CDM's high-efficiency diamond recovery circuit

Petra Diamonds has installed a modern, fit-for-purpose diamond processing plant at its Cullinan Diamond Mine (CDM), which incorporates thyssenkrupp autogeneous grinding (AG) mills and HPGRs (high-pressure grinding rolls) in the processing circuit.

The new design of CDM's milling circuit comprises two autogenous (AG) mills with a grate discharge with large ports, low-revolution jaw crushers and high-pressure grinding roll crushers with large operating gaps. "The design aims to address challenges experienced in the old plant, which was based on staged crushing technology. After assessing the performance of the CDM AG milling circuit from commissioning and early production stages, we have learned a lot about diamond liberation, energy consumption, and the future of diamond processing as a whole," says Lufuno Musenwa, plant superintendent, CDM.

CDM, is an underground diamond mine owned by Petra Diamonds, a leading independent diamond-mining group and a growing supplier of rough diamonds to the international market. Established in 1902, the mine rose to prominence in 1905 when the 3 106 carat Cullinan Diamond – the largest ever rough diamond of gem quality – was discovered there.

The mine has since produced over 750 stones that are larger than 100 carats and more than a quarter of all the world's diamonds that are larger than 400 carats. CDM is renowned for large, high-quality gem diamonds, including Type II stones, and is the world's most important source of very rare blue diamonds.

In September 2017, MDM Engineering completed the construction and commissioning of a modern, fit-for-purpose processing plant at CDM, with a throughput capacity of 6.0 Mt/a to replace the original 1947-commissioned plant at CDM.

The new plant relies on gentler processing – comminution by attrition and abrasion instead of extensive staged crushing. AG milling and high-pressure grinding rolls (HPGRs) were chosen to reduce diamond breakage and improve recoveries across the full spectrum of diamonds, including the larger, more exceptional stones for which the mine is renowned.

The top cut size of 55 mm caters for the very large diamonds in the 3 000 carat range, with X-ray luminescence (XRL) sorting technology being used to raise the recovery efficiency of diamonds of all sizes. The plant has a significantly smaller footprint – just 4.0 ha – and engineering infrastructure and equipment has been significantly reduced.

AG milling in diamond processing

Traditionally, Southern African diamond processing plants are designed to include several crushing stages to liberate diamonds from the host rock. Crushers rely on compression and impact forces to break the host rock. However, even when optimised to operate with large crushing gaps, there is still the potential for breaking diamonds between the steel surfaces. In addition, the cone crushers often used are associated with poor liberation of diamonds from the mined ore.

AG milling has slowly been introduced into diamond processing in Southern Africa having been used in Russia for many years. The Russian diamond producer, ALROSA, first applied the process in Southern Africa at its Catoca mine in Angola to liberate diamonds from relatively soft kimberlite ores. AG mills were also, until recently, successfully used in the Karowe mine in Botswana, which recovered the world's second-largest gem diamond; a 1 111 carat stone in November 2015.

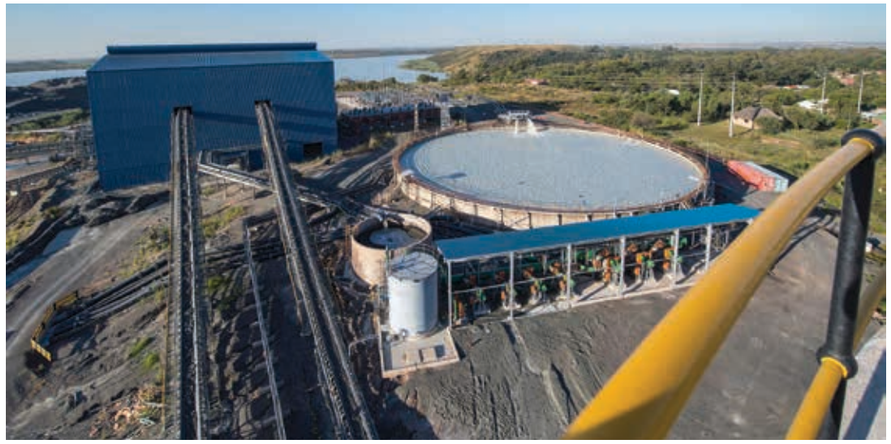
The new CDM milling plant design

The purpose of any comminution process is to liberate or expose locked-up valuable minerals within the host rock or gangue. This is an essential step in minerals processing as proper liberation allows for maximum recovery of minerals in the downstream processes.

Under-grinding leads to inefficient recoveries while over-grinding, especially in the diamond processing context, leads to major value loss due to breakage of the final product. This makes knowledge of the ideal product size essential in the design of any comminution circuit.

New plant process flow

The new CDM plant is designed to handle run-of-mine (ROM) ore as well as reclaimed tailings. ROM ore is conveyed from a 5 000 t capacity ROM silo and blended with reclaimed ore from a 3 000 t capacity silo. The plant is designed for 6.0 Mt/a, and will initially process 4.0 Mt/a of ROM plus 2.0 Mt/a of reclaimed ore using an overall fresh feed rate of 750 t/h from two mills feeding in parallel. Each mill is designed for a fresh feed rate of 375 t/h and a 152% circulating load.



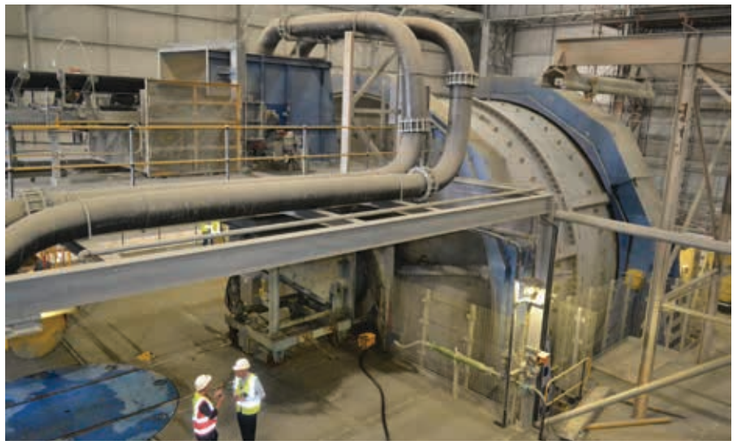
The mill discharge slurry (–150 mm) from each mill flows onto a dedicated scalping vibrating grizzly screen and the oversize is conveyed to the jaw crushers and on to the recycle ore silo. The crushers also have a bypass option to return excess load to the mills or to bypass the crushers during maintenance.

The undersize (–55 mm) gravitates to dedicated mill product sizing screens for each mill's stream. The sizing screen oversize (–55 +12 mm) is conveyed to the primary X-ray luminescence (XRL) sorting plant for recovery of large diamonds. The sizing screen undersize gravitates to the de-sliming section for the removal of –1.0 mm slimes through a series of trommels and dewatering screens. The –12 +1.0 mm product from the de-sliming section is conveyed to the dense medium separation (DMS) and mid diamond recovery plant.

The main purpose of the XRL section is to sort the –55 +12 mm diamonds in the mill product. The feed to XRL is concentrated on the basis of luminescence by five large (–55 +25 mm) and five coarse (–25 +12 mm) diamond XRL sorters supplied by Bourevestnik (BV). The coarse diamond XRL sorter tailings (–25 +12 mm) are conveyed to the HPGR crushing section or bypassed to the recycle silo if necessary.

The large diamond XRL sorter tailings (–55 +25 mm) are conveyed back to the recycle silo or, if required, are directed to the HPGR crushers. Concentrates from the large and the coarse XRL sorters are combined and conveyed to the final recovery section for further processing.

The HPGR crushing section is designed to have two crushers to assist with the rock breakage before the material is returned to the mill. Coarse XRL tailings (–25 +12 mm) and the mid-size (mids) diamond recovery tailings (–12 +6.0 mm) feed this section. The large XRL tailings (–55 +25 mm) can also be routed to the HPGR section if this size fraction builds up in the circuit or requires further crushing. The crushed product from this section is conveyed back to the silo.



Above: *The new CDM diamond recovery plant is designed to handle 6.0 Mt/a and will initially process 4.0 Mt/a of ROM plus 2.0 Mt/a of reclaimed ore.*

Above right: *The wet autonomous grinding (AG) mills supplied by thyssenkrupp have a 9.20 m inside shell diameter and a 4.88 m effective grinding length.*

Right: *The XRL section sorts the –55 +12 mm diamonds in the mill product using five large and five coarse diamond XRL sorters supplied by Bourevestnik (BV).*

Dense medium separation (DMS) is used to treat the –6.0 to +1 mm fraction and the –12 +6.0 mm fraction is separated on the DMS preparation screen and treated through the mid-sized diamond recovery plant, which consists of four BV XLR sorters. The –6.0 +1 mm fraction is treated though four 510 mm DMS cyclones. The concentrate from these cyclones and the mids diamond recovery is conveyed to the secondary recovery section, while the mids diamond recovery tailings are conveyed to the HPGRs. The DMS tailings are discarded.

In the final recovery plant at CDM, concentrates from the XRL large and coarse recovery, mids diamond recovery and the DMS are treated using BV XLR sorters to achieve the best possible diamonds recovery-efficiency.

CDM's AG Mill specifications

The two mills for the CDM circuit are wet autonomous grinding (AG) mills of the grate discharge type and are shell supporting with slide shoe bearings.

They were designed and supplied by thyssenkrupp to best suit the grinding circuit. The specifications include: a 9.20 m inside shell diameter; 4.88 m effective grinding length; 60 to 90% critical speed percentage; 6 400 kW of required motor power; 995 r/min motor speed; and a maximum feed size of 450 mm.

For value protection of large stones, the AG mills incorporate a large port discharge grate with openings ranging from 170 mm to 220 mm, which was expected to deliver higher throughputs and high recirculation loads of 130 to 200%.

The mill liner design was optimised to limit impact collisions inside the grinding chamber and enhance the attrition and abrasion forces, which the liner design was enhanced in the pulp chamber to accommodate the flow of large particles.

HPGR specifications

CDM, then called The Premier Mine, was the first mine to use HPGRs in a kimberlitic operation. Their use was retained in the new mill circuit because of their ability to minimise diamond damage in comparison to impact crushing. Diamond liberation takes place primarily through inter-particle crushing due to large operating gaps, which are usually bigger than the individual pieces of ore. The new HPGRs at CDM are designed to operate at a 55 mm gap to ensure optimal value protection.

Ongoing optimisation

While the CDM circuit is in full production, the production team continues to optimise the process to define the best operating condition for all circumstances. As Napier-Munn et. al. (1999) advise: 'optimisation of an AG mill should never be regarded as complete. It should rather be viewed as an ongoing process, which is aimed at ensuring that the circuit is operating at maximum efficiency regardless of other conditions'.

The CDM production team is, therefore, currently looking at different options for automated mill controls, which include controls based on DMS feed yield or the possible incorporation of an online feed and product PSD monitoring system.

Also being considered is the addition of vibration monitoring on the mill bearing housings and mill shell to generate accurate and instantaneous signals of the mill filling levels and the toe angle of the load in the mill. This information is not only essential to optimise the throughput of the mills, but can also be used to ensure that the mills are operated in the most diamond-friendly way. ❑

Extracted from the paper ***'The new Cullinan AG milling circuit – a narrative of progress'*** *by L Musenwa, T. Khumalo M. Kgaphola and S Masemola from Petra Diamond's Cullinan Diamond Mine; and G van Wyk from thyssenkrupp, South Africa.*