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Alteration of grindability of minerals due to applying different explosives in blasting operation

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ABSTRACT

This study aims to characterize the alteration in mineral grindability due to applying different types of explosives in the blasting operation. For this purpose, several experimental blastings have been carried out on some granite blocks using three kinds of explosives; ANFO, Emulite and Pentolite. Then the mechanical strength of the resulting fragments has been measured by point load index and P-wave velocity tests. In the next step, the performance of rock fragments in comminution processes was examined by conducting some crushing and grinding experiments. Results showed that the blasting process can reduce the Bond work index of fragments as much as 18% and enhances their crushability by 9.5%. Moreover, using different explosives brought about sensible changes in results, so that substituting ANFO with pentolite or emulite decreased the Bond index by 9.2% and 6.7% respectively, and increased the crushability index by 6.3% and 4.9% respectively. Besides, all results indicated that any increase in velocity of detonation (VOD) is followed by reduction of Bond work index and increase of milling throughput.

1. Introduction

Blasting operation is considered as the first step in the mineral supply chain in many mines. Therefore, blasting optimization is a prerequisite for optimizing the economy of whole mining complex. On the other hand, the objective of operation sequence of blasting, crushing and grinding is to deliver a certain degree of liberation to the minerals. Optimization of this operation sequence can be accomplished by minimizing the energy consumption. Among these three processes, blasting is the most efficient one in terms of energy consumption, while comparison of energy supply cost between explosives and electricity indicates that explosives have a 5-time benefit over electricity in terms of energy costs (Eloranta, 1997). However, it should be noted that nitrogen fixation requires a great amount of energy too. Therefore, any improvement in grindability or comminution productivity by blasting operation is desirable and in demand from economic point of view.

The primary objective of blasting operation is to fragment rock masses into smaller pieces of rock. However, in addition to rock fragmentation as the *visible* result of the process, blasting can induce some degrees of inner damage to the rock fragments, which is known as the *invisible* result of blasting. This inner damage is recognized as a consequence of generation and propagation of microcracks inside the fragments which reduces their strength compared to intact rock (Workman and Eloranta, 2003). This strength reduction influences all subsequent mining operations including comminution processes and facilitates further handling of materials and prepares them for downstream operations. This phenomenon is known as blasting induced preconditioning or conditioning and is defined as alteration of physical and mechanical characteristics of rock after blasting as a consequence of propagation of pre-existent cracks and generation of new ones (Parra et al., 2015).

In fact, conditioning effect of blasting can reduce the resistance of rock fragments against impact and abrasion and as a result, it can reduce the energy consumption in crushing and grinding units, which is economically and environmentally a preference and an important achievement (Chertkov, 1986; Michaux and Djordjevic, 2005). Therefore, it is desired to reduce strength of fragments as much as possible by changing the blasting design. Previous studies indicated that any increment in energy level applied in blasting, through increasing the powder factor, enhances the grindability of minerals (Nielsen and Kristiansen, 1996; Nielsen and Lownds, 1997; Nielsen and Malvik, 1999). However, changing the blasting agent is another option for changing the blasting design. It is assumed that proper selection of explosives may conduct the microcrack generation and strength reduction processes in the desired direction. In other words, an explosive should be applied that can increase the grindability of fragments as much as possible. The purpose of this study is to characterize and compare the influence of different explosives on the grindability of

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materials, with an emphasis on keeping the applied energy constant in all blasting experiments.

Most of the researches regarding the relationship between blasting operation and comminution are conducted in mine to mill research frameworks. In other words, they have studied the effect of blasting design variation on alteration of size distribution of fragments fed in comminution circuit and its subsequent influence on operational efficiency of these processes. Eventually they concluded that finer distributions lead to higher operational efficiencies (Mackenzie, 1967; McKee et al., 1995). Researchers started to attend to the preconditioning effect of blasting when several observations showed some changes in grindability of minerals as a result of alteration of blasting parameters. There have been many studies on this phenomenon during the last three decades.

All preconditioning effects are caused by alteration of microcrack network of rock fragments. Nielsen and Malvik focused their studies on variation of fragments' microcrack network induced by blasting. By adding more detonating cords as the main charge, they studied the influence of higher powder factors on microcrack network density of rock fragments. They concluded that increasing the applied energy level in blasting increases the density of all kinds of microcracks (Nielsen and Malvik, 1999). Hamdi et al. (2002) employed a novel approach by presenting the crack porosity concept and showed that the proximity to blasthole parameter is highly correlated with crack porosity. Also, Muñoz et al. (2007) showed that extent and types of microfracturing in granite demonstrate a direct relationship with proximity to blasthole. By analyzing the fluorescent microscopic images, Khademian and Bagherpour (2017) investigated the influence of different types of explosives on microcrack content of rock fragments and found out that increasing the VOD of blasting can cause an increase in microcracks density as much as 300%.

Another group of researchers focused on blasting-induced inner damages and mechanical strength reduction. By conducting 12 experimental blastings on granodiorite blocks and measuring P-wave velocity, Katsabanis et al. (2003b) showed that the damage level at individual points lays between 0.35–0.5 close to the blastholes and then decreases radially outward. Katsabanis et al. (2003a) found that increasing the powder factor can reduce the strength and elastic properties, too. Also, Michaux and Djordjevic (2005) showed that increasing the applied energy in blasting results in a reduction of point load index of granite fragments.

Nielsen and Kristiansen (1996) are among the first researchers who succeeded in isolating the role of blasting-induced microcracks in comminution performance of materials. They conducted some experimental blasting and grinding tests on different rock samples including taconite, gabbro, quartz diorite and monzonite and found out that changing the blast parameters have significant influences on Bond work index of the resulting fragments. As a part of these studies, the grinding results of three sets of taconite cores have been compared, while the first set remained unblasted and the other two sets of cores were blasted with one and two strands of detonating cords as the main charge. Results showed that the P_{80} of grinding products decreased from the 2.91 mm for the first set to 1.42 and 0.73 mm for the other two sets of samples. Also, the measured work index in the laboratory decreased from 14.4 kWh/ton to 6.7 and 3.9 kWh/ton, respectively (Fig. 1) (Nielsen and Kristiansen, 1996). Subsequent studies by Nielsen and Malvik (1999) confirmed previous results and indicated that the performance of materials could be enhanced by increasing the powder factor in blasting operation. This softening effect can be traced clearly down to a P_{80} of 200–300 μm. However, the differences became negligible as the fineness came down to less than 200 μm (Nielsen and Lownds, 1997). Based on these findings, Workman and Eloranta (2003) showed that increasing the powder factor to 0.45 kWh/ton in taconite blasting could cause 30% and 26% savings in input work and total cost of the mining unit, respectively.

Michaux and Djordjevic (2005) investigated the influence of increase in blasting energy level on comminution circuits. They used JKSimMet software for simulating a SAG mill circuit and then evaluated the milling performance of four batches of rock fragments which were blasted with different energy levels. The results showed that increasing the applied energy level in blasting can increase the mill throughput up to 21%.

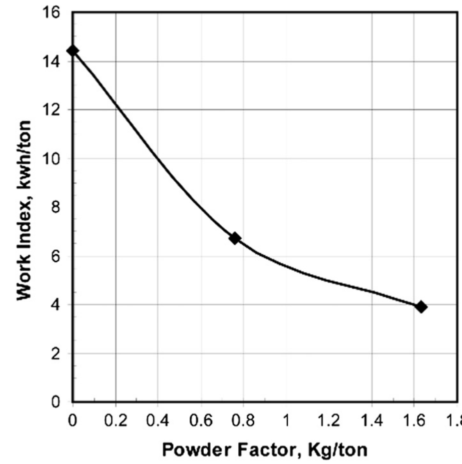

Fig. 1. Work index as a function of powder factor (Nielsen and Kristiansen, 1996).

Recent studies in the field of fragment conditioning showed that blasting can influence the mineral recovery in leaching process, too. Two series of experimental leaching processes on natural and synthetic cooper ore showed that increasing the applied energy of blasting through adopting higher powder factors led to an increase in microcracks density and then an increase in mineral recovery (Fribla, 2006; Parra et al., 2015).

Reviewing the above mentioned literature clearly indicates that increasing the level of applied energy and powder factor in blasting operation improves the grindability of materials in comminution processes. However, the role of explosives type applied has been ignored in most of these studies (Khademian et al., 2017). Different explosives release their energy in different ways and interact with the rock differently. Explosives differ significantly in their abilities to inflict exterior and interior damage (Singh, 1993). Therefore, it can be assumed that even with applying the same amount of energy, different explosives inflict different levels of internal damage to rock fragments. Accordingly, this study is intended to investigate the influence of different explosives applied in blasting on performance of rock fragments in comminution circuit and their grindability. In other words, this study intends to evaluate the impact of energy release rate and velocity of detonation (VOD) on the reduction of resistance of materials against comminution, independent of applied energy level in detonation.

2. Methodology

In order to implement this study, first 10 homogenous granite blocks were provided from a quarry. Then, three types of explosives, namely ANFO, emulite and pentolite, which have totally different detonation velocities, were selected for blasting. Applying each explosive, 3 granite blocks have been blasted in a blast chamber with the same blasting parameters and one block was kept unblasted. After each blast, the resulting rock fragments have been collected. In the next step, some rock fragments from each batch were prepared and their strengths were determined by point load index and P-wave velocity experiments. After preparing the same size distribution from each blast, the crushing experiments were performed on part of the rock fragments and the performance of each batch of fragments in crushing operation was examined. The ball mill Bond work index of each sample was determined by conducting separate standard experiments. Then, by feeding the same size distribution of each batch to a ball mill, the milling