

INVESTIGATION OF CHROMITE PRECONCENTRATION BY COMMINUTION

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ABSTRACT

Chromite is the main source of chromium. It is widely used in metallurgical, refractory and chemical engineering applications. Chromite occurs in earth crust generally with serpentine minerals as associated gangue. Serpentine minerals, hydrated alteration products of olivine minerals, are softer than chromite. Therefore, controlled size reduction is thought to be a beneficial way of chromite ore pre-concentration. This study was conducted to determine the possibility of chromite concentration by controlled-comminution and then by classification. Size reduction was conducted first by laboratory scale blake type jaw crusher, and then rod and ball mills. Product quality was assessed using loss on ignition (LOI, %) as a measure. Experimental results revealed that LOI value of chromite ore sample was 8.22%. Sufficient liberation was not achieved by crushing. Then, crushed ore sample was subjected to rod mill grinding for 5 minutes. But, phase segregation was thought not to be achieved sufficiently. Then, further grinding was applied on rod mill-ground product: 5/10min grinding by rod mill and ball mill. However, fine grinding by rod and ball mills resulted in more even distribution of high LOI value serpentine minerals among the product size ranges. Selective separation could not be achieved by comminution at finer sizes. Perfect correlation could not be seen between hardness and grindability of minerals constituting chromite ore.

Keywords: Chromite, serpentinization, grinding, comminution, loss on ignition.

INTRODUCTION

Chromite (FeCr_2O_4), a spinel group mineral, is the main source of chromium. It is one of the most important and strategic metal in modern society and is used extensively in the production of stainless steels and other corrosion resistant applications. Many other minerals contain chromium, but none of them are found in deposits that can be economically mined to produce it. Chromite has a wide range of application, particularly in metallurgical industry. In addition to refractory industry as bricks, glassmaking, cement, chemical, and non-ferrous alloy industries (Abubakre et al., 2007; Murthy et al., 2011). Mohs hardness value of the chromite is around 5.5 and specific gravity is between 4.5-5. It occurs in basic and ultrabasic igneous rocks and in the metamorphic and sedimentary rocks.

Mineral liberation plays an important role in beneficiation of the minerals. Liberation of the valuable minerals from unwanted gangue is accomplished by comminution (Veasey and Wills, 1991). Crushing and grinding stages are required to obtain relatively “free” mineral particles at the coarsest possible particle size during size reduction (Vizcarra et al., 2010). If the ore is liable to be liberated at such a size in terms of mineralogical possibilities, then not only is energy saved (Tromans, 2008) but also by reducing the amount of fine material produced which is not desired for the downstream processing (Veasey and Wills, 1991).

Comminution properties of the ore is determined by the hardness of minerals constituting the ore. If hardnesses of the minerals differ from each other, then pre-concentrate of different minerals at different size fractions of comminuted ore become possible. Olivine minerals in the chromite ore may

altered under temperature and pressure, over time. This geological process is known as “serpentinization” (Jasieniak and Smart, 2010; King, 2009). These minerals have relatively lower hardness value and contain crystal water compared with the olivine and chromite. This difference is beneficial during size reduction process of the ore: chromite is the hard mineral and therefore has the lower breakage rate contrary to remaining soft alteration products of olivine. It was found that these altered products has the Mohs hardness value around 2.5 according to the study on the Köyceğiz olivines which is less than half of the hardness of the chromite (Güler et al., 2014).

Experiments on comminution and breakage rate in milling circuits by many researchers have been performed using pure minerals as well as the artificial mixtures that contain hard and soft minerals. Holmes and Patching (1957) carried out grindability experiments using an artificial mixture of quartz and limestone. It was concluded that the proportion of limestone and quartz minerals in the mixture had no effect on the rates of breakage. Another study was performed on the same minerals (Somasundaran and Fuerstenau, 1963) for various size fractions, by applying ball and rod milling. The coarser mineral quartz consumed a greater proportion of the grinding energy in the case of different mineral size fractions but the same volume. On the other hand, they exhibit almost the same energy consumption in the milling when the minerals were equally charged in amount with the same sizes. This result was found more remarkable in rod milling stage, and the greater proportion of energy was consumed by hard quartz mineral: quartz, protecting the limestone fines from impact by the grinding media. Similar results were seen very slightly in the case of ball milling. The proportion of the mineral in the mixture plays important role and the energy consumption is in proportion to the mineral volume in the ball mill. Fuerstenau and Venkataraman (1988) examined the grindability of the binary mixture of calcite and quartz. It was stated that the soft calcite mineral consumes a greater amount of grinding energy than does quartz when they are ball milled together. The breakage rate function of calcite increased when ground in the presence of a harder mineral quartz, compared to the grinding of pure calcite. However the breakage rate of quartz was reduced when ground in the presence of calcite. A mixture made up of soft and hard minerals, it is expected to find the harder mineral to be ground at slower rate and hence comprise the greatest proportion of the oversize material (Yan and Eaton, 1994).

In this study, relationship between hardness and grindability of minerals constituting chromite ore was examined by staged comminution. Chromite ore was subjected to jaw crusher and then grinding was applied by rod and ball mill. The product quality assessed by the measurement of loss on ignition (LOI, %).

EXPERIMENTAL

Representative chromite ore sample was taken from chromimum ore deposits of Eti Krom Inc in Muğla. Supplied ore sample having a size of -20 cm was first crushed by laboratory scale single-toggle blake type jaw crusher down to -2.25 cm - the first stage of comminution (Figure 1). The crushed ore was sieved to obtain -2.25 cm product. Remaining coarse fraction was subjected to crushing again. Dry grinding was applied on the crushed product by rod mill as the second step of comminution for 5 min in order to increase the liberation rate of minerals. The ground material homogenously well mixed and representative sampling was made by conning-and-quartering followed by sampling using Riffle splitter to get desired amount of sample for second stage grinding. Laboratory size stainless steel rod mill (20x30 cm) and ball mill (20x20 cm) were used in grinding tests. The grinding time was set constant for 5 or 10 min in the last stage of comminution. In grinding stages, rotational speed of mills were applied as 60% and 80% of critical speed for rod and ball mills, respectively.

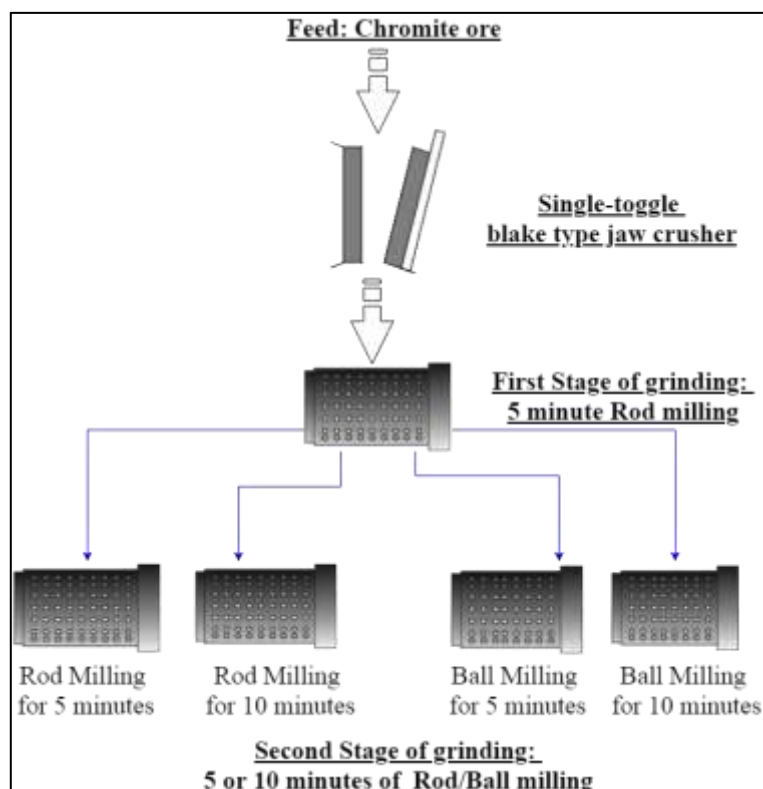


Figure 1. Schematic representation of experimental process

All products obtained from crushing and grinding were subjected to dry sieving and loss on ignition (LOI) analysis. Sieve analysis was performed using 20 cm diameter standard test sieves (Retsch) on a sieve shaker (Retsch AS-200). Shaking was applied for 20 min for all tests. LOI value was determined using a high-temperature muffle furnace (Ankatest): each chromite test sample was first dried in an drying oven (Memmer, TUNB 400) at 50 °C for at least 2 hours, and then taken to a desiccator. Dried sample was weighed and then heated in muffle furnace up to 950 °C at a heating rate of 50 °C/min for 30 minutes, at which temperature it was calcined. LOI value of calcined sample was calculated by measuring (Precisa, XT10200D) the weight loss after calcination.

RESULTS AND DISCUSSION

Particle size distribution and LOI (%) values of the products of jaw crusher and first stage 5 min rod mill grinding are plotted in Figure 2. Chromite ore sample having -20 cm size was first subjected to crushing by blake type jaw crusher as the first stage of size reduction to obtain a crushed product. The product was seen to be accumulated in the size range +150-22500 µm. The majority of crushed sample was above 2500 µm with average LOI value 8.2%. The measured LOI value of crushed ore is very close to that of feed, which indicated the insufficient liberation of ore after crushing. Negligible amount of the product (3.62%) with relatively lower LOI was obtained below 2500 µm. Then, the possibility to obtain chromite pre-concentrate just after crushing was thought not to be a beneficial way.

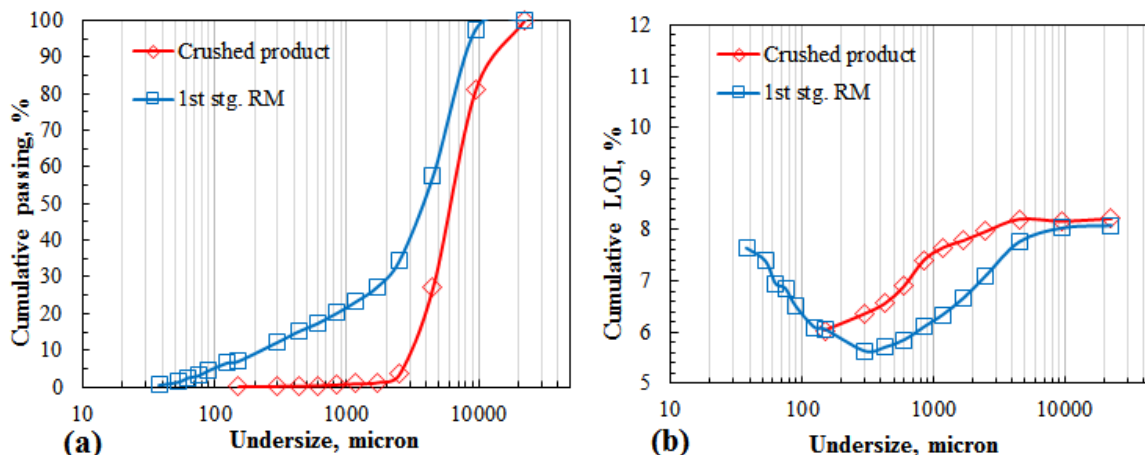


Figure 2. a): Particle size distributions for the products of jaw crusher and ground ore by rod mill for 5 minutes, b) LOI (%) distributions of the products of jaw crusher and rod mill (RM: Rod mill)

The jaw crusher product was subjected to further comminution processes. Rod mill grinding was applied for 5 min as a first stage grinding to increase the liberation rate (Figure 2). Sieve analysis showed that test sample was ground below 9500 μm by rod mill grinding. Ground ore was observed to be accumulated in the size range +2000-9500 μm . Figure 2b demonstrated that chromite concentration increased by decreasing particle size down to 300 μm and then increased gradually at finer sizes. Minimum LOI values were obtained in the size range +90-300 μm as seen in the Figure 3. In the cited range, about 8% of ore sample presents with a LOI value of 5.21%. Below 90 μm LOI value increased sharply indicating selective accumulation of hydrated serpentine minerals at ultrafine sizes.

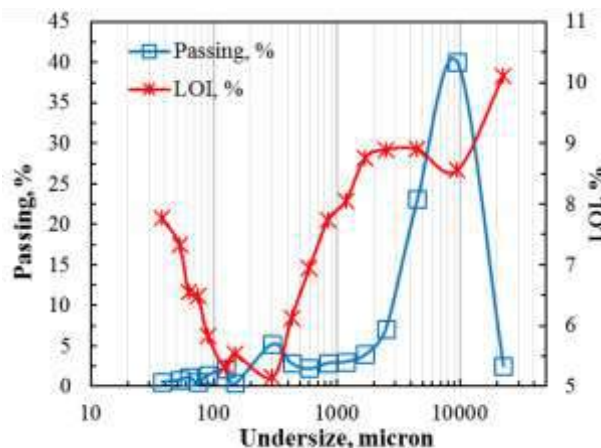


Figure 3. Particle size distributions for the products of first stage rod milling for 5 min and LOI (%) distributions

Phase segregation was not achieved sufficiently by first stage grinding. Then, ground chromite sample, having a size 80% below 6700 μm , was further subjected to grinding: 5 min and 10 min grinding by rod/ball mill were applied as second stage grinding to obtain a cleaner pre-concentrate (Figure 1, 4, 5). Rod mill grinding gave -1081 μm and -345 μm 80 % passing second stage ground product after 5 min and 10 min grinding, respectively (Figure 4a).

Similar LOI curves to that of first stage rod milling were obtained for the second stage rod milling (Figure 4b). Although V-shaped was drawn for both cases, more even distribution of hydrated minerals was observed down to about 100 μm . The minimum point of V-shaped curve, at which minimum LOI value was reached, shifted to lower sizes by increasing grinding time while minimum LOI

value increased gradually approaching to that of feed indicating more even distribution of minerals constituting the ore. The shielding effect of hard chromite on soft serpentine minerals resulted in more even distribution of minerals at coarser sizes (Yan and Eaton, 1994). LOI value increased sharply below the minimum value size. This finding was attributed to the concentration of serpentine group minerals at finer sizes due to selective grinding of hydrated soft minerals as compared with anhydrous chromite and olivine minerals especially by the grinding aid of hard chromite on soft minerals (Somasundaran and Fuerstenau, 1963; Fuerstenau and Venkataraman, 1988; Yan and Eaton, 1994; Güler et al., 2014). LOI value of fine fraction did not exceed 10%. Then, lower percentages of high LOI value finer fraction was thought not to be a promising result for pre-concentration of chromite ore by rod mill grinding.

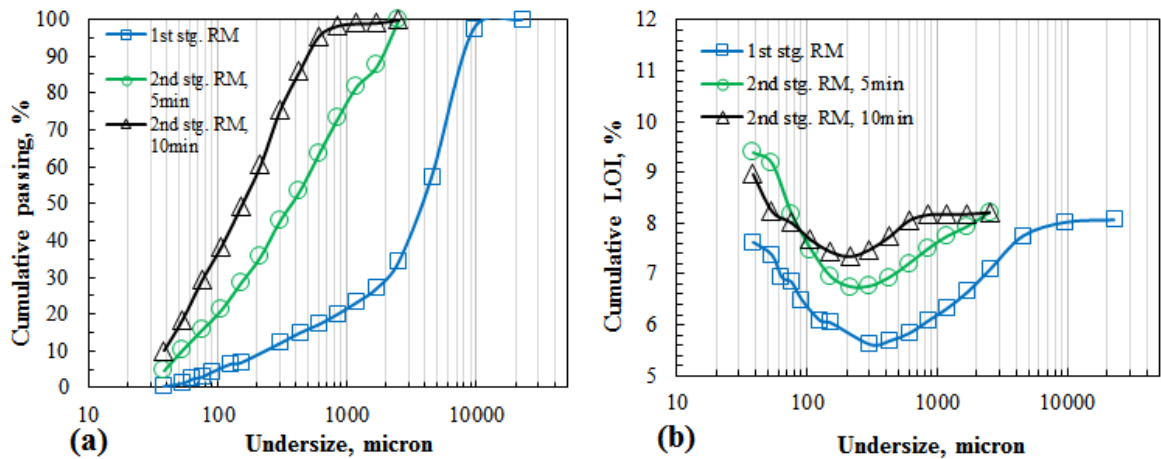


Figure 4. a): Particle size distributions for rod mill and, b): related LOI (%) distributions of rod milling products for 5 and 10 minutes (RM: Rod mill)

Further grinding of the first stage ground chromite ore sample was also performed by ball mill for 5 min and 10 min (Figure 5). Ball milling failed in size reduction of coarse fraction. Reasonable rate of coarse fraction could not be comminuted possibly due to small size of largest ball used. Then, necessary impact force could not be applied on the largest ore particle for crack propagation and grinding (Veasey and Wills, 1991; Tromans, 2008). Size distribution of ball milled product (Figure 5) was observed to be wider than that of rod mill one (Figure 4). This difference was attributed to grinding in ball mill by point contact during cataracting action (Wills and Finch, 2015; Gupta and Yan, 2016).

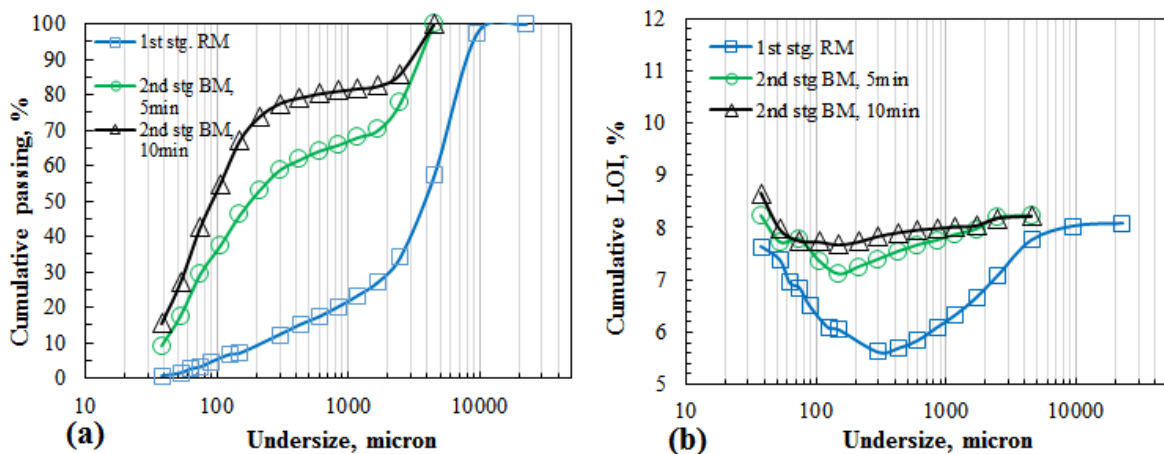


Figure 5. a): Particle size distributions for ball mill and b): related LOI (%) distributions of ball milling products for 5 and 10 minutes (RM: Rod mill, BM: Ball mill)

LOI curves of second stage ball mill products were given in Figure 5b. In contrast to the V-shaped LOI curves of rod mill product, extending the ball milling resulted in the disappearance of V-shaped. So that, minimum points of V-shaped LOI curves were hardly discriminated especially for 10 min grinding. This point shifted more finer sizes as compared with rod milling case. Size distribution demonstrated that higher rates of feed was ground down to finer sizes, which did not positively affect the phase segregation. In ball milling, all particles have the same chance to be ground due to random grinding opportunity of each particle as a result of point contact effect. Then, selective grinding and phase segregation could not be satisfied by ball milling.

CONCLUSIONS

Chromite is the valuable hard mineral in the test ore sample and gangue phases consist predominantly of soft serpentine alteration products. Mineral liberation and chromite pre-concentration possibilities by comminution was investigated and the findings are given below:

- Phase segregation was thought not to be achieved sufficiently only by applying single stage jaw crushing,
- Chromite tends to be concentrated more at the intermediate size fractions by moderate grinding, and decreases as it becomes fine-grained. But, this pre-concentrate may not be economic to be utilised particularly in metallurgical processes,
- The harder minerals are ground at slower rate in case the soft and hard minerals are equally distributed in the ore, in general. In the present study, relatively coarse chromite particles prevented soft alteration products of olivine from the grinding impacts particularly at +300 μm , while the grindability of softer fraction was more easier at -300 μm . This case is much more visible by applying 5/10 min rod grinding (clear V shape) as compared to ball,
- Serpentine minerals, hydrated alteration products of olivine minerals, are softer than chromite, and dominated more in fine size fractions,
- Perfect correlation could not be seen between hardness and grindability of minerals constituting chromite ore.

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