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Pre-treatment of rocks prior to comminution – A critical review of present practices

Somani Aditya [a,*], Nandi Tapas K. [b], Pal Samir K. [a], Majumder Arun K. [a]

[a] Department of Mining Engineering, Indian Institute of Technology, Kharagpur 721302, India
[b] Cryogenic Engineering Centre, Indian Institute of Technology, Kharagpur 721302, India

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ABSTRACT

It has been an established fact that comminution processes, crushing and grinding, are most energy intensive processes which account for more than half of the total energy consumed in mineral industries. Various alternative pre-treatment methods have been tried by experts around the globe. Although these methods yielded positive results in terms of reduction in energy consumption in crushing and particularly, in grinding operations at laboratory scale, their industrial application still remains an unresolved issue and challenge. Present review paper describes each one of these methods along with outcome of earlier studies and issues that need to be addressed through further rigorous experimental investigation. It also suggests the direction in which future studies can be carried out to meet the primary objective of making comminution processes more energy efficient than today they are.

1. Introduction

Comminution essentially involves two processes-crushing and grinding. This terminology is also applicable to blasting and drilling [1]. Crushing and grinding marginally differ from the fact that crushing liberates particles in coarser size ranges whereas grinding in finer size ranges. Grinding is deemed as an 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 limitations, so is the comminution. Through umpteen researches, it has been established that comminution is the most energy intensive process of concentrator. The audit of energy consumption by comminution in Australian copper and gold mines conducted by Ref. [2] revealed that, 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. According to the report on study of consumption of energy in Canadian underground base metal mines, comminution consumed energy in the range of 15.2–32.1 kW h/t of crushed and milled gold ores [3].

Among crushing and grinding, grinding is a more energy-consuming process than crushing [4]. It accounts for nearly 50% of total energy requirement of concentrator. Ref. [4] explained this disparity in two ways. First, as amount of fines increases, surface area resulting from it approaches 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 finer successively, 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 [5].

Ref. [6] recommended two ways 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. Uncontrolled wastage of energy has attracted the attention of researchers and industries globally in the wake of worldwide augmenting energy demands, frequent fluctuations in energy prices, and enhancement in global warming.

To address the grave issue of unrestrained power consumption in comminution, rigorous investigations were undertaken by various experts globally to develop alternative and novel methods of comminution. These methods can be commonly termed as Pre-treatment methods in the sense that rocks are exposed to some sort of treatment before their full-scale mechanical comminution by extant technology. As observed by Ref. [7], using Bond's law

* Corresponding author.
E-mail address: adityasomani88@gmail.com (A. Somani).

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of comminution, it is the strength of rock which controls the power consumption and product size under normal operating range of industrial-scale cone crusher. The principal objective of the development of a pre-treatment method is to weaken the mechanical strength of rock prior to comminution. As experimentally observed, it leads to hefty decrement in electrical energy consumption by the virtue of increase in crushability and grindability of treated rock.

However, although these methods have been found to efficient at laboratory scale, these have not yet been converted to economically viable and commercially feasible technology which can be employed for large-scale operations. The subject of current review paper is, thus, to summarize work done in these areas of pre-treatment methods and suggest main focus areas for future investigations.

Among several methods experimented globally, following are the methods which saw considerable efforts. These methods are listed below as:

(1) Thermal breakage.
(2) Microwave heating.
(3) High-voltage pulse breakage.
(4) Ultrasonic breakage.
(5) Thermal shock.

Following sections deal with these methods in detail.

2. Thermal breakage

Thermal breakage, commonly known as conventional heating, signifies heating rocks before comminuting them. The mechanism of heat transfer in rock is convection, conduction, and radiation. Heating of rocks induces inter-granular cracks in the rock matrix and facilitate easy grinding and generation of less fines.

Numerous studies have proved that temperature plays a major role in altering properties of substances than other operating conditions like pressure, magnetic field, electric field, etc. In the review paper, Ref. [8] highlighted the impact of subjecting rock to high temperature condition prior to comminution. As reported, generation of fines was minimized, which improved comminution characteristics and grindability of rock.

Ref. [9] attributed the enhancement in the metallurgical efficiency and increase in grade and recovery of valuable minerals to the heat treatment. The extensive investigation on the influence of heating of Tin ore on its comminution characteristics proved effectiveness of thermal pre-treatment method. It was reported that 80% passing size of ore was reduced from 27.2 mm for untreated ore to 22.3 mm for treated ore. This corresponds to 18% reduction in particle size. This dictates increase in brittleness of ore post heating of rock. The plots of results of single pass crushing reported by them are shown in Figs. 1 and 2. It can be seen that major proportion of product falls under 500 μm size range for

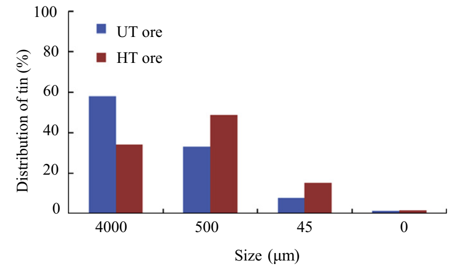

Fig. 2. Distribution of tin with product size.

heat-treated (HT) ore. This is in contrast to that observed for untreated (UT) ore. Tin is mainly concentrated in finer size ranges i.e. below 500 μm than for UT ore. It can also be seen that HT did not produce considerable loss of tin in slimes.

The crusher result showed that HT ore produced 14% lesser +4 mm product than UT ore. As a result of this, correspondingly lesser amount of material would be recirculated to crusher and bring down capacity requirement of crusher and screens. The product of crusher was used as feed for grinding. As reported, for the same grinding time, HT ore feed produced finer grinding product than UT ore feed. After 5 min of grinding, while the size of UT ore was about 300 μm, corresponding size of HT ore was about 225 μm. Another significance of this outcome was that the primary grinding stage could be eliminated, thus saving considerable chunk of energy and product of crusher could be sent directly for concentration.

Ref. [10] obtained similar kind of results for lignite coal. Fig. 3 depicts the data reported after 20 min of grinding. As reported, pre-treated coal ground finer than untreated coal. After 20 min of grinding, 84% of pre-treated coal was finer than 13 μm while only 70% of untreated coal in same size range.

Ref. [11] studied the influence of temperature on the mechanical strength of Tournemire Shale under hydrostatic, uniaxial and triaxial compression tests for three values of confining pressure of 5, 10 and 20 MPa. Fig. 4 depicts the results of triaxial tests for the confining pressures of 10 and 20 MPa, drawn from the data reported by them. It can be observed that increase in temperature causes increase in brittleness of shale and thus, decrease in its compressive strength.

In yet another study, Ref. [12] observed similar trend with granite and sandstone when subjected to temperature variation from room temperature to 800 °C. It was observed that granite showed gradual reduction in Uniaxial Compressive Strength (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. On the same line, [13] reported same pattern in the strength of granite when exposed to temperature ranging from 105 °C to 600 °C. Initially, for temperatures between 105 °C and 300 °C, a marginal (8%) fall

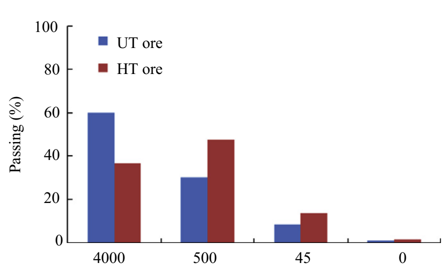

Fig. 1. Mass per cent passing of ore.

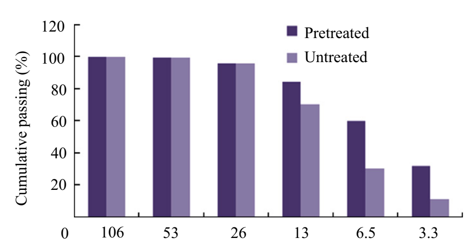

Fig. 3. Percentage passing of lignite coal after 20 min of grinding.