The Use of Shotcrete for Construction of Backfill Barricades in Mining Environments

By Craig McDonald and Joe Hutter

As we all know, the mining process is essentially the excavation and extraction of rock, ore, gems, or other minerals from the earth's surface. In an open-pit mining excavation, the hole in the ground simply increases in size until the resources are exhausted and often a new lake will be created by the crater left behind.

In underground mines, however, as the deposits are extracted, the voids left behind (also known as stopes) must be filled to maintain the integrity of the surrounding rock or earth mass. If these stopes were left empty, the stresses from the surrounding rock mass would result in ground collapses. To avoid these collapses, mining companies use a backfill system, of which there are many different types, depending on the mining method. There is, however, one constant. The entrance point to the excavation must be blocked and sealed off using a barricade to contain the backfill material within the stope.

For many years, the underground mining industry relied on timber for many purposes. Timber was used to support the tunnels as they advanced in length and also to construct barricades used to restrict or block the flow of backfill.

Many of the backfilling operations involve a three-step process, the most important (after construction of the barricade) being construction of "the plug." The plug is always filled using a higher binder content, which provides a higher-strength backfill mixture to withstand the vertical hydraulic head pressures created by the placement of subsequent backfill steps.

The second step involves filling "the body," a process that uses multiple lifts of a lower binder content mixture and fills the major portion of the stope.

The third step is to fill "the cap," a final section of backfill material that uses higher binder content similar to that used in the plug. For each step, the barricade must be strong enough to contain the backfill material in the stope and allow the water needed to transport the backfill solution to the stope to drain.

For many years, the timely and labor-intensive process of constructing backfill barricades changed very little. However, as advanced tools and technology improved processes in other areas of the mining industry, engineers began to look closer at the shotcrete process to solve problems and improve labor efficiency underground. Shotcrete was beginning to play an increasingly dominant role in many areas, including ground support and other forms of underground construction. It was not long before the benefits from the use of shotcrete quickly expanded to the construction of backfill barricades.

Construction of original shotcrete backfill barricades involved the use of panels constructed using two layers of welded wire reinforcement, separated with spacers to act as a vehicle for the shotcrete (Fig. 1). An engineered, high-quality coated woven polyolefin-based fabric, 24/11 weave Fabrene®, was usually fastened to the back of the first layer of mesh to provide a receiving surface for the shotcrete. Reinforcing bar was fastened to the mesh to provide structural reinforcement and dowels were installed in the surrounding rock to secure the barricade. After this preparation was complete, shotcrete placement was completed in less than one shift, allowing for a significant reduction in cost of the barricade, not to mention a reduction in the overall cycle time of the mining process.

Because it is the nature of the mining industry to constantly improve processes, it was not long before the shotcrete barricade was refined. Shotcrete soon became the material of choice and the benefits were obvious (Fig. 2):

Fig. 1: Construction of original shotcrete backfill barricades involved the use of panels constructed using two layers of welded wire reinforcement, separated with spacers to act a vehicle for the shotcrete. Fabrene was usually fastened to the back of the first layer of mesh to provide a receiving surface for the shotcrete

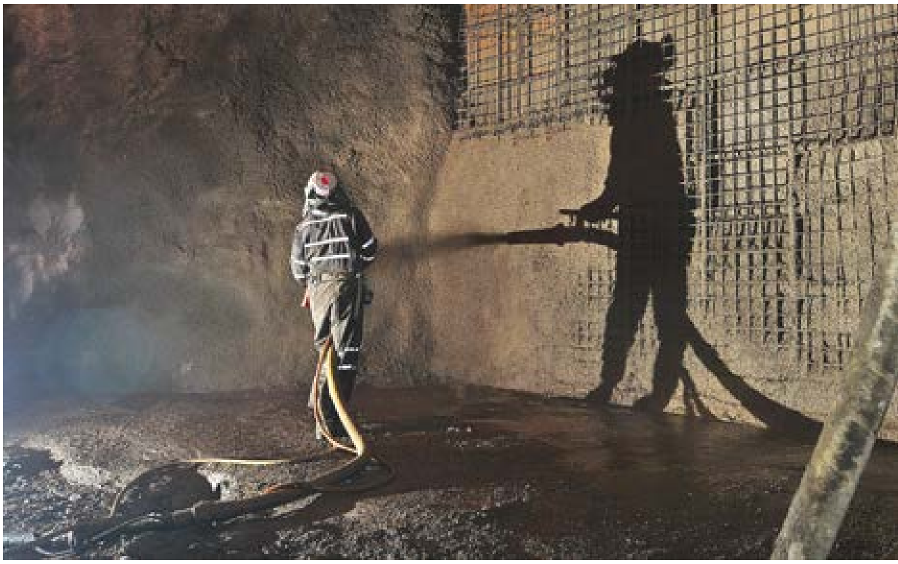

Fig. 2: Reduced manpower, reduced cycle time, and improved water retention soon made the shotcrete process the preferred method for constructing backfill barricades

- Reduced manpower;
- Reduced cycle time; and
- Improved water retention.

Process improvements led to many changes in the backfill barricade design. While some improvements were related to cost-reduction initiatives, it was recognized that a structurally sound barricade design was essential in mitigating the risk of a failure. The barricade was constructed in a section of the rock mass that allowed sufficient anchorage so that the structural integrity of the wall would not be compromised during the backfilling process. Barricades were designed with a convex curve to properly transfer and evenly disperse the load to surrounding ground. But did it have to be a solid wall?

A design concept was drafted by a mining company in the Sudbury, ON, Canada, area, using large, U-shaped troughs made with heavy-gauge sheets of wire mesh and shotcrete (Fig. 3). The perimeter of the barricade would still be mechanically anchored with reinforcing bar dowels and 24/11 weave Fabrene backed welded wire reinforcement would still be used to create a receiving surface for the shotcrete; however, the entire opening would not have to be sprayed with shotcrete. Shotcrete was placed only over the mesh troughs, which were arranged in a rectangular grid pattern. The size of the openings between the U-shaped troughs would determine if the grid arrangement would be viable. After a number of successful tests, it was determined that certain barricades could now be constructed using shotcrete in a predetermined grid pattern as opposed to a solid wall.

Fig. 3: A completed backfill barricade in a northern Ontario mine was constructed using the shotcrete process (note drainage pipes that allow water to drain from the backfill material)

Further improvements came from the development of early-age compressive strength testing equipment or end beam testers. Compressive strength of the shotcrete material was an important criterion in determining how soon the backfilling process could begin after construction of the barricade. Previous test methods for determining early-age compressive strength of shotcrete followed ASTM C1604/C1604M, which involved shooting a 2 ft x 2 ft x 4 in. (0.6 m x 0.6 m x 100 mm) wooden panel and then coring the panel to retrieve specimens for traditional compressive strength testing. The problem with this method was that the panel must remain in the position it was shot until the material had reached final set. In an underground environment, this usually meant leaving the panel underground for an extra shift before transporting it to the surface, where it was then shipped to a certified lab where the actual testing could begin. This process was time-consuming and cumbersome, resulting in the earliest available compressive strength values being 24 to 36 hours.

The end beam tester allowed a nozzleman to shoot directly into molds that were designed to be quickly and easily disassembled. After disassembling, each end of the beam could be broken on-site, using a hydraulic hand pump so that a compressive strength value could be determined at almost any stage of the hydration process.

One company's barricade and backfill procedures specified that the empty stope could not be backfilled until the shotcrete reached a minimum compressive strength of 2900 psi (20 MPa) which, based on the available test methods, meant 48 hours after the shotcrete was placed. Using the early-age compressive strength testing equipment, the company was able to determine that the shotcrete material reached the minimum 2900 psi (20 MPa) value only 24 hours after placement. This information allowed the mine to change their procedures so that the stope could be filled just 24 hours after placement, translating into a full day's reduction in cycle time (Fig. 4). Although this decision was based on the use of a special shotcrete mixture that provided high-early-strength gain, the early-age compressive strength of the in-place shotcrete could only be properly assessed through the use of the end beam testing apparatus, which allowed the engineers to properly quantify the results.

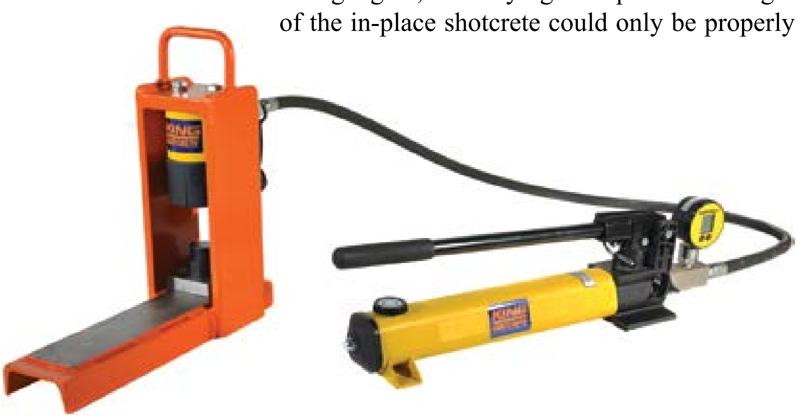

Fig. 4: The end beam tester provided one mine with the information required to change their procedures so that the stope could be filled just 24 hours after placement, translating into a full day's reduction in cycle time

Because there are many factors that can affect set time and rate of strength gain, including water-cement ratio, water temperature, air temperature, and product temperature, the company, to maintain their due diligence, completes frequent testing of their backfill barricades with the end beam testing apparatus.

Within the mining and tunneling industries, the popularity and diversity of shotcrete continues to grow. Engineers understand that the shotcrete process allows for the elimination of labor-intensive forming activities and the costly transportation of forming materials underground. The use of the welded wire reinforcement panels as a receiving surface for shotcrete has dramatically reduced the labor content and cost of projects, such as the construction of backfill barricades. Ventilation bulkheads, garage doors, refuge station walls, and many other projects that require concrete placement are now also completed using the shotcrete process. It is now understood that the shotcrete process is merely an alternative method for placing concrete, so with proper design and engineering, the use of shotcrete underground is only limited by the imagination of the design engineer.

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