Liberation of Oolitic Hematite Grains From Iron Ore, Dilband Mines Pakistan

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ABSTRACT

Dilband Mine is one of the main iron ore deposits of Balochistan Pakistan, containing about 200milion tones of ore. The Dilband iron ore is mainly composed of oolitic-hematite along with the quartz, calcite, fluorapatite, kaolin, and chlinochlore gangue minerals. The basic objective of the paper is to report the operating conditions of comminuting step where maximum liberation of oolitic hematite from the matrix enriched with calcite and fluorapatite minerals has been possible. Besides this quantitative and qualitative analysis of particles based on concentrate, middlings, and tailings susceptibility of particles is proposed. Comminution circuit for Dilband iron ore is designed on the basis of work index, grade and percent distribution of oolitic-hematite particles in concentrate, middlings and tailings.

Key Words: **Oolitic Hematite, Dilband Iron Ore, Work Index, Mesh of Liberation, Gravity Separation.**

1. INTRODUCTION

From a socio-economical point of view Dilband iron ore deposits, recently discovered in Kalat Division Balochistan, Pakistan, is of major importance among the indigenous iron ore deposits discovered so far in Pakistan. It is worth to note that grade wise Dilband iron ore shows close relevance with the world low grade ores [1]. To utilize the national asset, it is obligatory to develop a cost effective process for beneficiation of Dilband iron ore.

Petrographic study of the Dilband iron ore revealed that it is typically the oolitic ore [2], which has been known for many years as a source of raw iron for the steel industry worldwide [3]. Likewise Dilband iron ore deposits, Minette [4-5], Agbaja [6], Corby [6], Wadi Fatima [7-8], Ramim [9] and Alberta [10] iron ore deposits of France, Nigeria, UK, Saudi Arabia, Israel-Lebanon border, and Canada respectively are typical examples of oolitic iron ores mainly enriched with quartz and phosphorous impurities.

Abro, M.I., et. al. [11] based on results of mesh of liberation conceived that gangue minerals are so finely disseminated that the chances of successes for any physical concentration method to meet the requirements of Pakistan Steel Mills [1] are very rare. Liberation and

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thereafter concentration of ooilites have been found the only best option to remove the significant amount of fluorapatite, the basic steel pollutant mineral present in matrix, at preliminary stage. The means and methods used for liberation of oolitic hematite grains are therefore presented in this paper.

Another interesting issue addressed in this paper is the qualitative and quantitative assessment of the particles based on concentrate, middling and tailing susceptibility approach. Basically this technique utilizes the density attribute of the particles which is generally exploited in the gravity separation technique. The beauty of this technique is that it outlines the trajectory of the particles and estimates the quantity of high, medium and low grade particles present within the specific size fractions.

2. EXPERIMENTAL WORK

2.1 Material

The representative sample of Dilband ore deposits collected from Pakistan Steel Mills Karachi, Pakistan was used for present study. From petrographic study, conducted on polished samples using SEM, Abro, M.I., et. al. [2] revealed that oolitic hematite grains are almost present in the range of -500+315µm. Therefore, in present work the operating conditions of comminuting step are evaluated so as to yield major proportion of material with specified size fractions, i.e. -500+315µm.

For obtaining well defined particle size distribution, the feed of -5000+500µm size fraction with 80% passing at 5000µm was prepared first by wet sieving from the as received ore. The feed was thereafter dried in oven at 100^{o}C before grinding in the rod mill. The size distribution of as-received and feed ore for rod mill grinding is shown in Fig. 1.

2.2 Grinding Test

Rod mill of trunnion overflow type with 154mm inner diameter, 189cc volume and 50rpm speed was used in present study. The mass of the rods used in mill was 7838g. To obtain the narrow size distribution three test sieves with 1000, 700 and 500µm openings were used. In each test sieve 674g of feed material was grinded according to procedure given below.

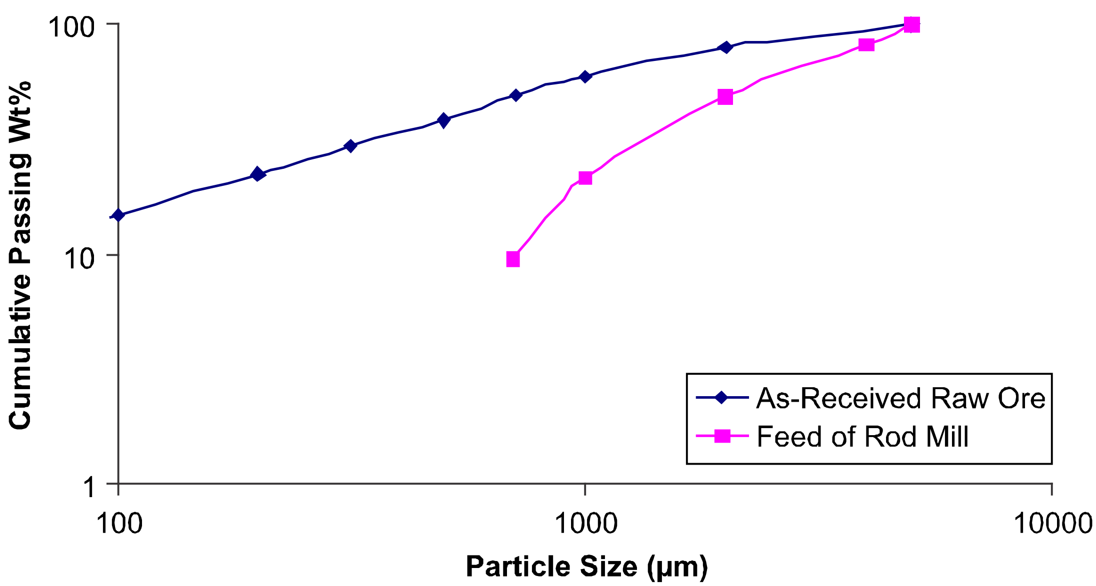

FIG. 1. PARTICLE SIZE DISTRIBUTION OF AS RECEIVED RAW AND FEED ORE USED FOR ROD MILL GRINDING

The first grinding cycle of an arbitrarily number of revolutions was started. At the end of first grinding cycle, the entire product was discharged from the mill and screened on a test sieve, 1000µm. The oversize fraction was returned to the mill for the second run, together with fresh feed, to make up 100% circulation load. The weight of product per unit of mill revolution, called specific mass per revolution of the cycle, was then calculated and used to estimate the number of revolutions required for the second run. The process was continued until an equilibrium condition with constant value of specific mass per revolution of the cycle was achieved. After reaching equilibrium, the ratio of fines per cycle needed to compute the grinding energy at given test sieve, say 1000µm, was determined by plotting the cumulative mass of fines (<1000µm) verses cumulative number of cycles. In order to determine the 80% passing of product (i.e. 80%P), particle size distribution of the material (product) collected from last equilibrium cycles was plotted. Finally grinding energy input (Δe), and thereby work index (W_i) of the Dilband iron ore was calculated using the following equations.

$$\Delta e = C_p . g . D_i . M_T . \frac{U}{F} \quad (1)$$

$$\Delta e = W_i \left(\frac{10}{\sqrt{80\%P}} - \frac{10}{\sqrt{80\%F}} \right) \quad (2)$$

Where Cp is the power factor and is equal to 1.1 for rod mill used for grinding test, g is gravitational force (9.8m/Sec^2), Di is the internal diameter of the mill, Mr is the mass of rods and U/F is the specific mass of fines per rpm, 80%P is the particle size of product and 80%F is the particle size of feed.

2.3 Gravity Test

After yielding the maximum amount of -500+315µm particles in comminuting step, the second major requirement was to find out the effectiveness of gravity separation technique in concentration of hematite oolites. Gravity separation test was conducted in concave type pan, known as handsachse (hand saxe), in which small amount (≈5g) of ore was diluted, agitated manually by to-and-fro and forward and backward movements of handsachse. The slimes were first poured into the container creating pulsations in floating material by means of small hand thrust. Action of dilution, agitation and pulsations was repeated till the slimes and tailings were separated in to particular containers. Finally the concentrate remained in handsachse was poured in to another container. The procedure was repeated till the whole feed material, weighing 50g, was splited into tailings, middlings, and concentrate. Thereafter products were dried at 100°C in oven for overnight. The gravity separation test was performed on material of -1000, -700 and -500µm size fractions obtained from comminution test.

To outline the trajectory of particles and estimate the quantity of high, medium and low grade particles the size analysis of concentrate, middlings, and tailings was done.

For quality check density analysis of the each size fraction from each product of gravity separation was determined using Pyknometer. Thereafter samples of concentrate, middlings and tailings were polished and examined under stereomicroscope.

3. RESULTS AND DISCUSSION

3.1 Grinding Test

To yield maximum amount of oolitic particles ranging mostly in -500+315µm size fractions the comminution of -5000+500µm material was carried out in rod mill. The results of grinding tests in closed circuit at different test sieves are shown in Figs. 2-4. Fig. 2 represents the amount of fines produced verses number of grinding cycles employed at different test sieves. Figs. 3-4 indicates the particle size distribution of feed and product under closed circuit at different test sieves.

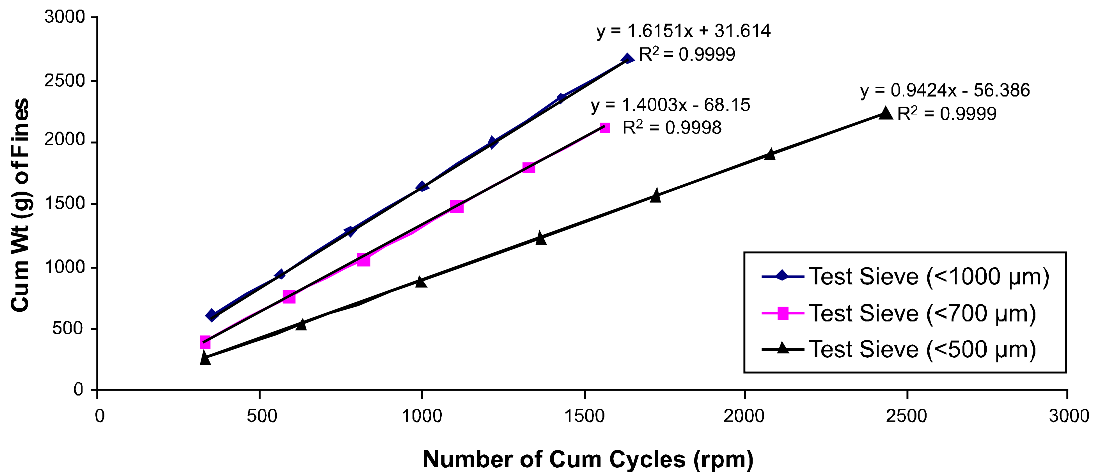

FIG. 2. WT% OF SPECIFIC FINES PRODUCED DURING ROD MILL GRINDING AT 1000, 700 AND 500µm TEST SIEVES

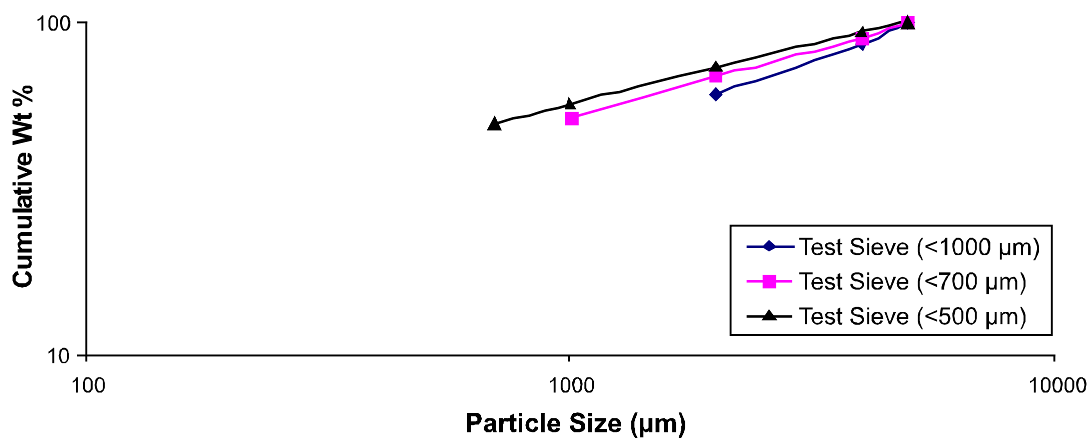

FIG. 3. PARTICLE SIZE DISTRIBUTION OF FEED/RECYCLED MATERIAL AT TEST SIEVE 1000, 700 AND 500µm

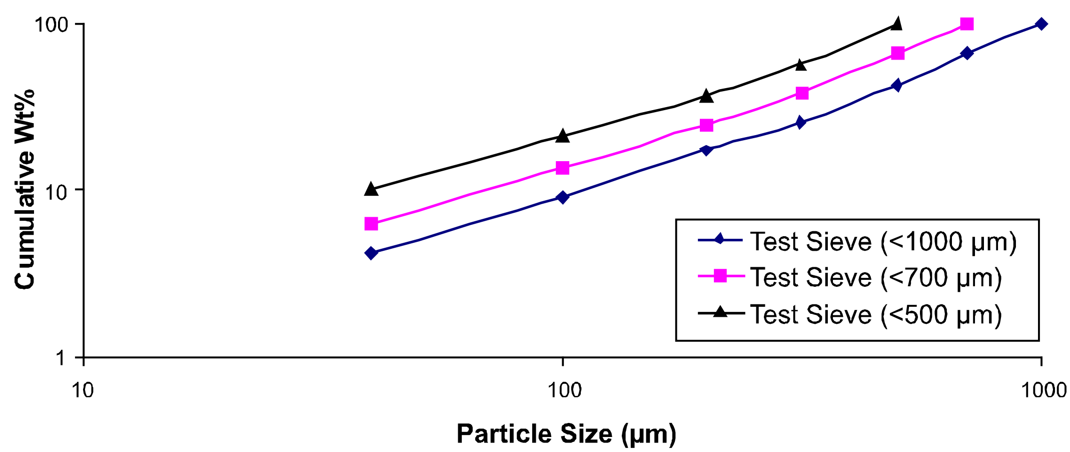

FIG. 4. PARTICLE SIZE DISTRIBUTION OF PRODUCT MATERIAL AT TEST SIEVE 1000, 700 AND 500µm

The basic aim of plotting the amount of fines verses number of cycles is to determine the specific amount of fines produced per cycle. The slope of line obtained by applying linear regression analysis is used as specific amount of fines. The specific amount of fines determined from the equations is used in the energy equation, given in Section 2.2. Fig. 2 depicts that slope of the lines indicating the relation between cumulative weight of fines and cumulative number of cycles decreases. Thus higher amount of work required to produce specific amount of fines can be conceived from decreasing trend of slope with decreasing the aperture size of test sieve.

Using the specific amount of fines produced per cycle the 8.09, 9.3 and 13.86 J/g amount of energy input in test sieves 1000, 700 and 500µm respectively is calculated. The increasing trend of energy input can be attributed to less fragility of fine material as compared to coarser. Decreasing trend of fragility of the mineral with decrease in relative size is widely acknowledged in literature [12-14].

In order to compute the work index using Bond's equation the value of 80%P and 80% F was obtained from the particle size distribution of feed and product material shown in Figs. 3-4 respectively. The values of 80%F and 80%P along with the work index values calculated using Bond's equation are given in Table 1.

Table 1 indicates maximum and minimum work index values in case of 500 and 700µm test sieve respectively whereas intermediate work index resulted at 1000µm test sieve. The minimum value of work index at test sieve 700µm is quite interesting, suggesting that energy input in rod mill is utilized efficiently thus more fines are produced as compared to 10000µm test sieve at the cost of low energy. Effective use of energy input in rod mill thus can be attributed to the specific particle size distribution of feed material. Furthermore, test sieve sensitivity of Bond's work index values is also confirmed.

Literature review indicated that behavior of mineral during comminution processes is widely studied. In this regard, effect of test sieve, ratio of 80%P and 80%F, specific surface area, and particle distribution of feed and circulating material in tumbling mills on specific grinding energy has been extensively evaluated [13-17]. Increasing trend in grinding energy with decreasing 80%P, 80%F, or mesh of test sieve has long been recognized as the characteristic phenomenon of all the minerals [13-17]. Whereas there is very less supporting evidence in literature that work indices or grinding efficiency of mill is the function of ratio of fines present in feed or circulating material. More data is, therefore, needed to defend this claim. However, authors are lucky to find the supporting evidence from the work of Yianatos, J., et. al. [18]. Findings of Yianatos, J., et. al. [18] indicates that addition of fines in circulating load enabled a mill to produce more fines than a mill operating without recycling of fines. In addition, it is worth to note the findings of Napier-Munn, et. al., 1999 incorporated by J. Yianatos, J., et. al. [18] that "fines should not be returned to the mill since these fines will be subject to over grinding and consume space that could be normally occupied by new mill feed. On the other hand, addition of fines in the rod mill feed act as a viscosity modifier, which helps the grinding efficiency".

TABLE 1. 80%F, 80%P AND WORK INDEX VALUES AT DIFFERENT TEST SIEVES

Test Sieve	80%F (µm)	80%P (µm)	g/cycles (µm)	Energy (j/g)	Power (k.watt.h/t)	Work Index (k.watt.h/t)
1000	3500	810	1.61	8.09	2.25	12.33
700	3000	595	1.4	9.30	2.58	11.37
500	2700	420	0.94	13.86	3.85	13.03

Thus decrease of work indices in case of 700µm test sieve could be attributed with increased fluidity of the feed within the mill due to presence of specific ratio of fines in circulating charge. Therefore with decreasing and increasing the content of fines at 1000 and 500µm test sieve respectively the increase in work indices is resulted due to increase in charge viscosity.

3.2 Gravity Separation Test

The gravity separation technique used in present work has long been recognized in gold processing at laboratory scale. The basic purpose of the test was just to know that whether density attribute of the ore is working efficiently or not. The results of the gravity separation test employed in present case are shown in Table 2. Table 2 indicates the marginal increasing trend in the amount of tailings at the cost of amount of concentrate with decreasing size of feed material in the gravity concentration process. The increasing trend in tailings with decreasing feed size would be either due to more content of gangue enriched particles relative to particles to be considered as concentrate, or due to presence of more content of fine particles. The increased liberation rate of gangue enriched particles as compared to concentrate due to excess grinding can be inferred from the former case. Plateau seen in the amount of middlings further substantiate that tailing grade particles are liberating more with increasing the grinding operation. While the latter probability of increasing tailings amount can be attributed with particle size-sensitivity of gravity concentration method. The impact of density quotient of the difference of specific gravities of valuable and gangue minerals, dilution ratio, stroke, and particle size distribution of feed material is widely addressed in the literature.

TABLE 2. DENSITY SEPARATION OF -1000, -700, AND -500MM FEED MATERIAL OBTAINED FROM COMMINUTION TEST

>1000µm Test Sieve					>700µm Test Sieve					>500µm Test Sieve				
Density Products	Weight (%)	Particle Size (mm)	Weight (%)	Distribution (%)	Density Products	Weight (%)	Particle Size (mm)	Weight (%)	Distribution (%)	Density Products	Weight (%)	Particle Size (mm)	Weight (%)	Distribution (%)
Concentrate	46.07	1000/500	28.90	13.31	Concentrate	44.01	1000/500	14.89	6.55	Concentrate	41.95	1000/500	-	-
		500/315	30.87	14.22			500/315	34.64	15.25			500/315	38.79	16.27
		315/100	33.72	15.54			315/100	42.21	18.58			315/100	51.53	21.62
		100/ 40	6.25	2.88			100/ 40	7.89	3.47			100/ 40	9.68	4.06
		< 40	0.26	0.12			< 40	0.37	0.16			< 40	0.00	0.00
		1000/ 40	99.74	45.95			1000/ 40	99.63	43.85			1000/ 40	100.00	41.95
		< 40	0.26	0.12			< 40	0.37	0.16			< 40	0.00	0.00
Middling	40.44	1000/500	67.91	27.46	Middling	40.54	1000/500	37.19	15.08	Middling	40.64	1000/500	-	-
		500/315	12.56	5.08			500/315	41.32	16.75			500/315	69.93	28.42
		315/100	8.12	3.28			315/100	15.36	6.23			315/100	22.56	9.17
		100/ 40	3.81	1.54			100/ 40	4.63	1.88			100/ 40	5.45	2.21
		< 40	7.60	3.07			< 40	1.50	0.61			< 40	2.06	0.84
		1000/ 40	92.40	37.37			1000/ 40	98.50	39.93			1000/ 40	97.94	39.80
		< 40	7.60	3.07			< 40	1.50	0.61			< 40	2.06	0.84
Tailing	13.49	1000/500	53.09	7.16	Tailing	15.45	1000/500	24.34	3.76	Tailing	17.41	1000/500	-	-
		500/315	1.82	0.25			500/315	25.67	3.97			500/315	44.15	7.69
		315/100	3.72	0.50			315/100	7.44	1.15			315/100	10.31	1.80
		100/ 40	11.78	1.59			100/ 40	10.58	1.63			100/ 40	9.65	1.68
		< 40	29.59	3.99			< 40	31.97	4.94			< 40	35.89	6.25
		1000/ 40	70.41	9.50			1000/ 40	68.03	10.51			1000/ 40	64.11	11.16
		< 40	29.59	3.99			< 40	31.97	4.94			< 40	35.89	6.25

To evaluate the effect of excess grinding on the percent liberation of high, medium and poor grade particles the concentrate, middlings and tailings susceptibility approach has been used. Susceptibility approach is basically based on intrinsic density property of the particles which renders the particles of particular size fraction to report to concentrate, middlings, or tailings. Higher the concentrate susceptibility is higher will be chances for the particles to report to concentrate. Similarly higher the content of concentrate susceptible particles is higher will be their contribution in the concentrate. Vice versa case is true for particles susceptible to middlings and tailings.

Based on susceptibility approach size analysis of particles reporting to concentrate, middlings and tailings was conducted. The results shown in Table 2 and plotted in Fig. 5 indicates that how best the trajectory of the particles is outlined and quantitative and qualitative assessment of the particles based on concentrate, middling and tailing susceptibility approach has been made.

Fig. 5 shows that with decreasing the size of feed material the increase in the amount of -500+315, and -315+100µm particles reporting to concentrate is marginal as compared to particles reporting to middlings and tailings. The significant increase in particles reporting to concentrate is noted in -315+100µm size fractions, while increase in concentration of -500+315 particles is minor. On the other hand, significant increase in the amount of -500+315, and -315+100µm reporting to middlings and tailing with decreasing size of feed material is resulted. The distribution of -100+40µm in concentrate, middlings and tailings at different test sieves is not significant. However the slightly increasing trend in concentrate and tailings with decreasing mesh of test sieve is noted. Reporting of certain amount of particular size fraction to concentrate and remaining part to middlings and tailing is solely due to their respective susceptibility.

The sufficient increase in the content of -500+315 and 300+100µm particle fractions reporting to middlings and tailings suggest that the excess grinding, achieved by decreasing the test sieve during rod mill grinding operation, is resulted in the increased production rate of particles more susceptible to middling and tailings as compared to concentrate. The evidence

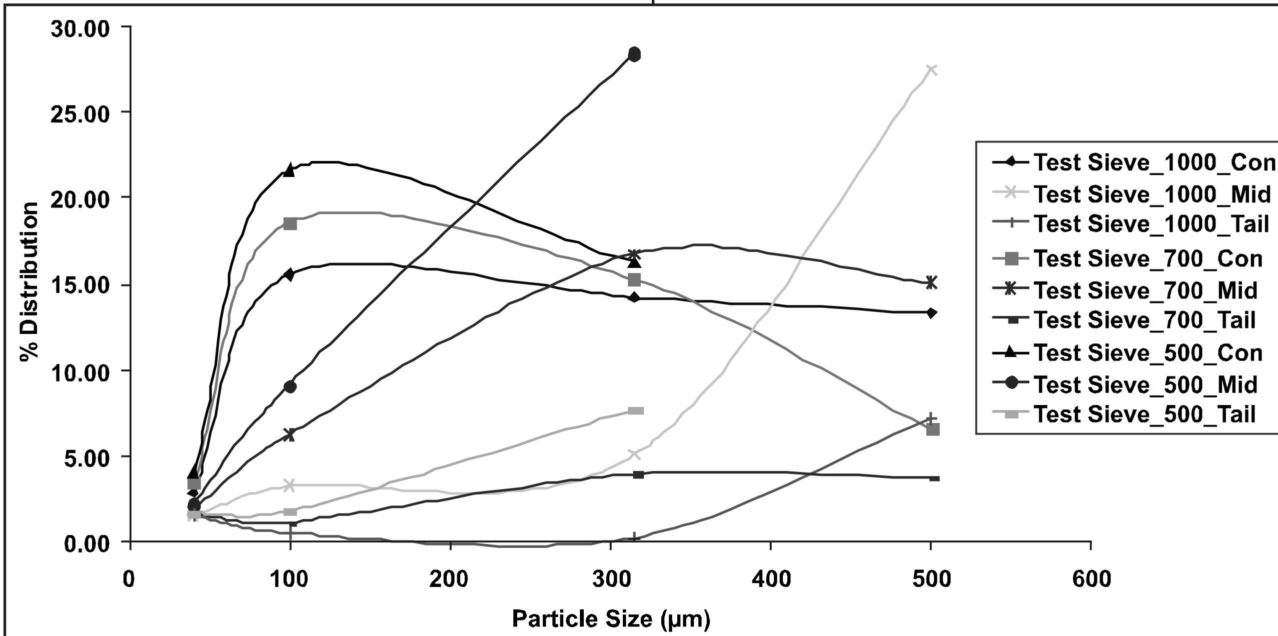

FIG. 5. PERCENT DISTRIBUTION OF PARTICLES IN CONCENTRATE, MIDDLINGS, AND TAILINGS AT DIFFERENT FEED SIZES

behind this postulation is the existence of +500µm particles whose poor grade is witnessed from their higher content in middlings in case of 1000µm test sieve. It is widely accepted that coarser particles experience higher grinding forces as compared to finer, thus excess grinding of +500µm particles present in circulating load with decreasing the mesh of test sieve can not be avoided. Concomitantly the production of -500+315 and -315+100µm size fractions more susceptible to middlings and tailings is resulted and therefore the population of -500+315 and -315+100µm particles in middling and tailings is increased.

The distribution trend of particles in concentrate, middlings, and tailings discussed above indicates that excess grinding of Dilband iron ore is resulted in the liberation of poor grade oolitic particles specially of -500+315µm size fractions. This suggests that excess grinding of Dilband iron ore is not producing the encouraging results. Thus it would be not worth full to comminute the Dilband iron ore in grinding circuit below 1000µm test sieve.

To ascertain the quality of particles reporting to concentrate, middlings and tailings the density measurement of individual size fractions was conducted. The results shown in Figs. 6-8 indicate the gradual decrease in density of particles reporting to concentrate, middlings and tailings. Marginally higher density of -500+315µm size fractions as compared to rest size fractions confirms the better quality of oolite particles present in Dilband iron ore. Furthermore, Figs. 6-8 shows slightly increasing trend in the density of -500+315µm particles from 1000µm test sieve to 500µm test sieve. Marginal increase in the density profile suggests that excess grinding has improved the grade of oolitic particles at the cost of excess liberation of poor grade of -500+315µm particles.

The results of particle size distribution and density profile of the particles reporting to concentrate, middlings, and tailings discussed above clearly establish the idea that density attribute is working quite effectively in separating the high grade and medium grade oolitic particles during gravity concentration method. Hence higher proportion of oolitic particles in concentrate as compared to middlings and tailings can be anticipated.

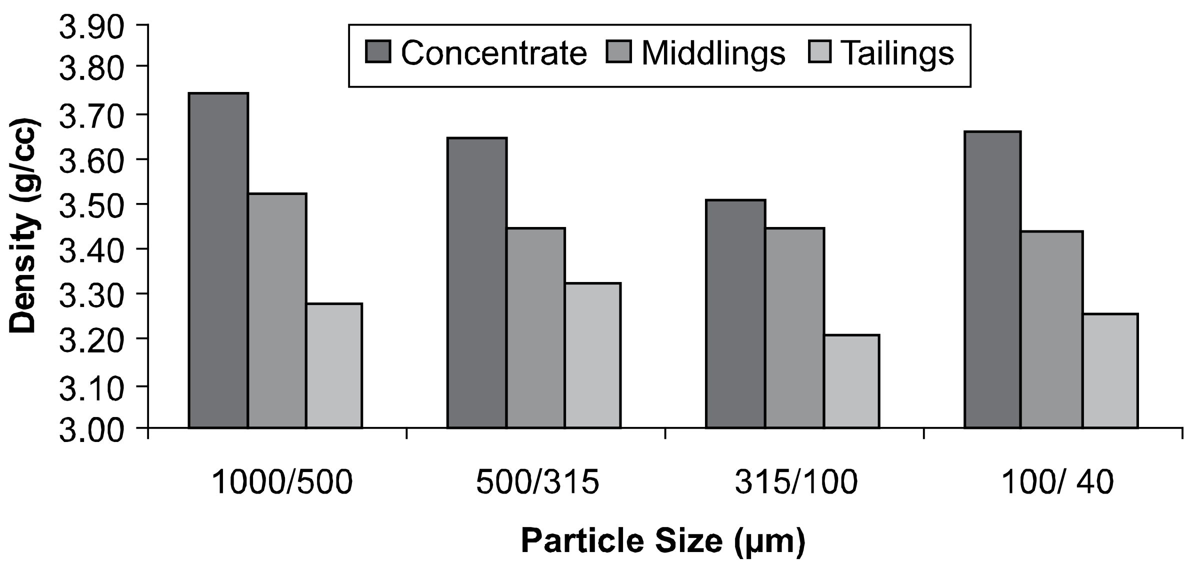

FIG. 6. DENSITY OF DIFFERENT PARTICLE SIZE FRACTIONS OBTAINED AT 1000µm TEST SIEVE

4. CONCLUSIONS

Following are the main conclusions of the present work.

(i) The grinding energy increases with decreasing the mesh of test sieve, whereas work index do not retained the similar trend. The minimum work index is resulted at 700µm test sieve.

(ii) Excess grinding has caused the excess liberation of poor grade oolitic-hematite particles. Therefore use of test sieve below1000µm in closed comminution circuit would be worthless.

(iii) Characterization of minerals on basis of concentrate, middlings, and tailings susceptibility approach seems worth full to be considered in the list of mineral characterization techniques.

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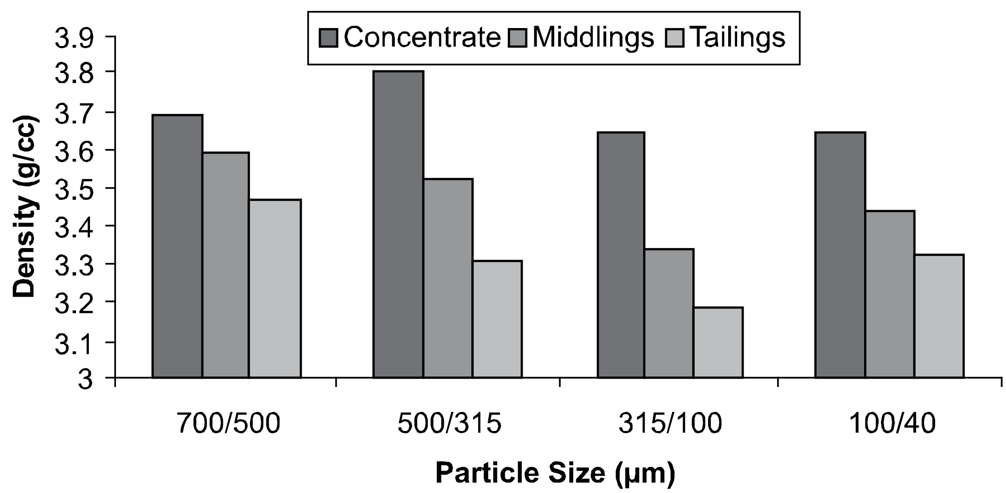

FIG. 7. DENSITY OF DIFFERENT PARTICLE SIZE FRACTIONS OBTAINED AT 700µm TEST SIEVE

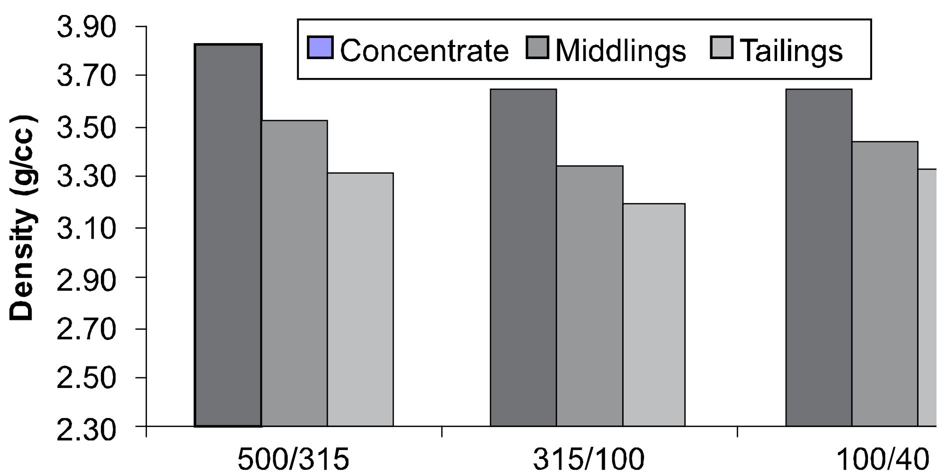

FIG. 8. DENSITY OF DIFFERENT PARTICLE SIZE FRACTIONS OBTAINED AT 500µm TEST SIEVE

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