

THE EFFECT OF BLAST DESIGN ON THE LUMP:FINES RATIO AT MARANDOO IRON ORE OPERATIONS

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ABSTRACT

A field study was undertaken at Marandoo iron ore operations to investigate the effect of blasting on the lump/fines ratio. Three blasts, each in a different ore domain were monitored and the blasted ore was subsequently audited through the treatment plant. At the same time, two truck loads of ore from each blast were selected and sized using a combination of a mobile screening plant and sieves. Rock samples from each blast and from each plant audit were also selected and subjected to a range of characterisation tests.

The field audits revealed that ore characterisation is critical because it defines the proportion of soft and hard ore, which respond differently in both the blast and plant processes. A two phase modelling approach has been used to predict the size distribution of soft and hard ore from the blasts and subsequent processing operations.

The models are used to simulate the effect of changes in blast design on the resulting lump:fines ratio. The simulations show potential to improve the lump/fines ratio of the crushed product by changing the blast pattern, particularly in the hard Upper Ridge ore.

INTRODUCTION

As part of Hamersley Iron's on-going programme of research into improving operational efficiency, a project was initiated to study the influence of ore type and feed size distribution on plant performance. Specifically, the feasibility of improving the lump/fines ratio by changing blast design was targeted. To this end a major site programme was conducted at Marandoo to provide data to model blasting and the subsequent crushing and screening operations. Once the models were calibrated, simulation was then used to explore the possibility of increasing the final lump fraction by changing blast design. The study was undertaken as part of the AMIRA P483 research programme being conducted by the JKMRC and sponsored by Hamersley Iron.

BACKGROUND

The Marandoo mine is located 35km NE of Mount Tom Price in Western Australia. It is a Marra Mamba ore deposit and has two distinct layers; the harder "Upper" and softer "Lower"

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horizons, which extend from the “Ridge” to the “Flats” areas. In the Ridge Upper ore there is a proportion of surface hydrated ore. The hematite-goethite ore in the Ridge section is somewhat harder than in the Flats area.

A field programme was undertaken by Hamersley Iron and JKMRC staff in which three blasts were monitored, each in a different ore domain. The blasted ore was subsequently audited through the treatment plant. At the same time samples from each blast were selected and sized using a combination of a mobile screening plant and sieves. The opportunity was also taken to photograph the ROM material and these images were used to assess the ability of the “Split” image analysis programme to produce accurate size distribution estimates (Atasoy et al, 1998).

Rock samples from each blast and from each plant audit were also selected and subjected to a range of characterisation tests. These results, together with the sizings were used to guide the development of appropriate blasting and crushing models.

ORE CHARACTERISATION

The three domains selected for the test work and subsequently audited were:

- Upper Ridge
- Upper Flats
- Lower Flats

According to the Hamersley Iron geologist, Table 1 describes the overall mineralisation of the domains tested in the audits:

Table 1 - Expected Geology in Audit Domains

Audit	Bench	Type	Hydrated	Upper	Lower
1	750/604	Ridge Upper	15%	70%	15%
2	200/227	Flats Upper	-	100%	-
3	300/212	Flats Lower	-	20%	80%

Rock properties measured included density, fracture toughness (K_{1c}), uniaxial compressive strength (UCS), Young’s Modulus and Schmidt Hammer hardness. Point load strength was used to estimate the Mode I Fracture Toughness. In addition, face mapping was conducted on the blasted benches to describe the rock mass structure. Drill hole geophysical logging was carried out on every second blast hole in each bench to provide detailed density and magnetic susceptibility data. The amenability of the ore to impact breakage was measured by using the

JKMRC's standard drop-weight test (Napier-Munn et al, 1996). This consists of breaking single particles at known energy levels to generate a "map" of the relationship between energy and product size distribution.

The Marandoo ore body is highly heterogenous. Initially attempts were made to model its behaviour using mean strength data. This was found to produce unsatisfactory results. From a rock strength viewpoint it was therefore decided to partition the rock into two classes, viz. soft and hard and to model their blasting and crushing behaviour independently. For the soft ore, of which there were no samples recovered for blasting tests, the rock behaviour was estimated from the density and UCS of small rock pieces obtained from the plant surveys. Values for density and UCS were measured to be approximately 1.5 t/m³ and 10 MPa, the latter being obtained from point load tests. The density of the harder ore was found to be around 4 t/m³ and strength in the UCS range of 75 to 100 MPa.

PROCESS PLANT MODELLING

All audit surveys were conducted in open circuit mode, as reaching steady state in each scenario would have exhausted each sample. The strategy was to calibrate the performance of the individual unit operations accurately enough to allow a full circuit simulation at any combination of feed rate and crusher settings.

Model parameters were fitted using the survey data for the following units:

- gyratory crusher
- secondary cone crusher
- double deck banana scalper screen
- double deck banana product screen.

The Andersen/Whiten crusher model (Andersen, 1988) was used to model the crushers whilst the screens were modelled using a simple classification curve equation (Napier-Munn et al, 1996).

To correctly simulate the ore treatment process it was necessary to incorporate degradation as well. This was considered to be particularly important in this case as degradation affects soft ore far more than hard ore. Using the breakage data for the soft and hard ore, two degradation steps were incorporated in the flowsheet for each simulation. This is illustrated in Figure 1. Mine degradation caused by excavation, hauling, dumping, crushing and screening was also included and was estimated to be equivalent to around 10 metres of potential energy (or 0.03 kWh/t). This new JKMRC model is based on the simple application of drop-weight test data to

BLAST FRAGMENTATION MODELLING

The conventional approach to the prediction of the ROM fragment size distribution resulting from blasting uses the Kuz-Ram method (Cunningham, 1987). This method uses the Kuznetsov equation to predict the mean fragment size as a function of the rock quality, volume of rock per blasthole and quantity of explosive. The Rosin-Rammler equation is used to describe the size distribution of the crushed rock as a function of some characteristic size (50% passing size) and a uniformity index which describes the slope of the curve.

However, work conducted by the JKMRC has shown that the Kuz-Ram model tends to underestimate the fines portion of the distribution. This deficiency of the model can be overcome by introducing a second uniformity index to describe the fines distribution, below the mean size (Kanchibotla et al, 1998). This approach looks at the detonation of an explosive in a blasthole and estimates the extent of the crushed zone based on the peak blast hole pressure and strength of the rock. The rock in the crushed zone is assumed to be completely pulverised to generate fines which are assumed to be less than 1mm in size. The percentage of fines (less than 1mm) is the ratio of the volumes of crushed and blasted rock. In the modified Kuz-Ram model, the fines uniformity index is back calculated to satisfy the criteria of percentage fines less than 1mm and 50 percent less than the mean size determined from the standard Kuz-Ram relationship. The coarse part of the distribution is predicted using the conventional uniformity index based on blast design parameters proposed by Cunningham (1987).

The application of the fragmentation model required a two phased approach because the properties of the soft and hard ores are significantly different to each other. The fines uniformity index for hard ore was calculated by substituting the estimated 50% passing size and the fines percentage estimated from the crushed zone. However, for soft ore this approach produces an unrealistic size distribution. Figure 2 compares the two predicted ROM size distributions for soft ore. The lower curve is for soft ore using the crushed zone approach combined with the 50% passing. Note the obvious inflection at the 50 percent passing size resulting in a ROM size distribution which is not realistic for the random breakage of ore. It was decided to estimate the fines uniformity index and the size distribution for soft ore by substituting the estimated top size (100% passing) instead of 50% passing size. The resulting size distribution is given by the upper curve in Figure 2.

The model parameters and fines uniformity index were calculated on the basis of the blast design information and given explosive density and VOD for each bench. The results are summarised in Table 2.

Table 2 - Summary of Blasting Model Parameters for Marandoo

Parameter	Area 1 750/604	Area 2 200/227	Area 3 300/212
Borehole Pressure, MPa	3400	3400	3400
<i>Hard Ore</i>			
Rock Factor, A	4.75	4.75	4.75
X50, cm	16.5	18.6	22.0
Crushing Zone Radius (m)	0.61	0.61	0.61
Fines % (<1mm)	3.34	2.90	2.32
n - coarse	1.63	1.60	1.49
n - fines	0.59	0.60	0.63
<i>Soft Ore</i>			
Rock Factor, A	0.72	0.72	0.72
X50, cm	2.49	2.81	3.31
Crushing Zone Radius (m)	1.91	1.91	1.91
Fines % (<1mm)	33.3	28.9	23.1
n - coarse	1.63	1.60	1.49
n - fines	0.17	0.21	0.28

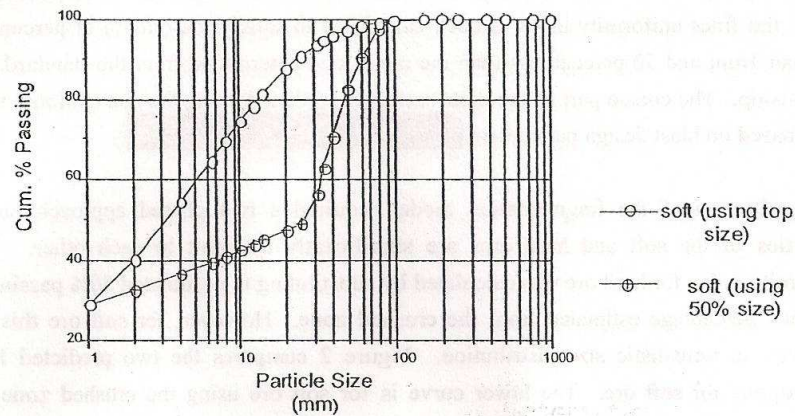


Figure 2 - Comparison of simulated blast fragmentation for soft ore, based on 200/227 bench fired at 0.24 kg/t powder factor
(Crushed Zone + Kuz-Ram and Crushed Zone + Rosin-Rammler)

Having modelled the blasting behaviour of the soft and hard components it was then necessary to determine the proportions of hard and soft ore in each of the three domains. These estimates were based on visual inspection by Hamersley geologists of selected rock samples collected during the ROM sizing trials. To ensure that the blast model predictions were consistent with these estimates, the measured ROM distributions were used to determine what ratio of hard and

soft ore the blasting model would need to reproduce the measured ROM size distribution. To this end the ratio of hard and soft ore was fitted to best match the measured ROM size distribution from each blast. The results are shown in Table 3 whilst Figure 3 compares the measured and simulated ROM distributions for the 200/227 Flats Upper blast.

Table 3 - Expected Ore Composition in Audit Ore Types

Audit	Bench	Type	Ave. Density	Source	Hard %	Soft %
1	750/604	Ridge Upper	2.7	JKMRC	59	41
				HI	60	40
2	200/227	Flats Upper	2.9	JKMRC	61	39
				HI	57	43
3	300/212	Flats Lower	2.5	JKMRC	43	57
				HI	40	60

The close agreement between the fitted and estimated ratios of hard and soft ore suggests that the three ore domains can be predicted using the new blast model and a simplified description based on a hard and soft ore components.

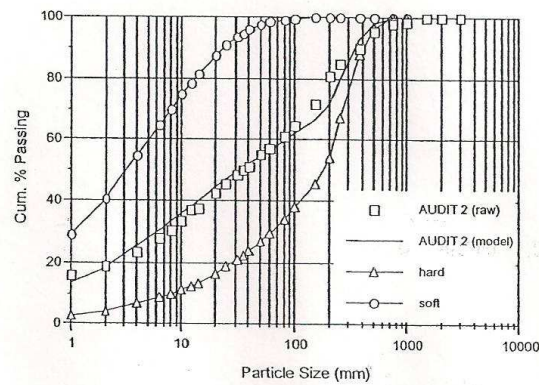


Figure 3 - Comparison of simulated and measured ROM blast fragmentation 200/227 bench fired at 0.24 kg/t powder factor

VALIDATION OF THE COMMINUTION PLANT MODELS

Using the predicted ROM size distributions and the relative amounts of hard and soft ore types in each domain, the individual degradation, crusher and screen models were put together in a simulation of the entire plant. The results of the simulations for the three audits (ore type combinations) are shown in Table 4. Also shown are the results from two surveys on each ore type which indicate the range in lump/fines ratio recorded by the Citec computer during the plant audits. *The results from the second audit were not able to be recovered from the computer due to a hardware problem.* It is clear that the estimate of hard and soft ore in each case controls the simulation.

Table 4 - Comparison of Audit and Simulated Plant Lump/Fines Ratio

	Audit 1 (750/604)		Audit 2 (200/227)		Audit 3 (300/212)	
	Upper Ridge		Flats Upper		Flats Lower	
Hard/Soft (%) - HI	60:40		57:43		40:60	
Hard/Soft (%) - JK	59:41		61:39		43:57	
	meas.	sim.	meas.	sim.	meas.	sim.
Lump (Gen + Nat.)	49-51	49	n/a	51	44-47	47
Fines (Gen + Nat.)	51-49	51	n/a	49	56-53	53

SIMULATIONS OF THE EFFECT OF CHANGING BLAST DESIGN

Marandoo currently uses ANFO which has a nominal density of 850 kg/m³ and a VOD of 4000 m/s. The drill and blast engineers there routinely use different designs to accommodate the different rock characteristics in each domain as shown in Table 5. The JK fragmentation model (corrected with the crushed zone approach) was used with the comminution models to determine whether their designs could be modified further to improve the final lump/fines ratio. Changes to the following were considered:

- Expansion of pattern.
- Use of low density (700 kg/m³) and low VOD (3000 m/s) explosive.
- Use of low density/low VOD explosive with an expanded pattern.

Expanded Pattern

The pattern was expanded by 16 to 52%, as summarised in Table 5, to give the same powder factor for all three benches.

Table 5 - Simulated Blast Design Parameters

Blast Design Parameter	Bench					
	750/604		200/227		300/212	
	old	new	old	new	old	new
Burden (m)	4.8	5.9	5.1	5.8	5.6	6.0
Spacing (m)	5.5	6.8	5.9	6.6	6.4	6.9
Powder Factor (kg/t)	0.30	0.19	0.24	0.19	0.22	0.19
Change in Pattern (%)	52		27		16	

The simulation results, summarised in Table 6 by the final lump/fines ratio and secondary crusher circulating load, suggest that expanding the pattern is expected to increase the final lump/fines ratio and the circulating load. The greatest change is seen in the Upper ore types which are predominantly harder (4-7 percent).

Table 6 - Effect of Expanded Blast Pattern (Plant treating 1900 tph)

Audit	Bench	Type	Blast Design	Lump/Fines %	Circulating Load tph
1	750/604	Ridge Upper	old	49/51	851
			new	56/44	1028
2	200/227	Flats Upper	old	51/49	823
			new	55/45	923
3	300/212	Flats Lower	old	47/53	651
			new	49/51	705

Low Density/Low VOD Explosive

Based purely on the manner in which commercial explosives deliver energy into rock, the general explosive/rock interaction criteria would suggest that Marandoo, with predominantly soft rock, should be using diluted ANFOs which have a very low VOD. The use of low VOD explosive with the same patterns, will alter the partition of explosive energy to reduce the percentage of shock energy whilst maintaining the heave energy. Therefore the use of low VOD explosive is aimed not only at increasing the lump to fine ratio but also improving muckpile looseness. However, these aspects require further investigation. The terms hard and soft rock relate not only to the intact rock strengths and mode of failure but also to the spacing and condition of the jointing. To test this hypothesis an explosive with a nominal density of 700 kg/m³ and 3000 m/s VOD (Relative Weight Strength of 98) was simulated using the modified Kuz-Ram model outlined previously.

The simulation results suggest that the low density/low VOD explosive has a pronounced effect on the lump/fines ratio, as shown in Table 7. The change in explosive type represents an eight percent improvement in lump production, for a moderate increase in circulating load. The low VOD explosives produce significantly lower peak borehole pressure resulting in smaller crushing zones and fines percentage in the ROM. This benefit will directly translates into a higher lump/fines ratio.

Table 7 - Effect of Low Density/Low VOD Explosive

Audit	Bench	Type	Blast Design	Lump/Fines %	Circulating Load tph
1	750/604	Ridge Upper	old	49/51	851
			new	58/42	1008
2	200/227	Flats Upper	old	51/49	823
			new	59/41	988
3	300/212	Flats Lower	old	47/53	651
			new	55/45	818

Expanded Pattern & Low Density/Low VOD Explosive

Simulations were also carried out on the combined effect of expanding the pattern whilst using the low density/low VOD explosive. The results showed that there would be a further improvement in lump/fines ratio over that already achieved in just changing the explosive type or pattern, at the expense of a major increase in crusher circulating load. The Upper Ridge would yield 62/38 at 1210 tph, Upper Flats 61/39 at 1082 tph and Lower Flats 56/44 at 904 tph. Note that the greatest change is in the hardest ore type. The increased circulating load would require the use of both secondary crushers in production.

CONCLUSIONS

Ore characterisation has been found to be critical as it defines the proportion of soft and hard ore, which respond differently in the blast and plant. Providing the ore characterisation is accurate, the prediction of the ROM fragmentation using a two phase approach is applicable at Marandoo. In this approach, the fines part of the size distribution was predicted from the expected radius of crushing around the blasthole, and the coarse end of the distribution was predicted using the JK fragmentation model based on the blast design and rock property data. The simulated and measured ROM distributions are in close agreement for all three benches.

Based on the detailed analysis of comprehensive plant audit data collect at Marandoo Iron Ore Operations, a JKSimMet circuit simulation model has been developed. This model has been used to simulate the effect of blast fragmentation (ROM) and ore type, both of which have been shown to affect the final product quality, as defined by the lump/fines ratio.

On the basis of simulations, there appears to be scope to improve the final lump/fines ratio by changing the blast pattern, particularly in the Upper Ridge ore. Alternatively, the use of a low density low VOD explosive should significantly reduce the fines in the ROM which represents 8-9% improvement in the final lump/fines ratio. The impact of the changes in ROM size distribution on excavation and productivity will also need to be considered.

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