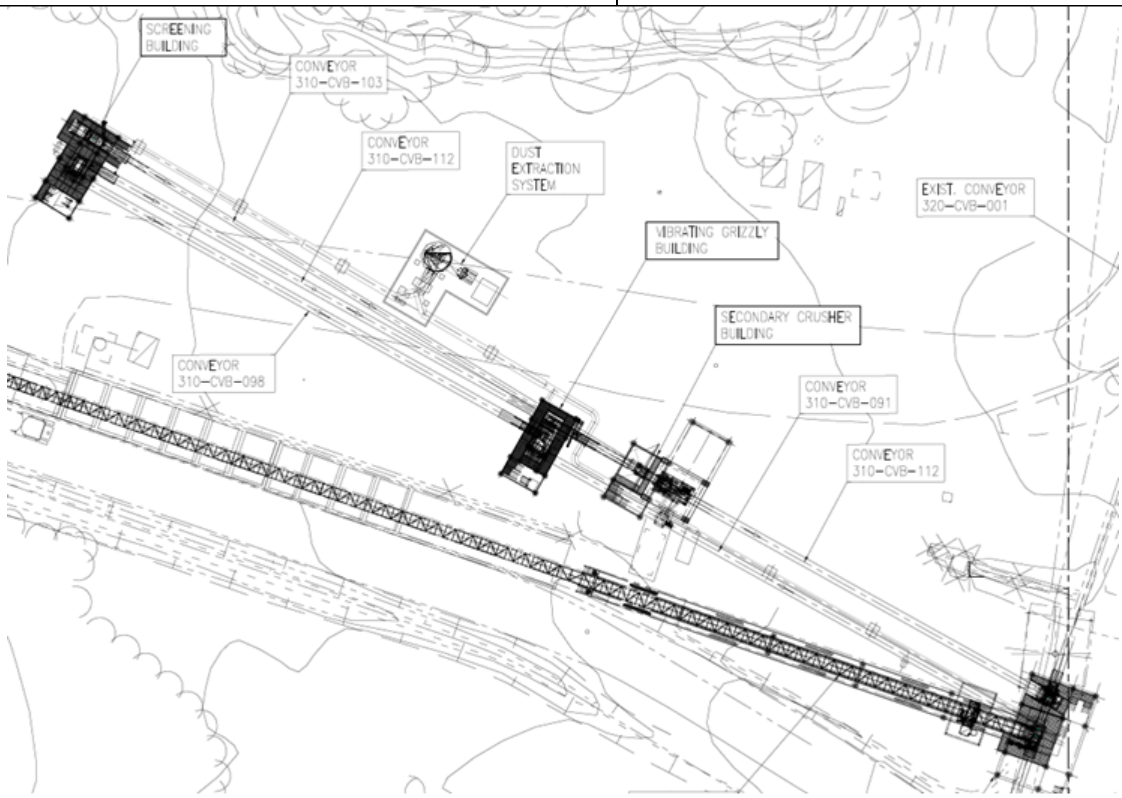
- Screening: It is important to achieve a high screening efficiency in order to crush efficiently the critical size fraction range.
- Preventing metal into the crushing chamber: A magnet should be implemented in the secondary crushing circuit to remove metals prior to the secondary crusher.
- Dust generation: Dust will be generated from screens, cone crusher and transfer points. Provision should therefore be made in the design to include dust suppression mechanisms.
- Choke feeding the secondary crusher: This is a requirement in order to achieve the required size reduction ratio. To achieve this, a bin is therefore necessary before the secondary crusher.
- Availability: The availability of the secondary crushing circuit should be studied to ensure that the circuit has enough capacity.



Secondary crusher layout at Geita (after Mwehonge, 2006)



Secondary crusher layout at Freda Rebecca (after Mudoti *et al.*, 2018)



Secondary crusher layout implemented at Zimplats SMC

Figure 4. Secondary crusher layout

Due to the high throughput required for the secondary crushing circuit at SMC and the challenges discussed above, the layout reported in Figure 4 was implemented. The screening is conducted in two stages (similar to Geita): A grizzly is used for the first screening a coarser size (135 mm) and a double deck screen (80 and 50 mm) is used for the second screening stage. The intermediate size (-135 +50 mm) reports to bin before feeding the secondary crusher.

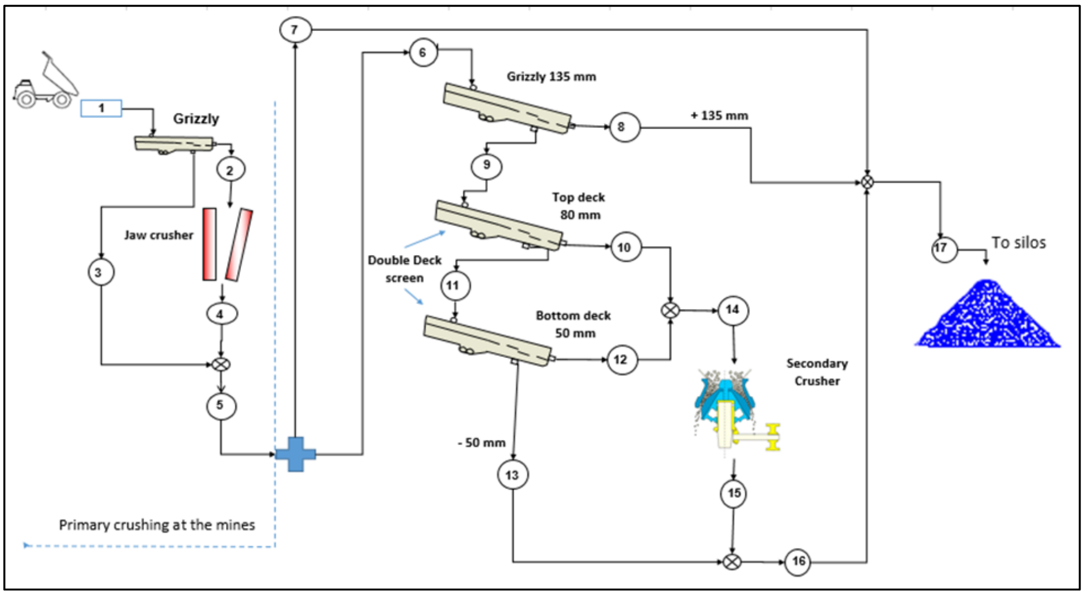


Figure 5. Simplified flowsheet of the secondary crushing circuit.

Table V. Secondary crusher circuit mass balance

Throughput	Stream 6	Stream 7	Stream 8	Stream 9	Stream 10	Stream 11	Stream 12	Stream 13	Stream 14	Stream 15	Stream 16	Stream 17
Min (t/h)	675	0	149.57	368.87	108.31	260.56	64.55	196.01	172.86	172.86	368.87	675.00
Max (t/h)	675.00	0.00	306.13	525.43	153.07	410.32	82.85	337.30	235.92	235.92	525.43	675.00
Average (t/h)	675.00	0.00	219.05	455.95	121.38	334.57	72.54	262.02	193.93	193.93	455.95	675.00
F80												
Min (mm)	121.75		161.49	69.98	107.45	40.48	57.77	26.03	99.65	25.88	26.04	110.92
Max(mm)	220.88		279.83	82.42	108.50	47.84	58.10	30.25	103.24	26.01	28.11	220.88
Average (mm)	164.18		215.88	77.28	107.87	45.11	57.91	28.55	101.04	25.96	27.28	159.26
F50												
Min (mm)	43.02		148.62	24.71	93.11	14.28	53.48	9.31	74.80	14.30	11.32	17.78
Max(mm)	100.77		210.87	39.35	95.02	23.40	53.87	15.34	78.33	14.38	14.82	36.68
Average (mm)	70.31		178.14	34.10	93.85	19.75	53.64	12.84	76.09	14.35	13.46	25.87

The secondary crusher was designed to take a throughput of 236 t/h from a F80=105 mm to produce a product of P80=26 mm (reduction ratio of ~ 4). SMC has indicated their desire to keep the same Sandvik crusher supplier for commonality of equipment purpose. To achieve the required size reduction a Sandvik CH660 (315 kW) with a coarser crushing chamber is required. It is also important to mention that the selected CH660 (315 kW) with a coarser chamber also offers the flexibility to increase the size range crushed from -135 + 50 mm to -180 +30 mm without requiring additional power.

Milling circuit simulations results

Simulations based on the population balance model were conducted to determine the expected throughput following the implementation of the secondary crushing stage before the SAG mill. The base case simulations were used to calibrate the model versus historical data provided by Zimplats SMC. All simulations were conducted to achieve a target grind of 80% passing 75 microns while keeping the percentage circulating load around the ball mill below 350%. The simulated results are represented in Figure 6. The results indicate that a throughput increase of 13.5% (from 273 t/h base case to 310 t/h) is expected by including a secondary crusher stage in the circuit and a HPGR on the pebble crusher product.

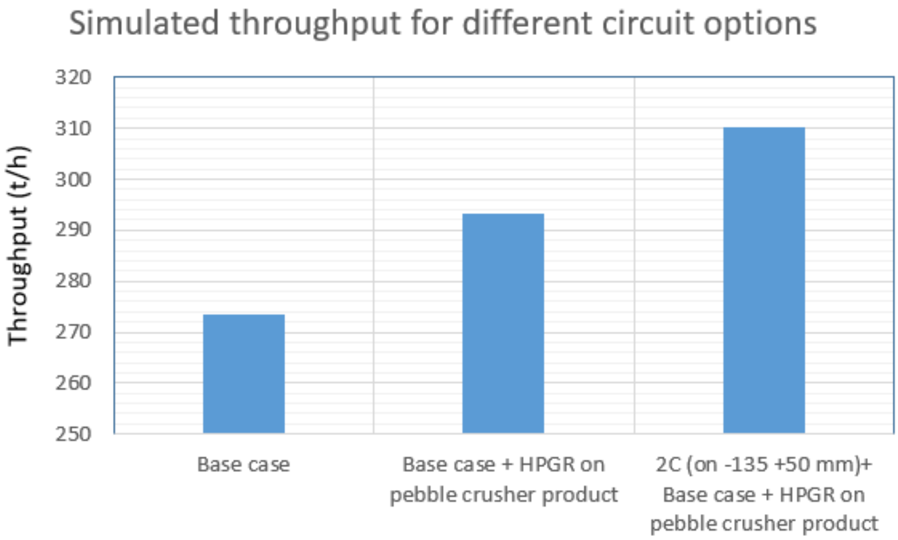


Figure 6. Summary results of different options.

CONCLUSIONS

The Zimplats SMC concentrator is equipped with a primary crushing stage followed by SABC circuit with a HPGR added on the pebble crusher product. Based on the ore hardness and the main equipment dimensions and installed power, the front-end circuit before the SAG mill was identified as the plant bottleneck to increase the plant capacity. Secondary crushing stage before SAG milling has been implemented in recent years in many operations in order to increase the throughput of SAG mill circuits or maintain the throughput when the ore is harder. There are currently more than 15 operations worldwide, which have successfully implemented a secondary crushing stage before a SAG mill. The operations range from low to high throughput and medium to hard ore. From different options of secondary crushing before a SAG mill which could be implemented, it was established that the option of crushing an intermediate or critical size fraction was the best option due to the ball milling circuit capacity limitations at Zimplats SMC. Based on data available and simulations conducted, it was established that the intermediate size range to be crushed was the -135 + 50 mm size fraction. A layout was proposed with two screening stages before crushing to ensure maximum efficiency and availability of the secondary crushing circuit. The secondary crushing circuit was designed to receive a feed of at 675 t/h and Sandvik CH 660 was selected for this duty. The selection of the Sandvik CH 660 offered not only an advantage due to commonality of equipment on site but also the flexibility to increase the range of intermediate size crushed from +50 – 135 mm to +30 – 180 mm. The milling circuit simulations results indicate that the throughput will increase from 273 t/h (base case SABC circuit) to 310 t/h (14% increase) when the secondary crushing circuit is implemented to the current circuit with a HPGR operating on the pebble crusher product. The target grind of 80% passing 75 microns will also be achieved. The secondary crushing circuit was successfully implemented and commissioned at Zimplats SMC resulting in an increase of throughput as predicted by the simulation. Further improvement can be achieved by recycling the SAG mill screen oversize (-12 +6 mm) to the HPGR instead of the SAG mill feed.

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