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COMMINUTION MODELING OF PRIMARY BALL MILLS OF MIDUK COPPER MINE USING MATLAB SOFTWARE

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ABSTRACT

Grinding is one of the most important and expensive steps in mineral processing allocating about 70% of the total energy in the plants. Nowadays, for optimizing the energy consumption in these equipments, the rock behavior and its size distribution during the crushing have been normally predicted using selection and breakage functions to be able to optimally model and design grinding circuits. For this purpose, the case of Miduk copper mine in Kerman province, Iran was studied. The samples were taken from primary ball mills feed and were subject to screen analysis to achieve uniform sizes. Then, selection and breakage functions were determined at the different grinding times in laboratorial ball mill. Finally, ore size distribution in different grinding times was estimated using MATLAB software.

Keywords: selection function, breakage function, matlab software, modeling

INTRODUCTION

Grinding operations have been the focus of attention for many researchers to optimize and reduce energy consumption due to considerable amount of energy used in such operations in comparison with other operations in mineral processing. Much of the research in this field is related to modeling and simulation topics of these units, based on determining breakage and selection functions of the mineral under study. Breakage distribution function or breakage function indicates size distribution as a result of grinding the material in a specific size range due to single impact. Considering " i " and " j " parameters as particle size classes, this function is expressed in the following two forms:

1. Cumulative breakage function: The amount of material converted from size j to a size smaller than i due to single impact and shown as Bij.
2. Non-cumulative breakage function: The amount of material reaching size i from size j due to single impact shown as bij.

The breakage may be assumed independent of the grinding medium (diameter and number of mill balls, milldiameter, etc.),If the ratio of ball diameter to particle size is selected properly. But it will be dependent on the type of mineral. Thus, breakage function can be calculated for a specific material in a mill using experimental dimensions then it can be used for scale up (industrial scale mills). Selection function, as a kinetic index of

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material grinding process, is an important parameter in the modeling of ball mills. It is determined by the material grinding capability experiments. This function, also known as breakage rate constant, indicates the rate of size decreasing of a mineral from a specific size due to grinding. It often follows the first order kinetics (refer Equations1-3):

$$\frac{dm_i}{dt} = -s_i m_i \tag{1}$$

$$\frac{dm_i}{m_i} = -s_i dt \tag{2}$$

$$m_i(t) = m_i(0)e^{-s_i t} \tag{3}$$

Where “s_i” is called selection function (S^{-1} as unit). By given selection function and assuming it remains constant during the grinding, the amount of residual material on the first screen can be calculated at any time (King, 2001).

The main objectives of this study are estimating the size distribution of Miduk copper ore at various grinding times and determination of the mill capability using MATLAB software

EQUIPMENTS AND SOFTWARES

In this study, laboratory screens with different pore sizes of 1400, 1000, 710, 500, 355, 250, 180, 125, 90, 63, and 45 micron were used. Precise weighing of remaining materials in various screens was carried out by accurate digital scale with an accuracy of 0.01 g. The specifications of used laboratory ball mill shown in Table 1. The BFDS (Breakage Function Determination Software) was used for calculating breakage and selection functions of the experimental. This software is able to calculate the breakage and selection functions parameters of the Berube, Herbst & Fuersteneau and modified Herbst & Fuersteneau methods. Also plotting the breakage and selection functions and determination of the breakage function coefficients including α, β and φ (at different grinding times)is the ability of the software (Yousefi, Farzanegan and Irannezhad, 2001). To estimate the ore size distribution in different grinding times, MATLAB software was used. Its most powerful programs for mathematical calculations which has matrix based approach even single numbers can considered as matrix (Brian et al, 2001).

Table 1. Profile of the used ball mill in grinding

Parameters	Value
Internal height of the mill (cm)	30
Internal diameter of the mill (cm)	20
Average diameter of the balls (cm)	2.5
Specific weight of the ball (gr/cm^3)	7.5
Rotation speed of the mill (rpm)	72
Critical speed of the mill (rpm)	93.56

RESULTS AND DISCUSSION

Screen analysis of ball mills feed of Miduk copper mine

First, to choose the screens for experiments, the representative sample was subject to screen analysis. The results of screen analysis of the feed are shown in Table 2. The screen set (shaded rows) was chosen for further experiments.

Table 2. Screen analysis results of the primary ball mills of Miduk copper mine

Size (micron)	Cumulative percentage remaining	Cumulative percentage passing
8000	0	100
5600	1.62	98.38
4000	0.58	97.8
2800	0.68	97.12
2000	1.01	96.11
1400	1.34	94.77
1000	2.53	92.24
710	3.61	88.63
500	7.02	81.61
355	10.75	70.86
250	17.24	53.62
180	17.46	36.16
125	12.80	23.36
90	9.43	13.93
63	0.62	13.31
45	5.61	7.7
32	1.1	6.6
25	1.28	5.32
-25	5.32	0

Grinding experiments

For determination of the breakage function in the laboratory scale, the used samples should be only in a single size range (e.g. about 100% of the particles be in the range 1000-1400 microns). In fact, we are not sure about these condary breakage of the particles, so the fractions have to grinded in a short time. Therefore, particle size distributions can be determined between two grinding times. Grinding operation continues(e.g. t, 2t, etc.)Until about40-60% of materials remain in the first fraction. Then the cumulative breakage function (Bij) is calculated using linear regression of results (Austin, Klimpel and Luckie, 1998).

To determine the breakage and selection functions of Miduk copper ore, the feed sample was divided to 11 size fractions (45, 63, 90, 125, 180, 250, 355, 500, 710, 1000 and 1400 microns). For this purpose, the feed sample was subject to wet screen analysis. About 1000 grams of homogenous sample was prepared in each fraction.

A procedure for choosing the optimum grinding times was used. First,1400 µm particles were crashed for 60 seconds by ball mill. During this period of time, more than50% of material left the fraction. It means the mentioned time is more than enough. In this respect 15, 30, 45, and 60 seconds were selected as grinding times.

After this step, a pulp with 60% solid of each fraction (equivalent to feed concentration of Miduk copper ball mills) was prepared. The pulps were crushed at selected time periods. After each grinding time, the material completely left the mill, and sent to screen analysis. Screen analysis results are shown in Figures (1) to (11). In Figure 1, the results of grinding the 1400 micron fraction, showed that through one stage grinding, the large amount of material transferred to the next fraction but the amount transferred to the smaller factions was relatively low. In Figures (9) to (11) where the fine particle fractions have been smashed, the number of the fractions (that materials are transferred after grinding) along with the material transfer volume have been reduced.

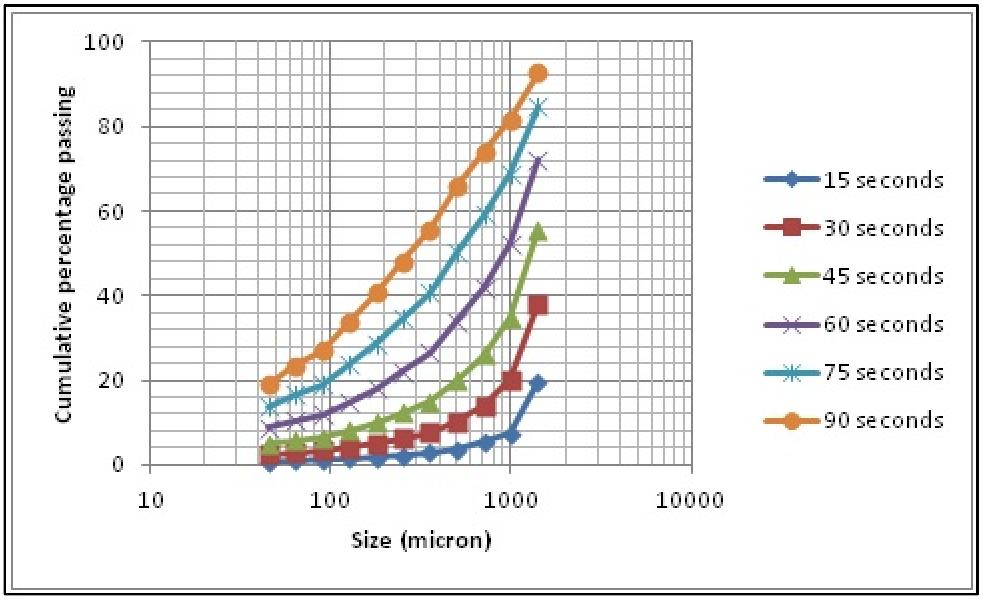

Figure 1. Cumulative percentage passing the screens at different grinding times (1400 micron fraction)

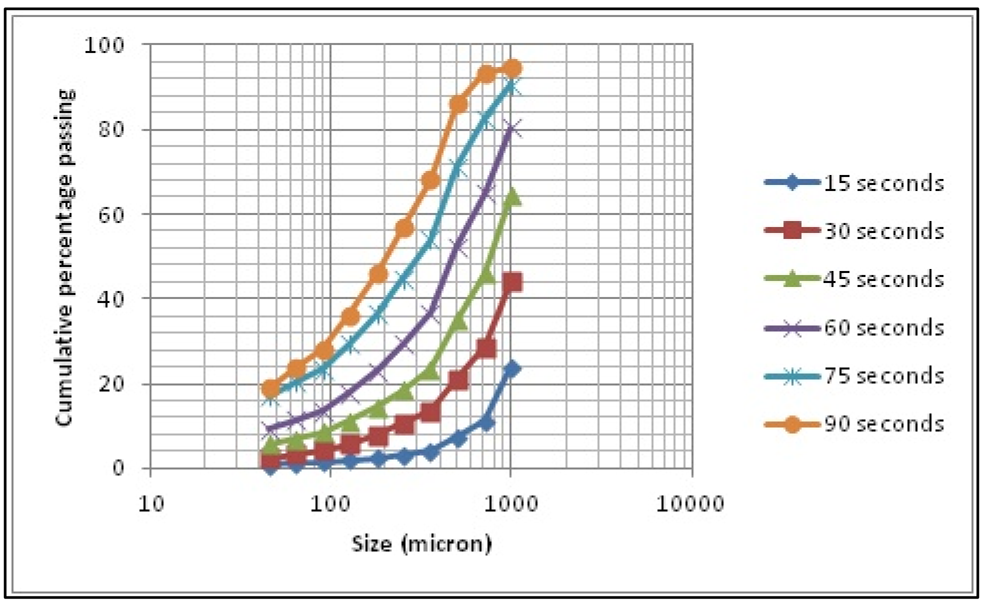

Figure 2. Cumulative percentage passing the screens at different grinding times (1000 micron fraction)

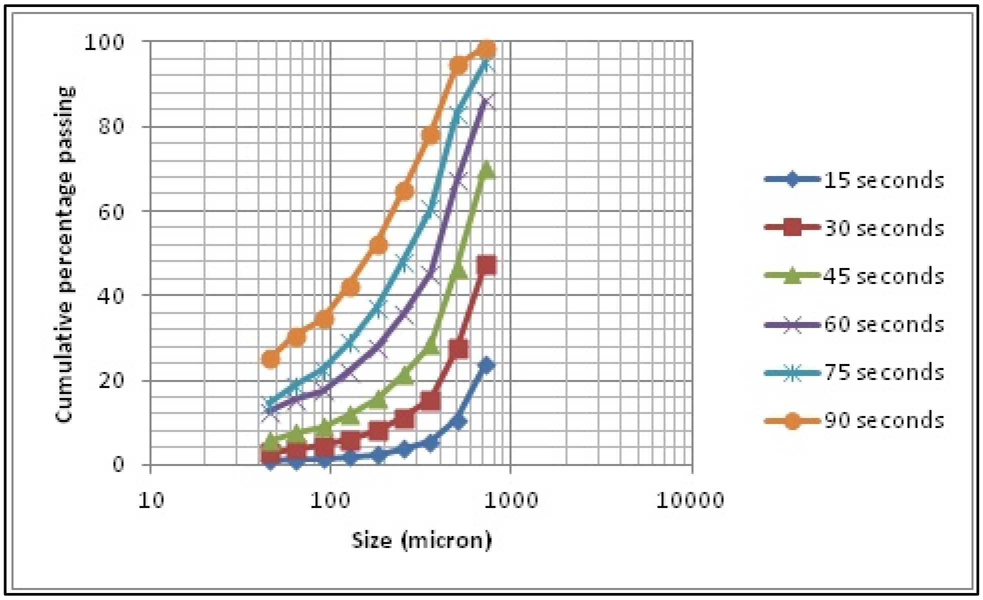

Figure 3. Cumulative percentage passing the screens at different grinding times (710 micron fraction)

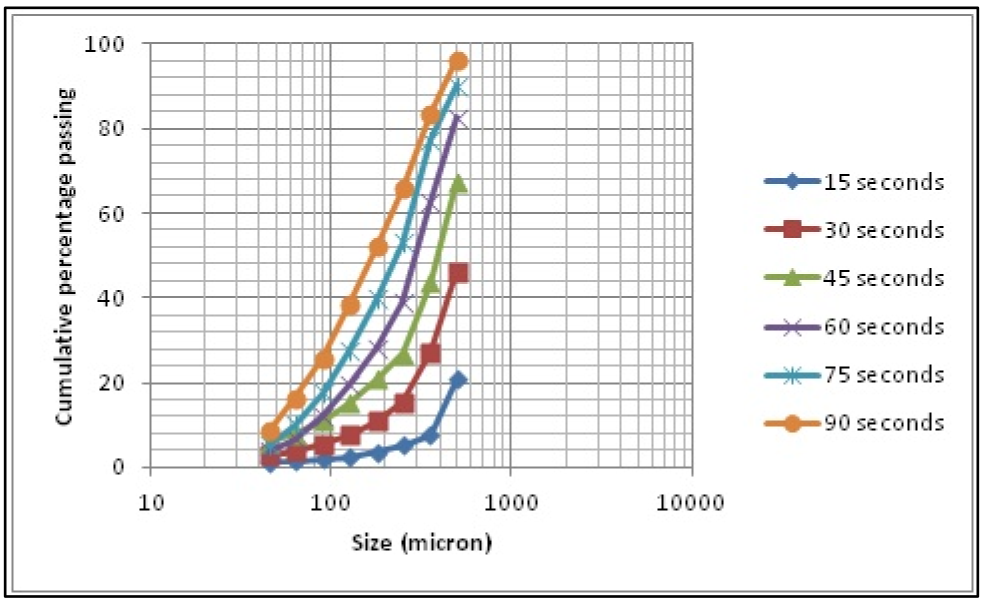

Figure 4. Cumulative percentage passing the screens at different grinding times (500 micron fraction)

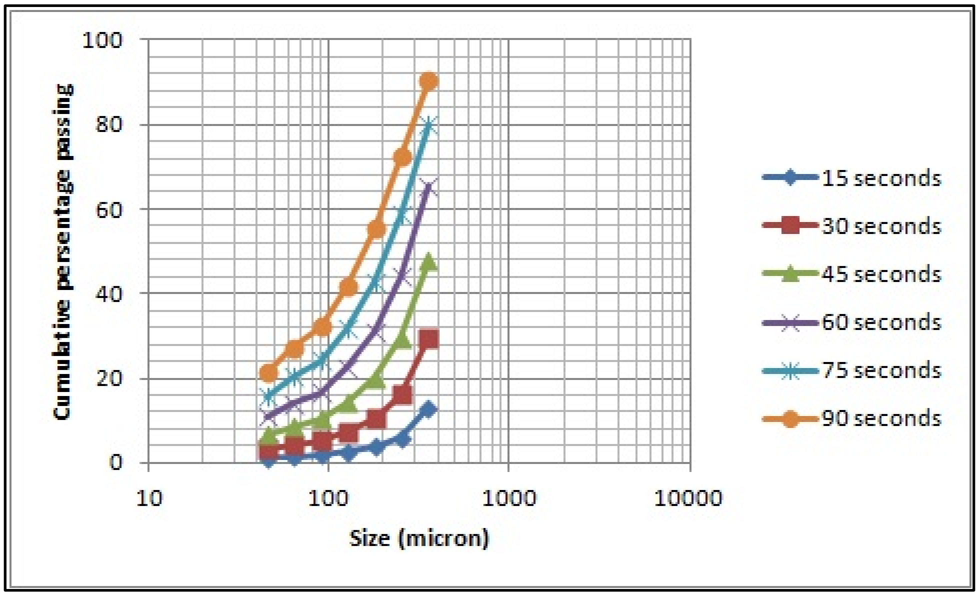

Figure 5. Cumulative percentage passing the screens at different grinding times (350 micron fraction)

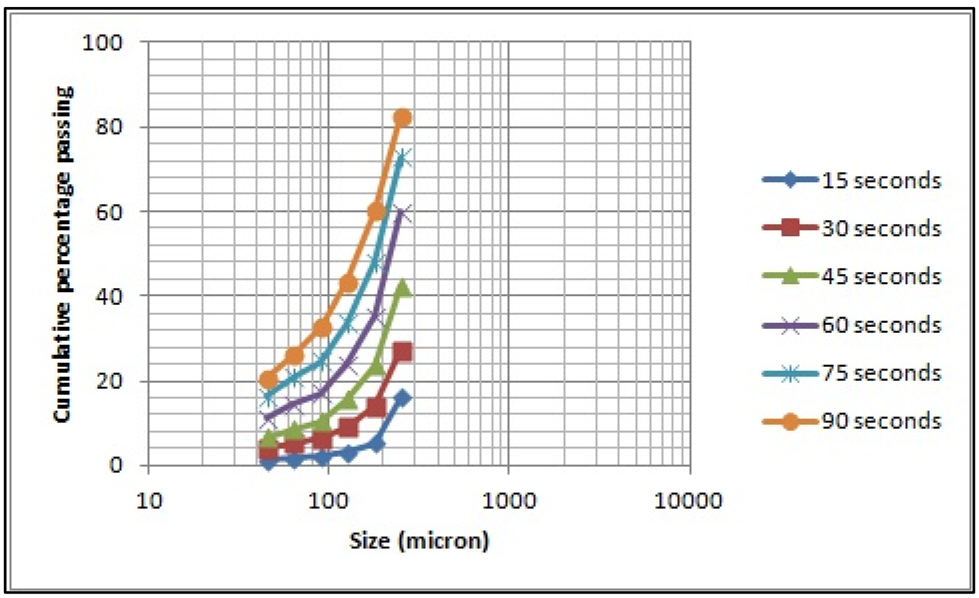

Figure 6. Cumulative percentage passing the screens at different grinding times (250 micron fraction)

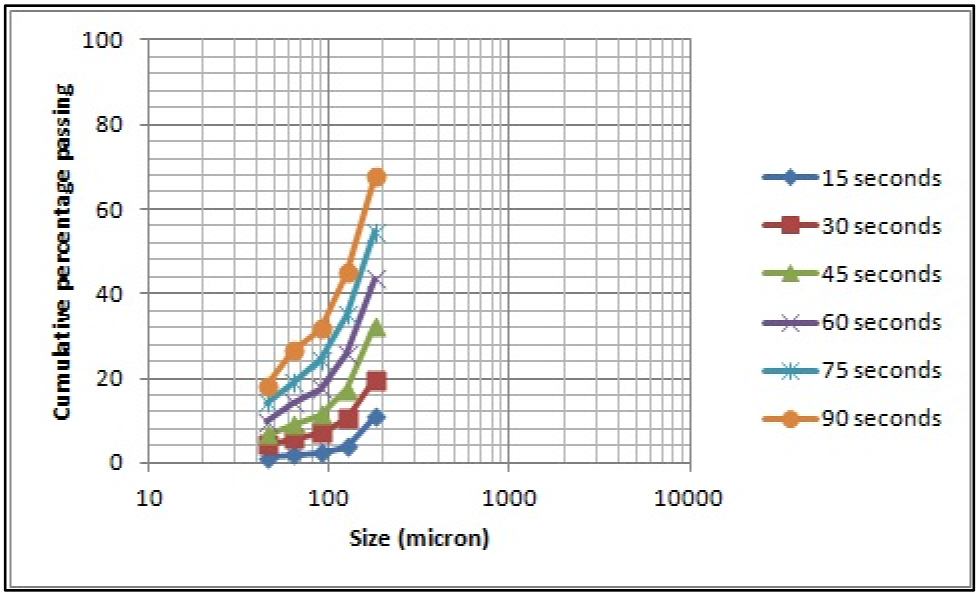

Figure 7. Cumulative percentage passing the screens at different grinding times (180 micron fraction)

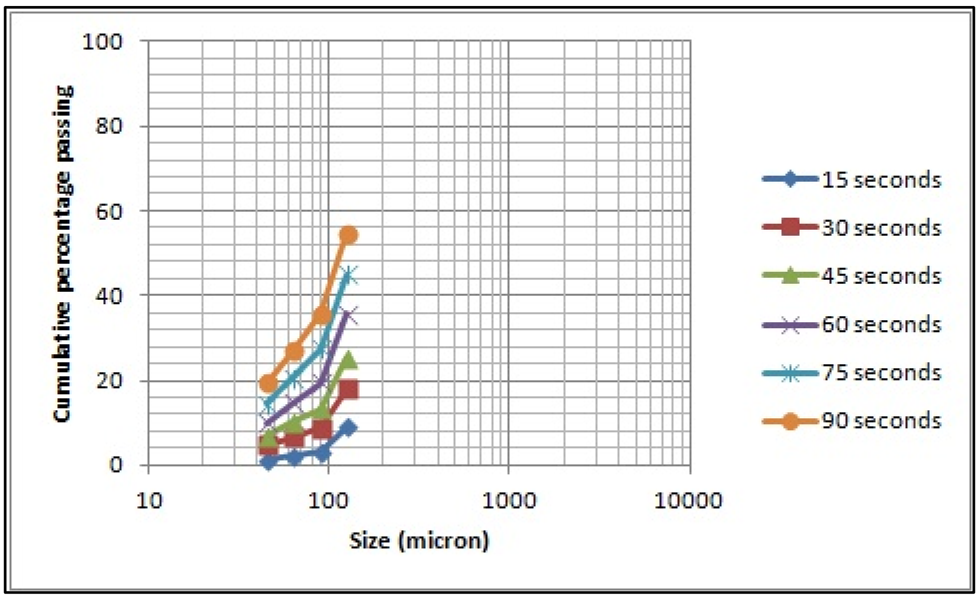

Figure 8. Cumulative percentage passing the screens at different grinding times (125 micron fraction)

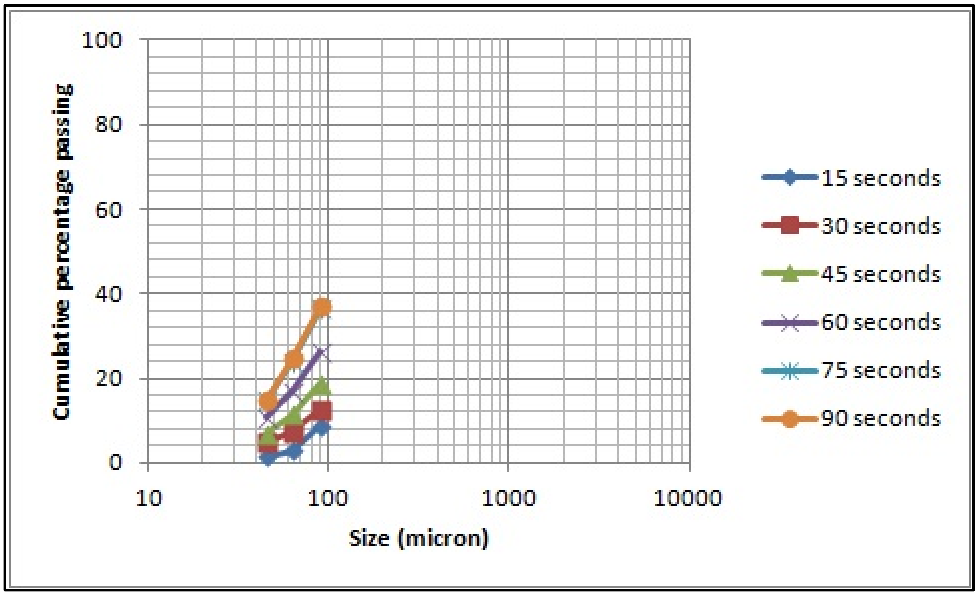

Figure 9. Cumulative percentage passing the screens at different grinding times (90 micron fraction)

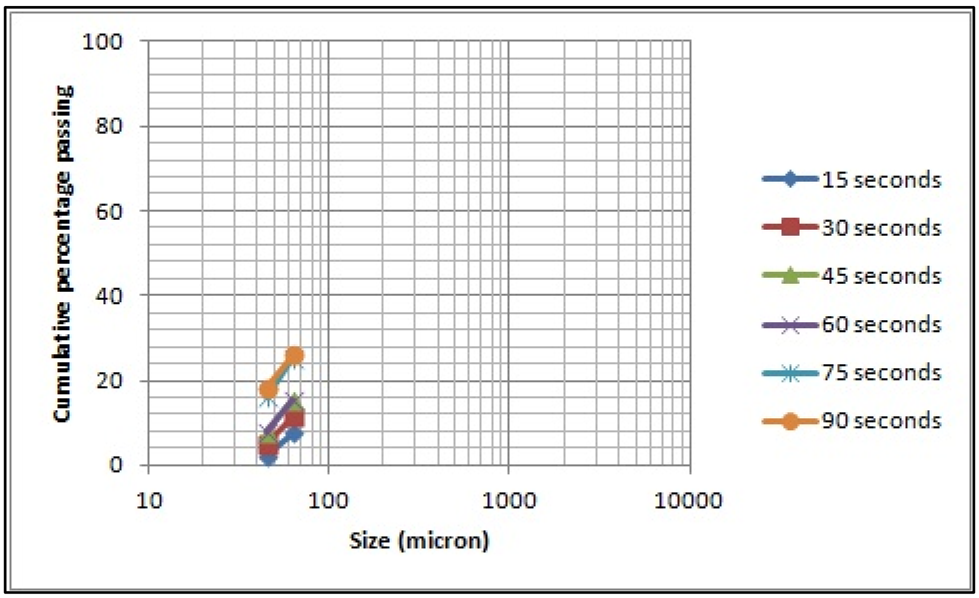

Figure 10. Cumulative percentage passing the screens at different grinding times (63 micron fraction)

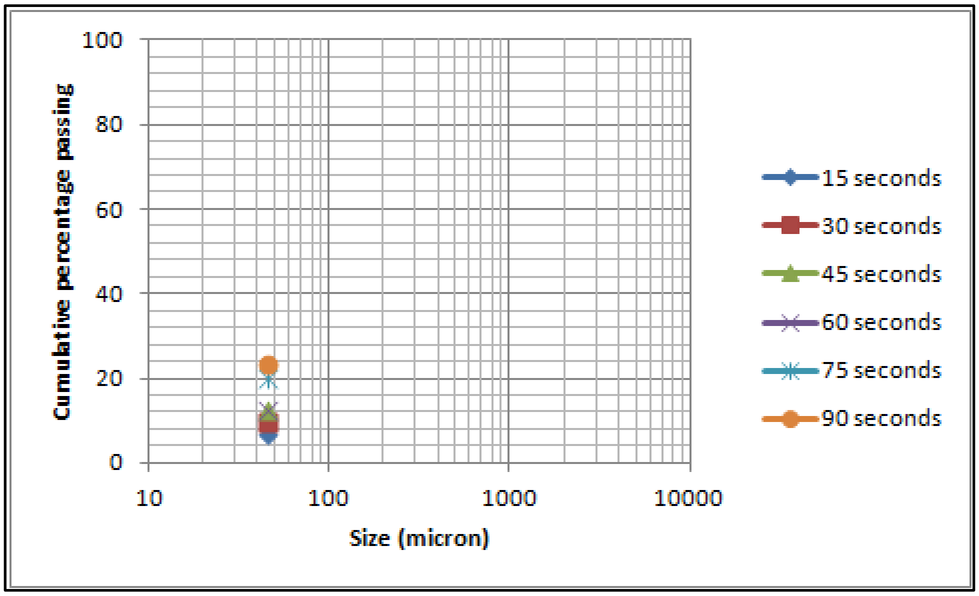

Figure 11. Cumulative percentage passing the screens at different grinding times (45 micron fraction)

The experimental breakage function of Miduk copper ore

As mentioned, BFDS software is able to measure the breakage function using three methods of Berube, Herbst & Fuersteneau and modified Herbst & Fuersteneau, but since the results of the modified Herbst and Forstna method lies between the other two methods, it's the criterion in this research.

Table 3 shows the non-cumulative breakage function of different fractions of Miduk copper ore. Each column represents the dimensional distribution of one grinding step of various factions. For example, in grinding the 1400-micron fraction, about 33% of the material has been transferred to the next fraction (1000 micron), 11% to 710-micron fraction, 11% to 500-micron fraction, and 6% to 355-fraction. The amount of material transferred to the other factions is also illustrated in the table. It found that the breakage function is non-normalizable.

The cumulative breakage function of different fractions of Miduk copper ore has been shown in Table 4. In 1400-micron fraction, about 67% of the material has been transferred to other fractions (-1400-micron) and 54% to -1000 micron fractions. The amount of material transferred to the other fractions is given.

The results indicated that in each fraction, high percentage of crushed material has been transferred to the next fraction (the second screen) while a smaller portion reach to the next. It means we have less fine particle in the circuit. For example, the percentage of material transferred from 1400 to 1000 micron fraction is about three times more than that to 710 microns fraction.

The experimental selection function of Miduk copper ore

Experimental selection function was also calculated using BFDS using the breakage function data. Results are shown in Table 5.The selection function represents the rate of disappearance of mineral from a fraction due to grinding. The results obtained in Table 5 indicated that the breakage rate in coarse particle fractions is more than fine particle fractions. it has been expected because it is a common phenomenon in the mills. According to the Table 5, 710-micron fraction had maximum grinding rate (about 0.05 min^{-1}) while the minimum grinding rate was elated to 45-micron fraction (about 0.003 min^{-1}).Therefore the result again confirmed that lower fine particle will product in Miduk mill circuit.

Table 3. Cumulative breakage function calculated for Miduk copper ore using modified Herbst & Fuersteneau's method

	1400	1000	710	500	355	250	180	125	90	63	45
1400	0	0	0	0	0	0	0	0	0	0	0
1000	0.327712	0	0	0	0	0	0	0	0	0	0
710	0.136362	0.077104	0	0	0	0	0	0	0	0	0
500	0.107645	0.255070	0.322741	0	0	0	0	0	0	0	0
355	0.105166	0.272500	0.323292	0.402492	0	0	0	0	0	0	0
250	0.061579	0.1019460	0.192284	0.260398	0.439631	0	0	0	0	0	0
180	0.052481	0.074331	0.070075	0.109081	0.209213	0.463329	0	0	0	0	0
125	0.045627	0.557410	0.447410	0.080786	0.114913	0.203414	0.445985	0	0	0	0
90	0.037199	0.416710	0.030696	0.060233	0.066507	0.102071	0.196485	0.416621	0	0	0
63	0.018462	0.019283	0.014854	0.039187	0.029802	0.049733	0.076360	0.169657	0.336294	0	0
45	0.221950	0.020856	0.017941	0.027094	0.034396	0.042756	0.092432	0.131268	0.289093	0.216978	0

Table 4. Cumulative breakage function calculated for Miduk ball mill feed using modified Herbst & Fiurentina method

	1400	1000	710	500	355	250	180	125	90	63	45
1400	1	1	1	1	1	1	1	1	1	1	1
1000	0.672288	1	1	1	1	1	1	1	1	1	1
710	0.535926	0.922896	1	1	1	1	1	1	1	1	1
500	0.428281	0.665822	0.677259	1	1	1	1	1	1	1	1
355	0.323115	0.393322	0.353966	0.597508	1	1	1	1	1	1	1
250	0.261536	0.291376	0.244682	0.337110	0.560396	1	1	1	1	1	1
180	0.209055	0.217045	0.174607	0.228029	0.351156	0.536671	1	1	1	1	1
125	0.163428	0.161304	0.129866	0.147243	0.236243	0.333257	0.554015	1	1	1	1
90	0.126229	0.119633	0.099170	0.087010	0.169736	0.231186	0.357530	0.583379	1	1	1
63	0.107767	0.100350	0.084325	0.047823	0.139934	0.181453	0.281170	0.413722	0.663706	1	1
45	0.085572	0.794940	0.066411	0.20729	0.105538	0.138697	0.188738	0.282454	0.374613	0.783022	1

Table 5. Rate of experimental breakage function (selection function)

Size	1400	1000	710	500	355	250	180	125	90	63	45
Selection function	0.031714	0.036627	0.053118	0.039851	0.028831	0.021260	0.013269	0.009206	0.005532	0.003183	0.002670

Simulation results of grinding in the primary ball mills

After obtaining the required parameters for modeling of mill grinding, a program (Appendix) was written in MATLAB for simulation purposes. As inferred from the Figure (12), by increasing the grinding time, d80 of sample is reduced. Within 15 minutes, size distribution of laboratory mill product is similar to that of in Miduk copper mine ball mill. In this time, d80 of the mill product is -0.3 mm. So the results are consistent with actual plant results.

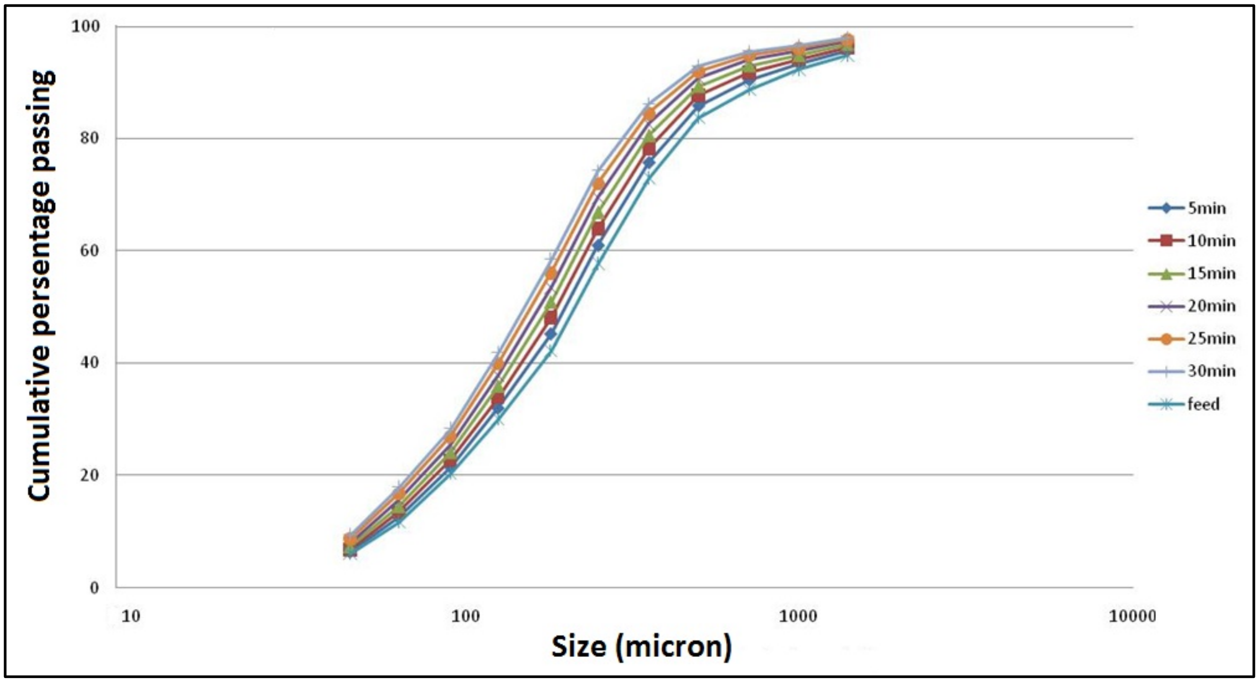

Figure 12. Mill simulation results at different grinding times

Figure 13 shows that the amount of sample present in higher screen classes have reduced but that in lower screen classes have increased by continuing the grinding. This phenomenon is natural in mills and represents a good simulation of grinding in the primary ball mills of Miduk copper mine.

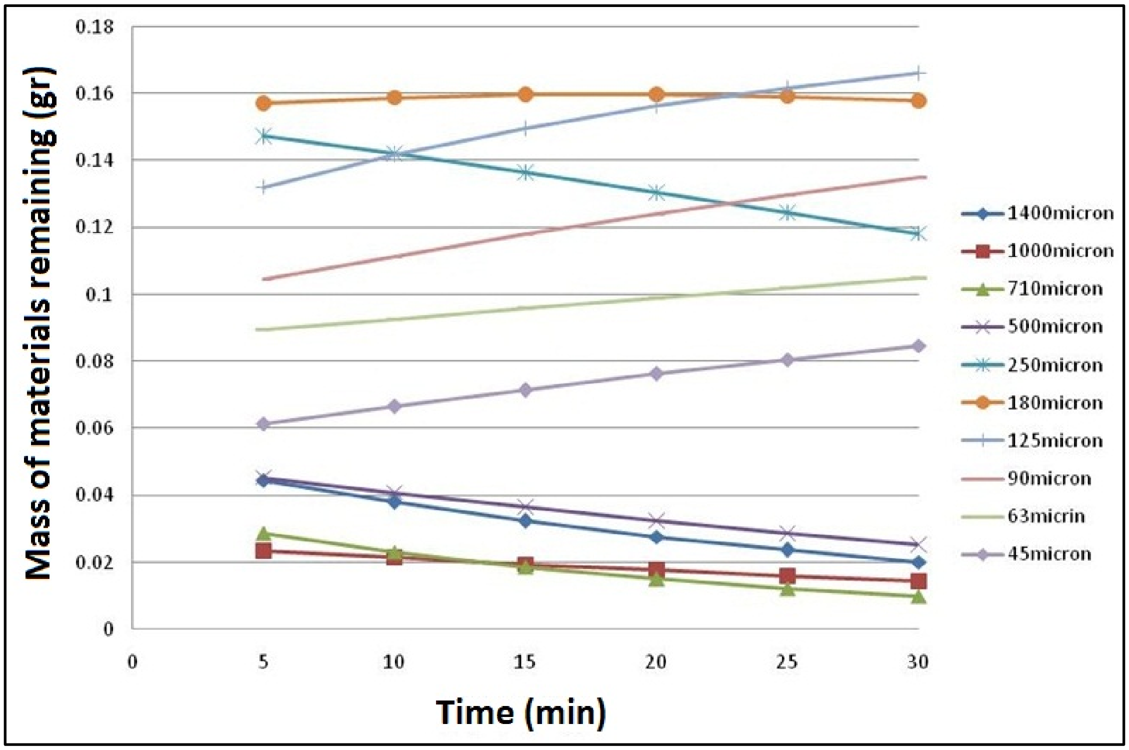

Figure 13. Mill simulation results at different grinding fractions

CONCLUSIONS

The overall results obtained in this study include:

- Non-cumulative breakage function of Miduk copper ore is non-normalizable.
- As expected, the rate of grinding and disappearance of mineral from a fraction is higher for larger particles.
- Results of breakage and selection functions represent low fine particle production in mill circuit.
- Mill grinding simulation results in MATLAB software are properly consistent with real ones.

ACKNOWLEDGEMENT

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APPENDIX

```
%function H=grinding(X)
b=[0   0   0   0   0   0   0   0   0   0   0;
0.327712   0   0   0   0   0   0   0   0   0   0;
0.136362   0.077104   0   0   0   0   0   0   0   0   0;
0.107645   0.257074   0.322741   0   0   0   0   0   0   0   0;
0.105166   0.27250  0.323293   0.402492   0   0   0   0   0   0   0;
0.061579   0.101946   0.109284   0.260398   0.439631   0   0   0   0   0   0;
0.052481   0.074331   0.070075   0.109081   0.209213   0.463329   0   0   0   0   0;
```

```
0.045627    0.55741 0.44741 0.080786    0.114913    0.203414    0.445985    0   0   0   0;
0.037199    0.41671 0.030696    0.060233    0.066507    0.102071    0.196485    0.416621    0   0   0;
0.018462    0.019283    0.014845    0.039187    0.029802    0.049733    0.07636 0.169657    0.336294    0   0;
0.22195 0.020856    0.017914    0.027094    0.034396    0.042756    0.092432    0.131268    0.289093    0.216978
0];
G=[0.031714;0.036627;0.053118;0.039851;0.028831;0.02126;0.013269;0.009206;0.005532;0.003183;0.0067];
S=diag(G);
fraction=[0.0523;0.0253;0.0361;0.0702;0.1075;0.1724;0.1746;0.128;0.0943;0.0062;0.0561];
%(dm/dt)=(B-I)*S*M
%L=(B-eye(17))*S*M;
Tfinal=30;
deltaT=0.01;
n=Tfinal/deltaT;
m=zeros(11,n);
m(:,1)=fraction;
fori=1:n
   m(:,i+1)=m(:,i)+deltaT.*((b-eye(11))*S*m(:,i));
end
mt=[5;10;15;20;25;30];
g=zeros(11,6);
fori=1:6
   g(:,i)=m(:,(mt(i)./deltaT)+1);
end
```

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