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THE RELATIONSHIP BETWEEN FRAGMENTATION IN MINING AND COMMINUTION CIRCUIT THROUGHPUT

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ABSTRACT

There is an increasing realisation that mining and mineral processing should be considered as linked activities, rather than as separate and unrelated activities. As an example of the new trend, the increasing dominance of autogenous and semi-autogenous grinding circuits in new operations is helping to focus attention on the linkage between fragmentation in mining and grinding circuit performance. The general mining rule is that coarse fragmentation is preferred within the constraint of limiting the amount of boulder size muck. Comminution circuits using fine crushing and rod and/or ball milling are largely insensitive to the size of muck produced in mining. However, AG/SAG grinding circuits are quite sensitive to the mix of fine and coarse material in the mill feed. This paper explores the relation between fragmentation size and grinding circuit tonnage by using simulation methods.

Keywords
Blasting; fragmentation; comminution; autogenous grinding

INTRODUCTION

For far too long, mining and subsequent mineral beneficiation have in practice been treated as quite separate activities. This is despite the obvious fact that the two activities are part of a chain which begins with the geological assessment of a deposit and often ends with a product which is the result of further treatment stages after beneficiation. Anecdotal evidence frequently suggests that the performance of a total operation would be improved with better integration between mining and processing. However, experience also suggests that there needs to be a compelling reason before better integration is sought.

This paper is concerned with some aspects of the linkage between fragmentation in mining and comminution throughput. This is only one of the direct links between mining and beneficiation. It serves to illustrate the dependence of one stage of an operation on a preceding stage. The examples considered draw heavily on the experience of the Julius Kruttschnitt Mineral Research Centre in the two areas of mine fragmentation and comminution.

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POSSIBILITIES FOR BETTER INTEGRATION OF MINING AND BENEFICIATION

There are a number of possible strategies which might be applied if mining and beneficiation are to be optimised as an integrated operation. These include:

- mining to produce a feed of consistent metallurgical treatment characteristics
- mining to maximise throughput of subsequent comminution
- integrating mining and beneficiation to optimise energy consumption
- mining and beneficiation to minimise the total production of fines in a final product.

These strategies could apply in different circumstances, depending on the type of operation and numerous other factors. The questions of fines optimisation and blended feeds for consistent flotation performance have been considered [1]. In the case of a complex sulphide operation, it was shown how flotation performance was critically dependent on careful blending of different ore types. This metallurgical requirement imposed significant constraints on mine scheduling and production, but the added effort and cost at the mining stage were more than offset by metallurgical gains.

The relationship between throughput for a SAG circuit and blasting design has been studied [2]. A greater degree of control of the grinding circuit was considered possible by careful manipulation of blast design. Overall optimisation of energy consumption in mining and ore preparation has been proposed [3].

These studies are all concerned with a search for productivity gains from better integration of mining and subsequent beneficiation. The reported flotation performance gains from ore blending [1] are of a magnitude much greater than is usually available from the commonly used methods applied in isolation within a flotation circuit. Flotation control, reagent adjustment and flowsheet modifications rarely result in 10% recovery gains.

There is however a serious practical problem in exploring the optimisation of an integrated mining–beneficiation operation. The cost and difficulty of conducting such studies at full production rates in an operation are both daunting. Modelling and simulation provides a practical alternative, particularly for fragmentation–comminution throughput studies, where coarse crushing and fully or semi autogenous grinding are utilised.

BLASTING REQUIREMENT IN MINING

In metalliferous underground and open pit operations, the primary blasting objectives during production are:

- to prepare the rock for subsequent ore handling systems, and
- to minimise damage and therefore dilution from the surrounding waste rocks or backfill materials.

In terms of draw point or bench face fragmentation, the aim is to minimise the amount of fines and/or large fragments (boulders) produced. Particles less than 25 mm are generally considered as fines and rock fragments greater than 0.8–1.0 m (longest dimension) are considered as boulders in most underground operations utilising LHD equipment. However, the actual boulder size depends upon the size of loading equipment, the dimensions of the ore pass grizzly and the crusher size used.

Fines cause poor rilling of muck in draw points, unfavourable or muddy ore handling conditions where water sprays are used, dusty conditions where water sprays are not used, ore pass hang-up and loss of ore. Boulders, on the other hand, cause production disruptions due to the required draw point action and an increased cost in explosive consumption due to secondary blasting.

In blasting, fines are generally caused by using high explosive energy concentrations (powder factors) per given blast volume, cluster blasting (number of holes blasted at any one time) or the use of very short delays between adjacent holes. The reverse of any of the above factors can result in the generation of coarse fragmentation and boulders.

Horizontal and vertical development blasts generally produce finer and relatively more even fragmentation (in terms of size) when compared to production rings and bench blasts. This is because of the relatively high powder factors and explosive concentrations used in development blasting. However some ores characteristically break into fines as a result of their breakage properties. This is believed to be due to mineralogical composition and textural properties of the ores.

From a mining point of view, an optimum fragmentation size distribution in both underground and open pit operations is that which produces the maximum draw point/bench face productivity given the size of the loading equipment and ore handling system.

AUTOGENOUS (AG) AND SEMI AUTOGENOUS (SAG) GRINDING CONSIDERATIONS

It is well established that the performance of AG/SAG grinding circuits is dependent on the size distribution of the mill feed. The exact degree of dependence is complex and is not well understood. Ore breakage characteristics are also clearly important. However, the following general feed size dependencies are indicated for fully and semi autogenous grinding [4].

- SAG mill throughput increases with a reduction in the amount of coarse material in the feed
- AG mill throughput decreases with a reduction in the amount of coarse material in the feed
- throughput is adversely affected in both AG and SAG mills if the feed distribution contains large amounts of critical size material (25–50 mm).

Feed distributions with such characteristics can result from certain blasting conditions or from segregation effects in stockpiles and ore bins.

It should be possible to determine an optimum feed size distribution for a given AG/SAG milling operation which is consistent with the ore characteristics, circuit design and product size requirements. However, this is rarely done, for the simple reason that milling operations are conditioned to accept the feed provided by the mine. In addition, such a distribution may be quite unrealistic in terms of what is sensibly possible at the mining stage. The linkage between mining and milling is complex. At the outset, two broad questions need to be considered:

- in practice, how dependent is comminution throughput on an actual range of feed size distributions resulting from mining, and
- given that there is a strong dependence, to what degree is it possible to tailor the mining outcome to produce an optimum size distribution for comminution.

This study is mainly concerned with the first question.

MINE FRAGMENTATION – COMMINUTION RELATIONSHIP

General Approach

For the purposes of this study, it is accepted that fragmentation in mining is achieved by drilling and blasting methods. This method produces the overwhelming proportion of metalliferous mine output at present and will clearly continue to do so. The main steps involved in total size reduction are shown in Figure 1.

The approach adopted in this study has been to use simulation techniques to examine the effect of fragmentation distribution resulting from different blast designs on primary crusher and SAG performance.

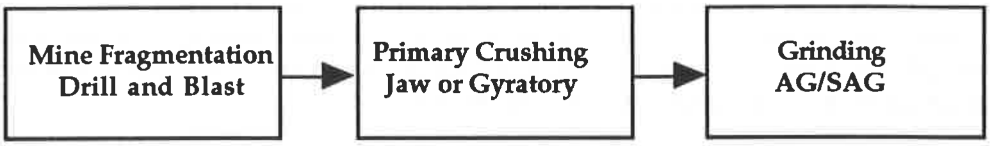

Fig.1 Stages in Rock Breakage and Grinding

FRAGMENTATION DISTRIBUTIONS FROM DIFFERENT BLAST DESIGNS

JKMRC blasting work has for many years examined the effect of different blast designs on fragmentation. Factors which influence blast performance are now largely known [5]. With the availability of improved explosive products and more accurate initiation systems it is becoming possible, within practical limits, to control the degree of rock breakage during blasting. For example, it is possible to design blasts to minimise the generation of fines and/or amount of boulders produced.

The ability to control the degree of rock breakage on a gross scale is demonstrated by examples of fragmentation distributions as shown in Figures 2 and 3. These distributions were obtained by fragmentation assessment using photographic and boulder count methods.

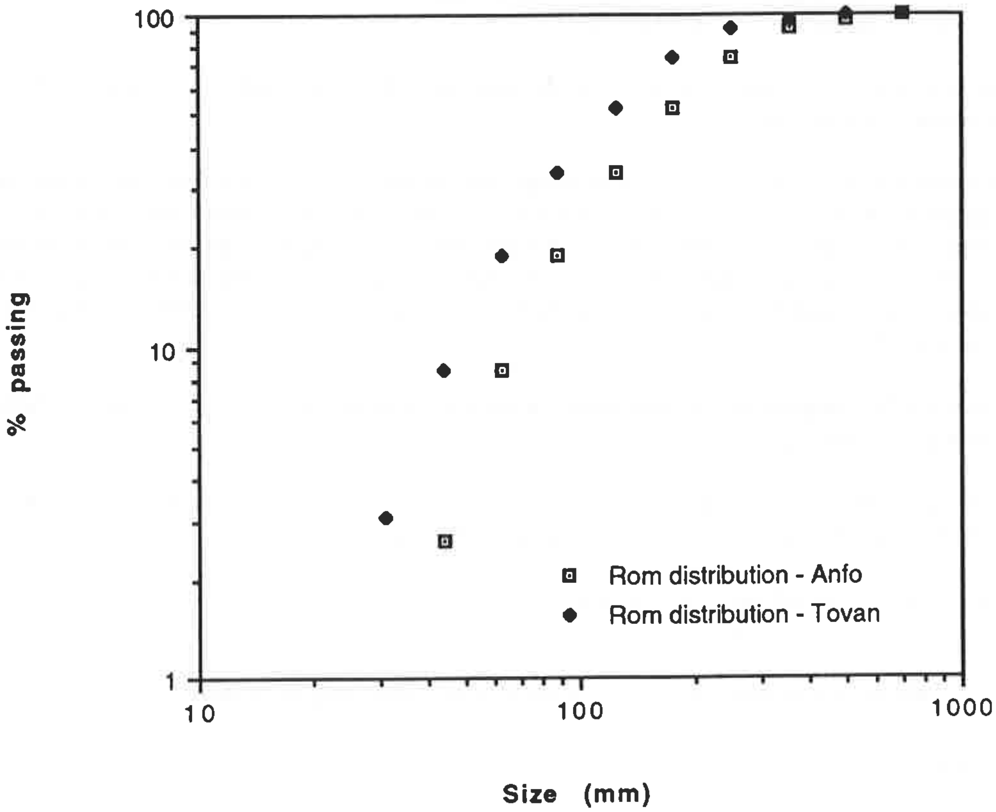

Fig.2 The effect of different explosive types on fragmentation in underground vertical development

Figure 2 shows a significant change in the "measured" fragmentation distribution by changing only the explosive type from ANFO to TOVAN during an underground vertical development exercise [6]. The TOVAN blast produced finer fragmentation over the entire distribution. Figure 3 shows changes in the "measured" size distributions achieved by changing blast patterns and the firing sequences in an open pit operation [7]. The blast changes made were as follows:

- Blast #1 Control blast using mine standard methods (5.0 m x 3.5 m staggered pattern) drilled with 165 mm diameter holes and initiated in a "VI" pattern.
- Blast #2 Mine standard fired using parallel facing firing.
- Blast#3 Expanded pattern (5.5 m x 3.8 m).
- Blast #4 Contracted pattern (3.3 m x 3.0 m) drilled with 114 mm diameter holes.

In all cases ANFO and the same powder factor were used.

The above practical examples serve to demonstrate that, within the practical requirements of mining, it is possible to change the degree of rock fragmentation by modifying the pattern, the explosive types and using different timing and sequencing.

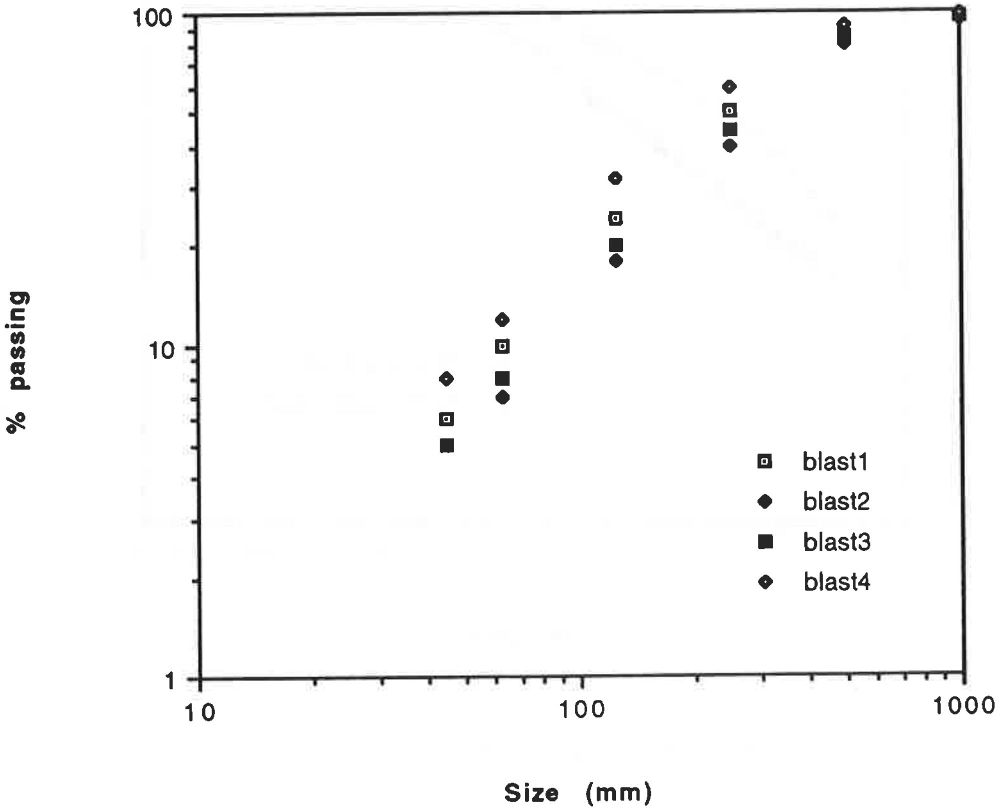

Fig.3 Effect of different blast designs on fragmentation from an open pit

However, the examples also highlight one of the important problems of assessing fragmentation distributions. As earlier indicated, fines in a mining sense are particles finer than about 25 mm. The finest fragments which can be identified by photographic and digitising methods are in the 30–50 mm range. Thus, the fragmentation distributions give no information for material finer than these sizes. The amount of fines (–30 to 50 mm) in the above distributions is certainly underestimated, but by unknown amounts. For grinding simulations, knowledge of the fines content is essential.

For this simulation study, the problem of adequate fragmentation distributions was overcome by using a distribution from a fully sized blast. 100 tonnes of run of mine ore from an open cut gold mine blast was sized using sieving methods to 40 µm. This distribution is presented in Figure 4 as the run of mine fine blast. Points to note include:

- 40% of the material is finer than 10 mm
- the distribution is approximately linear on a Rosin–Rammler plot.

In order to examine the effect of a different fragmentation sizing on crushing and grinding, a coarser fragmentation distribution was derived from the actual sizing. This was done by moving the real distribution of Figure 4 parallel on a Rosin–Rammler plot by an amount similar to that observed from actual blasts in Figures 2 and 3. The calculated coarser run of mine distribution is also shown in Figure 4.

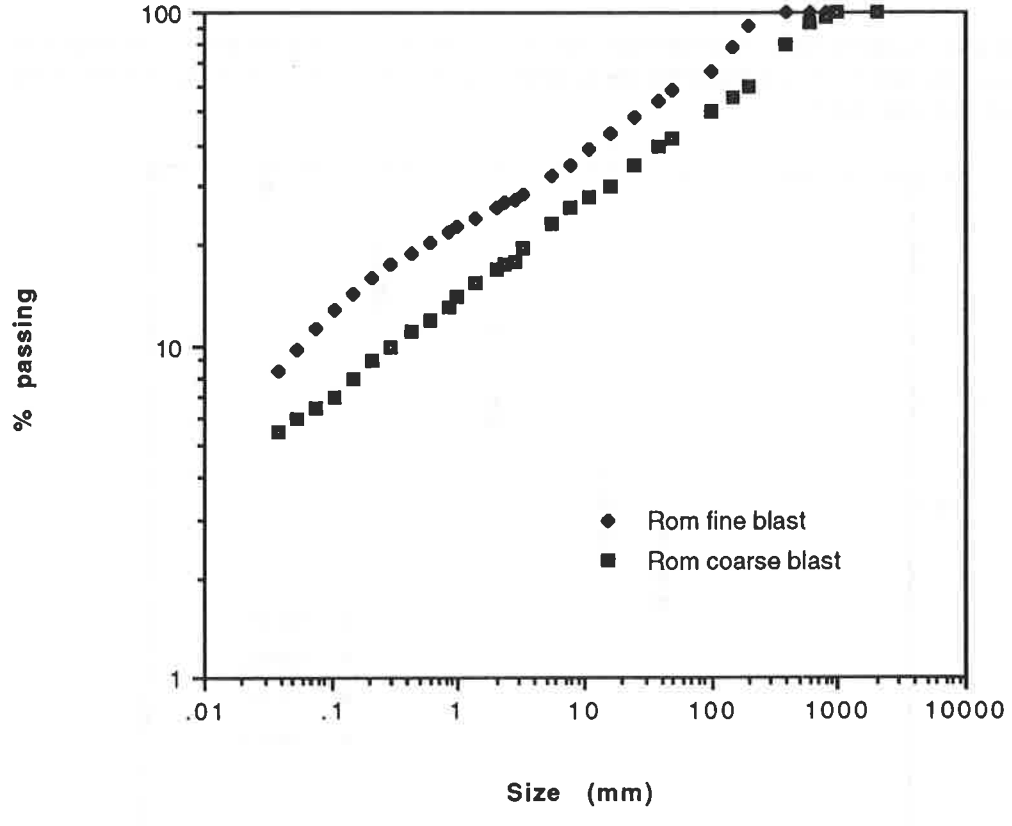

Fig.4 Run of mine fragmentation from an open pit

Primary Crusher Simulations

All crushing and grinding simulations were run on the JKSimMet process simulator. A primary crushing circuit consisting of a scalping screen and jaw crusher was used to treat both run of mine sizings. JKMRC models for both the screen and jaw crusher were employed, with the important model parameters summarised in Table 1. The complete comminution circuit simulated (including a SAG mill) is shown in Figure 5.

The resulting crushing circuit product size distributions are shown in Figure 6. The crusher removes the coarse run of mine material (+0.6 m) but has little effect on the remaining portion of the distribution. Importantly, the difference in the coarse and fine ROM distribution is largely preserved after crushing. As a result, the grinding circuit will receive quite different feed sizing for the two fragmentation cases. The coarser fragmentation results in a crushing circuit product P_{80} and P_{20} of 137 mm and 2.2 mm respectively and the finer fragmentation in a crushing circuit product P_{80} and P_{20} of 123 mm and 1.5 mm respectively.

TABLE 1 Model parameters for screen and jaw crusher

Screen d50	200mm
Crusher closed side setting	200mm
Crusher open side setting	250mm

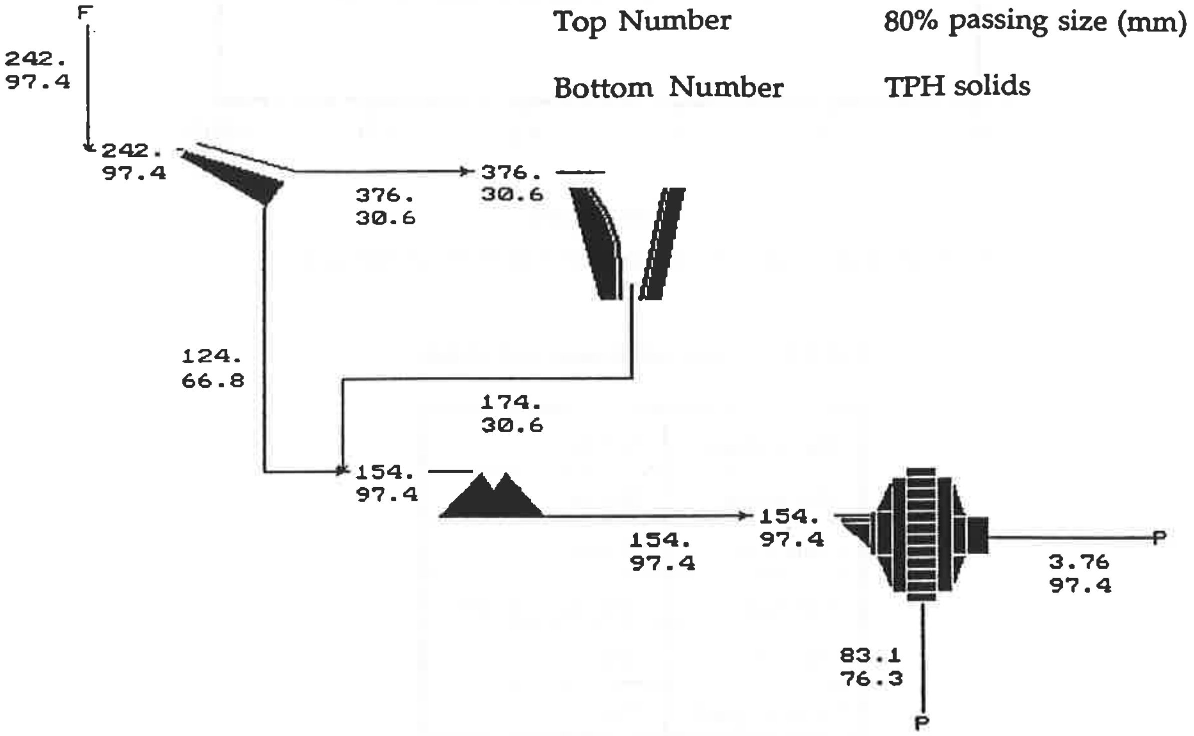

Fig.5 Crushing — autogenous mill circuit used for simulation studies

Grinding Circuit Simulations

For the purposes of simulation, an open circuit semi autogenous mill was chosen and a JKMRC developed SAG mill model [8] was used in simulations. This model calculates a mill load and the volume of the mill occupied by the load. The model also calculates a mill power value [9].

The gold ore was assumed to have breakage parameters similar to a bauxite ore for which the breakage parameters were known. The SAG mill used for the simulations was the same mill used for bauxite grinding with known breakage rates [10]. Details of the mill are set out in Table 2.

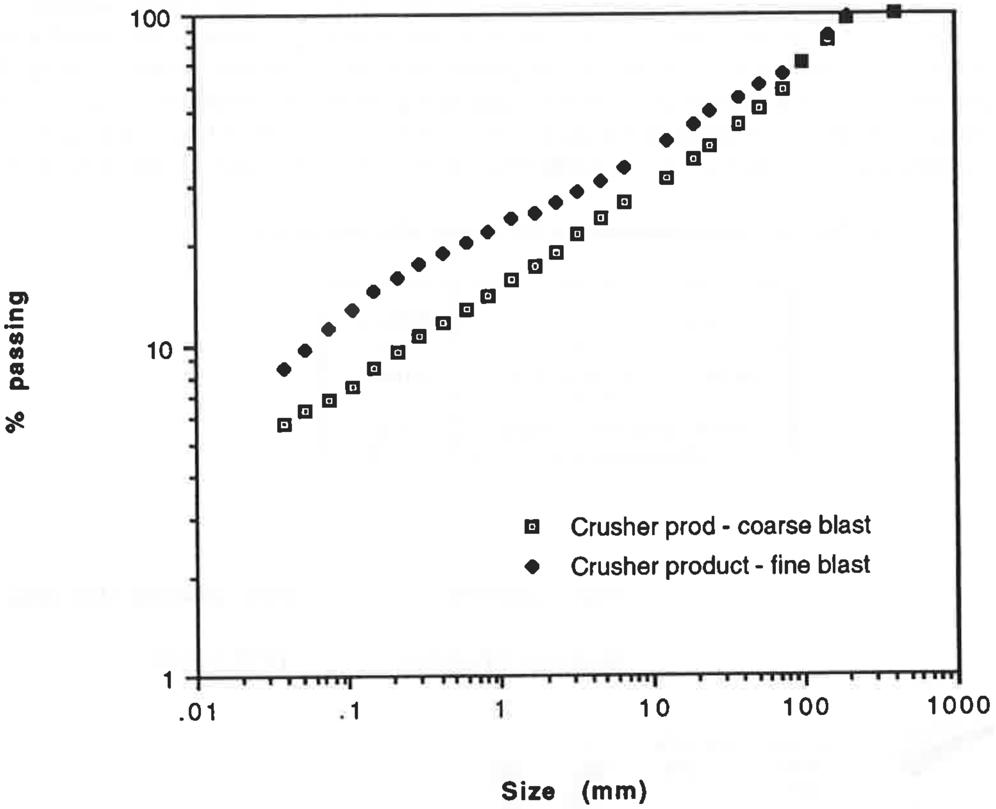

Fig.6 Product sizing after crushing different ROM distributions

TABLE 2 Semi autogenous mill details

Mill diameter	7.05 m
Mill length	3.66 m
Grate size	17 mm
Ball load	11% (by volume)
Feed solids	70%
Critical speed	72%

A base case simulation was performed with the coarse feed at 98 tph. This resulted in mill operating characteristics and performance which were known to be realistic. Simulation at the same feed tonnage of finer feed resulted in a significant reduction in mill load and power draw. The fine feed tonnage was then increased until the mill load and power draw were the same as for the coarser feed. These simulation results are shown in Table 3.

From a grinding only consideration, the analysis indicates that mill capacity in this case can be greatly increased by a reduction in the fragmentation sizing. The 20% tonnage increase can be considered as an indication of what may be achieved. In addition, actual reduction of the top size in the feed by secondary crushing was found to give performance increases of this order of magnitude for the bauxite mill used for simulation in this paper [11].

TABLE 3 SAG results for varying feed sizings

Mill Feed			Feed Rate (tph)	Mill Load		Mill Power (kW)
	F_{80} (mm)	F_{20} (mm)		Pulp (tonnes)	% Volume	
Coarse	137	2.2	98	97.6	24.4	2774
Fine	123	1.5	98	68.6	22.1	2649
Fine	123	1.5	123	97.7	24.4	2779

IMPLICATIONS OF THE STUDY

The result that autogenous grinding throughput can be increased via finer mine fragmentation is not surprising. However, the magnitude of the increase in capacity is substantial for changes in fragmentation which are well within the scope of acceptable blasting practice.

The study has considered only the effect of an overall reduction in feed size to grinding. The crushing product distributions both contained sufficient coarse material (20% + 150 mm) to provide an adequate grinding media. Much finer distributions, particularly those resulting from underground development blasting, may be predominantly –100 mm. In these cases, grinding throughput may decrease. Such behaviour has been observed during JKMRC grinding surveys.

CONCLUSIONS

The concept of providing an optimum size distribution to maximise autogenous grinding performance is novel in the mining sense. Historically, the emphasis in mine production blasting has been to achieve an optimum fragmentation to maximise mine production. This is done without any consideration of the impact on subsequent mill productivity.

The ultimate challenge is one of determining and achieving fragmentation which optimises the overall mine-milling operation. Simulation is an effective tool for determining an optimum feed sizing for the grinding part of an operation. Simulation using fragmentation models to determine the effect of different blast designs on fragmentation is less precise, but still possible.

Simulation can thus allow options to be studied which can lead to goals in both mining and milling which move towards an overall optimum. The real constraints of operating practice will then be applied to modify these goals. It is suggested that the gains from overall optimisation may be very significant and certainly large enough to focus attention on this aspect of the mine-milling link.

ACKNOWLEDGMENTS

The authors wish to acknowledge numerous colleagues within the mining and processing research sections of the JKMRC who have worked separately for many years on fragmentation and autogenous grinding topics. It is planned that in the future these two groups will work more closely together, just as it is hoped will their industrial mine and milling colleagues.

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