Research of explosive ore dressing intensification factors in open pits

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Abstract
One of the major problems during solid ores winning is setting of an optimum ratio of explosive and mechanical crushing, generally defining the efficiency of ore dressing. In this case primary gyratory cone crushers are the transfer function from explosive to mechanical crushing. The ratio of primary breaking is from 40% to 60% of capital expenditures and up to 50% of operational costs on cleaning circuit. It is recommended to reduce the output of +400 mm class in blasted out mined rock by blasting workings improvement.
Key words: EXPLOSION, FAILURE MECHANISM, PIT BANK, ORE DRESSING, CRUSHING UNIT

Analysis of previous studies

The characteristic feature of modern ore dressing is the desire to obtain not only the necessary size of mined ores, but also their grain size composition for further processing into crushers and mills.

Studies [1,2,3] show the effect of explosives and new blasting methods specific consumption on improving the crushing quality, reducing the ore mass strength and improving, due to change in ore dressing quality, the indicators of subsequent operations of mine-mill processing. Thus, the increase in explosives specific consumption in InMPP openpit, for example, made it possible to get the significant economic effect on subsequent stages of processing. Similar results were obtained at Poltava Mining and Processing Plant [4,5,6].

A number of works is dedicated to improving the efficiency of subsequent mine-mill processing due to blasted rock mass formation with desired granulometric and strength properties and its further processing in primary breakers [7,8,9].

Primary breakers, as a rule, are of cone type KKD 1500/180, with development of cyclic-flow technology have become an indispensable equipment of large openpits. At the same time, the interconnection between explosive, mechanical ore crushing and autogenous grinding is poorly studied.

The essence of crushing in cone crusher is as follows: during the inner cone eccentric rotation at the moment of its approach to the stationary outer cone it with greater force compresses (the wedged between cones at the time of cones surfaces removal) pieces, whereby they are crashed. Between the cones there is a constantly open slot of minimum width L_{min} (at the time of cones convergence) and of maximum width L_{max} - at the time of cones surfaces removal. It is obvious that the piece, which sizes are smaller than L_{min} pass through the crushing unit without changes, or rather, nearly unchanged. In fact, the pieces of size more than L_{min} $(+L_{min})$ are subjected to crushing. Here one feature of the process should be noted. Real pieces have three unequal sizes: as L.I. Baron showed [1], the ratio between the length, width and thickness of pieces in blasted out mass in average is 2: 1, 4: 1.

Purpose of work. To determine the interconnection between explosive, mechanical crushing and autogenous grinding depending on coarseness of grading.

Matter and results of research. Special measuring of more than 100 pieces of blasted out mass was carried out. Measurements showed that in bulk the ore pieces have a shape similar to the rotation ellipsoid - (ovoid, mainly up to 300 mm), or in the shape of cut columns (pieces up to 100 mm of maximum size).

Therefore, only two sizes - the maximum and minimum were measured. Thus for pieces with minimum size of more than 200 mm the average ratio (piece extension) $a_{+200} = l_{max}/l_{min} = 2{,}04$; $a_{-200} = 1.55$. Given that the average size of the cone crusher gap is 200 mm, then pieces of sizes up to 200 x 2.04 = 400 mm on maximum size can pass through such a gap.

Thus, grading fractions +400 mm are subjected to grinding in the KKD 1500/180 crushing unit. Grading fractions -400 mm pass through the crushing unit without any change. Thus, in the first approximation the transfer function of crushing unit will be generally described by the following equation

$$\gamma_{+aL\min} + \gamma_{-aL\min} = \gamma'_{-aL\min} \quad (1)$$

Or

$$\gamma_{+400} + \gamma_{-400} = \gamma'_{-400} \quad (2)$$

where γ - grading fractions output in the blasted out mass, γ' - grading fractions output after crushing unit.

As such, the transfer function is sufficient to determine, for example, the desired gap size, which limits the sizes of pieces at specified maximum size (for the rubber conveyor belt safety). But in order to determine the output of small bodies, "boulders" and fines i.e. three grain-size classes after crushing unit on grain size composition of blasted out mass a more complex function model is required.

For simplicity let us determine the crushing unit minimum gap

$L_{min} = L$ - gap width, a - piece lengthening. Suppose that $L_2 < L_1 < L$.

We are interested in grading fraction $a(L \div L_1)$, $a(L_1 \div L_2)$-aL_2, their outputs after crushing unit:

$$\gamma_a\ (L \div L_1),\ \gamma_a\ (L_1 \div L_2);\ \gamma_{-aL_2} \quad (3)$$

The above classes are already present in the blasted out mass:

$$\gamma_a\ (L \div L_1),\ \gamma_a\ (L_1 \div L_2);\ \gamma_{-aL_2} \quad (4)$$

They will pass through the crushing unit without changes. The class will turn into classes (3) with probabilities:

$$P_{a(L \div L1)};\ P_{a(L1 \div L2)};\ P_{-aL2} \quad (5)$$

Then

$$\begin{cases} \gamma'_{a(L_1 \div L_2)} = \gamma_{a(L_1 \div L_2)} + \gamma_{+aL} \cdot P_{a(L \div L_1)} \\ \gamma'_{a(L_1 \div L_2)} = \gamma_{a(L_1 \div L_2)} + \gamma_{+aL} \cdot P_{a(L_1 \div L_2)} \\ \gamma'_{-aL_2} = \lambda_{-aL_2} + \gamma_{+aL} \cdot P_{-aL_2} \end{cases} \quad (6)$$

This more complicated transfer function of crushing unit will enable to calculate the differentiated output of three grain-size classes of mills power after crushing unit on grain size composition of blasted out mass coming into the crushing unit. But for this it is necessary to determine the probabilities.

It is obvious that the model for the number of grading fractions of more and less than 3 can be constructed in a similar way. For example, for the model in which we are interested in grading fraction -400 ÷100 mm and 100 mm, the crushing unit transfer function will be:

$$\begin{cases} \gamma_{-400 \div 100} = \gamma_{-400 \div 100} + \gamma_{+400} \cdot P_{-400 \div 100} \\ \gamma_{-100} = \gamma_{-100} + \gamma_{+400} \cdot P_{-100} \end{cases} \quad (7)$$

Models of transfer function (6) and (7) are simple for calculations. The fact that the class +400 mm (or + aL) is heterogeneous. It consists of pieces of different size from 1500 to 400 mm. Therefore, models (5 and 6) will be true only in case if large pieces crushing mechanism is reduced to the serial splintering of pieces of approximately equal size from it (slabbing). In this case, the transition probability P will not depend on the initial piece sizes, and the model will be true in this form. If pieces fissuring occurs, in this case, the picture becomes complicated and the class γ_{+400} will be needed to divide into separate parts, for example, γ_{+600} and $\gamma_{-600+400}$, and for each define P_{+600} and $P_{-600+400}$.

Model (7) in this case will be of the form

$$\begin{cases} \gamma'_{-400+100} = \gamma_{-400+100} + \gamma_{+600} \cdot P_{-600+100} + \gamma_{-600+400} \cdot P_{-400+100} \\ \gamma'_{-100} = \gamma_{+600} \cdot P_{-100} + \gamma_{-600+400} \cdot P_{-100} \end{cases} \quad (8)$$

and in general

$$\begin{cases} \gamma'_{a(L_1 \div L_2)} = \gamma_{a(L_1 \div L_2)} + \gamma_{+A} \cdot P_{a(L_1 \div L_2)} + \gamma_{-A+B} \cdot P_{a(L \div L_1)} \\ \gamma'_{-aL_1} = \gamma_{-aL_1} + \gamma_{+A} \cdot P_{-aL_1} + \gamma_{-A+B} \cdot P_{-aL_1} \end{cases} \quad (9)$$

where A>B>aL.

These models differ from the previous ones by growing number of terms in the right side. To test the effect of initial pieces sizes on the transition probability P the laboratory experiments on laboratory roll-jaw crusher 60/20 were carried out. For this 10 pieces of ore from the pit, with dimensions +60 mm, 50 mm, 40 mm, 30 mm, 20 mm were prepared. These samples are shown in Fig.1.

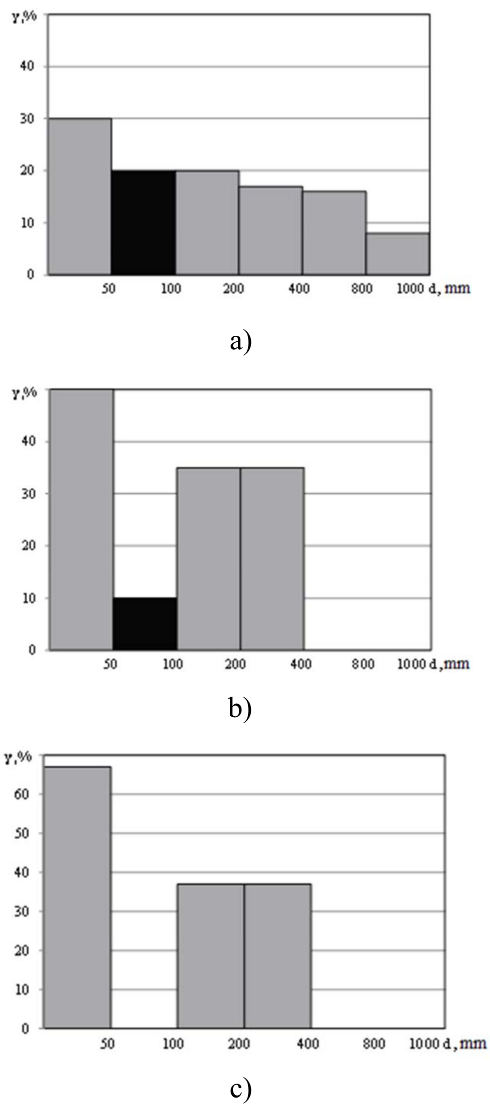

Figure 1. Histograms of blasted out ore coarseness of grading: a - the actual; b - is ideal for section with hollow autogenous grinding; c - for section with combined autogenous grinding

Sizes of pieces are chosen so that 4 of them are larger than average gap size and one is approximately equal to crusher gap. Pieces of the same size are loaded into the crushing unit. After crushing the crushed ore classification is carried out.

To make it possible to extrapolate the results of crushing in the laboratory conditions to industrial, represent the grading fractions borders in relative units, expressing them in fractions of gap size. For 1500/200 crushing unit the range of pieces sizes can be divided into the following grading fractions, mm: 1200÷600; 600÷400; 400÷200; 200÷100; 100÷50; <50, or in the gap sizes: 6L÷3L; 3L÷2L; *2L÷L; L* ÷0,5L; *0,5L* ÷ 0.25L; <0.25L.

Fractions greater than L are subjected to crushing and turn into grading fractions of sizes <L. Thus, the probability of transition of large grading fractions into small bodies (2 -0.5); "boulders" (0.5 - 0.25) and fines (0.25) can be estimates on the experiment results.

Crushing results are shown in Table 1. Converted data (Table 2) are shown in Table 3.

Table 1. Probability of large grading fractions transition into other

Pieces size before crushing	Pieces size after crushing	
	7 “boulders” 10.5 – 0.25	8 fines 0.25
3L	$P_{17} = 0.18$	$P_{18} = 0.16$
2.5L	$P_{27} = 0.17$	$P_{28} = 0.18$
2L	$P_{37} = 0.20$	$P_{38} = 0.14$
1.5L	$P_{47} = 0.18$	$P_{48} = 0.12$
L	$P_{57} = 0.06$	$P_{58} = 0.06$

The analysis of table 1 data shows that with the large-sized pieces approach in the original ore to crushing unit gap sizes the probability of their transition into grinding bodies increases and the probability of transition into "boulders" and fines decreases. In other words, to reduce the output of transition bodies, it is necessary to reduce the output of the large classes in blasted out mass. This dependence can be, assuming that the ore pieces not immediately split into parts, but they gradually break off small pieces, especially in the upper zone of crushing unit, where the crushing surface stroke is small and the loading rate is also low. It is also notable that in the 3L÷2L range transition probabilities are not very different, so that the model can be simplified.

Table 2. Probability of piece sizes change after crushing

Pieces size before crushing	Pieces size after crushing		
	> 0.5L	0.5L ÷0.25L	< 0.25L
> 21	P_{13}=0.65	P_{14}=0.2	P_{15}=0.15
2L ÷ L	P_{23}=0.8	P_{24}=0.1	P_{13}=0.65

Of course, it is impossible to completely transfer the results of probabilities determination on laboratory experiments to real cone crushers. Therefore, the industrial experiments on Annovskiy openpit of Northern MPP for ores similar in strength to oxidized ferruginous quartzites of Inguletskiy MPP were carried out to assess the actual transition probabilities for KKD 1500/180 crusher. For this purpose the coarseness of grading in four bottomholes, working on transfer unit with KKD 1500/180 crusher was measured. Then, for a few shifts, the grain size composition measurement in dumptruck bodies is carried out at the time of emptying to the crusher. At the same time the photographing of ore on conveyor-elevator feeder was carried out simultaneously. The measurements were made in volume of 110 dumptrucks, with transfer unit took about 4 ths. t of ore. At the time of measuring three bottomholes worked on ores of recumbent patch of southern and another on ores of recumbent patch of northern part of openpit. The average data are presented in Table 3.

Table 3. Change in mined rock coarseness of grading

Measurement place	Coarseness of grading, %							
	+1200 mm	+1000 mm	+800 mm	+400 mm	+200 mm	+100 mm	- 400 +200	- 400 +100
In bottomhole	2.3	3.4	6.6	18	35	57	17	37.0
In dumptruck body	2.1	3.1	6.0	7.5	34	55	16.5	36.5
On the feeder of CCM conveyor (KKD 1500/180)	-	-	-	2.3	17.5	38.5	17.2	36.2

The data presented in Table 3 indicate that when loading into dumptrucks the grain size composition of blasted out mass hardly changes. The output of +100 mm class on a conveyor belt averaged 35.8%, which almost exactly corresponds to the output of -400 +100 mm class in blasted out and dispatched ore. Thus, it was found that the -400 +100 mm class is basically the "generator" of grinding bodies in blasted out ore of Annovskiy openpit. Draws attention also the fact that the ore contains more than 3% of +1000 mm class, and "oversized" more than 2%, which is 20-30 times higher than by reportable data.

Thus, for simplified calculations it can be presented that transfer function of KKD 1500/180 crusher is as follows:

$$\begin{cases} \gamma'_{+100} = \gamma_{-400+100} \\ \gamma'_{-100+50} = 0.5\gamma_{+400} + \gamma_{-100+50} \\ \gamma'_{-50} = 0.5\gamma_{+400} + \gamma_{-50} \end{cases} \quad (10)$$

Researches allow to provide the ideal blasted out mined rock coarseness of grading, to which it is necessary to strive at ore breaking in openpit. This grain size composition is shown in Fig. 1 for the main scheme of autogenous grinding ROF-2 with ore-pebbly grinding in stage II, which requires about 10-15% of ore "boulders" from grinding stage I.

For scheme with spherical grinding in stage II "boulders" are not necessary, so they are a ballast for the 1st stage of autogenous grinding, and it is necessary to strive them to be as low as possible in blasted out ore.

As has already been shown above, quite a large number of "boulders" is formed in a crushing unit from coarse grading factions, therefore, a priority for breaking is decrease in the output of +400 mm class in blasted out ore. This task not only contradicts the requirements of mining operations, but also contributes to their improvement.

Conclusions

1. The relation on ore coarseness of grading between the explosive, mechanical crashing and autogenous grinding is set.

2. At autogenous grinding the main classes in blasted out mined rock, which function as grinding bodies are pieces of size - 400 + 100 mm.

3. It is found that pieces larger than 400 mm are processed in crushing unit mainly into the -100 mm class and into "boulders" and fines equally.

4. To improve the autogenous grinding process performance it is necessary to reduce the output of +400 mm class in blasted out mined rock at the same time bringing the output of - 400 +100 mm class to the level of 30 - 35% by improving blasting workings.

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