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Analysis of the design and performance characteristics of pumpable roof supports

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ABSTRACT

Pumpable roof supports are currently being used to provide a safe working environment for longwall mining. Because different pumpable supports are visually similar and installed fundamentally in the same manner as other supports, there is a tendency to believe they all perform the same way. However, there are several design parameters that can affect their performance, including the cementitious material properties and the bag construction practices that influence the degree of confinement provided. A full understanding of the impact of these design parameters is necessary to optimize the support application and to provide a foundation for making further improvements in the support performance. This paper evaluates the impact of various support design parameters by examining full-scale performance tests conducted using the National Institute for Occupational Safety and Health (NIOSH) Mine Roof Simulator (MRS) as part of manufacturers' developmental and quality control testing. These tests were analyzed to identify correlations between the support design parameters and the resulting performance. Based on more than 160 tests over 7 years, quantifiable patterns were examined to assess the correlation between the support dimensions, cementitious material type, wire pitch, and single-wall vs. dual-walled bag designs to the support capacity, stiffness, load shedding events, and yield characteristics.

1. Introduction

Developed in the 1990s, the first major use of pumpable supports systems in U.S. longwall operations was in the support of bleeder entries [1]. Since then, they have been utilized as yieldable concrete supports to provide a safe working environment for longwall mining gateroads, bleeders, and emergency escapeways while also maintaining adequate ventilation pathways. The basic structure of pumpable roof supports has remained unchanged over the years. Formed in place with a two-part fast-setting grout, the support material can be pumped into a containment bag from several thousand feet away, often through surface boreholes. The containment bag then acts as a form to fill the support and provides confinement to the grout during loading and after failure. Pumpable roof supports provide full contact with the mine roof and floor, which eliminates the need for secondary material to establish proper roof contact (see Fig. 1). They provide a high peak load capacity and a sustained, confinement-controlled yield behavior while maintaining stable ground conditions, which is essential to underground mining operations.

Over the years, considerable research has been conducted to develop pumpable support technologies and to evaluate their performance characteristics to improve the support design. Performance traits, installation patterns, and ground control observations in various geological and mining conditions were evaluated to determine the support performance characteristics and correlation to observed ground responses [2–4]. To examine performance, the load displacement characteristics of the pumpable roof support can be determined from full-scale testing conducted using the National Institute for Occupational Safety and Health (NIOSH) Mine Roof Simulator (MRS) located in Bruceton, PA [1].

Because pumpable supports all look similar, the tendency is to think that they all perform the same. However, several design parameters can affect the performance characteristics of the pumpable support system. This paper evaluates the impact of various support design parameters by examining full-scale performance tests conducted at the NIOSH MRS as part of various product development and quality control testing. These tests were analyzed to identify correlations between the support design parameters and the resulting performance. Based on more than 160 tests over 7 years, quantifiable patterns were examined to assess the correlation of the support dimensions, cementitious material type, wire

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Fig. 1. Pumpable roof supports in a longwall recovery room.

pitch, and single-wall vs. dual-walled bag designs to the support capacity, stiffness, load shedding events, and yield characteristics.

2. Design features

For many years, pumpable roof supports have been installed in mines to support the roof. The supports are designed to be installed in place using a pumpable cementitious grout. Typically, a two-component material is pumped from a surface installation through an access borehole into a containment bag to form the support, with the capability to pump the material a distance of over 5486 m [3]. The unfilled support bags are transported into the mine in a collapsed configuration, minimizing the transportation needs to the installation site. During installation, the bags are secured to the mine roof and then extended down to the floor. The solidified grout material captured by the containment bag provides a full support column between the mine roof and floor without the need for any additional materials, providing a significant advantage over most other support designs.

Pumpable roof support systems have evolved during the last 20 years, with improvements made to the bag design and several variations of cementitious materials in an effort to optimize cost and performance. Currently, there are two basic types of material used: calcium-sulfo-aluminate (CSA) and Portland-based cementitious grouts. The CSA grout contains no Portland material and generally has an inherently faster setup time and strength gain than Portland grouts without the use of accelerating additives. Both materials are pumped in separate two-part mixes such that the reactive chemistry only occurs once the materials are mixed together just prior to entering the support bag. One interesting physical difference between the two materials is that some samples of the Portland-based materials severely decompose (lose structural integrity) when exposed to air, while the CSA grout once cured is insensitive to air and does not physically deteriorate. The primary performance difference is that the supports made with the higher-modulus CSA material achieve peak compressive strength with less displacement, providing increased support stiffness compared to the supports constructed from Portland-based material.

Temperature can play a significant role in the support installation process. Most grouts are temperature-sensitive in terms of the reactive chemistry, which affects both the setup time and the material strength when the water temperature used to make the grout slurries falls beyond the required specifications. Typically, a water heater at the surface pumping station is used to ensure the water is the proper temperature in colder weather. Depending on the setup time, supports are often filled in several lifts. If the grout does not set up fast enough, the bag will tend to bow outward from the roof to the floor, potentially degrading the capacity of the support by as much as 10% [1].

A high loading stiffness with a sustainable residual load through several centimeters of convergence is one of the universal design features of pumpable supports. The high loading stiffness causes the support to reach a peak load capacity within a short amount of convergence. For a passive roof support, this is beneficial to roof control as the support resistance is mobilized quickly to work to control the roof deformation. The peak load is typically followed by a sequence of load shedding events, which results in sharp drops in load. These sudden drops in load are caused by the brittle grout fracturing induced from the stress of convergence. The subsequent residual load behavior is dependent on the confinement and integrity of the support bag. A full understanding of the impact of these design features is necessary to optimize the support applications and to provide a foundation for making improvements in the support performance.

3. Performance characteristics

The performance characteristics for pumpable roof support entail four main factors, as illustrated in Fig. 2, namely stiffness, peak load capacity, load shedding events, and residual load characteristics.

Stiffness is defined as the resistance offered by an elastic body to deformation. The pumpable support loading stiffness is calculated using the linear portion of the loading cycle prior to grout failure and load shedding events (see Fig. 2). It measures the capacity of the support to develop load as a function of convergence. Stiffness is important in designing supports since, as passive supports, the load resistance is only developed through convergence of the mine opening, and excessive convergence leads to unstable ground conditions. Therefore, high load stiffness is desirable.

Peak load capacity is the maximum capacity of the support and is often referred to as the support strength. The compressive strength of the cementitious grout and the confinement pressure provided by the pumpable support bag control the peak load capacity. When the compressive strength of the grout is exceeded, the grout will fracture and the support will abruptly shed some of its load capacity.

As with most structures made from brittle material, failure is associated with a major drop in load once the compressive and shear strength of the material are exceeded. This is common in all pumpable supports. As illustrated in Fig. 2, the support quickly recovers from the initial load shedding event, restoring a loading stiffness that is very close to the pre-failure loading stiffness. It is believed that the restoration of the support stiffness following a load shedding event is attributed to reestablishment of confining pressure caused by the dilation of the support body and resistance provided by the bag and wire wrap system. As shown in Fig. 2, this restoration of confinement and subsequent loading stiffness may be sufficient to allow continued development of load capacity. The peak load capacity occurs when this confining pressure can

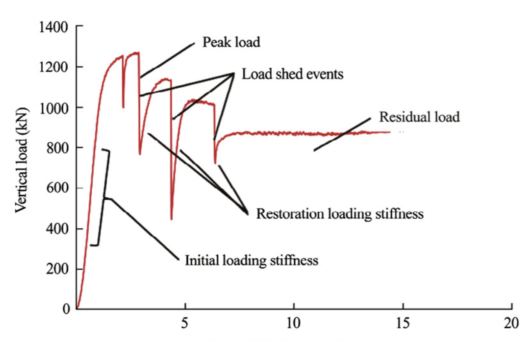

Fig. 2. Illustration of performance characteristics for a pumpable roof support loading profile.