The Effect Of Cryogenic Treatment Of Ores On The Comminution Process And Analyze The Saving Of Energy

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Abstract

Mineral processing is the process of separating valuable minerals from gangue. The process is estimated to account for 6 % of global energy consumption and is little as 3% efficient. With the increased focus on environmentally friendly practices, the optimization of comminution is of vital importance. Comminution essentially involves two processes- crushing and grinding. World's most industrialized countries suggested that this process is consuming the greater amount of energy. One of the suggestions was to develop a pre-treatment process to weaken mechanical properties of rocks before subjecting them to comminution. Haphazardous wastage of energy has attracted the attention of researchers and industries world over in the wake of worldwide augmenting energy demand, frequent ups and downs of energy price and enhancement in global warming. In order to achieve covetous goal of bringing down energy consumption of comminution, present project proposes to develop a process which enables reducing mechanical properties of solid material thus helping in their easy breakage. Being aware of wide spread application of comminution not only in mining and mineral industries but also in other industries, this development would save energy significantly. This method is based on the fact that mechanical properties of material changes significantly with temperature.

Keywords: Comminution, Cryogenic, Energy, Global warming

1. Introduction

Comminution essentially involves two processes-crushing and grinding. This terminology is also applicable to blasting and drilling [NAS-NRC, 1966; Cheatham, 1966]. Crushing and grinding marginally differs from the fact that crushing liberates particles in coarser size ranges whereas grinding in finer sizes ranges. Grinding is deemed to indispensable method of comminution for separation of minerals from gangue producing cleaner concentrate. Producing nearly gangue-free concentrate calls for fine grinding of material

As no process is without its drawbacks, so is the comminution. Through umpteen researches, it has been established that comminution is most energy-intensive process of concentrator. According to DOE (1981), comminution process accounted for 2% of total energy consumed in US. The audit of energy consumption by comminution in Australian copper and gold mines conducted by Ballantyne *et al.* (2012) reveals on an average 36% of total energy used by mines was consumed by comminution. On the national level, it accounted for 1.3% of Australia's gross electrical energy consumption (Ballantyne *et al.*, 2012; Cuevas-Gubria *et al.*, 2011). According to CIPEC (2005) report on study of consumption of energy in Canadian underground base metal mines, comminution consumes energy in the range of 15.2 kw-hr to 32.1 kw-hr per tonne of crushed and milled gold ores.

Amongst crushing and grinding, grinding is more energy-consuming process that crushing. It accounts for nearly 50% of total energy requirement of concentrator. Tavares *et al.*, 1995 explained this disparity in two ways. First, as amount of fines increases, surface area resulting from it approached nearly infinity. Consequently, energy consumption increases monotonically with it. Another description relates to the fact that failure of material occurs from cracks. As particles get smaller and smaller, this cracked zone disappears. This makes it more difficult to break material further. High energy consumption in comminution can also be understood from the fact that more than 90% of total energy supplied is dissipated as heat, kinetic energy, noise, and ineffective breakage of material. The repercussion of high energy consumption is generation of huge grinding zone temperature. This temperature is sufficient enough to create cracks on ground surface thus impairing the integrity of whole system (Paul *et al.*, 1995). Tromans *et al.*, 2008, has recommended two solutions to curtail wastage of energy in comminution. One of the suggestions was to develop a pre-treatment process to weaken mechanical properties of rocks before subjecting them to comminution. Haphazardous wastage of energy has attracted the attention of researchers and industries world over in the wake of worldwide augmenting energy demand, frequent ups and downs of energy price and enhancement in global warming. In order to achieve covetous goal of bringing down energy consumption of comminution process, present project proposes to develop a process which enables reducing mechanical properties of solid material thus helping in their easy breakage. Being aware of wide spread application of comminution process not only in mining and mineral industries but also in ceramic, cement, chemical, agro-based, paint industries to name a few, this development would save energy significantly. This method is based on the fact that mechanical properties of material changes significantly with temperature.

Through various researches carried out over the years, it has been seen that temperature plays a more important role in altering properties of substances than other operating conditions like pressure, magnetic field, electric field, etc. There have been umpteen studies depicting effect of thermal shock on the mechanical and elastic properties of rock. Brotóns *et al*., 2013, showed the effects of thermal shock on Calcarenite, a porous rock. According to study, Uniaxial Compressive Strength (UCS) of Calcarenite reduces up to 35% and 50% when subjected to temperature variation of 105°C to 600°C followed by air-cooled and water-cooled condition respectively. A decrement of over 75% and 78% of Young's Modulus were recorded for aforementioned conditions respectively. It was concluded through this exercise that UCS of Calcarenite is the most sensitive parameter to cooling condition.

In yet another study, Shi Liu et. al., 2014, observed similar trend with granite and sandstone when subjected to temperature variation from room temperature to 800°C. It has been observed that granite show gradual reduction in UCS with increase in temperature whereas UCS of sandstone did not change substantially in the given temperature range but exhibited rapid fall in UCS beyond 800°C. Young's Modulus of granite climbed down at a rate faster than that of sandstone. Similarly, on the same line, Takarli *et al*., 2008, found same pattern in the strength of granite when exposed to temperature ranging from 105°C to 600°C. Initially, for temperatures between 105°C to 300°C, a marginal (8%) fall in UCS has been recorded. This reduction surged to 20% at 500°C and to 47% at 600°C. Young's Modulus also followed similar trend under same temperature range. Rocks are composed of varied sizes of mineral grains of dissimilar thermal and mechanical properties. On application of liquid nitrogen on the rock surface, sudden cooling will occur in different mineral grains lying in close contact. As mineral grains generally have different thermal conductivity and thermal expansion co-efficient, a differential volumetric contraction among adjacent mineral grains will occur, which can give rise to a potential thermo-mechanical stress leading to weakening of rock by generating inter-granular and trans-granular cracks. It may even cause cryo-cracking of mineral matters, which may be termed as 'cryo-fragmentation' of rocks. Moreover, change in brittleness of mineral matters will also cause the rock to fail under lower stress. Thus, the possibility of rock grinding at cryogenic temperature with much reduced energy consumption will be explored in this investigation.

Cryogenic grinding is already an established technology for crushing non-metallic such as polymer, rubber etc. However, economic viability or suitability of crushing of rocks with cryogenic treatment is yet to be established. Banerjee *et al*., 2013, experimentally observed an energy saving of about 47% when tests conducted on cooled red stone quartzite after dipping in liquid nitrogen for 40 minutes. Stones are crushed under compressive stress when induced strain energy exceeds the material's capability to withstand maximum strain energy. Unlike the metals, rock materials have high modulus of elasticity and exhibit small strain before failure. When a rock material is cooled to cryogenic temperature and a compressive load is applied, strain developed in the material is due to the applied load and the thermal stress that is developed because of thermal contraction.

One of the major concerns in cryogenic grinding is the time required for penetration of cold into the rock. Smaller the size of the rock particle, lesser will be the time requirement for cooling. In conventional method of grinding, cost increases very rapidly with reduction of the particle size. On the other hand, smaller size particles can be quickly made brittle at cryogenic temperature. Thus, cryogenic grinding might be an effective way of grinding the smaller particles. Changes in properties of mineral matters due to cryogenic treatment may even alter the liberation size of a particular ore type.

2. Sample preparations

Granite and sandstone were used as the raw materials on which effects of pre-treatment were studied by measuring Bond work index. These tests of the rock samples were done by Ball mill. Various types of pre-treatment that were applied on the samples are

Liquid Nitrogen dipping

The samples were dipped in liquid nitrogen (temperature -196 ^{o}C) for 60 minutes followed by heating upto room temperature in open air.

Oven treatment and liquid nitrogen quenching

The samples were heated at 110 ^{o}C for four hours inside a furnace and quenched in liquid nitrogen for 60 minutes.

Bond Work Index test

The work index is used when determining the size of the mill and grinding power requirement to produce the required ore throughout in a ball mill. The work index represents the energy required to reduce one ton of the ore from a very large size to 100 um

Work Index

$$\boldsymbol{Wi} = \frac{\boldsymbol{W}}{\sqrt{100}/\sqrt{P} - \sqrt{100}/\sqrt{F}}$$

Where,

$\boldsymbol{W}$ = mill energy consumption

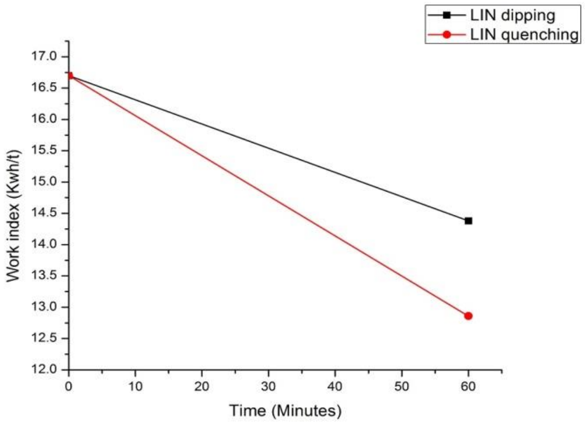
$\boldsymbol{Wi}$ = work index

100 = 100 um , which is product size in the definition of work index

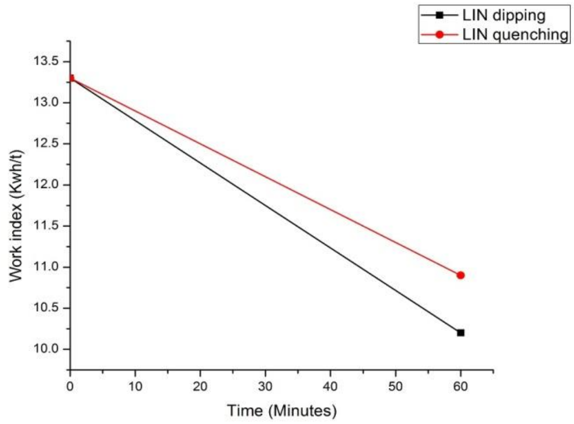
P, **F** = 80% passing sizes in um of feed (F) and product (P)

Table 1. Work index calculation

Sample	F_{80} (80% passing sizes of feed)	P_{80} (80% passing sizes of product)	W	W_i
Granite without treatment	30mm	1457µm	3.41kWh/t	16.7kWh/t
Granite LIN dipping for 60 minutes	27mm	1136µm	3.39kWh/t	14.38kWh/t
Granite LIN quenching for 60 minutes	24mm	1223µm	2.84kWh/t	12.86kWh/t
Sandstone without treatment	30mm	1184µm	3.10kWh/t	13.3kWh/t
Sandstone LIN dipping for 60 minutes	23mm	776µm	2.98kWh/t	10.2kWh/t
Sandstone LIN quenching for 60 minutes	24mm	848µm	3.03kWh/t	10.9kWh/t



Bond work index reduction of Granite



Bond work index reduction of Sandstone

Figure 1. Bond work index vs LIN dipping time of rock

3. Results

I. The Bond Work Index was established for the untreated rock; it was found to be 16.7 kWh/t for granite and 13.3 kWh/t for sandstone

II. Another tests were performed on the rock after being treated for 60 minutes in LIN dipping and LIN quenching

III. The Bond Work Index of the treated Granite samples were found to be 14.38 after LIN dipping and 12.86 kWh/t after quenching

IV. The Bond Work Index of the treated Granite samples were found to be 10.2 kWh/t after LIN dipping and 10.9 kWh/t after quenching

4. Conclusion

Cryogenic pre-treatment reduces the energy input required in grinding to obtain a designated level of reduction

Cryogenic pre-treatment shows diminishing returns after an optimal LIN dipping time has been achieved

Optimization the pretreatment process to produce the greatest reduction to the energy input during comminution

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