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Experimental investigation and field application of foam used for suppressing roadheader cutting hard rock in underground tunneling

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ABSTRACT

Dust is a serious threat to workers' health and safety in underground tunneling. Suppressing dust with foam is an efficient means in the confined workplace. The performance test of foaming agent showed that the new complexing one had a smaller contact angle against dust, less than 50% of water, and its viscosity reached up to 358 times that of water. Then a noble foam preparation method was proposed with a jet device adding foaming agent. Using a venturi foam generator, high performance foam was generated. Field application was carried out through locating the foaming system and foam nozzles on the roadheader. Testing results indicated that the foam efficiencies on suppressing total dust and respirable dust were 85.7% and 88.1% at the driver position. They were 2.26 and 2.47 times higher when compared to the water spraying. The air visibility improved from 0.39 m to 5.0 m after a short time of foam spraying. The foam technical cost only accounted for 1–1.5% of construction investment. Therefore, there is reason to believe that the study will promote foam technology widely used for dust suppression in underground tunneling.

1. Introduction

Dust is one of the primary air contaminants in the underground, which is difficult to clean thoroughly. Especially in recent decades, tunneling intensity is gradually increasing with the popularization of large-scale mechanization equipment for excavation (Acaroglu and Ergin, 2006), causing the dust capacity rising sharply. Accidents induced by dust were frequently reported, such as pneumoconiosis and dust explosion. According to official statistics, pneumoconiosis caused 69,377 deaths among U.S. underground miners from 1970 to 2004, and over $ 39 billion was paid to their families between 1980 and 2005 (Colinet et al., 2010). In China, 87.32% of the 532 national key mines face the risk of coal dust explosion. The proportion was larger for town-owned and private coal mines. In the period 1949–2007, there were 103 coal dust explosion accidents that occurred, causing 4613 casualties (Zheng et al., 2009).

To control dust in the underground, various technologies have been developed and applied all over the world (Kissell, 2003; Xi et al., 2013). They have played an important role in reducing dust concentration, but still have obvious drawbacks. For instance, water spraying has low dust suppression efficiency, especially for dust particle with diameter less than 2 μm (Wang et al., 2013), and it has a high water pressure demand that is hard to meet in practical application (Xie et al., 2007). Worse more, spraying nozzles are easily blocked and damaged (Ren et al., 2012) subjected to the bad water quality in the underground. The overall efficiency of scrubber is only 60–75% (Kissell, 2003). The complicated power system and cumbersome structure also restrict its applicability in the underground. Water infusion uses a considerable amount of water and demands on a high injection pressure (Cheng et al., 2012), which may cause water running from fractures and coal skeleton damage (McClelland, 1987). Using exhausting ventilation, dust can be discharged from the working face timely (Toraño et al., 2011), while the discharge effect is not obvious when the dust concentration is high. Although being effective on suppressing respirable coal mine dust (Li et al., 2013), chemical agent spraying is at a high cost and tends to cause soil acidification or calcification (Xi et al., 2013). The foam-sol appears to be a good idea, but the foam expansion ratio may be too low to capture dust effectively, which still needs to be improved (Xi et al., 2013).

Dust suppression with foam refers to a new technology to suppress dust using foam generated by physical mixture of air, water and foaming agent (Lu et al., 2014). The foam can intercept and

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moisten dust, adhere to it and then settle it effectively (Mukherjee and Singh, 1984). It can trap almost all kinds of dust, especially respirable dust (Hiltz, 1975). The foam can reduce the dust concentration by 89.73%, and showed a 30% increase than the water spraying at a belt transfer point (Seibel, 1976; Lu et al., 2011). When used in the heading face or longwall coal face, the foam raised the dust suppression efficiency by 50–64.4% compared to the water spraying, and the water consumption reduced by 50% (Mukherjee and Singh, 1984; Wang et al., 2013, 2014). Although the foam has made a good dust suppression effect, the dust concentration mentioned above is low. There is not too much field evidence shown that this superior is also obvious when foam is applied in a high concentration dust area, like roadheader cutting hard rock in underground tunneling.

To improve the foam application effect on suppressing roadheader cutting rock dust, the present paper introduced a new complexing foaming agent. Its wettability and viscosity was investigated compared to those of water and other foaming agents. Then a foam preparation method for dust suppression was proposed and the operation conditions were determined. Field trials of foam dust suppression were conducted and evaluated at a heading face tunneled by a powerful roadheader. It is the first systematic research on the foam used for dust suppression, which has a great guiding significance for its practical field application. Therefore, this study will lay an important foundation for the large-scale application of foam technology, making it an efficient means of increasing the protection of workers' health and safety in underground tunneling.

2. Performance test of foaming agent

The effect of foam capturing dust particles is determined by the wetting ability and adhesive capacity of foam, which is closely related to the foaming agent performance. In this Chapter, a new complexing foaming agent used for foam dust suppression was investigated. Its wettability and viscosity were tested compared to water and other foaming agents. The criterion that selected the optimal foaming agent was established by the smallest contact angle and the strongest viscosity.

2.1. Contact angle

As shown in Fig. 1, there is a contact angle shaped at the liquid–solid interface when the liquid contacts with solid. The contact angle θ was used to describe the wettability of liquid against dust, and a smaller contact angle means the liquid has a better wettability (Nowak et al., 2013; Xi et al., 2013). The rock property has a certain effect on the liquid wettability, which is mainly represented by the protodyakonov coefficient f (Ryu et al., 2006), and the harder the rock is, the higher the f is. Therefore, we conducted two group experiments to compare their wetting effects, one with $f = 12.6$ and the other $f = 4.7$. The rock sample size was 20 mm (length) × 15 mm (width) × 5 mm (height).

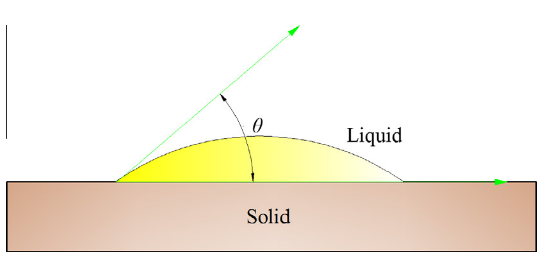

Fig. 1. Sketch map of contact angle at the liquid–solid interface.

The contact angles of four reagents, including water, new complexing foaming agent (CFA), sodium dodecyl benzene sulfonate (SDBS), sodium alcohol ether sulfate (AES), were measured with a *HARKE-SPCA* instrument, the precision of which was 0.01°. Since the contact angle was declining over time (Li et al., 2013; Xi et al., 2013), five groups of contract angles were recorded at intervals of 10 s and plotted in Fig. 2. It can be seen that the contact angle of CFA was only 20–30°, smaller than those of SDBS and AES. The water contact angle even reached up to 68.7°, which was 2–3 times that of CFA. Rock with a less protodyakonov coefficient produced a smaller contact angle, and the contract angle differences between CFA and other foaming agents decreased. Therefore, it can be deduced that foaming using the new foaming agent has a better wettability on rock dust than other foaming agents and water, especially on the hard rock dust.

Fig. 3 shows the wettability comparison between CFA and water on rock powder. It was tested under the same conditions, with the same liquid drop mass and temperature. It was found that the water had little wetting ability and the water drop kept its original shape above the rock powder more than 10 min. However, the wetting ability of foaming agent was strong. Its wetting scope was much larger than that of water, and the action time was shortened to less than 1 min.

2.2. Viscosity

The foaming agent viscosity varied with the foam expansion ratio (Ren, 2009). Using a *ZNN-D*6 rotational viscometer, the new complexing foaming agent viscosity was tested at different foam expansion ratio. The inner diameter and external diameter of rotational viscometer were 17.25 mm and 18.42 mm. The reagent was placed in the annulus and rotated with the outer cylinder at a shearing rate of 4.8 s^{-1}.

Table 1 provided the measurement data of the new complexing foaming agent viscosity coefficient μ_f at different foam expansion

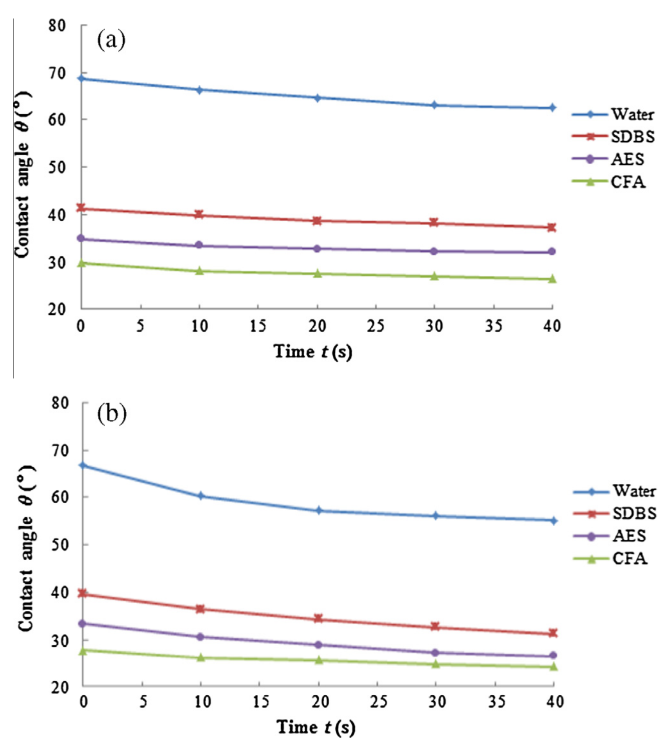

Fig. 2. The contact angles of different foaming agents and water. (a) $f = 12.6$, (b) $f = 4.7$.