Bendigo Utilises High Pressure Grinding Rolls To Maximise Gravity Recovery

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Bendigo Mining Ltd has engaged Ausenco Limited to design and construct a 600 000 t/a processing plant for the underground ore at the Bendigo Gold Project. In order to maximise gold recovery, the project team has opted to utilise the benefits of High Pressure Grinding Rolls (HPGR) to achieve a fine product size from the crushing circuit in order to maximise gold recovery in the primary gravity gold recovery circuit prior to fine grinding in a ball mill.

Bendigo Mining Ltd has 350 sq km of tenements that cover the entire Bendigo Goldfield. The Bendigo Goldfield has produced over 22 million ounces of gold. 82 per cent of this was derived from quartz reef mining carried out from surface to an average depth of 700 m with the deepest mine reaching 1,400 m. Between 1854 and 1954, quartz reef mining yielded around 18 million ounces of gold from 40 million tonnes of ore; the average recovered grade was 14.3g/t Au. An Inferred Resource of 11 million ounces of gold has been identified beneath the historic workings on 5 of the 15 major lines of reef (anticlines) and forms the basis of the Bendigo Gold Project.

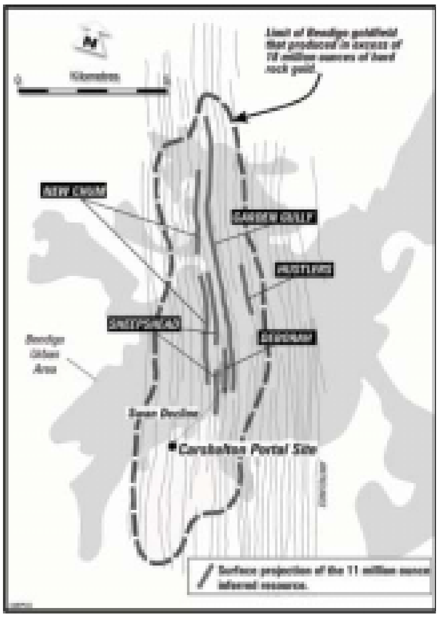

Figure 1. Aerial Photograph of Project.

Figure 2. Example of Gold Bearing Reefs.

ORE CHARACTERISTICS

Gold mineralisation at Bendigo is exclusively associated with quartz reefs, commonly found within or near anticlinal fold hinges. The gold is typically coarse grained (0.1 mm to 10 mm), free milling and displays a complex, nuggetty distribution within the veins. The Bendigo ores are characterised by the following:

- They have relatively high grades (9 to 14 g/t Au) and an extremely coarse liberation size. Observations from the extensive test work and mineralogical analysis indicated significant liberation of the free nugget gold occurred at coarse grind sizes around 2 mm.
- Gold is typically of nuggetty occurrence within quartz veins, along the vein contact boundary and associated with host rock fragments and sulfide grains with quartz veins.
- Particle size distribution analysis showed a high proportion of metal value occurs in the coarser sizes whereby 60 per cent of the metal value is coarser than 1.0 mm. This size distribution is much coarser than most other mines in Australia.
- Gold distribution in bulk samples showed that approximately 75-80 per cent of gold from head grades 7-15 g/t Au reported to total gravity at a grind size of 500 micron. This identified the gravity recoverable gold potential in the ore.

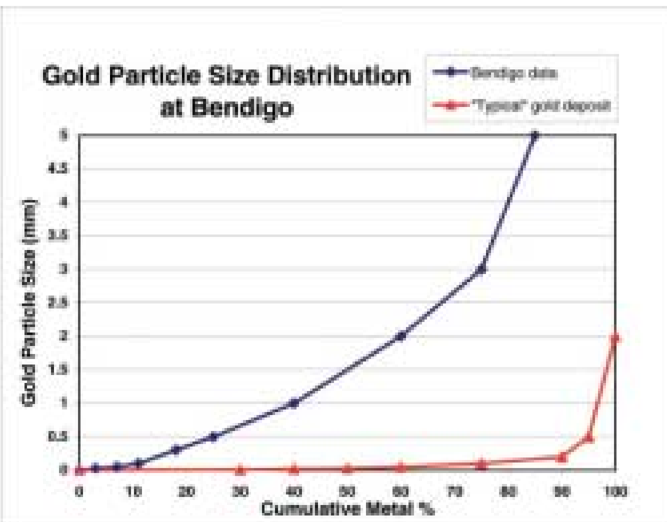

Figure 3. Graph of gold particle size distribution for Bendigo.

- For similar head grades the pilot plant trials recovered mid to high 80s per cent gold for total weight to concentrate of nearly 2 per cent w/w and mid 70s per cent for just under 1 per cent weight to concentrate.

In excess of one hundred 100-tonne bulk samples were collected and processed at the New Moon processing plant in Bendigo. In addition to the bulk samples, some 35,000 tonnes of development ore has been processed through the pilot processing plant attached to the bulk sample circuit. This trial processing has provided extensive metallurgical testing for use in the design of the planned full-scale plant. The ore has excellent metallurgical characteristics with approximately 80 per cent of the gold expected to be recovered in the gravity circuit, with flotation of the gravity tail increasing gold recovery to 95 per cent.

The principal objective of the process plant is to maximise gold recovery in the gravity circuit in a cost effective manner. Maximising gravity gold recovery is expected to maximise overall gold recovery, as any coarse gold that passes gravity recovery to the flotation circuit may be lost to flotation tailings.

The concern with a flowsheet based on conventional coarse crushing and ball milling is that the optimum plant metallurgical performance would not be achieved due to "flattening" and "overgrinding" of the gold in the ball mill, reducing overall gold recovery.

To maximise gold recovery, a flowsheet was developed based on the following criteria:

- fine crushing;
- maximise gravity recovery of coarse gold prior to ball milling;
- grinding of residual ore for secondary gravity separation and flotation of a sulfide/gold concentrate, and
- carbon-in-leach recovery of the gold from the flotation concentrate.

FLOWSHEET DEVELOPMENT

The flowsheet developed during the January 2004 Feasibility Study nominated a standard two-stage crushing and ball milling as the preferred comminution route. The proposed flowsheet produced a crushed product with a P_{80} of 14 mm and ore fed directly to the ball mill, and thus provided no opportunity for coarse gold recovery prior to the ball mill.

A number of circuit variations were considered with the aim of maximising the fines generation in the crushing circuit. These included the use of conventional three-stage crushing and an HPGR. The product size distributions ranged from 30 per cent < 4 mm for the base case (two-stage crushing) to 100 per cent for a case including the use of HPGR in closed circuit with a 4 mm screen. The options were evaluated using "order of magnitude" capital and operating cost estimates to determine the necessary increase in gold recovery required to justify each flowsheet.

HPGR testwork was completed on parcels of Bendigo ore by Polysius and Koeppern. The samples tested were similar in size distribution to the stream to be crushed in the proposed Bendigo plant, F_{80} of approximately 20 mm, and produced a product of about 78 per cent passing 4 mm in a single pass.

The objective was a crushing circuit that produces a high proportion of minus 4 mm material in a final product achieving the "natural" liberation size and allowing significant gravity recovery ahead of the grinding circuit.

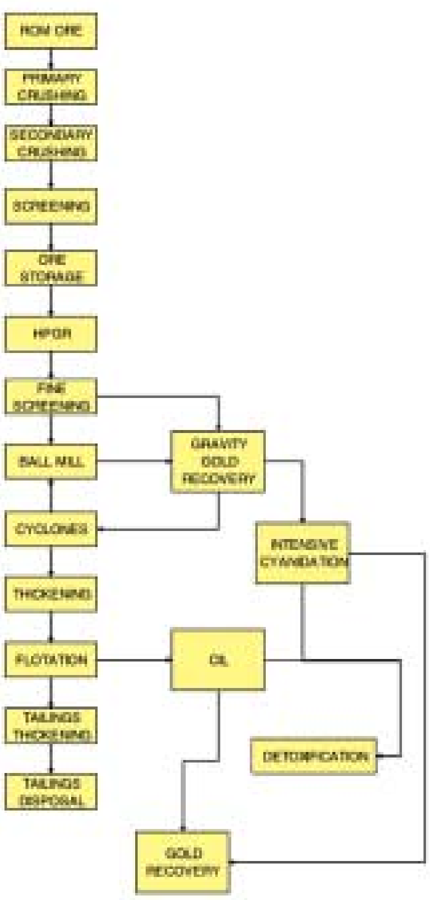

Figure 4. Proposed Plant Flowsheet.

Comparative distributions of product passing 4 mm for a number of crusher options are:

- 30-40 per cent in a secondary crushed product, closed circuit with a 20 mm aperture screen;
- 50-55 per cent in a tertiary crushed product, closed circuit with a 12 mm aperture screen;
- 65-70 per cent in HPGR product, open circuit, and
- 100 per cent for a HPGR closed with a 4 mm screen.

Each of the flowsheets was assessed on the basis of:

- capital cost;
- operating cost;
- pay back period;
- operability
- maintainability;
- potential gravity gold recovery, and
- project risk (catastrophic failure and/or long term impact on plant operations).

The HPGR cases involved higher capital expenditure, which required only an additional 1 per cent Au recovery to justify with a short payback period. HPGR has been an emerging technology in hard rock comminution for a number of years and the Bendigo Gold Project stands to reap the benefits of recent advances in this area. The HPGR machine was considered to be sufficiently robust to provide in excess of the required plant availability and vendors have provided warranties on wear surface life and machine availability.

STATUS OF HPGR TECHNOLOGY

High pressure grinding rolls (HPGR) technology was developed by Schönert (1979, 1980) and is comprised of two horizontally opposed rolls with one "floating" roll positioned using pneumo-hydraulic pistons and one roll "fixed" to the frame (Figure 5). The main components of the HPGR are the rolls, bearings, frame, pressure beams, hydraulic system, drive system, lubrication and cooling systems, feed chute, roll wear surfaces and lateral wear protection or cheek plates. Feed is introduced between the rolls. The rolls must be choke-fed to insure optimum operation. The HPGR relies on the production of a compression bed and interparticle breakage, rather than the liner-rock-liner contact crushing occurring in conventional gyratory and cone crushing.

HPGR technology was introduced first to the cement industry, where in excess of 500 units operate. Most of these machines are utilised for pre-treating ball mill feed. The introduction of this technology increased the capacity of the downstream ball mills and the total energy consumption of the grinding process was reduced by up to 50 per cent. Application of the technology to hard rock processing began in 1986, with 12 machines installed in kimberlite and lamproite crushing applications in South Africa and Australia by 1990. Since 1990, HPGR has been applied to progressively harder, tougher and more abrasive materials. As with all developing technologies, some issues have arisen during pilot plant operation, testing and full scale plant operation. These issues, principally related to roll surface wear rates, have resulted in the adoption of HPGR in hard rock crushing progressing in a stepwise manner.

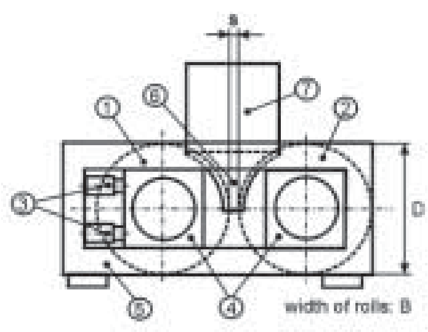

Figure 5. Schematic of HPGR Machine.

Figure 5 shows the main components of a roller press: The roller nip of width "s" is formed between the floating roller (1) and the fixed roller (2). The diameter of the rolls is denoted with D, the width with B. The total press force F can be adjusted using a pneumo-hydraulic system with two or four pistons (3). In order to compare machines with different roll geometries the specific pressing force p is introduced:

$$p = \frac{F}{D \cdot B}$$

The rolls are normally supported using roller bearings, which are located in compact bearing housings (4). The press force is confined in a sturdy machine frame (5). The pressing area is sealed at the roller side by cheek plates (6). Finally a feeding bin (7) is assembled at the top of the press.

The pressure applied to the rolls determines the degree of breakage. Pressures in the gap are typically between 50 and 200 MPa with the force applied to the rolls varying with roll diameter (750 to 20 000 kN). Table 1 summarises the typical range of HPGR physical characteristics.

The roll wear resistant liners are the principal consumable cost. The liners are typically shrink fitted on the roll and equipped with hardened studs or other suitable surface. The studded rolls maintain an autogenous layer on the rolls to reduce liner wear when treating hard and abrasive ores. Ore is crushed between the liners and constrained by cheek plates at either end of the rolls.

Table 1. Summary of HPGR Characteristics

Parameter	Unit	Range
Roll diameter	M	0.5 to 2.8
Roll width	M	0.2 to 1.8
Typical throughput	t/h	20 to 2500
Installed motor power	kW	2 x 50 to 2 x 3000

A brief chronology of HPGR application is provided below:

- first machine (2 m diameter rolls) installed at Premier diamond mine in 1985;
- first machine in Australia in 1989 at Argyle processing diamond ore, second machine installed in 1991;
- subsequent issues with HPGR wear and associated impact on availability;
- Cypress Sierrita trial in 1995/6 on copper ore using 2.4 m diameter Polysius unit processing nearly 2000 t/h was a technical success, but tyre wear was still an issue;
- pilot runs in Australia at 60 t/h in 1995 and 1996 at KCGM (Watson 1994) and Boddington on -25 mm feed indicated issues with tyre wear rates;
- Argyle recrush circuit installed 2002 (1.7 m x 1.4 m) using new generation studded rolls with marked reduction in tyre wear and improvement in availability;
- first gold ore installation at Zapadnoye in Russia in 2003 (Kirsch 2004);
- Lone Tree pilot trial in 2003 (60 t/h) on very abrasive ore to test new wear systems using a 0.7 m diameter Polysius unit indicated good tyre wear life, and
- recent (October 2004) approval of the Cerro Verde project incorporating five 2.4 m diameter, 4 MW, HPGR units treating a moderately abrasive copper ore.

Over 500 HPGR machines are installed, mostly in the cement industry. Principal suppliers are Köppern, Polysius and KHD Humboldt Wedag. Applications in minerals processing include:

- kimberlites/lamproite, in tertiary and recrush roles;
- iron ores, for coarse crushing, autogenous mill pebble crushing, regrinding, pre-pelletising and briquetting;
- quartzite ore for tertiary crushing prior to ball milling;
- limestone crushing, and
- iron ore concentrate fine grinding.

In the past, issues with tyre wear rates have resulted in limited application in minerals processing outside the diamonds industry. The diamond industry used HPGRs due to the reduced potential for diamond breakage and the preferential liberation along mineral boundaries.

The installation at Zapadnoye processes ore from the Suchoj Log gold ore body located near Irkutsch in Russia. The ore is about 30 per cent silica but is not abrasive. The KHD machine installed at the site has functioned with high availability and without mechanical issues since start-up. The tyres are expected to last in excess of 12 000 hours.

Newmont completed an extensive pilot trial in 2004 at Lone Tree using a machine of similar specification to that proposed for Bendigo. The ore processed was generally more abrasive than Bendigo ore and the tyres were expected to last 3200 hours when processing over 60 t/h. No significant mechanical issues were experienced, and machine availability was greater than 90 per cent. This was the first large-scale pilot trial on an abrasive ore that did not result in excessive tyre wear.

Data from the Bendigo HPGR testwork has been benchmarked against published data from Lone Tree and other projects.

HPGR SELECTION

The HPGR machine was selected on the basis of the following:

- capital cost;
- operating cost;
- lead time;
- vendor support, and
- performance warranties.

Koeppern Process Australia was selected as the technology provider. The HPGR provided by Koeppern will be equipped with the Hexadur® wear system.

The wear resistant HEXADUR®-system has been developed primarily for HPGR applications. In this system, a forged steel tyre is coated with a thick wear resistant layer by the "HIP-cladding"-technique. A mixture of metal powder is consolidated under extreme high pressure and temperature in the process known as hot isostatic pressing (HIP).

HEXADUR®-surface shows regions with different material compositions (Figure 7). The hexagonal tiles are made of a hard wear resistant metal matrix composite (MMC) consisting of a metal matrix and ceramic hard phases. Composition and morphology of the material within these hexagons determines the wear resistance of the surface. The hexagons are separated by softer areas which initially wear out relatively quickly until a grooved pattern develops. Fine feed material particles fill these grooves and build up autogenous wear protection. The friction between tool surface and feed material increases by the hexagonal profile and this in turn improves intake behaviour and throughput of the machine. The newest generation of HEXADUR®-rollers are equipped with special edge tiles (Figure 8), which give improved wear protection for the roller edges.

Figure 6. KOEPPERN HP GR TEST FACILITY

Roller Diameter:	*750 mm*
Roller Width:	*220 mm*
Feed System:	*gravity*
Wear Protection:	*Hexadur® WTII*
Maximum Pressing Force:	*1600 kN*
Max. Spec. Pressure:	*8.5 N/mm²*
V/S Drive:	*up to 1.55 m/s*
Total weight:	*25 t*

The benefits of Hexadur® wear system in application for high pressure comminution can be summarised as follows:

- Hexadur® is capable of operating at full pressure range – up to 7.5 N/mm².
- Hexadur® wear protection is not sensitive to the presence of oversize particles in the feed. In general, larger top size feed material can be presented to the press.
- Hexadur® is applied on the full width of the roller thus eliminating the need for edge maintenance.
- Minor damage to the surface caused by tramp metal does not require repair.
- Development of 'bath tub' profile during tyre service can be corrected by grinding the roller surface *in situ*.

PROJECT IMPLEMENTATION

Initially, throughput will be at a lower rate of 450,000 t/a, and as additional Reserves become available the plant will run at the design capacity of 600 000 t/a.

The HPGR will arrive at site in August 2005 and will be installed by October 2005, in line with the Bendigo Gold Project construction schedule, for initial production in 2006. ■

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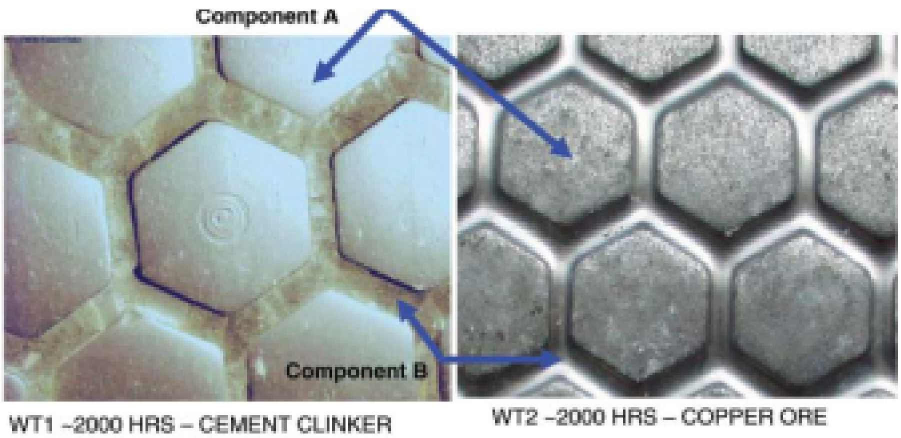

Figure 7. Hexadur® wear protection system.

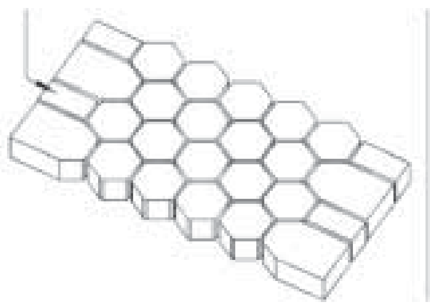

Figure 8. Configuration of edge Hexadur® tiles.