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INFLUENCE OF FEED SIZE ON AG/SAG MILL PERFORMANCE

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ABSTRACT

Fluctuations in feed size distribution are second only to ore competence variation in their influence on autogenous and semi-autogenous mill performance. For some operations where feed size is not well controlled this creates significant problems with mill stability and is understandably seen as a major problem area. Some operations, however, have recognized an opportunity in the relationship between feed size and mill performance and manipulate feed size to obtain efficiency improvements. Examples include changes to blasting practices, ROM stockpiling, partial or fully secondary crushing and selective pre-screening of sag mill feed. This paper presents and analyses a variety of plant data which illustrates the influence of feed size distribution variation on mill performance and discusses the reasons why ag and sag mills respond the way they do. From this analysis recommendations for optimum feed size distributions are made.

INTRODUCTION

The introduction and subsequent ascendancy of autogenous and semi-autogenous milling for comminution circuits has undoubtedly lead to many economic advantages. From a process viewpoint, however, at least one downside has been the sensitivity of these machines to process input variations. Foremost among these is ore competence, though feed size comes a close second. This sensitivity is due to the reliance of ag/sag mills on the feed ore for their grinding media competence and size. Ag mills are the most sensitive in this respect with sag mills being increasingly less so as the ball charge is increased. This contrasts with ball mills whose grinding media are generally constant with respect to competence and size distribution and whose size reduction performance is relatively independent of feed size distribution.

Although often considered to be a curse by some, the performance dependence of ag/sag mills on feed size can be turned to advantage through its manipulation. To do so, however, it is important to understand the relationship between feed size and performance. This paper illustrates some of the observed relationships between feed size and ag/sag mill response and provides examples of cases where feed size has been successfully manipulated.

MEASUREMENT OF FEED SIZE

Successful manipulation of feed size starts with successful measurement. Over a relatively short time period taking a belt cut and sieving the material is the most accurate method of determining the size distribution of the ag/sag mill feed. However, fluctuations in feed size make such sizings valuable only if they can be done very frequently, which is clearly impracticable in a production environment. To illustrate how much fluctuation may occur Table 1 page I-205 shows belt-cut data from a number of sites where repeat sizing were carried out over a relatively short period of time, during which it was expected that feed ore characteristics should not change. It can be seen that the repeat surveys all return standard deviations of 15-17mm in the P80. The 95% confidence interval is therefore of the order of +/- 30mm – a sizeable variation.

Table 1: Variation in Measured Feed size

Plant	No.Surveys	Mean P80 (mm)	S.D (mm)
1	9	113	15
2	5	92	17
3	12	57	17

A more satisfactory source of data would be from an on-line non-contact measurement technique as this would provide continuous data without the downtime associated with belt cuts. Image analysis is able to satisfy these requirements and even though there are some issues with its resolution at finer size fractions it has been shown to give very useful size distribution information which can be correlated with performance (Simkus and Dance, 1998). To illustrate how accurate image analysis can be, Figure 1 shows the results of a comparison between sieving and estimation using the "Split" system.

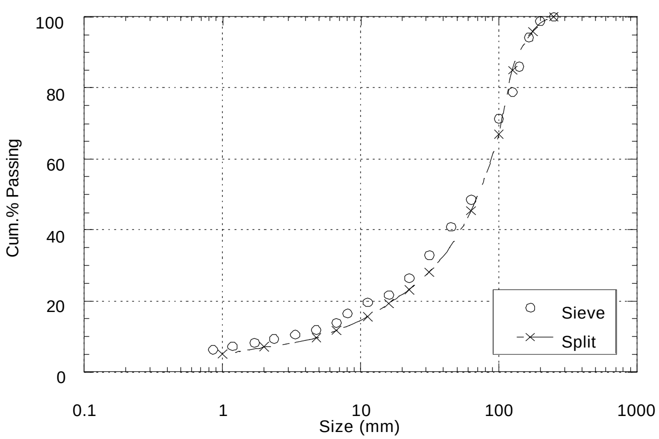

Figure 1: Sag Mill Feed Size Comparison Between Sieving and Image Analysis Using the "Split"

RELATIONSHIP BETWEEN FEED SIZE AND PERFORMANCE

The 80% passing size is often used to describe a size distribution. It is a useful approach when broad associations between size distribution and

performance are being looked for. Such an example is shown in Figure 2, which contains a large volume of on-line data and shows the correlation between the F80 (as estimated using image analysis) and mill throughput and specific power. There is clearly a great deal of scatter in the data which is caused by variations in operating conditions, variations in ore competence and the imprecision in representing an entire size distribution by a single (F80) parameter. This latter effect is illustrated in Figure 3 page I-207, which shows two distributions, which have the same F80 but clearly have different distributions. These would be expected to behave in a different manner when fed to a sag mill.

Despite the limitations of using the F80 it can be seen from Figure 2 that on average an increase in F80 for this particular mill (sag mill with 12-15% balls) causes a higher specific energy and a consequent lower throughput at constant mill power. Over the range of F80 covered (70-110mm) the effect is considerable with the specific energy and throughput varying by about 30%.

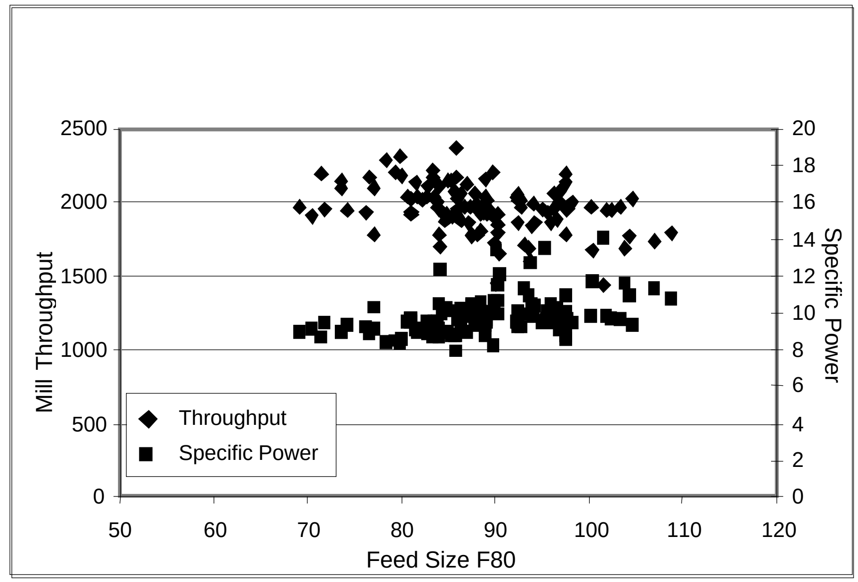

Figure 2: Correlation Between F80 and Mill Performance for a SAG Mill

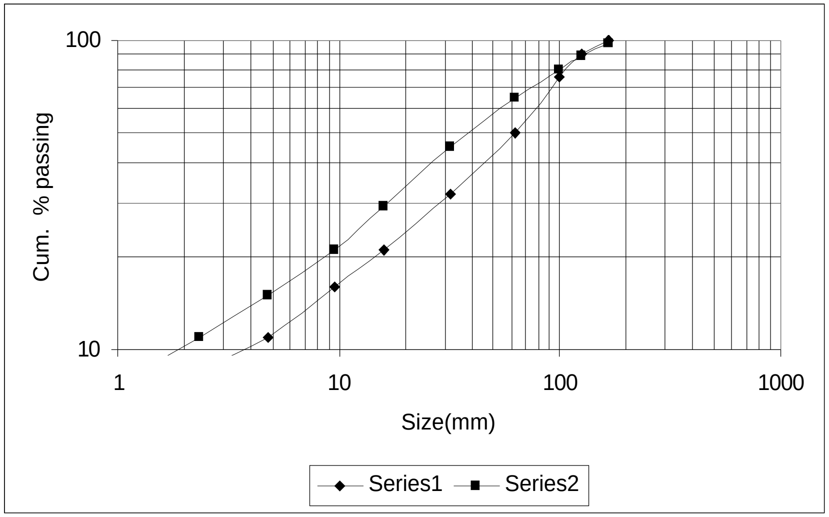

Figure 3: Different Distributions with the Same F80

Feed top size tends to be correlated with F80. This is a useful relationship as image analysis systems are particularly good at identifying bigger rocks. The relationship between top size and the performance of a large diameter sag mill is shown in Figure 4 page I-208. The top size data has been plotted in both raw and smoothed form. It clearly shows that as top size increases the mill weight increases as the mill finds it increasingly difficult to break down the bigger rocks. Power responds to the increased mill weight by also increasing. With a constant mill weight/power draw control strategy this would result in a decrease in throughput. It is important to stress that this response is similar to that shown in Figure 2 and relates to sag mill operation. The same response is not necessarily obtained with ag mills. To illustrate this point data from the mill to which Figure 4 refers were obtained with this mill running in ag mode. These are shown in Figure 5 page I-208. A very different picture is seen. In this case over the range of feed top sizes covered it was found that as top size increased the mill weight decreased ie the mill found the feed size distribution represented by this condition easier to grind. Response of the power draw was to fall, providing the opportunity to increase feed rate.

The different response of ag and sag mills to changes in feed size is not unexpected and has been reported previously (Morrell and Morrison, 1996). It arises from the fact that in ag mills some large rocks are required to break intermediate sized ones. If these large rocks are not present in sufficient numbers then the intermediate-sized ones are not

broken at a sufficiently high rate, thus developing the so-called critical size build up which results in limiting throughput.

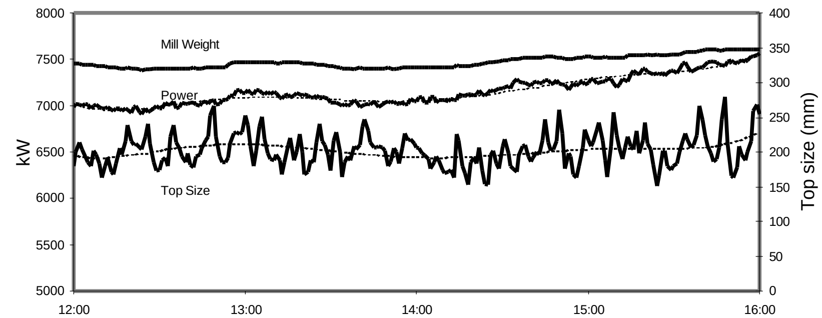

Figure 4: Feed Top Size vs. SAG Mill Performance

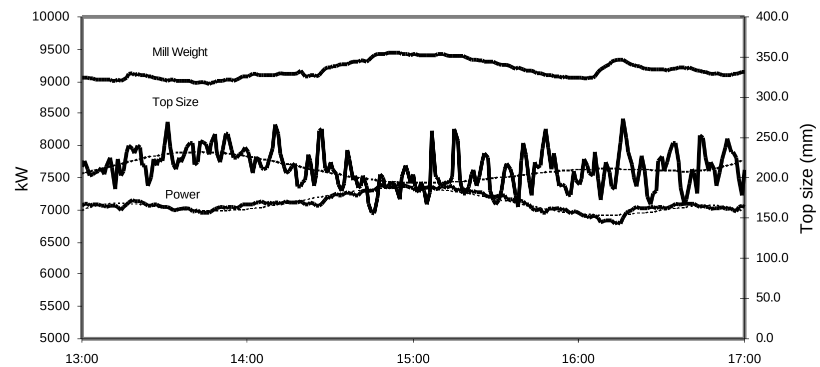

Figure 5: Feed Top Size vs. AG Mill Performance

This is not say that ag mill performance can be improved *ad infinitum* by continuing to increase feed size. A balance needs to be struck between the numbers of coarse rocks and intermediate sized ones. If too many coarse rocks are fed to the mill they will cause an imbalance and will themselves start to build up, resulting in throughput limitations. The same conditions apply in sag mills. However, in this case the required balance between coarse and intermediate size rocks is different to that for ag mills. This is because the steel balls in the sag mill do the duty of the larger rocks. As a result the more balls that are loaded into the sag mill the fewer larger rocks are required. Hence the general trend in sag mills is that finer feeds tend to perform better than coarser feeds.

Although F80 and top size are useful indicators it is dangerous to rely on them exclusively. Figure 3 and to a greater extent Figure 6 are very good examples of this. The data in Figure 3 come from different sites whereas in Figure 6 the two distributions come from the same stockpile. The disparity between the two is due entirely to stockpile segregation and asymmetric conveyor off-takes to the 2 sag mills (12% balls) that the stockpile feeds. The F80s of each stream are almost identical. However, the finer feed size distribution consistently results in 50% higher throughput than the coarser one.

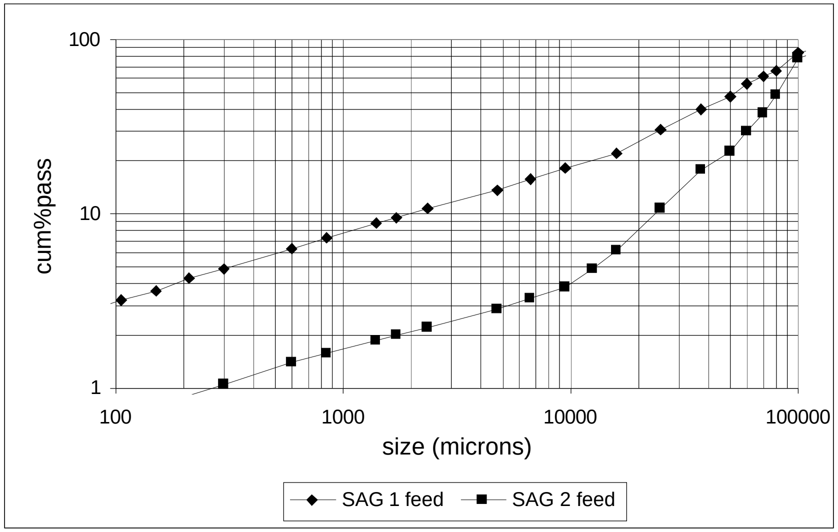

Figure 6: Feed Size Variation Caused by Stockpile Segregation

MANIPULATING FEED SIZE

Once it has been identified what the relationship is between feed size and performance for a given mill it is then possible to change the distribution to improve performance.

Segregation caused by stockpiles provides one opportunity to do so. Figure 6 showed the different distributions that can be obtained from a stockpile. Figure 7 page I-210 shows data from another stockpile that shows this effect in a dynamic environment. The data were obtained from a sag mill circuit that was being fed by a stockpile which was drawing down. The sag mill feed conveyor was fitted with an on-liner sizer using image analysis, whilst the stockpile had an ultra-sonic indicator which tracked its level down to a certain point below which excessive noise made further measurement inaccurate. The data show that as the stockpile

level dropped the feed size to the sag mill became coarser and as a result the sag mill specific energy increased. The increase in feed coarseness was caused by the well-known phenomenon where bigger rocks preferentially gravitate to the outside of the stockpile. As the stockpile draws down these outer rocks are then progressively drawn into the cone that develops above the feeder. The segregation causing the response shown in Figure 7 also gives rise to the fact that, where multiple feeders under a stockpile are arrayed along the length of the feed belt, each feeder will typically give a different size distribution. Hence different feeders will give different throughputs. This can be used to ensure that a constant feed size is presented to the mill by appropriate "blending" of different feeders. Alternatively when throughput is being limited by a non-sag mill problem a coarse feeder can be selected during this time. This will result in the formation of a stockpile that is relatively fine. When the production problem is removed the sag mill feeders can be switched to those giving finer feeds and throughput increased to relatively high levels to make up for the lost production.

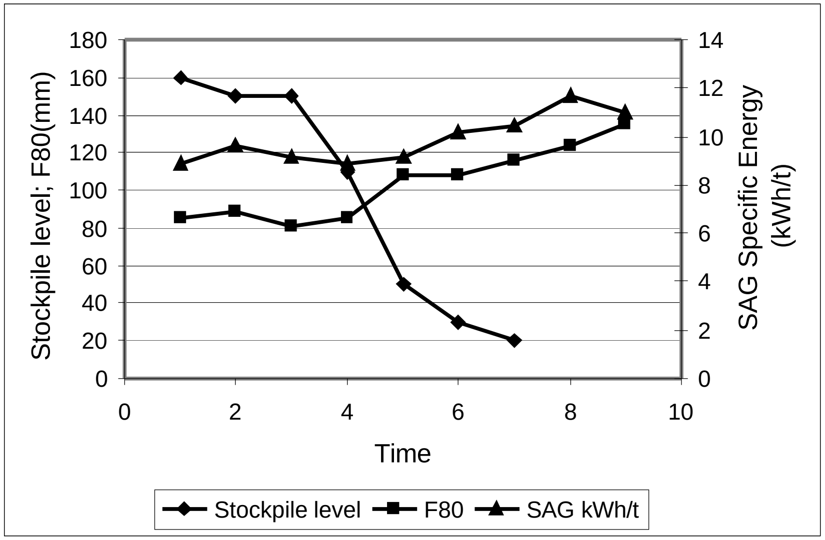

Figure 7: SAG Mill Response to Changes in Feed Size as Stockpile is Drawn Down

Clearly these are only short-term measures as eventually what is fed on to the stockpile must be treated through the ag/sag mill. Hence for longer term gains the feed size going on to the stockpile must be modified.

There are two ways that this can be done viz.

- Installing additional crushing capacity ahead of the ag/sag mill
- Modify the ROM through blast changes and utilize existing crushing capacity better

Secondary Crushing

Installing additional crushing capacity after the primary crusher to provide a finer feed to the primary mill has provided throughput benefits at a number of sites. Figure 8 shows a typical secondary crushed feed compared to the primary crushed one. Clearly no ore grinding media remains in the feed and hence this practice is only suitable for sag milling.

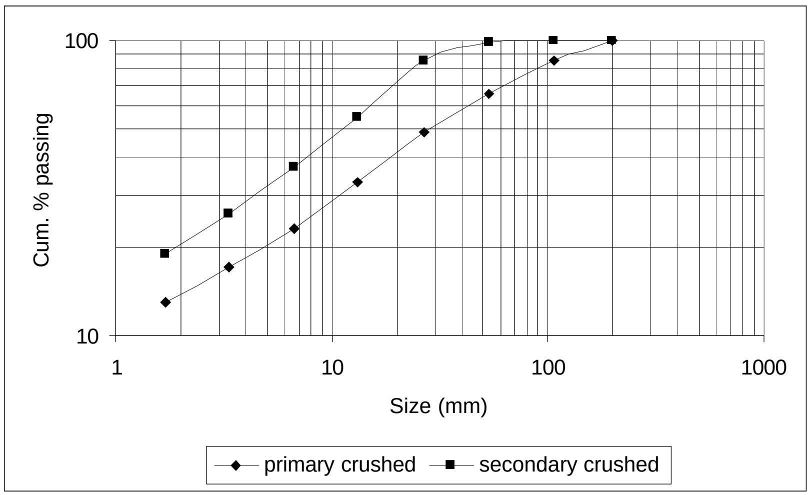

Figure 8: Secondary Crushed vs. Primary Crushed Feed

Kidston is perhaps one of the most well known mill where secondary crushing was adopted and has been well reported on (Needham and Folland, 1994). Throughput gains were considerable (up to 50% increase reported). Secondary crushing has been used elsewhere, though to date reported gains in throughput have not been as spectacular as at Kidston. For example trials at Alcoa (Morrell, 1992) produced gains of the order of 15% whilst KCGM (Nelson et al, 1996) recorded gains of about 10%. Of particular note from both Kidston's and KCGM's experience was the fact that with secondary crushed feed control of the rock level was critical to avoid overloading. If the rock level

was allowed to exceed only a few % of mill volume above the ball charge, the mill rapidly filled with 1-2'' rocks.

A significant downside to running in this way is that liners are very exposed and as result wear rates can be very high. One solution to this problem is to run with a feed size which is a blend of primary and secondary crushed material (Nelson et al, 1996). This results in a size distribution which allows higher rock loads to be obtained, yet still provides significant throughput gains.

A further development of this approach is to further crush the secondary crushed portion in a high pressure grinding rolls machine. This circuit has been piloted with great success and results in very large throughput gains.

Changing Blast Design

It is clear from data such as that shown in Figure 6 that in sag mill circuits the finer feed size distribution will result in significant throughput increases. Such distributions are favorable from a sag milling viewpoint because they have a large amounts of sub-grate material (which passes through mill rapidly), coupled with reduced levels of intermediate-sized material which sag mills (and ag mills) find difficult to break. As all ex-primary crusher ag/sag mill feed size distributions are the result of how in-situ rock has been blasted and subsequently treated by the primary crusher, it is reasonable to expect that by changing how blasting is carried out and how the primary crusher is operated significant changes can be made to the distribution. This is the philosophy of the so-called "mine to mill" approach which has been successfully implemented at sites such as Highland Valley Copper, Porgera, Mt. Keith and KCGM.

Broadly the approach entails increasing powder factor, often accompanied by changes to blast design and drill hole size, to produce a ROM which has a reduced (or better controlled) top size and more fine material (particularly sub-grate) (Scott et al, 1999). This may be coupled with reducing primary crusher gap as the finer ROM enables this change to be made without compromising crusher throughput. Where possible the primary crusher is also choke fed as this produces additional fines in the sag mill feed (Simkus and Dance, 1998).

To illustrate what can be achieved, Figure 9 page I-213 shows the ROM size distribution from a more intense blast compared with the normal one. After passing through the primary crusher the size distributions shown in Figure 10 page I-213 were obtained. These were fed to the sag mill which was running with 12% balls. The finer distribution resulted in the mill throughput increasing by 20%.

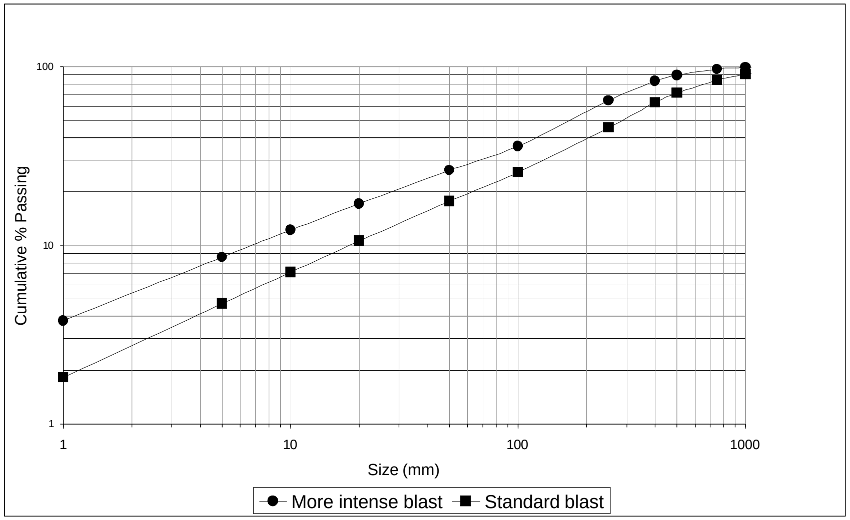

Figure 9: Normal Blast ROM vs. More Intense Blast

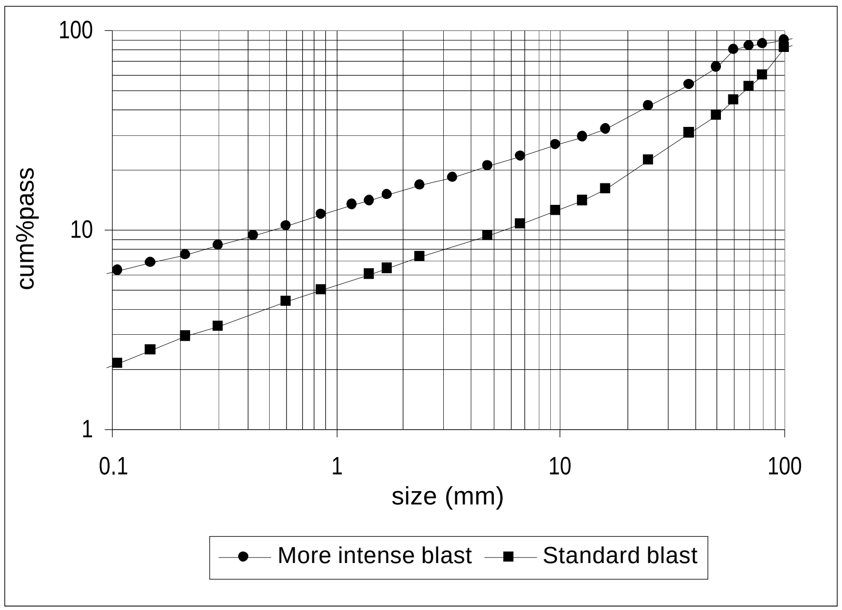

Figure 10: SAG Mill Feed from Normal and More Intense Blasts

The benefit of this approach over the use of additional crushing capacity is that no additional capital expense is required. However, detractors of

the mine to mill approach point to the additional cost of explosives. Interestingly in many cases the cost of additional explosives is more than offset by improved load and haul productivity ie it is cost neutral. This contrasts with the secondary crushing route where additional working costs are incurred.

CONCLUSIONS

Feed size sensitivity of ag/sag mills is inescapable. However it need not be a phenomenon that is always detrimental to operational performance. Opportunities exist where this response can be put to good effect and may lead to significant improvements in overall performance. Such examples include using stockpile segregation to help reduce the effect of short term non-ag/sag mill production stoppages, using secondary crushing to increase throughput and modifying blast intensity and design to manipulate ROM size distribution to improve overall productivity.

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