Mr M. Hunt	Section Head, Water Projects, Diamond Research Laboratory, De Beers Industrial Diamond Division (Pty) Ltd
Mr G. Millar	Manager, Strategic Planning, Middelburg Steel & Alloys (Pty) Ltd
Mr N.W. Munro	Research Consultant, Explosives and Chemicals Technical Department, AECI Ltd
Dr A.E. Patterson	Executive Director, Aluminium Federation of South Africa
Mr D.H. Walker	Director of Special Projects 1976-1984, Middelburg Steel & Alloys (Pty) Ltd.

References

1. MINERALS BUREAU OF SOUTH AFRICA. *Mineral production and sales statistics*. 1987 and 1988 (provisional).
2. SOUTH AFRICAN RESERVE BANK. *Quarterly Bulletin*. Dec. 1988. pp. 5–64.
3. KÖHLER, K. Private communication. Johannesburg, AECI Ltd.
4. DAVIES, H. *Boart International 50 years 1936-1986*. p. 22.
5. BROWN, T. *Boart International 50 years 1936-1986*. p. 9.
6. CHASTON, I.R.M., and NAPIER-MUNN, T.J. Design and operation of dense-medium cyclone plants for the recovery of diamonds in Africa. *J. S. Afr. Inst. Min. Metall.*, Dec. 1974. p. 132.
7. COETZEE, J.J. The technical development of Amcor Limited, with particular reference to the production of ferro-alloys. *Infacon 74. Proceedings of the 1st International Conference on Ferro-alloys*. Glen, H.W. (ed.). Johannesburg, South African Institute of Mining and Metallurgy, 1974. pp. 107–113.
8. HUNT, M. Private communication. Johannesburg, De Beers Industrial Diamond Division (Pty) Ltd.
9. PATERSON, A.E. Private communication. Johannesburg, Aluminium Federation of South Africa.
10. DE JAGER, J. Private communication. Johannesburg, Hulett Aluminium Ltd.
11. SMITH, E. *From veld to ferrochromium*. Johannesburg, Southern Cross Steel Company (Pty) Ltd, 1972.
12. HOTZ, B. Private communication. Johannesburg, Chromium Centre.
13. WALKER, D. Private communication. Johannesburg, Middelburg Steel & Alloys (Pty) Ltd.
14. MILLAR, G. Private communication. Johannesburg, Middelburg Steel & Alloys (Pty) Ltd.
15. GREENHUT, M.L. *Plant location in theory and practice. The economics of space*. Berkeley, University of North Carolina Press, 1956. pp. 1–100.
16. FAGERBERG, J. International competitiveness. *Econ. J.*, vol. 98. Jun. 1988. pp. 359–363.
17. *Ibid.*, p. 360.
18. CAMPBELL, R.H., SKINNER, A.S., and TODD, W.B. (eds). *The Glasgow edition of the works and correspondence of Adam Smith*. Oxford, Oxford University Press, 1976. vol. II. p. 458.

Semi-autogeneous (SAG) milling

by W.K. BRISDEN*

The SAG Milling Seminar, which was held at Murdoch University in Perth on 30th November and 1st December, 1989, was a very successful technical seminar. Organizer Dr Norm Stockton reported a total attendance of 130, which was higher than the 70 expected: 20 delegates came from the eastern States and the remainder were from Western Australia.

The Seminar included 20 papers. Of these, 8 discussed plant operations, 4 reviewed design approaches, 2 reviewed modelling and process control, 1 dealt with the design of mill liners and grates, 1 discussed the lubrication requirements of SAG bearings, 1 summarized the recent 1989 Canadian SAG Milling Conference, 2 discussed grinding techniques to complement SAG mills, and 1 summarized comminution improvements and the current need to make comminution more efficient. Discussion periods after each session enabled many people to discuss their operating problems and the actions taken to improve the performance of their respective SAG circuits.

In 1984 Australia had only 6 semi-autogenous and autogenous grinding mills. This increased to over 40 in 1989, 95 per cent of which are in new gold mines. A fully autogenous mill uses only coarsely crushed, competent rocks as grinding medium, approximately minus 200 mm plus 100 mm. A SAG mill uses between 2 and 15 per cent steel balls by volume, and a ball mill uses around 40 per cent balls by volume. Conventional crushing circuits previously used crushing and screening plants to crush ore from approximately 400 mm to about minus 13 mm. This frequently caused bogged crushers, blinded screens, and chute build-up, whereas a single-stage SAG mill can reduce particles of 200 mm diameter to approximately 75 per cent passing 75 μm, usually in closed circuit with a cyclone. A secondary ball mill is frequently included to grind the cyclone underflow. In some plants, a small crusher is used to crush a portion of the critical-size material, i.e. minus 50 mm plus 12 mm. This material would otherwise accumulate in the circuit of the SAG mill.

* Wayne Brisden, Murdoch University, Perth, Australia (telefax: (09) 384-6790).

Papers Presented

As described by Rob Morrison, the JKMRC has developed a reliable pendulum testing method to determine the impact breakage characteristics of an ore sample. This test relates the actual energy consumed in breaking a piece of rock to the initial and resultant product sizes. Pendulum tests are used in conjunction with tumbling tests to model the breakage characteristics of a particular ore. The tests can be used even on drill core.

John Angove of AMMTEC presented a useful paper on how to determine SAG-milling requirements using autogenous-medium tests, abrasion index, impact crushing work index (CI), SAG-milling tests (SAGWI), and rod-mill and ball-mill work indices (BBWI). If the SAGWI lies between the work index for the CI and the BBWI, a SAG mill should be the logical choice. It must be capable of breaking the critical-size material. The test sample should also be representative of the orebody, and must include the hardest ore for meaningful test results.

Operating papers such as Normet's paper by Lincoln McCrabb and Peter Sperring indicated that the operators of SAG mills require different training techniques from those required by the operators of conventional grinding circuits. Many SAG plants have exceeded the designed

feed throughput and have also improved liner life by the use of bolted grid liners that trap the grinding medium and become self-renewing. Steel liners were also generally considered to be more appropriate than rubber liners in SAG mills.

Chris Campbell-Hicks of Sundowner Minerals described how a low-aspect autogenous (AG) mill, 4 m dia. by 6 m long, at Mt Fisher was successfully relocated 140 km from a chert orebody to a softer clay–quartz mine where the mill performance immediately exceeded targets. It was a fully autogenous mill at Mt Fisher and became a SAG mill at Darlot. The target of 420 kt per annum was achieved within ten days, and 140 per cent of the forecast gold production was obtained within one month.

Two of Dominion Mining's circuits are currently being compared, i.e. one with a SAG/ball-mill flowsheet, and the other with a conventional crushing and grinding circuit. Paddy's Flat (SAG/ball) had a 20 to 25 per cent lower power consumption than the Haveluck conventional plant. The comminution costs were also 20 to 25 per cent lower at Paddy's Flat. The downtime was lower at Paddy's Flat.

Don Burgess of Boliden Allis claimed that up to 2500 kW low-aspect mills (small diameter to length) can be approximately 16 per cent less efficient than high-aspect mills (high diameter to length), and also have a shorter delivery and installation time than high-aspect mills. However, low-aspect mills can be approximately 16 per cent less efficient than high-aspect mills owing to overgrinding and lower impact forces. Impact crushing and attrition are more efficient forms of comminution than abrasion. This is possibly one of the reasons why high-aspect mills exceed the performance of low-aspect mills of similar volume.

Rob Darrington and John Hadaway of ANI Ruwolt presented a paper about the need to operate at low stresses in today's large mills. Strain gauges are employed to measure the strain at points of high stress on a mill's shell. This is a valuable tool for the design and reliability of grinding mills.

Brian Chapman of Alcoa described the types of liners used to prolong liner life and to increase throughput. A change from 12 mm-diameter tapered slots in the grate discharge liners to 20 mm-diameter holes increased the throughput significantly by raising the available discharge area from 3 to 7 per cent. Self-filling liners were also used on the mill shell, and lasted for 15,5 months or 2,3 Mt. Wedge-type blocks were also used to allow easier removal of worn liners.

Darryl Butcher of Metana Minerals gave a paper on AG/SAG milling of run-of-mine ores at Black Cat, Mt Magnet, and Rand circuit, Reedy. The paper emphasized that both high-aspect mills can take a wide variety of ore feed up to a particle size of 600 mm. The capital and operating costs are very low at both plants.

At Black Cat, from run-of-mine ore to leach feed costs $2,15 per tonne, and the total treatment cost was $5,80 per tonne. At the Rand plant, the corresponding costs were $3,83 and $8,60 per tonne respectively. In both circuits, the AG/SAG and ball mills are each in closed circuit with some form of size classification. Most other plants use single-stage cyclones in their SAG/ball mill circuits.

The HELPSAG computer-based decision-support system was demonstrated by Bernie Siddall of Orway Mineral Consultants. This system can be installed in the mill operator's control room, and would be an invaluable aid in the training of SAG-mill operators. One HELPSAG unit is now being used by Dominion Mining at Paddy's Flat under the control of Ivan Hunter.

Closing Address

Professor Alban Lynch, 1989 President of The Australasian Institute of Mining and Metallurgy, gave the closing address. He described past and recent improvements in comminution, and forecast an increase in the demand for Australia's minerals because of an expected doubling of the world's population. Comminution is the most expensive part of a plant's circuit, and the trend has been towards larger mills.

Only about 1 to 10 per cent of the energy used in comminution is actually expended in the size reduction of valuable minerals and associated gangue. Australia will therefore have to spend far more on research in order to improve the efficiency and cost of comminution if it is to compete in the world. A slide was shown of an ancient labour-intensive crushing and screening plant. Professor Lynch then said, 'We have always found it difficult to determine the circulating load'.

Notes

Notes from the SAG seminar are being printed and should now be available. Those interested should contact Dr Norm Stockton of Murdoch University (telefax (09) 310 1711).