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Recent trends in rock dust modifications for improved dispersion and coal dust explosion mitigation

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ABSTRACT

Underground coal mine explosions is perhaps the most hazardous danger in the coal mining industries. Efforts have been made to abate the coal dust explosion by applying rock dust either dry or wet. Dry dust has the best lift characteristic which efficiently quenches the flame propagation of a potential explosion. As a trade-off, undesired respirable dust particles are thereby generated imposing a severe health hazard on coal miners. Wet dusting is an alternative to dry dusting which significantly reduces the exposure to respirable dust particles. However, wet dust is subject to adverse caking issues which lead to a drastic reduction in the dispersibility of the particles. The present work summarizes the studies conducted to date regarding the surface modification of rock dust particles for the purpose of eliminating or alleviating the problems accompanying coal mine dusting applications, meanwhile improving the dispersive properties of dust particles and the ability to suppress the coal dust explosion.

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1. Introduction

Coal dust explosions are virtually as old as coal mining and continuously remain as the cause of numerous disasters in mines (Cybulska, 1988). During mining operation, methane can be easily accumulated at the work face which is ready to be ignited by as small ignition energy as machine sparks creating a subsequent gas explosion. The pressure wave resulting from the gas explosion is able to disperse the loose coal dust deposited on the floor, roof and ribs as it travels out from the face and acts as an ignition source for coal dust (Dastidar et al., 2001). A coal dust explosion is thereby created which generates sufficient air pressure and associated air turbulence further increasing the violence of the explosion (Harris et al., 2010). Highly advanced and mechanized underground coal mine production has gradually generated finer coal dust which is more explosive (Cashdollar et al., 2010; Harris et al., 2010). Rock dusting has been used for about 100 years by applying the inert rock dust (typically limestone or dolomite) to increase the total incombustible content of admixtures and effectively quench the

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flame propagation and coal dust explosion by acting as a thermal inhibitor or heat sink (Rice, 1914; Amyotte et al., 1995; Man and Teacoach, 2009; Cashdollar et al., 2010).

Rock dusting can be applied either dry or wet (Snell, 1956). According to an early summary paper by Greenwald (1938a), rock dust may be distributed by air current, by hand and by machine. Distribution by air current is usually not satisfactory due to the carrying limitations of the current. A crew of men can also do the work by carrying a bag of rock dust and spreading the material by hand onto the mine roof, ribs and floors. The commonly utilized way is through mechanization. In this manner, rock dust is mechanically fed and discharged through fixed openings or flexible pipes. The dust is forced through hose lines by high-pressure machines with a blower which allows applications in trackless entries or other places that the machine cannot enter. The most common mechanical types of rock dust applicators currently in use include high pressure bulk, Bantam, Slinger, Trickle, Wet/Slurry and Mine-wide automated dusting systems (The U.S. Mine Safety and Health Administration, 2016). Normally dry rock dust can be applied through all three aforementioned methods while wet rock dust is typically applied by mechanization due to its high fluidity.

The dry dust generates the best lift characteristics and dispersibility as the buoyant nature of rock dust is essential for coal dust explosion mitigation (McDonald, 1938). When an underground coal mine explosion occurs, rock dust must be readily disperse so as to effectively quench the flame front of the propagation (McDonald, 1938; Greenwald, 1938a; Cybulska, 1988). However, the adverse effect of dry dusting is the airborne dust which is detrimental to coal miners' health after being inhaled. A health surveillance program administered by the National Institute for Occupational Safety and Health (NIOSH) was conducted among US coal miners in 2011 to detect the proportion of miners who had been diagnosed with pneumoconiosis (NIOSH, 2011). As shown in Fig. 1, percentage of miners examined with pneumoconiosis by tenure in coal mining indicates that followed 30 years of declines, a recent resurgence of black lung disease occurred from the beginnings of 2000s which is unexpected. The U.S. Mine Safety and Health Administration (MSHA) issued a final rule in 2014 to lower the concentration limits for respirable coal mine dusts which imposes a severely restricted regulation on the upper limits of respirable dust coal miners can be exposed to (MHSA, 2014). Wet dusting is able to greatly reduce the amount of respirable dust during the application but results in another problem pertaining to the caking of the wet rock dust which results in a significant reduction in the dispersion characteristics necessary to be effective for mitigating dust explosions (Greenwald, 1938a; McDonald, 1938; Mozumdar and Singh, 1974). Caking is mainly caused by moisture migration through the bulk solids driven by the fluctuation of the atmospheric environment, mineral dissolution into the moisture and the formation of rock bridges between particles upon drying (Rumpf, 1958; Bradley et al., 2000; Christakis et al., 2006).

Advantages and Disadvantages coupled with either dusting application method and mine operators baffle with the hazards that accompany with the chosen dusting application. Significant effort has been focused over several decades to remedy or reduce the associated problems with the two dusting applications. A common approach has been to modify the surface chemistry of the dust particle to render the surfaces hydrophobic which would cause the water to drain more readily through the applied rock dust. This present paper reviews the comprehensive knowledge to date pertaining to the rock dust modifications for the purpose of improving their dispersibility (lessening caking) and abating underground coal mine explosion.

2. Caking mechanism of rock dust

Caking is usually used to describe the change of bulk solids from free flowing materials into lumps bonding together by inter-particle forces and commonly occurs with bulk solids (Specht, 2006; Johanson and Paul, 1996). In general, inter-particle forces include the attractive dispersion force and the electrostatic force which can be attractive or repulsive depending on the conditions of the medium (Fowkes, 1964; Bargeman and Van Voorst Vader, 1972; Takase, 2009). When rock dust is applied in a damp underground coal mine or wet form, saturated solution of soluble materials comprising the dust particles is formed at the contact points of particles and water bridges are thereby created. Water bridges that form between the particles due to humid conditions or the wet application process provide the medium through which the particles can agglomerate if the balance of the inter-particles forces is attractive. With or without particle agglomeration, the water bridge gradually evolves into a 'rock bridge' through water evaporation and dust particle recrystallization over time as a result of the fluctuation in the atmospheric temperature or humidity (Rumpf, 1958; Tardos et al., 1996; Purutyan et al., 2005; Farber et al., 2005; Bika et al., 2005). Normally the caking process among bulk solids is completed within multiple wetting and drying cyclic stages (Christakis et al., 2006), which is represented in Fig. 2. This process eventually forms a caked bed of solids that is not as effective as free moving particles for suppressing dust explosions.

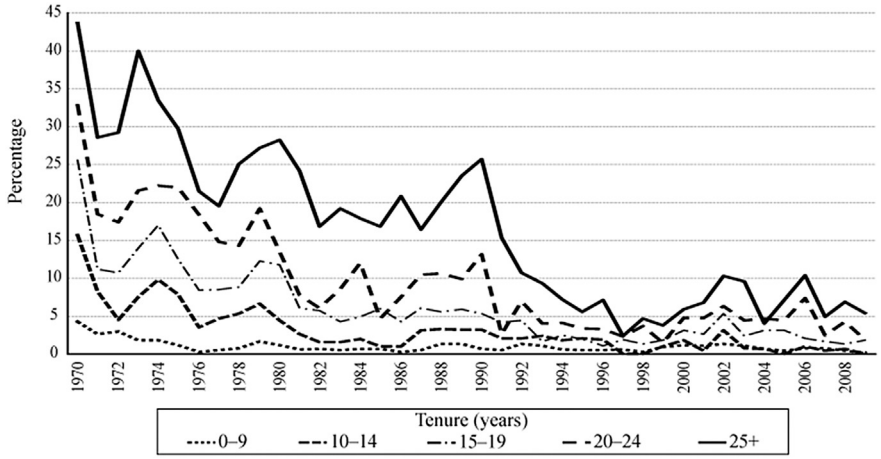

Fig. 1. Percentage of miners examined with pneumoconiosis by tenure in mining, 1970 to 2009 (NIOSH, 2011).